EFFECT OF POST-HARVEST STORAGE ON QUALITY OF FRESH AND PROCESSED ASPARAGUS

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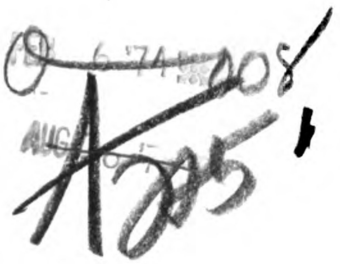

ABSTRACT

EFFECT OF POST-HARVEST STORAGE ON QUALITY OF
FRESH AND PROCESSED ASPARAGUS

By

Young Chun Lee

Martha Washington and Viking varieties were stored in normal atmosphere and controlled atmosphere at 35°F. Controlled atmosphere with 6.2% carbon dioxide and 2.3% oxygen was maintained during storage test by a Tectrol generator.

Samples from "Control," "Chlorinated," and "Butts standing in water" were taken at 1 week interval to study effects of post harvest storage conditions on bacterial soft rot, off-odor development, changes in texture, fiber content, total solids content, chlorophyll content, and reflectance color. Canned and frozen asparagus were subjected to reflectance color and organoleptic evaluation.

Asparagus stored in controlled atmosphere had significantly less bacterial soft rot than that stored in normal atmosphere. The best combination of storage conditions to retard bacterial soft rot was "Butts standing in water" in controlled atmosphere. Development of off-odor in fresh asparagus during storage was closely associated with bacterial soft rot.

Shear force measured at 7.5 inches from tip increased as storage period was extended in all samples, except "Butts standing in water." There was no effect of controlled atmosphere on texture during storage.

Crease of fiber content in asparagus during storage was significantly retarded by controlled atmosphere storage. "Butts standing in water" stored in controlled atmosphere decreased in fiber content during storage.

Asparagus stored in controlled atmosphere retained higher chlorophyll content than that in normal atmosphere. It was found that reflectance color values for fresh asparagus, L, $\sqrt{a^2+b^2}$, and ΔE (total color difference) were very closely associated with chlorophyll content in fresh asparagus, and L, $\sqrt{a^2+b^2}$, and ΔE increased as chlorophyll content in fresh asparagus decreased. This result indicated that reflectance color could be used to trace destruction of chlorophyll in fresh asparagus. "Butts standing in water" stored in controlled atmosphere had more glassy and greener appearance than others.

In canned and frozen asparagus, highly significant correlations between visual color score and L, -a/b, $\sqrt{a^2+b^2}$, and ΔE were found. Visual color score decreased as L, $\sqrt{a^2+b^2}$, and ΔE increased. Therefore, L, -a/b, $\sqrt{a^2+b^2}$, and ΔE values provided objective methods for measuring visual color of canned and frozen asparagus. Effect of controlled atmosphere, in general, on visual color of canned and frozen asparagus and on reflectance color of canned asparagus was significant.

"Chlorinated" asparagus had significantly lower flavor score than "Control" and "Butts standing in water." "Control" and "Butts standing in water" stored in controlled atmosphere had fairly good asparagus flavor until 3 weeks of storage, compared with those stored in normal atmosphere until 2 weeks of storage.

"Butts standing in water" stored in controlled atmosphere was found to be the best method to maintain over all quality of fresh and processed asparagus.

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INTRODUCTION

Asparagus spears (Asparagus officinalis L.) are immature and succulent, respire rapidly, and develop fiber and become tougher in storage. Because of relatively high costs of production, perishability, and difficulties in storage of the fresh spears, asparagus is an expensive vegetable (Bisson, Jones, and Robbins, 1926). Asparagus spears are eaten as the fresh, canned, or frozen product. The important factors of quality in asparagus are color, flavor and freedom from fibrousness (Kramer et al., 1949). Good quality asparagus spears should be fresh and firm with closed compact tips and the entire green portion tender.

Asparagus ages rapidly after cutting; tips become partially open, spread, or wilted, and the stalks become tough and fibrous (Ehlert and Seelig, 1966). Loss of quality through development of fiber, loss of flavor, and development of off-odor by microbial spoilage which occurs rapidly at high temperatures, are usually retarded by storage at 32 - 35°F (Lougheed, 1964). Maximum duration of storage is 3 to 4 weeks at 32 - 35°F (Wright, Rose, and Whiteman, 1954).

Atmospheres modified with respect to CO_2 and O_2 are widely used to retard deterioration of apples, cherries, and other fruits

during storage or in transit to market. Ryall (1963) reported that certain atmospheres are beneficial for some vegetables. It has been also shown that CO_2-enriched atmospheres tend to retard toughening and to reduce the amount of bacterial soft rot in harvested asparagus (Lipton, 1960). Previous studies (Barker and Morris, 1937; Carolus, Lipton, and Apple, 1953; Franklin et al., 1960; Lipton, 1960; Lougheed, 1964) have shown that atmospheres of 5-15% carbon dioxide with reduced oxygen levels may be useful adjuncts in the storage of asparagus.

The aim of this study was to investigate the effect of modified atmosphere (controlled atmosphere) storage on the quality of fresh asparagus during storage and on the quality of processed asparagus.

REVIEW OF LITERATURE

Carbon Dioxide and Post Harvest Physiology of Asparagus

Many researchers (Barker and Morris, 1936; Platenius, 1942; and Tewfik and Scott, 1954) have studied the respiratory rate of asparagus held under various conditions, and found asparagus respires more rapidly than other vegetables at a given temperature. Initial respiration rates range from about 40mg per Kg fresh weight per hour at 32°F to about 400mg at 70°F (Pentzer et al., 1936). Carbon dioxide evolution declines rapidly after harvest, the rate of decrease becoming less as the storage period is prolonged and it eventually reaches a nearly constant rate at low temperatures. Respiration can be controlled not only by temperature, but also by carbon dioxide and oxygen and in fruit by ethylene (Biale et al., 1962).

Carbon dioxide can exert on the metabolism of many fruits and vegetables an effect that is beneficial from the point of view of retention of edible quality. However, certain limits of concentration and duration of exposure must not be exceeded (Smith, 1963). Thornton (1933) found that carbon dioxide in the atmosphere lowered the oxygen uptake in asparagus and that oxygen uptake was decreased significantly when the carbon dioxide concentration was 10% or higher.

However, the effect of carbon dioxide upon the respiratory process cannot be considered properly without reference to the effects of reduced oxygen concentration. Platenius (1943) found that a minimum in respiratory activity of asparagus was reached at an oxygen concentration of 2.3% at 20°C. At this point the respiration rate was only 40% of that occurring in normal air. At lower levels of oxygen, carbon dioxide production began to rise, while oxygen consumption fell off sharply. Under the above specified conditions where 2.3% oxygen was attained in the storage atmosphere, the respiration of asparagus reached its extinction point. Above 2.3% oxygen was available to maintain aerobic respiration and to suppress fermentation completely. With less than 2.3% oxygen, anaerobic respiration and incomplete oxidation took place. There was tissue injury. External tissues collapsed to form deep longitudinal channels in the upper portion of the spear and a pronounced musty and alcoholic odor was noted.

Temperature has a quantitative and qualitative effect on post harvest respiration (Biale et al., 1962). The Q_{10} value for initial rates, as presented by Platenius (1942), decreases from 3.7 for the interval 0.5 to 10°C to 2.5 for interval 10 to 24°C. To extend storage life of fruits and vegetables or to improve their quality for marketing or processing, it is necessary that proper combination of carbon dioxide, oxygen concentration, and temperature conditions should be obtained.

Barker and Morris (1936) found that the storage life of asparagus could be extended up to 35 days at 34°F in 5 to 10% carbon dioxide with either 5 or 10% oxygen. Recent studies (Lougheed, 1964; Lipton,

1965) indicated that asparagus held under 5 or 15% CO_2 improved the market quality in comparison to asparagus held in air.

Platenius (1939) found that rate of asparagus deterioration increased with increasing temperatures. Studies of the symptoms of deterioration by Lipton (1957) revealed that with all green asparagus, bacterial soft rot infection was the chief factor limiting storage life at temperatures between 10 and 30°C. Further symptoms of deterioration included yellowing, development of longitudinal surface depressions, fungal infection and the development of undesirable odors and flavors. Increasing levels of CO_2 reduced the incidence and severity of bacterial soft rot infection at the tips and cut end of the spears. Oxygen concentration in the range of 1 to 21% had little effect on soft rot either in the presence or absence of CO_2. Generally, the market quality of asparagus was higher after holding in 5-10% CO_2 than after holding in air (Lipton, 1965).

Fiber Changes

The continued increase of tough elements in asparagus spears was recognized by earlier workers (Bitting, 1915; Morse, 1917; Bisson, 1926). As in many vegetables, fibrous materials are objectionable due to their deleterious effect on palatability. Studies by Bitting and Morse showed that the fiber content rose as the storage period and the storage temperature are increased, and the content of tough elements increased from the tip to the base of the spear.

Bisson et al. (1926) extensively studied factors influencing the quality of fresh asparagus after it was harvested. There were

general increases in the amount of fiber of spears at all storage temperatures. The greatest increase in fiber at all temperatures came during the first 24 hours after the asparagus was cut, but was least at the lowest temperature.

Objective methods for measuring fibrousness of asparagus spears have been developed by many researchers. MacGillivray (1933) used the conventional fruit pressure tester with 1/8 inch plunger and found that resistance increased with duration of season and distance from the tip. Lee and Sayre (1940) established tenderometer as being suitable for measurements of tenderness of asparagus, and found a significant correlation of 0.729 ± 0.029 between tenderometer reading and crude fiber content. They also reported a correlation of 0.9000 between tenderometer readings and organoleptic tests. Lee (1943) recommended the use of alcohol insoluble solids content as a measure of toughness of frozen asparagus, suggesting that samples having more than 4.35% A.I.S. be considered fancy, and those lower than 4.04%, off grade.

Smith and Kramer (1947) presented a rapid method for determining the fibrous materials in canned green asparagus, and showed that the fiber content increased rapidly beyond the natural snapping point of the stalk. Values obtained by the same method were not affected by various canning procedures. Fiber of fresh and frozen asparagus may be determined by the same method if it is preceded by a cooking treatment.

The material obtained by the official method (AOAC, 1965) should probably be designated as "crude fiber"; whereas "fiber"

should be reserved for material which is estimated by the blender method. Scott and Kramer (1949) stated that the blender method gave a better estimation of "organoleptic fibrousness" than the official method. The limitations of chemical analysis for "crude fiber" have been discussed by Joslyn (1950) who reported that the recovery of cellulose varies from 68 to 86% and the lignin recovery from 4 to 67%. This variability in the recovery of lignin, the substance generally held responsible for imparting toughness to cell walls (Isherwood, 1955) where lignification is the primary factor involved, makes this method almost useless for the detection of small amounts of lignin.

Wilder (1948) developed an instrument called the "Fiberometer" for measuring the fibrousness of canned asparagus. The instrument consisted of a stainless steel wire to which a 3-pound weight was attached. A stalk was considered tender to the point farthest from the tip that the wire will cut. The measurements reflect the degree of development of the perivascular fibers, which were the structures chiefly responsible for imparting toughness to asparagus (Lipton, 1957).

The applicability of the shear press to measure the quality of foods had been tested by Kramer (1953). This device was similar to the fibrometer in principle. Kramer (1956) showed a relationship between shear press value (lbs) and fiber (%) and defined fibrousness according to fiber percent and shear-press value. Asparagus whose fiber content was 0.5% which corresponded to 200 lbs of shear-press was defined as substandard. Recently, "Instron" has been used to

evaluate texture of asparagus, specially fibrousness (Segerlind, 1971). A spear is cut with a single blade of Instron and shear force (in pounds) to cut a spear is measured. This instrument has higher sensitivity than others. The level of crude fiber has been found to increase with time in storage and with increasing temperature (Bisson et al., 1926; Morse, 1917), although reports have indicated that the amount of fiber may decrease under the same conditions (Carolus et al., 1953, Scott and Kramer, 1949). The increase in fiber is attributed to utilization of sugars in lignification in the pericycle and the vascular bundles (Bisson et al., 1926; Brennan, 1958; Lipton, 1958).

Wiley et al. (1956) found that fiber content, as measured by the blender method, actually decreased when asparagus was stored standing in water. Brennan (1958) attributed some of this decrease in water to stem elongation. Because the fiber content decreased towards the tip of spears, sampling for fiber at a specific distance from tip would give a small reduction because of stem elongation.

Asparagus may gain weight up to 20% or more, when asparagus is stored standing in water, and the uptake of water increase with temperature (Kramer, 1949). This water uptake causes tenderizing effect on asparagus (Franklin et al., 1960). Morse (1919) showed that this tenderizing effect of water uptake could be detected by subjective measurement. However, Brennan (1958) could not find differences between pressure reading of turgid and flaccid asparagus. Wiley et al. (1956) found lower pressure readings in asparagus standing in water because the fiber content actually decreased.

Modified atmospheres containing carbon dioxide have been noted as causing tenderness of both raw and cooked asparagus (Carolus et al., 1953). Franklin et al. (1960) found very marked effects of carbon dioxide on tenderness of asparagus when the asparagus was stored standing in water. Although the overall effect of oxygen was slight compared to carbon dioxide, there was a significant lowering of the tenderometer readings with oxygen concentrations lower than that of air down to 5%. This experiment was carried out at 35°F and 5-15% oxygen with carbon dioxide concentrations 0 to 15%. Thornton (1931) on the other hand, observed toughening of asparagus in some modified atmospheres.

Carolus et al. (1953) mentioned that the tenderizing effect might be due to break down of fiber, and they found fiber levels (by Smith & Kramer method) decreased with increasing carbon dioxide levels. Franklin et al. (1960) argued that the breakdown of crude fiber probably did not occur, and the tenderness effect might only have been due to some softening of the tissues causing easier disruption of the cells by a shearing force. Lougheed (1964) found that only a minor portion of the tenderizing effect could be attributed directly to uptake of water. The major portion of the tenderizing effect of carbon dioxide was due to some dissolution of intercellular materials. This dissolution led to less fibrous material in the asparagus treated with carbon dioxide as analyzed by Smith and Kramer method, although the crude fiber content did not change. The tenderness obtained by treatment with carbon dioxide was retained in the cooked asparagus.

Color Change

An important quality loss of excised asparagus is yellowing which is a normal procedure of plant senescence. It has been known for a long time that controlled atmospheres consisting of relatively high carbon dioxide concentrations and low oxygen levels retard undesirable post harvest changes in fruits and vegetables. Chlorophyll retention has been used as a measure of quality in green vegetables (Dietrich et al., 1959; Gilpin et al., 1959; Sweeney and Martin, 1958). Color is also an important factor in consumer acceptance. Kramer estimated "eye appeal" to be about 45% of the total quality scale (Kramer and Twigg, 1956). Kramer et al. (1949) showed a loss of chlorophyll in asparagus at an air storage temperature above 50°F after 4 days. Guyer and Kramer (1950) found a significant loss in the green color of green beans stored 10 days in air at 50-70°F. Lieberman and Hardenburg (1954), working with broccoli at 75°F, found that the presence of some oxygen could cause yellowing and that carbon dioxide retarded yellowing.

Lyons and Rappaport (1962) found no change in the color of Brussels sprouts over 16 days storage in air at 32°F. At 41 and 50°F, an increase in carbon dioxide at 21% oxygen delayed the loss of chlorophyll. A lowering of the oxygen content below 10%, in the absence of carbon dioxide, was also effective in retention of green color. The combination of increased carbon dioxide and reduced oxygen concentration was slightly more beneficial in maintaining quality than the same concentration applied independently.

James (1953) stated that yellowing was caused by a breakdown of chlorophyll. He suggested that breakdown of the protein which was attached to the chlorophyll molecule within the chloroplasts removed the natural protection it afforded the chlorophyll. The chlorophyll was then labile. Michael (1935) and Wood et al. (1943) showed a similar protein-chlorophyll relationship in regard to the yellowing of excised grass and leaves. In the air storage of green beans, Parker and Stuart (1935) showed that, over a 4 days storage period, only a very slight change in nitrogen distribution occurred. Platenius (1943) found that protein breakdown in asparagus was less as the level of oxygen in the storage atmosphere was lowered.

However, the mechanism of chlorophyll breakdown during post harvest storage is not completely understood. The better retention of chlorophyll in the modified-atmosphere stored sample was always accompanied by a higher pH than in the air-stored sample (Groeschel et al., 1966). These findings were consistent with the suggestion that pheophytin formation was a function of tissue pH. Wang (1971) studied chlorophyll degradation during modified atmosphere storage of asparagus and found that there was more retention of chlorophylls in the modified-atmosphere stored asparagus. This effect became more pronounced as the concentration of carbon dioxide in the atmosphere was increased. The degradation products of chlorophylls in the modified-atmosphere stored samples were exclusively the pheophytins. Groeschel et al. (1966) studied changes in color and other characteristics of green beans stored in controlled refrigerated atmospheres and concluded that the greatest advantage

of controlled-atmosphere (or modified atmosphere) storage for green beans lay in improving the color of stored product by retarding chlorophyll breakdown.

Measurement of the relative amounts of chlorophyll and pheophytin present in vegetables is of importance because it provides information regarding the condition of vegetables when received. Changes occurring during the cooking process can also be followed by measuring progressive conversion of chlorophyll to pheophytin. Estimation of chlorophyll in plants depends fundamentally on the complete extraction of the pigment in known form from the plant material and on a reliable measurement of the pigment content of the extract (Sweeney et al., 1958).

Pigments can be measured by colorimetry, fluorometry, or by estimation of magnesium content. Of these, only the colorimetric methods have been used for routine purpose. The several spectrophotometric methods which have been developed may be divided into two general groups: the first includes methods which allow a determination of chlorophylls by measuring absorbances at the absorption maxima of the two chlorophylls, and therefore are not applicable to a system with pheophytins present (Arnon, 1949). The second group is concerned primarily with determining the extent of conversion of the chlorophylls, and includes several ways of relating absorbance changes to chlorophyll concentration (Dietrich, 1958; Mackinney, 1940; and Sweeney et al., 1958; Vernon, 1960; Wang, 1971).

It was shown by Gold and Weckel (1959) that the percentage of pigment chlorophyll lost correlated very well with certain color

functions. In this study, a high linear correlation was found between a/b, a function of hue, determined for heat processed peas with the Hunter Color and Color Difference Meter, and the degree of conversion of chlorophyll to pheophytin. The correlation coefficient, was -0.992 and highly significant. A significant correlation also was found between the value $\sqrt{a^2 + b^2}$, a function of chroma, and degree of degradation of chlorophyll. A close correlation was also found between L (brightness) and the degree of chlorophyll degradation. These results indicated instrumental color functions could be used to trace the percent loss of chlorophyll.

However, pigment loss is not the best means to evaluate color, because pigment content does not take into consideration the physical state of the sample and therefore, does not adequately represent what the eye sees, and pigment analysis are generally a great deal more difficult and time consuming than reflectance color measurements. For these reasons, there has been a search for adequate means to describe the color of green vegetables in terms of objective values.

The Maxwell spinning disc principle has been used for color measurement for over 100 years. Newhall (1929), Mitchell (1935), Emanuele and Mauri (1951), and McGillivray (1938) described the use of the spinning disc for agricultural products. With development of filters that approximate the I.C.I. tristimulus functions, simple objective physical measurements of color were possible.

Kramer (1950) compared the Hunter Color Difference Meter and the Photovolt Reflection Meter and concluded that the Color Difference Meter was superior in accuracy and convenience. Many

researchers have applied the Color Difference Meter to tomato products (Younkin, 1950; Robinson et al., 1951; Robinson et al., 1952). The tristimulus values obtained have then been reduced to one function that describes the color, or have been converted to some other color system to make the definition of color simpler.

Sistrunk and Frazier (1963) used the Hunter - a/b ratio for measuring color changes in canned snap beans during serving table exposure. In this study, they found this function to correlate well with visual judgments. Clydesdale and Francis (1968) studied chlorophyll changes in thermally processed spinach as influenced by enzyme conversion and pH adjustment. They measured color on the Colormaster Differential Colorimeter and then converted tristimulus values obtained to Adams tristimulus values. They found that none of the color functions calculated from the Adams data correlated well with the visual judgments over the whole storage period. Initially, when the products were dark green, a measure of hue ($\tan^{-1}$ a/b) correlated well, but after storage this formula was not satisfactory, since the coordinates were in another quadrant.

Correlation of raw, transformed and reduced data with visual ranking for spinach puree was reported by Clydesdale and Francis (1969). They mixed freshly processed spinach puree and stored processed puree in proportions varying from 0 to 100% in increments of 10% to provide 3 different sets of 11 samples each. These sets simulated the range of color values actually obtained with samples in storage after processing. Color measurements were performed by means of a General Electric Recording spectrophotometer, a Hunterlab

Color Difference Meter, and a Colormaster Differential colorimeter. Tristimulus values from the instruments were reduced to common color functions, and all data were correlated with visual rankings. Good correlations of instrument versus rank were obtained. Reduced data calculated from instrumental read-out correlated well with visual rank.

Huang et al. (1970) applied the Kubelka-Munk concept for color measurement to samples of pureed squash and carrots containing very small color differences. They found that a panel could rank visually, samples differing in approximately 0.2 ΔE ($\Delta E=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2}$). They also observed that a single color parameter was not sufficient for ranking samples instrumentally. The best correlations being obtained when all three parameters either X, Y and Z or Hunter L, a and b were included.

GENERAL MATERIALS AND METHODS

Three series of tests (preliminary studies, the first principal test and the second principal test) were conducted during 1972 harvest season on the East Lansing campus. The preliminary studies were exploratory in nature to develop methods which could reduce microbial spoilage during storage and extend shelf life of packaged asparagus after storage for retail market. Procedures for preliminary studies are given in Appendix. The principal series of tests were performed to study post harvest quality changes of asparagus during storage and to investigate effects of such storage on quality of processed asparagus.

Test Series I

Hand harvested asparagus of Martha Washington variety was purchased for test at Benton Harbor on the 10th of June. The material was filled in polyethylene bags with water sprayed over spears in bags to prevent weight loss and immediately transported to East Lansing campus by truck. Due to large quantities handled, temperature control for the 2-1/2 hour transportation was not made.

As soon as the asparagus reached the processing laboratory, it was stored in the cold room at 35°F until sorted, washed and

treated. Asparagus was stored according to diameter at 6 inches from tip of spear. Diameter was measured using a V-shaped asparagus diameter measuring rule. Asparagus ranging 3/8 to 6/8 inch in diameter (about 73% of the spears, after sorting, were of 3/8 to 4/8 inch in diameter) were used.

Due to large quantities handled, sorting took about 7 hours by 3 persons, but the asparagus which was not required for sorting work was held in a cold room at 35°F. All undersized, oversized, short (shorter than 6 inches), misshapen, or damaged asparagus spears were discarded. Length of asparagus spears used for tests ranged from 6 to 10 inches. The sorted and weighed material was washed in a tank for 3 minutes and drained for an hour. The material was then divided into 3 lots, each weighing about 90 pounds. The divided lots were held in cold room at 35°F until treated.

Storage Method

Control (A).--Asparagus was filled in polyethylene bags (12 x 20 inches), each weighing 3.5 pounds ± 1 oz. Eighty ml of water was poured in each bag to prevent weight loss during storage. Asparagus was kept butt ends down and mouth of bag open.

Chlorination (B).--Asparagus was chlorinated in a water bath containing 200ppm of chlorine (using "Oxine" manufactured by Lily Products Company) at 125± 3°F for 2 minutes. The spears were cooled immediately after the hot dip with cool water running over the spears for 5 minutes, and then held in a cold room at 35°F for 1 hour to remove residual heat and to drain surface water.

Weighed asparagus, after further removing surface water by fan at room temperature, was filled in polyethylene bags, each weighing 3.5 pounds± 1 oz.; 80ml of water was added to each bag as in the "Control."

Butts in water.--Weighed asparagus (3.5 pounds ±1 oz.) was bunched with polyethylene strips and butt ends of spears were immersed in 2 inches of water in a shallow pan. About 40 hours elapsed between receipt and placing treated samples in storage. The material was kept in the cold room, except when sorted, graded, washed, and treated.

Test Design

storage condition	normal atmosphere			controlled atmosphere		
treatment	control	chlori-nated	butts in water	control	chlori-nated	butts in water
code	I-N-A	I-N-B	I-N-C	I-C-A	I-C-B	I-C-C

Storage Condition and Sampling

Normal atmosphere storage.--Eight bags or bundles of asparagus from each treatment were stored in storage room (8 x 10 x 8 feet; width x length x height) at 35°F. Temperature was controlled by cold air blast system. Relative humidity was maintained at 85± 5% by spraying water on the floor of storage room. The storage room was located at the Horticulture Research Center.

Eight bags or bundles of samples from each treatment were taken at 8 day interval for various measurements of microbial

spoilage, development of off-odor, texture measurement, fiber determination, reflectance color measurement, and chlorophyll determination. The last samples were stored for 32 days. No spoiled spears, except the beginning of soft rot development on tip of heads were included in samples for measurements.

Controlled atmosphere storage.--Eight bags or bundles of asparagus per treatment were stored in a Tectrol controlled atmosphere storage room (8 x 10 x 8 feet; width x length x height) which was located in Horticulture Research Center at southern campus. The average controlled atmosphere of 6.1% carbon dioxide and 2.5% oxygen was produced by Tectrol generator (model: GN-2N, Whirlpool Corp.). Temperature and relative humidity were maintained the same as normal atmosphere storage. A Tectrol unit breakdown occurred from the 6th to 12th day of storage period. Sampling and observation were made at the same time by the same method as normal atmosphere storage samples.

Preparation of Frozen and Canned Asparagus

The stored asparagus which was not required for measurements, was divided into two lots. One lot was washed, steam blanched at 205°F for 2-1/2 minutes, and cooled for 5 minutes with cold water sprayed over spears. The drained asparagus was then placed in polyethylene bags (6 x 12 inches), each bag weighing about 1.5-2 pounds. The bags were fastened tightly with thread and frozen at -30°F in air blast freezer. The frozen asparagus was stored at -10°F in walk-in freezer until used for measurements.

The other lot was cut into 4 inches spears (from 2 to 6 inches from tip of asparagus), steam blanched for 1 minute at 205°F, and cooled for 5 minutes. Nine oz. of drained asparagus was placed in can and 2% brine was used as a filling medium. The cans were processed at 248°F for 18 minutes and then cooled. The canned asparagus was held at room temperature until used for measurements.

Test Series II

Six hundred pounds of asparagus of Viking variety were hand harvested from 4-6 year old field at Hart between 10 to 11 A.M. on June 23, 1972. Soon after harvest, asparagus was placed in polyethylene bags with water sprayed over spears, and then transported to campus. The transportation required about 4 hours. Temperature control was not made due to large quantities involved, and outdoor temperature was about 66°F. The asparagus was held in a cold room at 35°F in the processing laboratory until used.

Asparagus was sorted according to diameter at 6 inches from tip of spear. Spears ranging 3/8 to 6/8 inch in diameter and longer than 6 inches were chosen for test use. Length of asparagus spears used for tests ranged from 6 to 10 inches. About 89% of material selected was in the range of 3/8 to 5/8 inch in diameter. Asparagus was of average commercial quality, but careful selection yielded reasonably uniform test lots. Sorted material was washed, drained, and divided into 3 lots, each weighing about 130 pounds. The divided lots were held in a cold room at 35°F until treated. Other details which are not stated here were same as Test Series I.

Test Design

storage condition	normal atmosphere			controlled atmosphere		
treatment	control	chlori-nated	butts in water	control	chlori-nated	butts in water
code	II-N-A	II-N-B	II-N-C	II-C-A	II-C-B	II-C-C

Storage Method

Control (A).--Asparagus without treatment was placed in 20 polyethylene bags (12 x 20 inches), each weighing 4 pounds ± 1 oz. Eight polyethylene bags containing 6 pounds of asparagus were provided for use in fresh packaging studies following various periods of storage. Eighty ml of water was added to each bag to avoid wilting during storage. Bags containing samples were held with open mouth and butt end of asparagus down.

Chlorination (C).--Asparagus was chlorinated in diluted "Oxine" solution (100ppm as chlorine) at 125 ± 3°F for 1.5 minutes. After chlorination the material was immediately cooled in running water for 5 minutes, and then held in a cold room at 35°F for 1 hour to remove residual heat. Other conditions which are not described here were the same as "Chlorination" method in Test Series I. Twenty bags, each containing 4 pounds ± 1 oz. of asparagus, were provided for storage test. Eight bags, each weighing 6 pounds of asparagus, were also treated similar to "Control" in Test Series I.

Butts in water (C).--Twenty bundles, each weighing 4 pounds, were made. Besides these, 8 bundles (6 pounds per bundle) were

provided for fresh packaging studies as described in "Control." During storage tests, butt ends of asparagus were immersed in 2 inches of water in a pan.

Due to large quantities involved, about 19 hours elapsed between the time of material receipt in processing laboratory and the time the lots were placed in storage room. When being sorted, treated, and filled or bundled, the portion of asparagus which was needed for the works was exposed to the processing laboratory temperature of approximately 68°F. During the remainder of the 19-hour period, material was held in a cold room at 35°F.

Storage Conditions and Sampling

Normal atmosphere.--Eight bags or bundles (each weighing 4 pounds) and 4 bags or bundles (each weighing 6 pounds) from each treatment A, B, and C were stored in a normal atmosphere storage room at 35°F and 85 ± 5% relative humidity. Sampling was done at 1 week interval and 2 bags or bundles from each treatment were taken for measurements of microbial spoilage, off-odor development, texture measurement, reflectance color measurement, and chlorophyll determination. Details on normal atmosphere storage which are not stated here were same as that in Test Series I.

Asparagus from 6 pound bags taken after each storage period was sorted and good spears were packaged in plastic trays with water vapour-gas permeable film overwrapped (film used: Resinite packaging film, VR-71, Gauge 60, produced by Borden Inc.). Fresh packages, each weighing about 1 pound, were held at 55°F. Microbial spoilage was observed during storage.

Controlled atmosphere storage.--The same quantities of samples from treatment A, B, and C as normal atmosphere storage were stored in a controlled atmosphere room at 35°F and 85 ± 5% relative humidity. An average controlled atmosphere of 6.2% carbon dioxide and 2.3% oxygen was produced by a Tectrol generator. Sampling and observations were made at the same time by the same method as normal atmosphere storage samples. Other details on controlled atmosphere storage not described here were same as that in Test Series I.

Asparagus remaining after measurements was divided into 2 lots. One lot was canned and the other was frozen. The procedure for canning and freezing was same as that in Test Series I.

Test Procedure

Asparagus removed from storage was examined for off-odor development and microbial spoilage. Good spears were weighed to measure weight change during storage, after removing surface water.

Off-Odor Development

Asparagus removed from bags or bundles was spread on a table and rated for off-odors. Scoring was made using the following 5-point rating system and examination was done in duplicate:

1: trace of detectable off-odor development.

2: mild off-odor developed, acceptable as commercial produce.

3: considerable degree of off-odor detectable, not acceptable as marketable fresh produce.

4: strong off-odor detected, not edible.

5: very strong off-odor developed and most of spears spoiled and inedible.

Microbial Spoilage

In preliminary studies, microorganisms causing spoilage in harvested asparagus were identified in Department of Botany at Michigan State University. It was found that Erwinia carotovora was the microorganism causing bacterial soft rot which was the major problem. Bacterial spoilage was examined based on symptoms observed in this study.

On removal from storage, asparagus spears were carefully examined to determine microbial spoilage. Observations were made in duplicate and expressed as percent of spoiled spears over total number of spears in each sample. Degree of spoilage was also examined subjectively using following rating system. This was applied to bacterial soft rot on tip of spear.

1: beginning of soft rot development on tip end.

2: disintegration of tip developed to about 1/3 of head.

3: half of head was spoiled.

4: 2/3 of head spoiled.

5: whole head disintegrated.

In this study, all spears infected by bacteria, regardless of severity of spoilage were counted as spoiled spears.

Texture Measurement

Shear force in pounds to cut a spear at 7.5 and 6 inches from tip with single blade was recorded using "Instron" (Table Model-TM).

Ten spears from each treatment, diameter of spears ranging from 3/8 to 9/16 inch at 7.5 inches from tip, were used. Length of spears used for texture measurement ranged from 8 to 10 inches. Shear force was measured for each spear with a cutting speed of 4 inches/minute.

Fiber Determination

Analysis by the blendor method was performed according to the procedures outlined by Smith and Kramer (1947) and modified by Lipton (1957). The asparagus samples were frozen at -30°F right after removal from storage and stored at that temperature for about 2 weeks before analysis.

The frozen spears whose diameter ranged from 3/8 to 9/16 inch at 7.5 inches from tip, were cut into 4 inch sections (4 to 8 inches from tip of spears) and sliced into small pieces. After mixing, 100 ± 5 g. of sample was weighed, filled in a No. 1 can, and cooked in a steam kettle at 212°F for 15 minutes. The samples were cooled in cold water for a few minutes, 70 ml of water was added and the sample blended in a Waring blendor jar for 2 minutes. The fiber was caught on 30 mesh screen. The fibrous material was then transferred to tared filter paper in a Buchner funnel by means of a jet of water. After removal of water, fibrous residue on filter paper was dried to a constant weight at 100°C (about 2 hours). Fiber content was expressed as percent based on corrected fresh weight of sample.

$$\% \text{ fiber} = \frac{\text{weight of fiber}}{\text{weight of sample}} \times 100 \times \frac{\text{weight after storage}}{\text{weight before storage}}$$

Chlorophyll Determination

Asparagus with 3/8 to 4/8 inch diameter at 4 inches from tip of spear was used for determination. Two inch cut spears (2 to 4 inches from tip of asparagus) were diced, and 20 g. of weighed sample was homogenized with 80ml of acetone in a Sorvall Omni-mixer at high speed for 1.5 minute. The material was filtered through a sintered glass suction funnel. The residue was blended with 40ml of 80% acetone for 1.5 minutes, and then filtered again. The residue was washed with 80% acetone and the volume of the filtrate was made to 250ml with 80% acetone. For each sample, a control and a converted sample were prepared for spectrophotometric measurements.

The control was prepared by adding 3.0ml of 80% acetone to a volumetric flask and diluting to 100ml with the filtered extract. The conversion sample was prepared by placing 3.0ml of saturated oxalic acid in 80% acetone in a volumetric flask and diluting to 100ml with the same filtered extract. The converted sample was stoppered and kept in the dark at room temperature, for at least 4 hours before measurement. The control was kept in the dark at 40°F. The absorbances of the samples were determined at 536, 645, 662, 666, and 750 nm.

Chlorophyll a, b, and total chlorophyll present were calculated from the following equations (Vernon, 1960):

$$\text{chlorophyll a (mg/100g of sample)} = (25.38 \times \Delta A662 + 3.64 \times \Delta A645) \frac{100}{\text{sample weight}}$$

$$\text{chlorophyll b (mg/100g of sample)} = (30.38 \times \Delta A645 - 6.58 \times \Delta A662) \frac{100}{\text{sample weight}}$$

$$\text{total chlorophyll (mg/100g of sample)} = (18.80 \times \Delta A662 + 34.02 \times \Delta A645) \frac{100}{\text{sample weight}}$$

Chlorophyll was determined on duplicate samples, and chlorophyll content was expressed on basis of corrected fresh weight. In case of processed asparagus, chlorophyll content was expressed on basis of sample weight.

Reflectance Color

Color of asparagus spears was determined using a Hunterlab Model D25 Color and Color Difference Meter. In case of fresh asparagus, spears cut into 6 inch lengths (2 to 8 inches from tip of spear) were placed in the sample cell (made of Plexiglas with dimensions of 6 x 6 x 2 inches; length x width x height) such that the maximum surface area of the bottom of the cell was covered with single layer of spears. The cell was then filled with a few more layers of spear cuts. This arrangement of product in the cell was sufficient to prevent incident light from the instrument from being lost through spaces between individual cuts. The cell was placed on the aperture and covered to exclude any room light from striking the photocells.

In case of canned or frozen samples, asparagus spear cuts were very flexible, unlike fresh asparagus. Therefore, asparagus was arranged in the sample dish (round glass dish) as a single layer with

which the bottom of the dish was fully covered, and was further filled with spear cuts. The dish placed on the aperture was covered with a black colored can to avoid any interference from room light. L, a, and b values were recorded.

Reflectance color was determined on triplicate samples. Standardization of the instrument was accomplished using the Standard White Tile 2810 (L 94.8, a -0.7, and b 2.7) and the Standard Green Tile 2813 (L 60.4, a -16.4, and b 7.4).

Organoleptic Evaluation

Canned asparagus was cut into 1.5 inch pieces and placed on a translucent plastic weighing boat. A reference sample was used to provide a constant basis for comparison among test samples evaluated at the many sensory evaluation sessions. A new can of the same code number of commercial product was used for each panel session. One reference and 6 samples were presented to judges, consisting of faculty members, secretaries, and graduate students who were asked to rate 6 samples by comparing with a reference sample.

A color photograph illustrating certain degrees of color difference among selected canned asparagus samples was offered to help judges in color evaluation of samples. Tests were held in the afternoon between 2:30 to 3:30. Each judge was provided with a color and flavor evaluation sheet. The samples were warmed up in an oven at 180 ± 10°F for 5 minutes before evaluation.

Frozen asparagus was subjected to only color evaluation. Frozen asparagus which was processed from fresh asparagus without storage was used as a reference for color comparison. Six samples,

each consisting of 5 whole spears and a reference sample, were placed in a white plastic pan which was divided into sections for each sample. Samples and color scoring sheet were presented to panelists. Tests were carried out in the afternoon between 2:30 to 4:00. About 15 screened panelists were used for these tests.

Instructions Given to Panelists

(A) Color evaluation:

Rate color only, and ignore all other differences. Determine by color comparison with the reference sample the degree of color difference for each numbered test sample.

6: greener than reference.

5: no difference between sample and reference.

4: slight difference between sample and reference.

3: moderate difference between sample and reference.

2: large difference between sample and reference.

1: extreme difference between sample and reference.

As color score decreases, sample has less green color and more yellow color.

(B) Flavor evaluation:

Rate flavor only, and ignore all other differences. A reference sample is provided to indicate good, normal, frozen or canned asparagus flavor. After tasting the reference sample, taste each of the test samples and indicate your preference.

5: as good as reference, or better.

4: good, but not as good as reference.

3: fair, slightly objectionable off flavor.

2: poor, decidedly objectionable off flavor.

1: inedible due to bad flavor.

Statistical Analysis

Significance of differences in various observations of samples were determined by analysis of variance of factorial design with storage conditions, treatments, and time as factors and by Duncan's Multiple Range test wherever differences at the 5% level were found. Analysis of variance was calculated using a computer program (1604 analysis of variance, G4 WISC ANOVA).

Relationships between variables were evaluated by calculating correlation coefficients (r) and linear regression equations. Significance of correlation coefficient was determined by the t-test. Calculations for linear regression equations and correlation coefficients were made using a Wang calculator (Wang Laboratories, Inc., Tewksbury, Mass.) with a Wang series program for linear regression analysis (Wang 520/600 series Program Description).

RESULTS AND DISCUSSION

Bacterial Soft Rot and Off-Odor Development during Storage

Results of preliminary studies summarized in Tables 26, 27, and 28 in Appendix indicated that chlorination at 125°F and butts standing in water were the most effective methods to reduce bacterial soft rot and mold spoilage during storage. Therefore, these two methods were employed in Test Series I and II. Means of duplicate observations on bacterial soft rot and development of off-odor during storage are summarized in Tables 1 and 2. Summaries of the analysis of variance are given in Tables 29 and 30 in Appendix.

It was found in this study that bacterial soft rot (Erwinia carotovora) was a major cause of microbial spoilage of asparagus, though small negligible number of spears showed mold as well. This result agreed with previous findings (Ramsey and Wiant, 1941; Lipton, 1957) that bacterial soft rot was an important market disease of asparagus and recognized as a major factor in microbial deterioration. Results of Test Series I and II shown in Table 29 in Appendix indicated that effect of controlled atmosphere on reducing bacterial soft rot was highly significant. This was in agreement with Lipton's statement (1965) that increasing levels of carbon dioxide reduced the incidence and severity of bacterial soft rot infection at the tips and cut ends of the spears. Lipton also found that oxygen

Table 1.--Development of bacterial soft rot during storage in normal and controlled atmosphere.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
			percent			
8 days	7.3	0	0	0.5	0	0
16	30.4	25.3	2.5	21.0	16.2	10.9
24	68.7	55.5	19.4	42.4	44.1	20.1
32	92.2	89.9	43.5	88.3	85.6	31.7
mean	49.6	42.7	16.3	38.1	36.5	15.8

Duncan's multiple range test at 5% level: N-A, N-B, C-A, C-B, N-C, C-C*

A, B, C

Test Series II (Viking Variety)

Storage perios	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
			percent			
7 days	0	0	0	0	0	0
14	16.0	1.7	1.2	1.2	0.9	0.4
	(2.3)**	(1.8)	(0.5)	(1.0)	(0.5)	(0.5)
21	73.7	66.7	15.8	20.5	44.3	0.4
	(4.0)	(3.8)	(1.8)	(1.5)	(4.0)	(1.0)
28	89.9	98.2	47.4	58.3	87.5	22.7
	(4.8)	(5.0)	(3.0)	(3.5)	(4.8)	(2.0)
mean	44.9	41.6	16.1	20.0	33.1	5.9

Duncan's multiple range test at 5% level: N-A, N-B, C-B, C-A, N-C, C-C

B, A, C

Note: *Batches underlined have no significant differences to each other.

**Number in parenthesis indicates degree of bacterial spoilage. This was not examined in Test Series I.

concentration had little effect on soft rot either in the presence or absence of carbon dioxide.

Effects of storage methods on development of bacterial soft rot were highly significant in both Test Series I and II. Of three storage methods, "Butts standing in water" (C) was the most effective method to reduce bacterial soft rot during storage. The effect of "Chlorinated" (B) was not significantly different from that of "Control" (A) (Table 1).

A Tectrol unit breakdown occurred during the early storage period of Test Series I (from the 6th to 12th day of the storage period), as noted under Materials and Methods. This might have been responsible for the less significance of interaction (Table 30 in Appendix) between atmospheric condition and storage method in Test Series I. This might also have caused the much higher bacterial soft rot in the samples of Test Series I stored in controlled atmosphere, as compared with comparable samples in Test Series II.

In Test Series II, each storage method in controlled atmosphere (C-A, C-B and C-C) had significantly less bacterial soft rot than its corresponding storage method in normal atmosphere (N-A, N-B, and N-C). Similar results were obtained from Test Series I, except "Butts standing in water" (C). In Test Series I, "Control" stored in normal atmosphere (N-A) had the most severe bacterial soft rot in 6 storage batches. "Butts standing in water" stored in the air and controlled atmosphere (N-C and C-C) had significantly less bacterial soft rot than other 4 (N-A, N-B, C-A, and C-B) (Table 1). In Test Series II, bacterial soft rot in "Control" and

"Chlorinated" stored in normal atmosphere (N-A and N-B) was significantly higher than that in other 4 (C-B, C-A, N-C, and C-C) (Table 1). "Butts standing in water" stored in controlled atmosphere (C-C) had least bacterial soft rot of all storage batches.

Capellini (1960) emphasized chlorination (100ppm) and quick cooling of harvested asparagus to maintain quality of asparagus for a considerable length of time. In Test Series I and II, chlorination effect on reducing bacterial soft rot was demonstrated to some extent, especially in normal atmosphere, for first few weeks, but 4 weeks stored asparagus which was chlorinated had more bacterial soft rot than the "Control." This might be due to fact that chlorination at 125°F for 1.5-2 minutes caused some tissue damage, especially skin of asparagus, by heat, which might provide favorable condition for bacterial growth after certain storage period.

From these studies, it was shown that the best method to reduce bacterial soft rot during storage was to store asparagus in controlled atmosphere with "Butts standing in water." Asparagus could be stored for about 3 weeks without a spoilage problem.

Bacterial infection invariably caused the characteristic milky exudate of nauseating odor which degraded fresh quality of asparagus considerably. Controlled atmosphere storage significantly reduced off-odor development, and variation in storage method also gave highly significant differences in both Test Series I and II (Table 30 in Appendix). In Test Series I, "Control" and "Chlorinated" stored in normal atmosphere (N-A and N-B) developed significantly more off-odor than the other four treatments. "Butts

standing in water" (C) had significantly less off-odor development than A and B (Table 2).

In Test Series II, "Chlorinated" stored in normal and controlled atmosphere (N-B and C-B) had markedly more off-odor developed than others. "Butts standing in water" stored in controlled atmosphere (C-C) had significantly less off-odor developed than others (N-B, C-B, N-A, N-C, and C-A) (Table 2).

It was noticed that off-odor of chlorinated asparagus was partially from the chlorine compound used. However, the chlorine off-odor became less noticeable when the other off-odor became stronger. Mercer and Somers (1957) reported that the lowest concentration of chlorine which gave off-odor in asparagus was 50ppm. One hundred to two hundred ppm of chlorine was used in Test Series I and II mainly to reduce bacterial infection, knowing that could cause off-odor in asparagus to some extent.

Since bacterial soft rot usually caused off-odor development in stored asparagus, relationship between development of bacterial soft rot and off-odor was evaluated by linear regression and correlation coefficient. Linear regression equations and correlation coefficients of Test Series I and II are given in Figure 1. This proved that off-odor developed during storage was mainly caused by bacterial soft rot. Correlation coefficients of Test Series I and II were highly significant at 1% level. Objectionable off-odor was detected when about 40% spears was infected by bacterial soft rot. This result might be partly because asparagus was stored in bag with open mouth and off-odor developed was not all accumulated

Table 2.--Off-odor score of asparagus during normal and controlled atmosphere storage.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlorinated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlorinated (I-C-B)	Butts in water (I-C-C)
			score			
8 days	0	0	0	0	0	0
16	1.5	1.5	0	1.0	1.0	0
24	3.0	3.0	1.0	2.3	2.25	0.5
32	4.5	4.8	4.0	3.0	4.25	3.0
mean	2.3	2.3	1.3	1.6	1.9	0.9

Duncan's multiple range test at 5% level: N-B, N-A, C-B, C-A, N-C, C-C

B, A, C

Test Series II (Viking Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlorinated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlorinated (II-C-B)	Butts in water (II-C-C)
			score			
7 days	0	0.5	0	0	0.5	0
14	0	0.5	0	0	0.5	0
21	1.5	3.0	1.5	1.0	2.0	0.5
28	3.5	4.0	1.5	1.5	4.0	1.0
mean	1.3	2.0	0.8	0.6	1.8	0.4

Duncan's multiple range test at 5% level: N-B, C-B, N-A, N-C, C-A, C-C

B, A, C

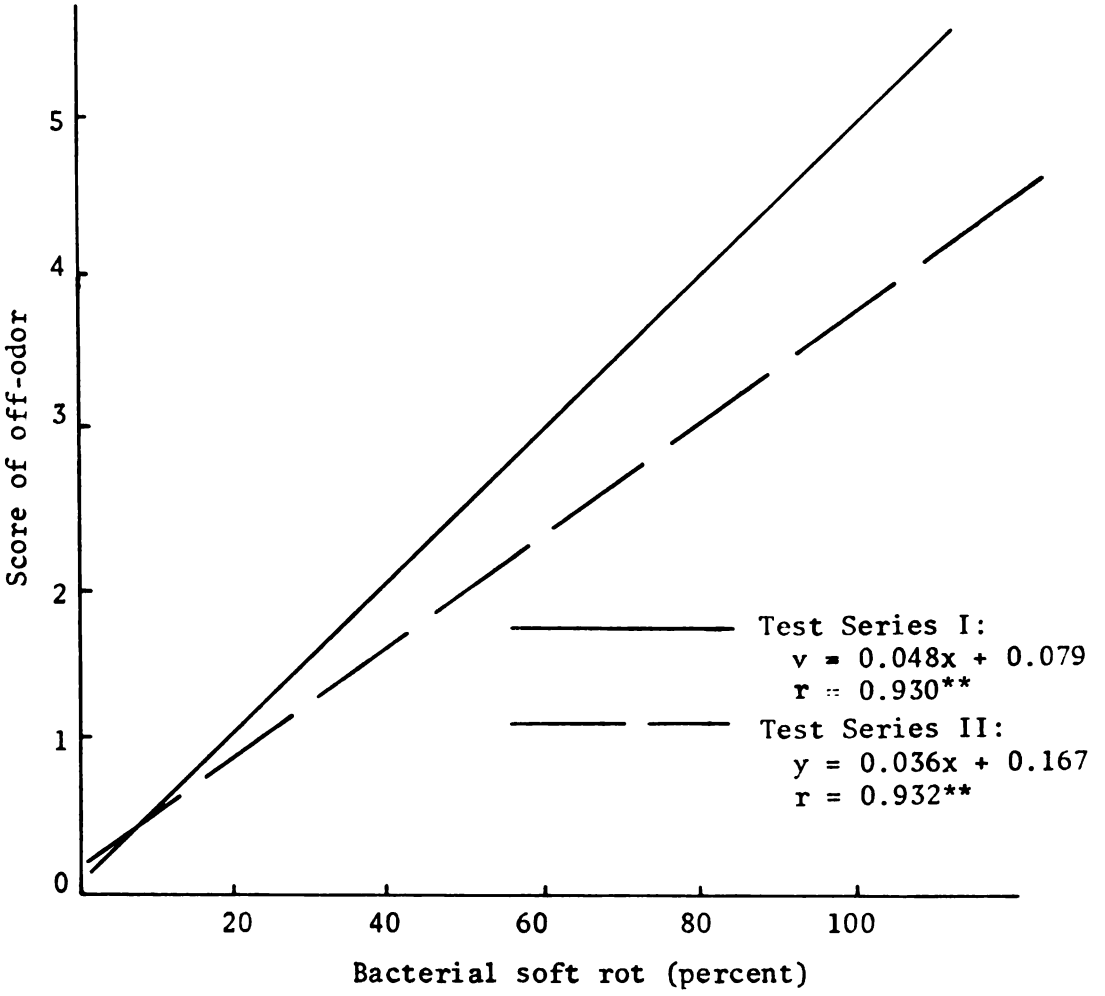

Figure 1.--Relationship between development of bacterial soft rot and off-odor.

in bag, and partly because degree of bacterial infection was not considered here.

Texture Changes

Shear force to cut asparagus was determined at 7.5 and 6 inches from tip of spear using Instron, and expressed as force in pounds. The test was performed on fresh asparagus right after removal from storage. The results (means of 10 measurements) are shown in Table 3, and summaries of analysis of variance are given in Table 31 in Appendix.

Effect of controlled atmosphere as well as interactions on texture during storage was not found in either Test Series I or II (Table 31). The one exception to this was the significant effect of storage method on texture in Test Series I. "Control" (A) had significantly higher shear force than "Chlorinated" (B) and "Butts standing in water" (C) in Test Series I (Table 3). Shear force measured at 7.5 inches from tip increased as storage period was extended in all batches, except "Butts standing in water" (C). Shear force of "Butts standing in water" stored in controlled atmosphere (C-C) decreased during storage and was significantly lower than that of other 5. Though decreasing tendency of shear force during storage was also observed in "Butts standing in water" stored in normal atmosphere (N-C), the average shear force was not significantly different from that of other 4 (except C-C). Since asparagus stored with "Butts standing in water" had stem elongation during storage (about an inch), decrease in shear force measured at

Table 3.--Effect of post harvest storage condition on texture change of asparagus which was measured by Instron (Martha Washington variety).

Test Series I (7.5 inches from tip)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
	pounds force					
0 day	23.2	19.5	23.2	23.2	19.5	23.2
8	25.1	18.6	20.6	26.9	18.6	17.3
16	23.0	21.7	21.0	23.4	22.2	18.2
24	25.5	23.0	22.5	21.9	22.3	18.9
mean	24.2	20.7	21.8	23.9	20.7	19.4

Duncan's multiple range test at 5% level: N-A, C-A, N-C, N-B, C-B, C-C

A, B, C

Test Series I (6 inches from tip)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
	pounds force					
0 day	21.1	18.5	21.1	21.1	18.5	21.1
8	22.2	17.7	17.3	22.6	15.1	12.8
16	19.7	17.6	18.3	19.4	19.2	15.2
24	20.5	19.7	18.7	17.9	19.3	15.7
mean	20.9	18.4	18.9	20.3	18.0	16.2

Duncan's multiple range test at 5% level: N-A, C-A, N-C, N-B, C-B, C-C

A, B, C

Table 3.--Continued.

Viking Variety

Test Series II (7.5 inches from tip)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
	pounds force					
0 day	20.7	18.8	20.7	20.7	18.8	20.7
7	21.6	23.7	20.3	21.1	22.2	22.5
14	22.6	22.2	24.3	20.8	24.1	21.8
21	23.4	21.7	19.5	22.0	19.8	21.3
mean	22.1	21.6	21.2	21.2	21.2	21.6

Duncan's multiple range test at 5% level: N-A, N-B, N-C, C-A, C-B, C-C

A, B, C

Test Series II (6 inches from tip)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C
	pounds force					
0 day	17.9	15.9	17.9	17.9	15.9	17.9
7	17.8	19.0	17.3	18.1	20.6	18.7
14	19.7	18.5	21.1	18.2	19.4	17.5
21	20.3	18.1	17.4	16.4	17.3	18.0
mean	18.9	17.9	18.4	17.7	18.3	18.0

Duncan's multiple range test at 5% level: N-A, N-B, N-C, C-A, C-B, C-C

A, B, C

specific length from tip might be partially attributable to stem elongation. The lower initial shear force in "Chlorinated" (B) must be due to effect of heat during chlorination at 125°F.

Shear force measured at 6 inches from tip slightly decreased, compared with initial values, as storage period was prolonged. However, these decreases were not significant, except "Butts standing in water" stored in controlled atmosphere (C-C). Shear force-differences among 6 batches measured at 6 inches from tip were similar to those measured at 7.5 inches from tip.

In case of Test Series II, shear force measured at 7.5 as well as 6 inches from tip increased in all 6 batches, as storage period was lengthened. No effect of storage method and no significant differences among 6 mean values of shear force were observed. The asparagus used for Test Series II was harvested near the end of season, and had higher initial fiber content than that used for Test Series I. The variety was Viking. These seasonal and varietal differences in raw material might result in slightly different results from those of Test Series I.

Bisson et al. (1926) and Morse (1917) reported that the level of crude fiber was found to increase with time in storage. Thereafter, many researchers indicated that texture of post harvest asparagus became tougher during storage (Carolus et al., 1953; Brennan, 1958; Lipton, 1958). Results of Test Series I and II are in agreement with these previous reports. The modified atmosphere caused tenderness of both raw and cooked asparagus (Carolus et al. (1953), and

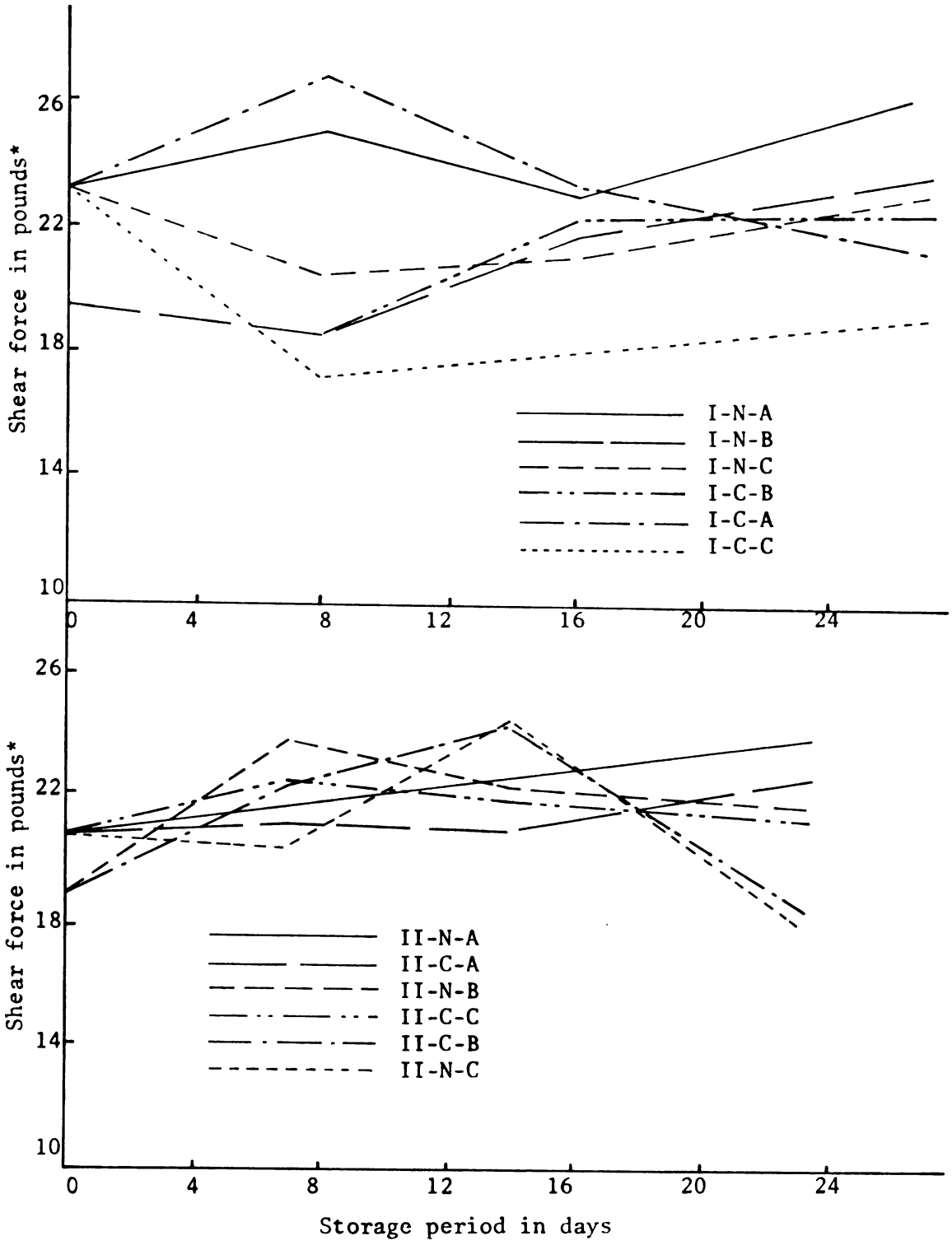

Figure 2.--Texture change of post harvest asparagus during storage.

*Shear force measured at 7.5 inches from tip of spear.

combination of butts standing in water and carbon dioxide gave very marked effects on the tenderness of asparagus.

The significant decrease of shear force during storage in "Butts standing in water" in controlled atmosphere (C-C) in Test Series I, agreed with these findings.

Fiber Changes

Fiber content in 4-inch sections, ranging from 4 to 8 inches from tip of spear, was determined by modification of Smith and Kramer method (or blendor method). The fiber determination was performed on fresh asparagus of Test Series I and II, and frozen asparagus of Test Series I. Fiber content was expressed as percent based on corrected fresh weight. Mean values of duplicate fiber determinations are shown in Tables 4 and 5.

Controlled atmosphere significantly affected the changes in fiber content in asparagus during storage. Asparagus stored in controlled atmosphere developed less fiber than that stored in normal atmosphere. Among the 3 storage methods (A, B, and C), "Butts standing in water" (C) was the best one to retard increase of fiber content in asparagus during storage (Table 4). This result was obtained from both Test Series I and II, even though initial fiber content in asparagus used for Test Series II was higher than that used for Test Series I.

Segerlind (1971) has indicated that asparagus spears grown at an average temperature between 50 - 54°F and 70 - 74°F have a higher percent of fibrous chunks than asparagus grown in the 55 - 70°F. Since asparagus harvested for Test Series II was grown under

Table 4. Changes in fiber content in asparagus during post harvest storage.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
	%, fresh weight basis					
0 day	0.013	0.013	0.013	0.013	0.013	0.013
8	0.025	0.021	0.021	0.019	0.010	0.011
16	0.017	0.020	0.009	0.010	0.009	0.009
24	0.016	0.023	0.008	0.013	0.018	0.008
32	0.014	0.014	0.009	0.006	0.008	0.009
mean	0.017	0.018	0.012	0.012	0.012	0.010

Duncan's multiple range test at 5% level: N-B, N-A, C-A, N-C, C-B, C-C

A, B, C

Test Series II (Viking Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
	%, fresh weight basis					
0 day	0.021	0.022	0.021	0.021	0.022	0.021
7	0.019	0.038	0.018	0.018	0.019	0.021
14	0.024	0.028	0.018	0.017	0.030	0.017
21	0.052	0.046	0.029	0.034	0.031	0.019
28	0.038	0.032	0.023	0.035	0.018	0.015
mean	0.031	0.033	0.022	0.025	0.024	0.019

Duncan's multiple range test at 5% level: N-B, N-A, C-A, C-B, N-C, C-C

B, A, C

unusual cold weather condition of the season, high initial fiber content in asparagus could be partially attributed to abnormal weather.

In Test Series I, all batches stored in controlled atmosphere (C-A, C-B, and C-C) and "Butts standing in water" stored in normal atmosphere (N-C) had significantly lower fiber content than other two batches stored in normal atmosphere (N-A, N-B). However, the differences among mean fiber content of the 4 batches (C-A, N-C, C-B, C-C) were not significant. These findings were confirmed in Test Series II. The minor difference was the fact that fiber content in "Butts standing in water" stored in normal and controlled atmosphere (N-C and C-C) were similar, but fiber content in the latter was significantly lower than that in other 4 (N-B, N-A, C-A, and N-C) (Table 4).

The significant increases in fiber content in asparagus samples which were stored in normal atmosphere, were clearly shown in Test Series I and II, specially in Test Series II (Table 4). These results agreed with those of Bitting (1915), Bisson et al. (1926), Carolus et al. (1953), and Lipton (1957).

In texture study, shear force measured at 7.5 and 6 inches from the tip of spear from "Butts standing in water" stored in controlled atmosphere in Test Series I (I-C-C), significantly decreased as storage period was extended (Table 3). This tendency was again demonstrated in the fiber study; fiber content in "Butts standing in water" stored in controlled atmosphere decreased as storage period was prolonged.

Marked effects of carbon dioxide on the tenderness of asparagus when the asparagus was stored standing in water was reported by researchers (Franklin, 1960; Lipton, 1960; and Lougheed, 1964). Brennan (1958) attributed the effects of carbon dioxide on the increase of tenderness of asparagus that was stored with butts standing in water, to stem elongation. Since the fiber content decreases toward the tip of spear, sampling for fiber at a specific distance from the tip would give a small reduction because of stem elongation. Since there was stem elongation during storage (about an inch), decrease in fiber content observed in asparagus stored with "Butts standing in water" might be partially due to stem elongation in this study also. As asparagus stored standing in water in controlled atmosphere took up the maximum water, Franklin et al. (1960) developed the theory that the uptake of water by itself might tenderize asparagus as measured by tenderometer.

Carolus et al. (1953) stated that the increase in tenderness might be due to breakdown of fiber, and they found that fiber levels decreased with increasing carbon dioxide levels. However, Lougheed and Dewey (1966) indicated that most of the tenderizing effects appeared to be the result of a breakdown of intercellular components, even though a small portion of the tenderizing effect was attributable to high turgidity due to water uptake.

Fiber content in frozen asparagus was studied in Test Series I and the results which are expressed as percent based on weight of frozen sample, are shown in Table 5. Since blanching caused weight loss, fiber content in frozen asparagus appeared higher than that

Table 5.--Effect of post harvest storage on fiber content in frozen asparagus.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
	%, sample weight basis					
0 day	0.024	0.026	0.024	0.024	0.026	0.024
8	0.026	0.034	0.037	0.020	0.032	0.017
16	0.038	0.028	0.018	0.016	0.019	0.015
24	0.027	0.029	0.015	0.018	0.030	0.019
32	0.025	0.026	0.019	0.016	0.021	0.017
mean	0.028	0.029	0.023	0.019	0.026	0.018
Duncan's multiple range test at 5% level:			N-B, N-A, C-B, N-C, C-A, C-C			

B, A, C

in fresh asparagus. The results obtained from frozen asparagus were quite similar to those of fresh asparagus. Effect of atmosphere and storage methods were highly significant in this study also (Table 32 in Appendix), but interactions were more highly significant in frozen than in fresh asparagus.

Fiber content in "Chlorinated" stored in normal atmosphere (N-B) was not significantly higher than that in "Control" stored in normal atmosphere (N-A), but was significantly higher than that in the other 4 batches (C-B, N-C, C-A, and C-C) (Table 5). Fiber content in "Control" and "Butts standing in water" stored in controlled atmosphere (C-A and C-C), which were not markedly different from each other, were significantly lower than the other 4 samples (N-B, N-A, C-B, N-C). Decrease of fiber content during storage in controlled atmosphere was shown in frozen asparagus, specially "Butts standing in water" stored in controlled atmosphere (C-C). In normal atmosphere, increase of fiber content in frozen asparagus, as storage period of fresh asparagus was prolonged, was observed, except "Butts standing in water" (N-C). Therefore, changes in fiber content shown up in fresh asparagus during post-harvest storage also appeared in frozen asparagus.

Since texture of asparagus is very much associated with fiber content, relationship between fiber content measured by blendor method and shear force measured by Instron at 7.5 and 6 inches from tip of shear was evaluated by linear regression equation and correlation coefficient. The results are shown in Figure 3. In Test Series I, increase of shear force was proportional, to some extent, to increase

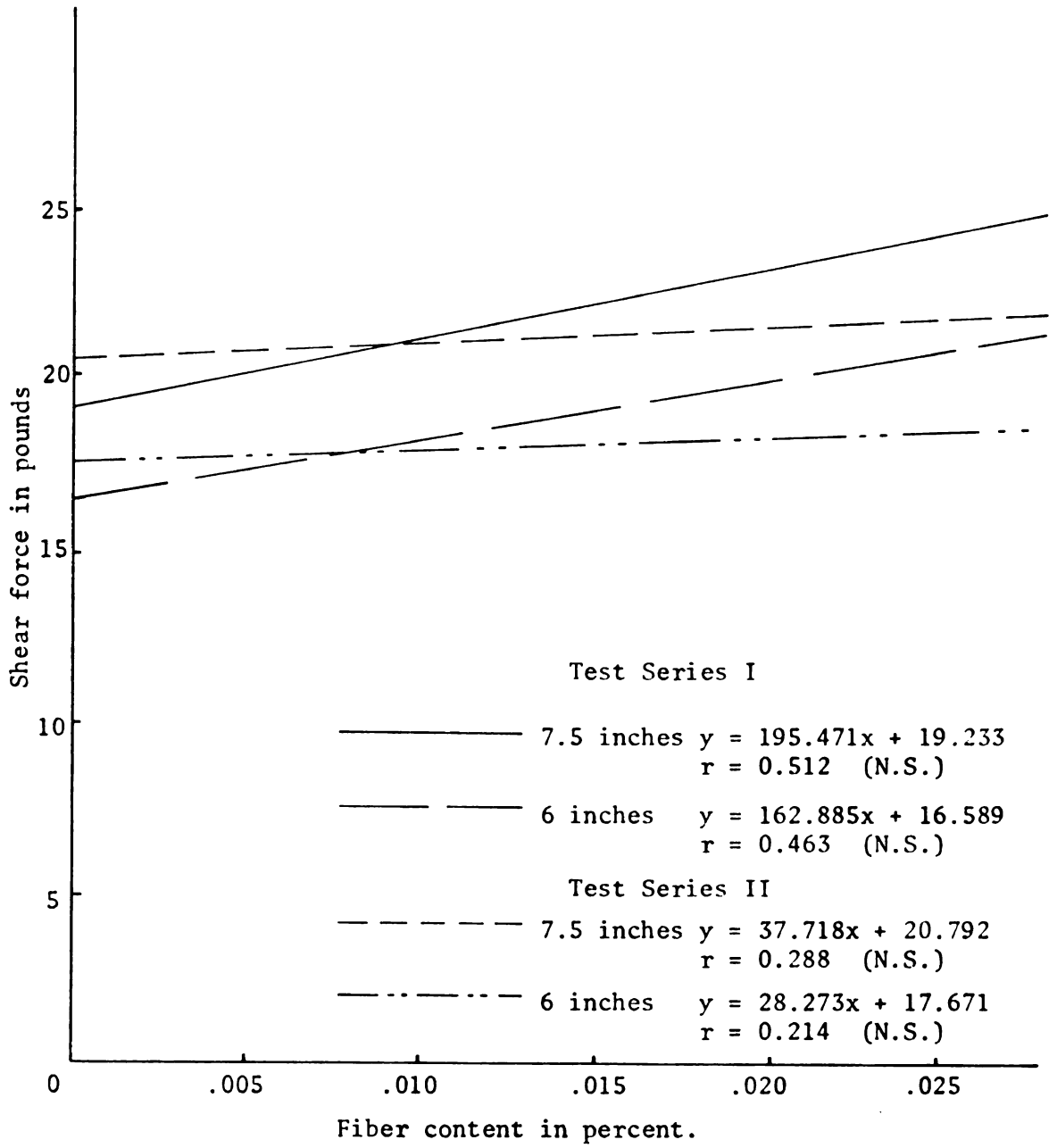

Figure 3. Relationship between fiber content in asparagus and shear force to cut spear measured at 7.5 inches and 6 inches from tip of spear.

of fiber content in spears. Slopes of two linear regression equations, one between fiber content and shear force at 7.5 inches from tip and the other at 6 inches from tip, were similar. Correlation coefficients of these two correlations were not significant. Linear regression equations calculated from Test Series II had flat slopes, indicating that the rate of increase in shear force as increase in fiber content was very small. Correlation coefficients between fiber content and shear force at 7.5 and 6 inches from tip of spear were both not significant.

The material recovered with the blendor method consists of all elements, regardless of origin, too large to pass through 30 mesh screen after maceration. The weight of these elements is, therefore, a measure of the total quantity of fibrous material present without reference to either type or distribution in spear (Lipton, 1957).

On the other hand, shear force recorded by Instron may reflect the resistance to cutting encountered near the surface of a spear. The degree of this resistance seems primarily a function of the nature of perivascular fibers. Factors of consequence appear to be their degree of lignification, type of lignin present, cell wall thickness, and the arrangement of the fibrous layer. It is suggested that the poor correlation between fiber content by the blendor method and shear force measured by Instron may be partially due to the fact that the different variables which influence fibrousness of spear in different ways are measured by the two methods.

Segerlind (1971) studied shear force related as function of diameter of spears. Shear force = 17.5 + 2.5 (diameter in sixteenths

of an inch). This clearly indicates that spears with uniform diameter should be chosen as sample to get reasonable results.

Changes in Chlorophyll Content

Chlorophyll a, b, and total chlorophyll were determined by a modification of Vernon's methods. In this study, extraction of chlorophyll was performed twice, because blending sample once at high speed for 3 minutes and washing with 80% acetone in sintered glass filter did not completely extract pigments, specially when asparagus was stored for a long period.

Sample was first blended with 80ml. of acetone for 1.5 minutes and filtered through a sintered glass filter. The residue after filteration, which still contained some chlorophyll, was blended with 40ml of 80% acetone for 1.5 minutes. This was filtered, then washed with 80% acetone. After second extraction, the absorptivities of filtrate from washing portion at 645, 662, 666nm. were negligible (Table 6). Chlorophyll content was determined in fresh asparagus of

Table 6. Absorbance of series of chlorophyll extracts.

Series of extraction	Absorbance			
	645nm	662nm	666nm	750nm
First	0.328	0.725	0.815	0.001
Second	0.035	0.077	0.084	0.001
Washing	0.003	0.005	0.006	0.001

Test Series I and II and in frozen asparagus of Test Series II. The mean values of duplicate determinations are shown in Tables 7, 8, and 9. Summaries of analysis of variance for total chlorophyll content are given in Table 33 in Appendix.

Effect of controlled atmosphere on retention of chlorophyll in asparagus was highly significant in Test Series II, while was not in Test Series I (Table 33 in Appendix). Difference between storage methods (A and C) was not observed in Test Series I, but markedly significant difference between storage methods was shown in Test Series II. These might be due to failure to maintain controlled atmosphere for 6 days because of Tectrol unit breakdown in Test Series I. However, more highly significant interactions were found in Test Series I than in Test Series II.

Initial chlorophyll content in asparagus of Martha Washington variety was much higher than that of Viking variety. More chlorophyll destruction during storage was observed in Test Series I than in Test Series II. In Test Series I (Table 7), chlorophyll content decreased rapidly during storage and over 50% of chlorophyll b was destroyed in 16 days. Further decrease in chlorophyll b content after 16 days storage was not considerable. However, destruction of chlorophyll a was rather steady, though more destruction of chlorophyll a occurred during the early period of storage. Therefore, chlorophyll a/b ratio increased as storage period was prolonged.

In "Control" (A), the rate of chlorophyll b destruction was similar either in controlled atmosphere or in normal atmosphere,

Table 7.--Changes in chlorophyll content during post-harvest storage of asparagus: Test Series I (Martha Washington Variety).

Storage period	Normal Atmosphere						Controlled Atmosphere					
	Control (I-N-A)			Butts in water (I-N-C)			Control (I-C-A)			Butts in water (I-C-C)		
	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll
0 day	34.6	18.5	53.1	34.6	18.5	53.1	34.6	18.5	53.1	34.6	18.5	53.1
8	29.3	15.5	44.8	29.8	17.0	46.8	33.7	13.3	47.0	30.1	10.3	40.4
16	24.8	9.8	34.6	25.2	9.2	34.4	28.1	9.5	37.6	24.6	8.7	33.3
24	23.6	8.1	31.7	23.9	8.1	32.1	25.2	8.6	33.7	22.7	8.7	31.4
32	15.9	6.6	22.5	20.8	8.1	28.9	23.4	9.3	32.7	22.7	8.5	31.2
mean			37.4			38.9			40.8			37.9
Duncan's multiple range test at 5% level:				C-A, N-C, C-C, N-A								
				A, C								

Note: Unit of chlorophyll content: mg/100 g. of corrected fresh weight.

but the rate of chlorophyll a destruction was less in controlled atmosphere than in normal atmosphere, which resulted in higher chlorophyll a/b ratio in controlled atmosphere. But this trend was not obvious in "Butts standing in water."

About 50% of total chlorophyll was destroyed after 32 days storage in normal atmosphere, compared with about 40% of total chlorophyll in controlled atmosphere. Similar results were obtained from Test Series II. However, the rate of chlorophyll destruction was less in Test Series II (Table 8 and Figure 4). After 4 weeks storage, about 35% of total chlorophyll was destroyed in normal atmosphere, compared with about 29% in controlled atmosphere.

Effect of controlled atmosphere over normal atmosphere was significantly shown in Test Series II, and Table 8 also showed that "Butts standing in water" (C) was better than "Control" (A) to maintain higher chlorophyll content, either in controlled atmosphere or in normal atmosphere. There was no significant difference between total chlorophyll content in "Butts standing in water" (C-C) and "Control" (C-A) stored in controlled atmosphere, but total chlorophyll content in the former was significantly higher than other 2 stored in normal atmosphere (N-A and N-C).

In Test Series II, total chlorophyll content steadily decreased till third week of storage, and then minor changes in chlorophyll content were observed (Figure 4). The results indicating effect of controlled atmosphere on maintaining higher chlorophyll content were in agreement with findings of Lyons and Rappaport (1962), Groeschel (1966), and Wang (1971). Lyons and Rappaport

Table 8.--Changes in chlorophyll content during post-harvest storage of asparagus: Test Series II (Viking Variety).

Storage period	Normal Atmosphere						Controlled Atmosphere					
	Control (II-N-A)			Butts in water (II-N-C)			Control (II-C-A)			Butts in water (II-C-C)		
	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll
0 day	26.6	13.1	39.7	26.6	13.1	39.7	26.6	13.1	39.7	26.6	13.1	39.7
7	24.5	10.2	34.7	25.0	10.5	35.6	24.9	10.7	35.7	26.0	10.0	36.0
14	22.7	8.0	30.7	23.3	8.3	31.6	23.8	8.7	32.5	26.1	8.6	34.7
21	19.1	6.5	25.6	20.8	7.3	28.1	21.3	7.2	28.5	21.7	7.5	29.2
28	18.4	7.2	25.5	20.2	6.3	26.5	20.6	7.6	28.2	20.7	7.8	28.6
mean			31.1			32.3			32.9			33.7
Duncan's multiple range test at 5% level (total chlorophyll):				C-C, C-A, N-C, N-A								
				C, A								

Note: Unit of chlorophyll content: mg/100g. of corrected fresh weight.

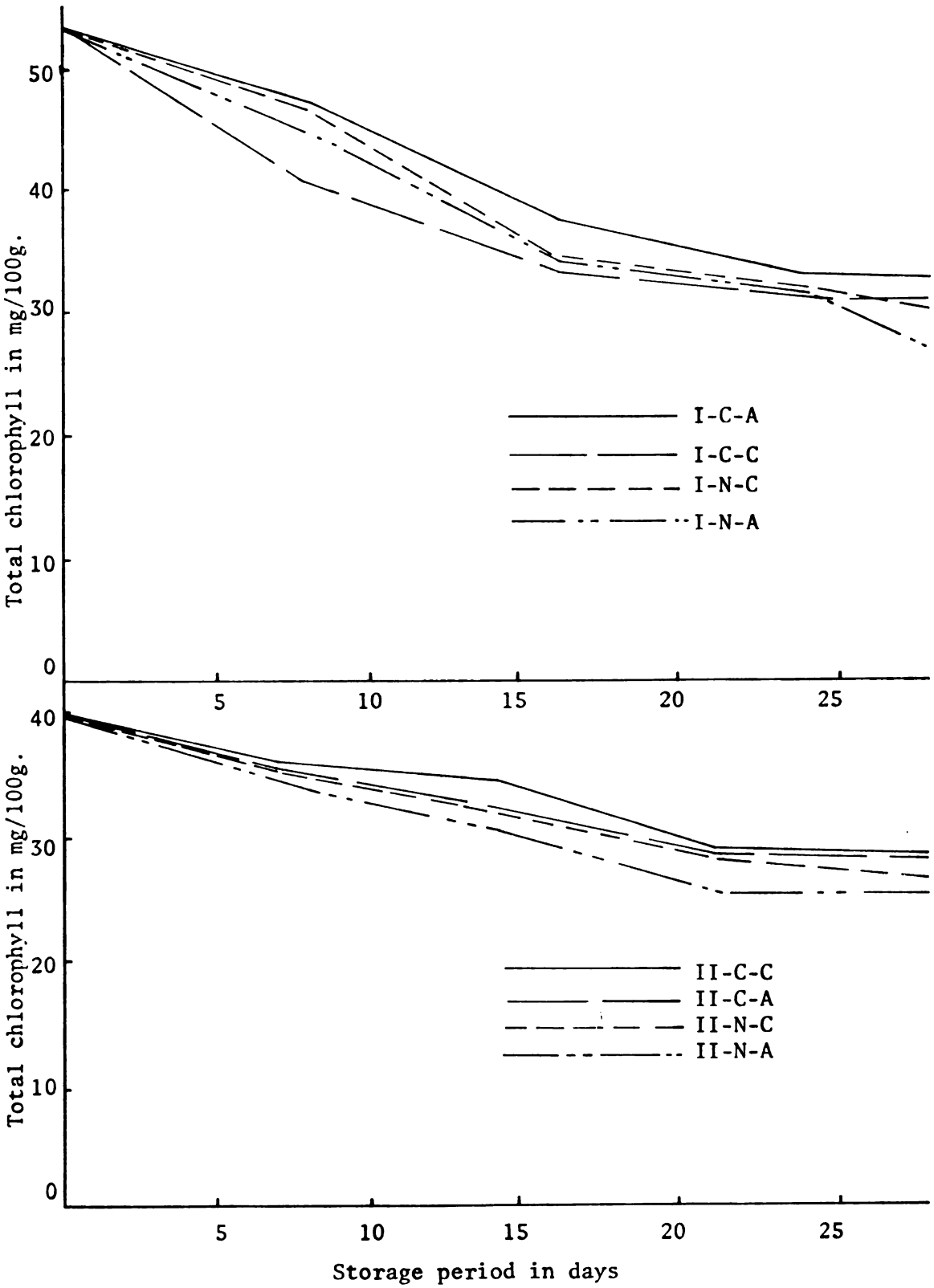

Figure 4.--Changes in total chlorophyll content during storage.

(1962) reported that changes in the color of Brussels sprouts depended on storage temperature, carbon dioxide and oxygen concentration. Groeschel (1966), in his study on effect of controlled atmosphere on green beans, concluded that the greatest advantage of controlled atmosphere storage for beans lay in improving the color of the product by retarding chlorophyll breakdown. Recently, Wang (1971) reported that there was more retention of chlorophyll in the controlled-atmosphere stored asparagus. He also stated that the degradation products of chlorophylls in asparagus stored in the controlled atmosphere were exclusively the pheophytins.

Effect of controlled atmosphere on chlorophyll retention in frozen asparagus was also studied in Test Series II. This was mainly to see whether storage effect would remain in product after freezing. It was found that highly significant effect of controlled atmosphere storage on chlorophyll retention, which was shown in fresh asparagus, was completely masked by freezing process. Moreover, asparagus stored in normal atmosphere had significantly higher chlorophyll content than in controlled-atmosphere (Table 9). Amount of chlorophyll destruction during storage was less in frozen samples than in fresh ones (compare Figure 4 with Figure 5). This might be due to destruction of chlorophyll by blanching and freezing process. About 22% of chlorophyll was destroyed by blanching and freezing. "Control" stored in normal atmosphere (N-A) had significantly higher total chlorophyll content than that stored in controlled atmosphere (C-A), but did not have significantly higher total chlorophyll

Table 9.--Effect of post-harvest storage on changes in chlorophyll content in frozen asparagus: Test Series II (Viking Variety).

Storage period	Normal Atmosphere						Controlled Atmosphere					
	Control (II-N-A)			Butts in water (II-N-C)			Control (II-C-A)			Butts in water (II-C-C)		
	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll
0 day	22.4	7.7	30.1	22.4	7.7	30.1	22.4	7.7	30.1	22.4	7.7	30.1
7	21.9	7.0	28.9	20.0	6.8	26.8	18.3	6.5	24.8	18.2	6.2	24.4
14	17.9	6.3	24.2	18.4	6.6	25.0	19.2	6.4	25.5	18.0	6.7	24.7
21	17.2	6.5	23.8	17.8	6.4	24.2	18.7	6.5	25.3	16.2	7.6	23.8
28	14.8	6.9	21.7	15.4	6.8	22.2	12.6	5.8	18.4	16.6	6.8	23.4
mean			25.9			25.7			24.8			25.3
Duncan's multiple range test at 5% level (total chlorophyll):					N-A, N-C, C-C, C-A							

Note: Unit of chlorophyll content: mg/100g. of sample.

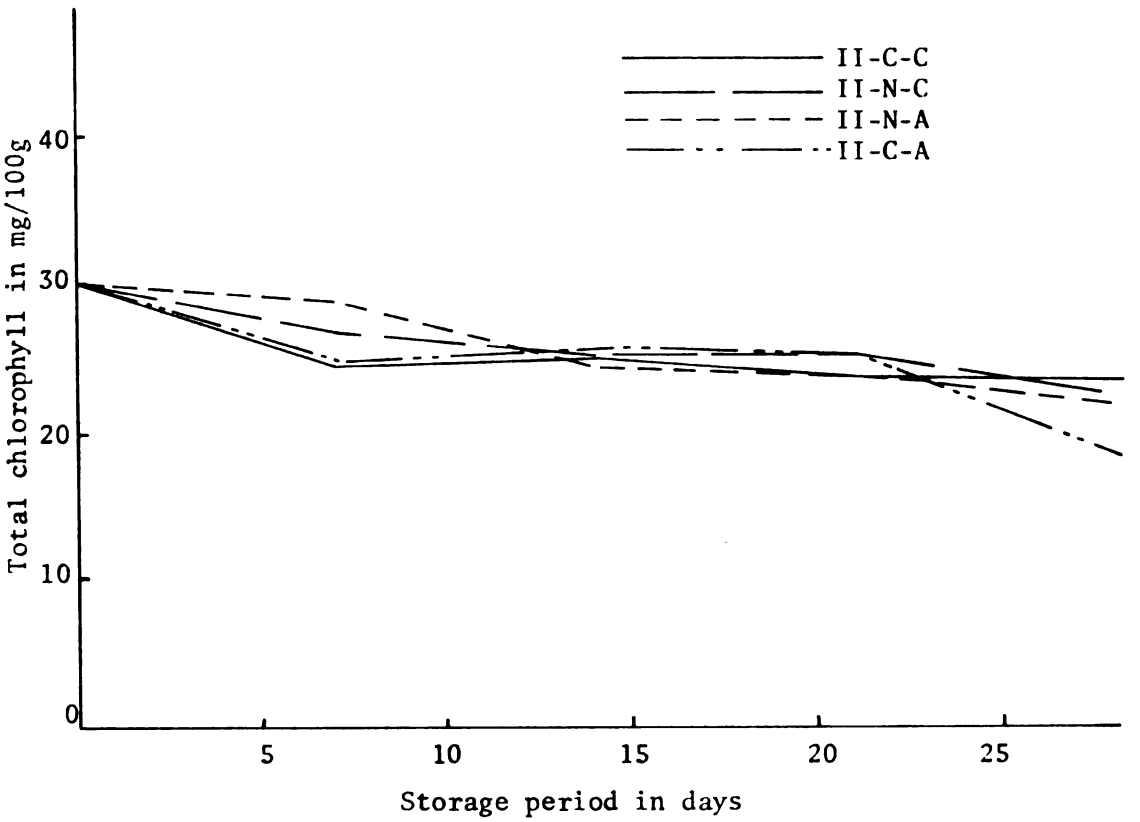

Figure 5.--Changes in total chlorophyll content in frozen asparagus.

content than "Butts standing in water" either stored in normal atmosphere (N-C), or in controlled atmosphere (C-C) (Table 9).

The mechanism of chlorophyll retention in controlled atmosphere is not well understood. Michael (1935), Wood et al. (1943), and James (1953) suggested that breakdown of the protein which is attached to the chlorophyll molecule within the chloroplasts removes the natural protection it affords the chlorophyll, and chlorophyll becomes labile. It was found that protein breakdown in asparagus was less as oxygen concentration in storage atmosphere decreased. Groeschel et al. (1966), and Wang (1971) found that the better retention of chlorophyll in the modified atmosphere stored sample was always accompanied by a higher pH than in the air stored samples. These results suggest that conversion of chlorophyll to pheophytin is a function of tissue pH. The yellow color of pheophytins contributes to large extent to yellowing of asparagus during storage.

Yellowing of asparagus, however, may be partially due to the presence of yellow pigments other than pheophytin. These yellow pigments which are masked by chlorophyll color reveal their yellow color as masking effect of chlorophyll is reduced by chlorophyll destruction. This is more obvious in processed asparagus.

Czukor and Aczel (1970) studied the effect of blanching and sterilization processes on the color of peas and found that 10-16% of chlorophyll was lost by blanching and chlorophyll completely disappeared after sterilization, while the yellow pigments, like carotenes and xanthophylls, were not affected. Complete destruction of chlorophyll in peas by sterilization was also reported by Aczel (1971).

Color of Asparagus

Reflectance color was measured using Hunter Color and Color Difference Meter on triplicate samples. Fresh spears were cut into 6-inch sections, ranging 2 to 8 inches from tips and filled in sample box, which was made of plexiglas, to measure reflectance color. Reflectance color of canned asparagus was measured using glass cell after spears in can were drained for 2 minutes. Frozen asparagus was thawed for 12 hours at 40°F and filled in glass cell to measure reflectance color. Results on reflectance color of these 3 types of asparagus are discussed separately.

Color of Fresh Asparagus

Reflectance color of fresh asparagus was measured right after removal of samples from storage. Mean values of triplicate measurements are shown in Table 10 and summaries of analysis of variance in Tables 34 and 35 in Appendix. The Hunter Color values were reduced to -a/b, a function of hue, and $\sqrt{a^2 + b^2}$, a function of chroma.

Effect of controlled atmosphere on L value (lightness) of fresh asparagus was not found in either Test Series I or II, but effect of storage methods on L value was highly significant in both Test Series I and II (Tables 34 and 35). "Chlorinated" asparagus (B) had markedly lower L value than other two (A and C) in both tests (Table 11). Mercer (1957) stated that chlorine up to 60ppm did not affect asparagus color. Since asparagus was treated at higher concentration of chlorine at 125°F, effect of heat and

Table 10.--Changes in reflectance color of fresh asparagus during storage: Test Series I (Martha Washington Variety).

Storage period	Normal Atmosphere														
	Control (I-N-A)					Chlorinated (I-N-B)					Butts in water (I-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	39.5	10.0	16.9	0.60	19.7	38.4	10.9	17.5	0.62	20.6	39.5	10.0	16.9	0.60	19.7
8	39.7	9.3	16.5	0.55	18.9	37.8	9.8	16.2	0.60	18.9	38.6	10.0	16.4	0.62	19.0
16	40.0	9.9	17.4	0.51	20.0	38.7	10.2	16.6	0.62	19.5	41.3	9.7	16.8	0.57	19.4
24	40.6	9.8	17.1	0.58	19.7	40.1	10.3	17.8	0.58	20.6	42.5	10.0	17.6	0.57	20.2
32	41.1	10.2	18.2	0.56	20.8	40.7	10.2	18.2	0.56	20.9	41.4	9.5	18.4	0.52	20.7
mean	40.2			0.57	19.83	39.2			0.60	20.10	40.7			0.57	19.80
	Controlled Atmosphere														
Storage period	Control (I-C-A)					Chlorinated (I-C-B)					Butts in water (I-C-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	39.5	10.0	16.9	0.60	20.6	38.4	10.9	17.5	0.62	19.7	39.5	10.0	16.9	0.57	20.6
8	37.6	9.5	16.5	0.58	19.3	38.4	9.6	16.8	0.56	19.4	39.5	10.2	17.2	0.59	19.8
16	40.7	9.9	17.1	0.58	19.8	39.4	10.3	17.1	0.61	19.6	40.3	10.1	16.8	0.61	19.6
24	42.2	10.3	17.9	0.57	20.7	39.5	10.2	17.0	0.60	19.8	39.5	10.2	16.8	0.60	19.7
32	42.3	10.4	18.8	0.55	21.5	40.2	9.1	17.4	0.53	19.6	41.0	10.4	18.2	0.57	21.0
mean	40.5			0.58	20.35	39.2			0.58	19.61	40.0			0.59	20.13

Table 10.--Continued.

Storage period	Test Series II (Viking Variety)														
	Normal Atmosphere														
	Control (II-N-A)					Chlorinated (II-N-B)					Butts in water (II-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	40.4	8.6	17.7	0.49	19.8	41.1	8.7	17.9	0.49	19.7	40.4	8.6	17.7	0.49	19.8
7	40.5	8.5	17.4	0.49	19.4	40.1	9.0	17.9	0.53	19.2	41.6	9.0	18.0	0.50	20.1
14	42.0	9.0	18.3	0.49	21.1	40.2	9.0	18.7	0.51	17.7	41.7	8.5	17.9	0.48	19.8
21	41.7	9.1	18.6	0.49	20.7	40.9	9.4	18.9	0.50	21.1	41.9	8.6	18.2	0.47	20.1
28	42.6	8.9	19.8	0.45	21.7	41.6	9.3	19.1	0.49	21.2	42.0	8.2	18.0	0.45	19.9
mean	41.5			0.48	20.52	40.6			0.50	19.80	41.5			0.48	19.96
	Controlled Atmosphere														
Storage period	Control (II-C-A)					Chlorinated (II-C-B)					Butts in water (II-C-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	40.4	8.6	17.7	0.49	19.8	41.1	8.7	17.9	0.49	19.7	40.4	8.6	17.7	0.49	19.8
7	40.1	8.9	16.7	0.53	18.9	39.2	8.2	16.4	0.50	18.3	41.6	9.0	17.6	0.51	19.7
14	40.3	8.6	16.6	0.52	18.7	40.1	8.0	16.3	0.49	18.2	41.2	9.4	18.3	0.52	20.6
21	40.6	9.0	18.0	0.50	20.2	41.0	9.0	18.0	0.50	20.1	41.5	9.9	18.8	0.53	21.2
28	41.8	9.0	18.2	0.49	20.2	40.1	9.1	18.0	0.50	20.2	41.4	9.9	18.5	0.54	21.0
mean	40.7			0.51	19.56	40.3			0.50	19.3	41.22			0.52	20.46

Table 11.--Duncan's multiple range test at 5% level to compare mean values of reflectance color among 6 samples.

Test Series I

Color	Difference among 6 means	Difference among 3 treatments
L	N-C, C-A, N-A, C-C, C-B, N-B	C, A, B
-a/b	N-B, C-C, C-B, C-A, N-C, N-A	B, C, A
$\sqrt{a^2+b^2}$	C-A, C-C, N-B, N-A, N-C, C-B	A, C, B

Test Series II

Color	Difference among 6 means	Difference among 3 means
L	N-C, N-A, C-C, C-A, N-B, C-B	C, A, B
-a/b	C-C, C-A, N-B, C-B, N-A, N-C	A, B, C
$\sqrt{a^2+b^2}$	N-A, C-C, N-C, N-B, C-A, C-B	C, A, B

chlorine caused lower L value of "Chlorinated" asparagus (B). Generally, L value increased during storage.

Since asparagus gradually gained yellowness during storage, the increase of L value might be caused by increase of yellowness and decrease of green pigments. "Butts standing in water" stored in normal atmosphere (N-C) which did not have significantly different L value from "Control" stored in controlled atmosphere and normal atmosphere (C-A and N-A) had higher L value than other 3 batches. "Chlorinated" stored in controlled atmosphere and normal atmosphere (N-B and C-B) had markedly lower L values than other batches in both Test Series I and II (Table 11).

A function of hue, -a/b, generally decreased during storage. This trend was more obvious in Test Series I than II in which -a/b slightly increased in samples stored in controlled atmosphere. This decrease was not due to decrease of a value, but mainly due to increase of b value during storage. Effect of controlled atmosphere on -a/b was not shown in Test Series I, but was highly significant in Test Series II. In other words, color change from green towards yellowish green was markedly less in asparagus stored in controlled atmosphere. This difference between two experiments could be due to Tectrol unit breakdown for 6 days in Test Series I. It was found that effects of interactions among atmosphere, storage method, and time on -a/b were statistically significant (Tables 34 and 35).

"Control" (A) had markedly lower mean -a/b value than other two (B and C) in Test Series I, but there was no difference among

3 batches in Test Series II (Table 11). Difference of mean -a/b among 6 batches were more obvious in Test Series II than in Test Series I.

"Butts standing in water" stored in controlled atmosphere (C-C) had significantly higher -a/b value than other 5 (C-A, N-B, C-B, N-A, and N-C), and "Control" and Butts standing in water" stored in normal atmosphere (N-A and N-C) had significantly lower -a/b value than others. These differences of -a/b value among sample were similar to those of total chlorophyll content among batches (Table 9). "Control" and "Butts standing in water" stored in controlled atmosphere (C-A and C-C) had obviously higher -a/b values than same stored in normal atmosphere (N-A and N-C), but this difference was not shown in "Chlorinated" (B) (Table 11).

A function of chroma, $\sqrt{a^2 + b^2}$, increased during storage and this increase was mainly due to increase of b values (yellowness). There was no controlled atmosphere-effect on $\sqrt{a^2 + b^2}$ in Test Series I, but the effect was highly significant in Test Series II (Tables 34 and 35). This difference between Test Series could be attributable to the same reason as in case of -a/b. However, effects of storage method and interactions were very clear in both Test Series.

In Test Series II, "Butts standing in water" (C) had significantly higher $\sqrt{a^2 + b^2}$ than others (A and B) and "Chlorinated" (B) lower $\sqrt{a^2 + b^2}$ than others (C and A) (Table 11). This was not clear in Test Series I, and "Control" (A) had significantly higher $\sqrt{a^2 + b^2}$ than "Chlorinated" (B), but not "Butts standing in water" (C). These results indicated that "Chlorinated" asparagus (B) had darker green color with less glossiness. "Butts standing in water" stored in

controlled atmosphere (C-C) was the best method to maintain greener and glossy appearance of fresh asparagus.

Tristimulus values of Hunter Color and Color Difference Meter were further reduced to one value, ΔE. $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$, which indicates total color difference between samples. Tristimulus values of 0 day-control sample was taken as initial values of fresh asparagus, and then color difference between initial sample of control and series of stored samples were calculated. The results of calculated total color difference, ΔE, are shown in Table 12 and Figure 6.

Generally, there was more increase of total color difference in Test Series I than in Test Series II. Except "Chlorinated" (B), total color difference increased as storage period was prolonged. In case of "Chlorinated" (B) batches, reflectance color of initial chlorinated asparagus had lower L and a, and higher b than those of control. This might be due to combination effect of chlorine and heat during chlorination. Therefore, ΔE of initial sample of "Chlorinated" (B) was higher than others. This total color difference induced by chlorination treatment decreased for about 15 days storage period and then total color difference increased.

In Test Series I, "Control" stored in controlled atmosphere (C-A) and "Butts standing in water" stored in normal atmosphere (N-C) had quite marked increase in total color difference during storage, whereas "Butts standing in water" and "Chlorinated" stored in controlled atmosphere (C-B and C-C) maintained small increase in total color difference during storage. It was found in Test Series II that asparagus stored in controlled atmosphere had

Table 12.--Changes in total color difference, ΔE, during storage of harvest asparagus.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
0 day	0.0	1.5	0.0	0.0	1.5	0.0
8	0.5	1.8	1.0	2.0	1.2	0.4
16	0.7	0.9	1.8	1.2	0.4	0.8
24	1.1	1.1	3.1	2.9	0.2	0.2
32	2.1	1.8	2.5	3.4	1.2	2.0

Test Series II (Viking Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
0 day	0.0	0.7	0.0	0.0	0.7	0.0
7	0.03	0.5	1.3	1.1	1.8	1.3
14	1.8	1.1	1.3	1.1	1.6	1.3
21	1.7	1.5	1.6	0.5	0.8	2.0
28	3.1	2.0	1.7	1.5	0.7	1.8

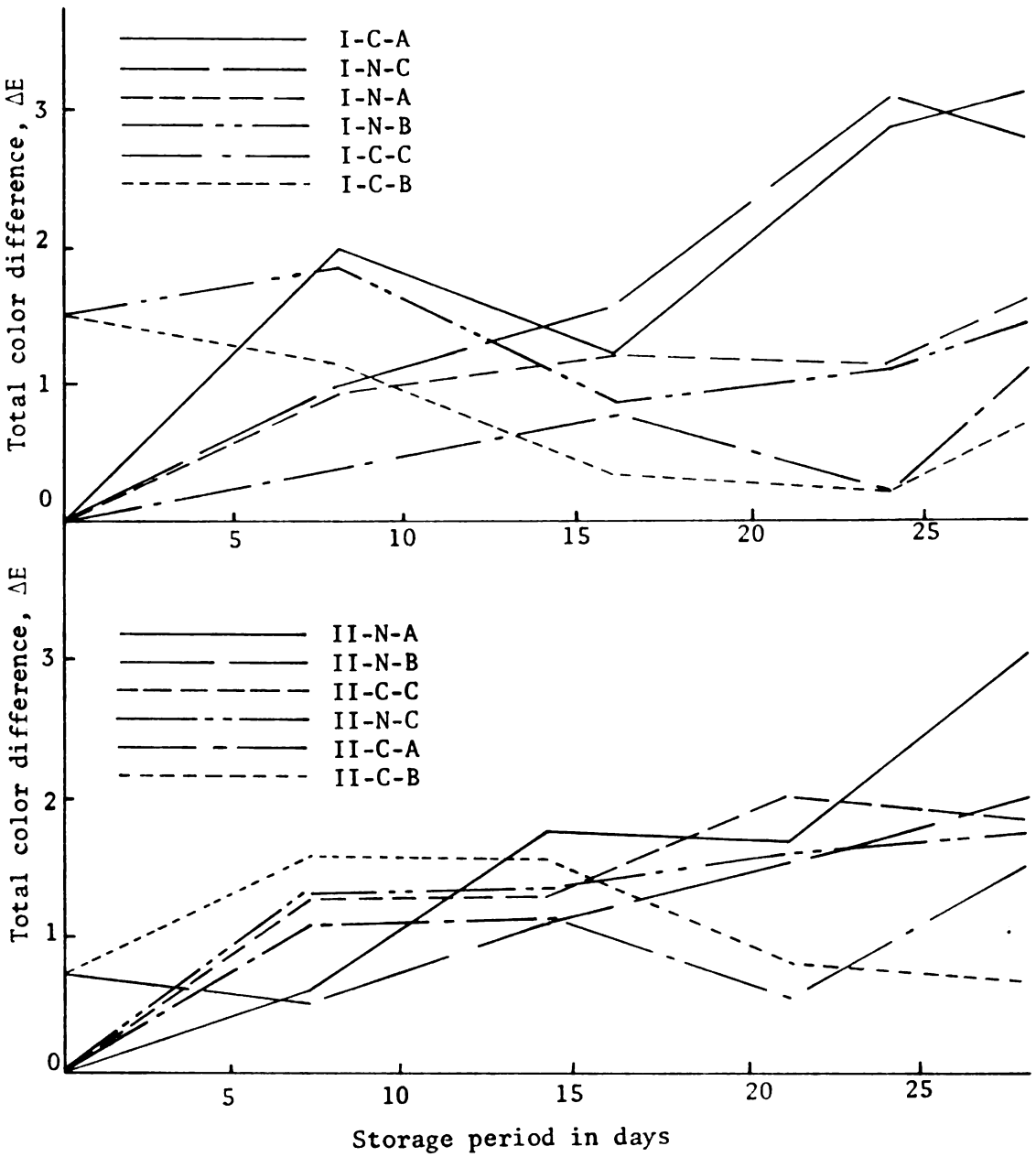

Figure 6.--Changes in total color difference during storage of post harvest asparagus.

less increase in total color difference than that stored in normal atmosphere. Sharp increase of total color difference after 3 weeks storage might also be caused by bacterial soft rot.

The relationship between reflectance color and chlorophyll content was examined and the results are shown in Table 13. Chlorophyll content correlated highly significantly with L value of reflectance color. Correlation coefficients between chlorophyll a, chlorophyll b, and total chlorophyll, and L value, were highly significant in Test Series I and II (Table 13). However, correlation coefficients between total chlorophyll and L value were slightly higher than those between chlorophyll a or chlorophyll b and L value. Negative correlation coefficients indicated that L value increased as chlorophyll content decreased. The increase of L which was observed in both tests, therefore, was mainly associated with decrease of chlorophyll in asparagus as storage period was prolonged.

Relationship between chlorophyll content and -a/b, a function of hue, was also evaluated. Linear regression equations between chlorophyll a, chlorophyll b, and total chlorophyll and -a/b and correlation coefficients of these correlations are shown in Table 13. Correlation coefficients of these correlations were not significant in either Test Series I or II, except one between total chlorophyll and -a/b in Test Series II. These results might indicate that changes in hue (-a/b) of asparagus during storage were influenced considerably by some other pigments, like anthocyanins, rutins etc. These results are in disagreement with these shown by Gold and

Table 13.--Correlation between chlorophyll content and reflectance color.

Chlorophyll	Versus	Reflectance color	Linear regression equation	Correlation coefficient
Test Series I (Martha Washington Variety)				
Chlorophyll a	vs.	L	$y = -0.212x + 45.976$	$r = -0.681^{**}$
Chlorophyll b	vs.	L	$y = -0.246x + 42.999$	$r = -0.653^{**}$
Total chlorophyll	vs.	L	$y = -0.129x + 45.169$	$r = -0.717^{**}$
Chlorophyll a	vs.	-a/b	$y = 0.002x + 0.513$	$r = 0.440^{N.S}$
Chlorophyll b	vs.	-a/b	$y = 0.002x + 0.552$	$r = 0.371^{N.S}$
Total chlorophyll	vs.	-a/b	$y = 0.001x + 0.530$	$r = 0.401^{N.S}$
Chlorophyll a	vs.	$\sqrt{a^2+b^2}$	$y = -0.105x + 22.694$	$r = -0.604^{*}$
Chlorophyll b	vs.	$\sqrt{a^2+b^2}$	$y = -0.115x + 21.157$	$r = -0.548^{*}$
Total chlorophyll	vs.	$\sqrt{a^2+b^2}$	$y = -0.061x + 22.183$	$r = 0.606^{*}$
Total chlorophyll	vs.	ΔE	$y = -0.652x + 3.877$	$r = -0.483^{*}$
Test Series II (Viking Variety)				
Chlorophyll a	vs.	L	$y = -0.169x + 45.120$	$r = -0.616^{**}$
Chlorophyll b	vs.	L	$y = -0.237x + 43.307$	$r = -0.606^{**}$
Total chlorophyll	vs.	L	$y = -0.107x + 44.611$	$r = 0.635^{**}$
Chlorophyll a	vs.	-a/b	$y = 0.004x + 0.406$	$r = 0.415^{N.S}$
Chlorophyll b	vs.	-a/b	$y = 0.004x + 0.464$	$r = 0.278^{N.S}$
Total chlorophyll	vs.	-a/b	$y = 0.003x + 0.405$	$r = 0.504^{*}$
Chlorophyll a	vs.	$\sqrt{a^2+b^2}$	$y = -0.175x + 24.112$	$r = -0.575^{*}$
Chlorophyll b	vs.	$\sqrt{a^2+b^2}$	$y = -0.124x + 21.972$	$r = -0.495^{*}$
Total chlorophyll	vs.	$\sqrt{a^2+b^2}$	$y = -0.105x + 23.418$	$r = -0.564^{*}$
Total chlorophyll	vs.	ΔE	$y = -0.114x + 4.921$	$r = -0.689^{**}$

Weckel (1956) who found highly significant correlation between degradation of chlorophyll and -a/b in heat processed peas.

Correlations between chlorophyll a, b, and total chlorophyll, and $\sqrt{a^2 + b^2}$, a function of chroma, was also studied in Test Series I and II, and linear regression equations and correlation coefficients are given in Table 13. Correlation coefficients between $\sqrt{a^2 + b^2}$ and chlorophyll a, b, and total chlorophyll were all significant at 5% level. It was found that chlorophyll a and total chlorophyll correlated better with $\sqrt{a^2 + b^2}$ than chlorophyll b did. These results found in Test Series I were clearly confirmed in Test Series II. Gold and Weckel (1956) also reported a significant correlation between $\sqrt{a^2 + b^2}$ and degree of degradation of chlorophyll. The correlation coefficient was -0.388 and the number of observations was 174.

Correlation between total color difference, $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$, and total chlorophyll content was statistically significant at 5% level in Test Series I and at 1% level in Test Series II. Therefore, changes in total color difference calculated from tristimulus values of Hunter Color and Color Difference Meter was obviously associated with degradation of chlorophyll during storage. These results indicated that reflectance color measured by Hunter Color and Color Difference Meter could be used to trace the loss of chlorophyll content in asparagus. L value and ΔE was better for this purpose than $\sqrt{a^2 + b^2}$.

Color of Canned Asparagus

Reflectance color of canned asparagus was measured by Hunter Color and Color Difference Meter and visual color was evaluated by panelists. Mean values of triplicate measurements for reflectance color are shown in Table 14 and summaries of analysis of variance are given in Tables 36 and 37 in Appendix.

Tristimulus values of Hunter Color and Color Difference Meter were reduced to -a/b, $\sqrt{a^2 + b^2}$, and ΔE. Effect of controlled atmosphere on L value was not shown in Test Series I, but highly significant effect was found in Test Series II (Tables 36 and 37). There was effect of storage method only in Test Series II, and "Control" (A) had markedly higher L value than "Chlorinated" (B). But no significant difference was found between L value of "Control" (A) and "Butts standing in water" (C) (Table 15).

In Test Series II, "Control" stored in normal atmosphere (N-A) had significantly higher L than others (N-B, C-A, C-C, and C-B), except "Butts standing in water" stored in normal atmosphere (N-C). Generally, L value increased during storage as observed in fresh asparagus (Table 10). Since highly significant negative correlation between L and chlorophyll content of fresh asparagus was obtained (Table 13), higher L in "Control" and "Butts standing in water" stored in normal atmosphere (N-A and N-C) might be attributable to higher chlorophyll degradation, in these samples (Table 8). Asparagus stored in controlled atmosphere had lower L values than those in normal atmosphere. Studies on chlorophyll content and reflectance

Table 14.--Changes in reflectance color of canned asparagus due to preprocessing storage conditions: Test Series I (Martha Washington Variety).

Storage period	Normal Atmosphere														
	Control (I-N-A)					Chlorinated (I-N-B)					Butts in water (I-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	33.3	3.0	19.4	0.16	19.6	33.6	3.0	19.2	0.15	19.5	33.3	3.0	19.4	0.16	19.6
8	35.0	3.4	20.0	0.17	20.3	34.1	3.1	19.7	0.16	20.0	35.2	3.3	20.2	0.16	20.4
16	35.5	3.1	20.2	0.15	20.5	35.7	3.2	20.4	0.16	20.6	35.6	3.7	20.3	0.18	21.2
24	36.5	3.4	21.3	0.16	21.5	35.3	3.0	20.2	0.15	20.4	35.8	3.6	20.6	0.17	20.9
mean	35.9			0.16	20.41	34.7			0.15	20.12	35.0			0.17	20.56

Storage period	Controlled Atmosphere														
	Control (I-C-A)					Chlorinated (I-C-B)					Butts in water (I-C-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	33.3	3.0	19.4	0.16	19.6	33.6	3.0	19.2	0.15	19.5	33.3	3.0	19.4	0.16	19.6
8	34.8	3.2	20.0	0.16	20.2	35.3	3.1	19.8	0.16	20.6	33.2	3.1	19.2	0.17	19.2
16	35.1	3.2	20.1	0.16	20.3	34.8	3.5	19.8	0.18	20.1	35.4	3.7	20.2	0.18	20.3
24	35.5	3.2	20.5	0.15	20.8	35.2	2.9	20.3	0.15	20.5	35.7	3.5	20.7	0.17	21.0
mean	34.7			0.16	20.23	34.7			0.16	20.15	34.4			0.17	20.02

Table 14.--Continued.

(Test Series II (Viking Variety)

Normal Atmosphere

Storage period	Control (II-N-A)					Chlorinated (II-N-B)					Butts in water (II-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	36.5	4.0	21.1	0.19	21.5	36.5	3.5	21.2	0.17	21.6	36.4	4.0	21.1	0.19	21.5
7	36.4	3.3	21.4	0.15	21.7	36.6	3.5	21.5	0.16	21.8	37.0	3.5	21.8	0.16	22.0
14	37.4	3.5	22.1	0.16	22.3	36.7	3.5	21.4	0.16	21.7	37.3	3.4	21.9	0.16	22.2
21	38.3	3.6	22.6	0.16	22.9	37.7	3.2	22.1	0.14	22.3	37.6	3.6	22.1	0.16	22.4
28	40.0	3.4	23.6	0.15	23.8	39.3	3.5	23.3	0.15	23.6	39.0	3.6	22.9	0.16	23.2
mean	37.7			0.16	22.46	37.4			0.16	22.21	37.5			0.17	22.29

Controlled Atmosphere

Storage period	Control (II-C-A)					Chlorinated (II-C-B)					Butts in water (II-C-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	36.5	4.0	21.1	0.19	21.5	36.5	3.5	21.2	0.17	21.6	36.4	4.0	21.1	0.19	21.5
7	36.9	3.6	21.8	0.17	22.1	37.2	3.6	21.4	0.17	21.7	36.5	3.5	21.5	0.16	21.8
14	37.2	3.6	21.8	0.17	22.0	36.1	3.6	21.2	0.16	21.5	37.4	3.7	22.1	0.17	22.4
21	37.9	3.8	22.3	0.17	22.6	37.2	3.5	22.0	0.16	22.2	38.0	3.5	22.4	0.16	22.6
28	38.1	3.3	22.6	0.15	22.9	38.0	3.2	22.5	0.14	22.8	37.8	3.5	22.2	0.16	22.2
mean	37.3			0.17	22.21	37.0			0.16	21.96	37.2			0.17	21.12

color of fresh asparagus supported well these findings in canned asparagus.

-a/b, a function of hue, of canned asparagus decreased as storage period of fresh asparagus was prolonged. This tendency was clear in Test Series II, whereas there was slight increase in Test Series I. The decrease of -a/b as storage period of fresh asparagus was prolonged, was mainly due to increase of b (yellowness), even though there was slight decrease in -a (greenness).

Significant effect of controlled atmosphere on -a/b was shown in Test Series II, but not in Test Series I. However, highly significant effect of storage method on -a/b was found in both Test Series I and II. Less effect of controlled atmosphere on color in Test Series I might be due to breakdown of Tectrol unit for a week during storage experiment, as explained in other cases.

In Test Series I, "Butts standing in water" stored in controlled atmosphere and in air (C-C and N-C) had significantly higher -a/b than other 4 (C-B, N-A, C-A, and N-B). "Control" stored in controlled atmosphere (C-A) and "Butts standing in water" stored in controlled atmosphere and normal atmosphere (C-C and N-C) had significantly higher -a/b than others (C-B, N-A, and N-B) in Test Series II. This indicated that "Butts standing in water" (C) was the best storage method to maintain higher -a/b (more green and less yellow) in canned asparagus. These results were in agreement with these on -a/b of fresh asparagus (Table 11).

$\sqrt{a^2 + b^2}$, a function of chroma, of canned asparagus increased as storage period of fresh asparagus was extended. The increase in

$\sqrt{a^2 + b^2}$ was mainly due to increase of b (yellowness), as found in studies on color of fresh asparagus. This would indicate that strength of yellowness in canned asparagus increased as fresh asparagus was stored longer. The effect of controlled atmosphere on $\sqrt{a^2 + b^2}$ of canned asparagus was highly significant at 1% level in both Test Series I and II, but the effect of storage method was statistically significant at 1% level in Test Series II (Tables 36 and 37).

"Control" (A) had higher $\sqrt{a^2 + b^2}$ than "Chlorinated" (B) and "Butts standing in water" (C), which were not significantly different from each other in $\sqrt{a^2 + b^2}$ value. In Test Series II, "Control" stored in normal atmosphere (N-A) had markedly higher $\sqrt{a^2 + b^2}$ than (C-A, N-B, C-C, and C-B), except "Butts standing in water" stored in normal atmosphere (N-C) (Table 15).

Asparagus stored in normal atmosphere had higher $\sqrt{a^2 + b^2}$ than those stored in controlled atmosphere. This tendency was also true in Test Series I. These results indicated that asparagus stored in normal atmosphere, held in polyethylene bags or in water, developed more yellow color in canned asparagus, which resulted in higher L, lower -a/b and higher $\sqrt{a^2 + b^2}$ in canned asparagus. Studies on chlorophyll content and reflectance color of fresh asparagus also supported these findings.

L, a, and b of Hunter Color and Color Difference Meter were reduced to total color difference, $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$, which indicated color difference between initial canned asparagus of "Control"

Table 15.--Duncan's multiple range test at 5% level to compare means of reflectance color among 6 samples.

Test Series I

Color	Difference among 6 means	Difference among 3 treatments
L	N-A, N-C, C-B, N-B, C-A, C-C	A, B, C
-a/b	C-C, N-C, C-B, N-A, C-A, N-B	C, A, B
$\sqrt{a^2+b^2}$	N-C, N-A, C-A, C-B, N-B, C-C	A, B, C

Test Series II

Color	Difference among means	Difference among 3 treatments
L	N-A, N-C, N-B, C-A, C-C, C-B	A, C, B
-a/b	C-A, C-C, N-C, C-B, N-A, N-B	C, A, B
$\sqrt{a^2+b^2}$	N-A, N-C, C-A, N-B, C-C, C-B	A, C, B

and canned asparagus processed from other stored samples. The results are summarized in Table 16, and illustrated in Figure 7.

As storage period of fresh asparagus was prolonged, total color difference of canned asparagus increased. In Test Series I, total color difference among samples developed much during first 15 days' storage period. Asparagus stored in controlled atmosphere had lower total color difference than that in normal atmosphere (Figure 7). Effect of controlled atmosphere was more prominent in Test Series II. After 2 weeks' storage total color difference among samples became greater, and ΔE of asparagus stored in normal atmosphere increased rapidly (Figure 7). Increase in total color difference was less in canned asparagus whose fresh asparagus had been stored in controlled atmosphere. After about 3 weeks of storage, asparagus stored with "Butts standing in water," whether in controlled or normal atmosphere (N-C and C-C), generally gave higher ΔE value after canning than did the other 3 week storage samples.

Decrease in ΔE during early storage period in "Chlorinated" asparagus (B) which was shown in fresh asparagus, was not found in canned asparagus. Canning process might mask effect of chlorination on reflectance color of fresh asparagus.

Color of canned asparagus was also evaluated for visual color by panelists. The results and their statistical analysis are shown in Table 17 and Table 38 in Appendix. Generally, visual color score of canned asparagus was higher in Test Series I than in Test Series II. This was mainly due to lower chlorophyll content in raw asparagus used for Test Series II (Tables 7 and 9). There was no effect

Table 16.--Changes in total color difference, ΔE, of canned asparagus as storage period of fresh asparagus is extended.

Test Series I (Martha Washington Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
0 day	0.0	0.4	0.0	0.0	0.4	0.0
8	1.8	0.9	2.1	1.6	1.1	0.2
16	2.3	2.6	2.6	1.9	1.6	2.4
24	3.7	2.2	2.8	2.4	2.1	2.8

Test Series II (Viking Variety)

Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
0 day	0.0	0.2	0.0	0.0	0.2	0.0
7	0.5	0.6	1.1	1.0	1.0	1.1
14	1.4	0.6	1.3	1.2	1.0	1.6
21	2.6	1.8	1.9	2.1	1.1	2.2
28	4.5	3.6	3.2	2.4	2.0	1.9

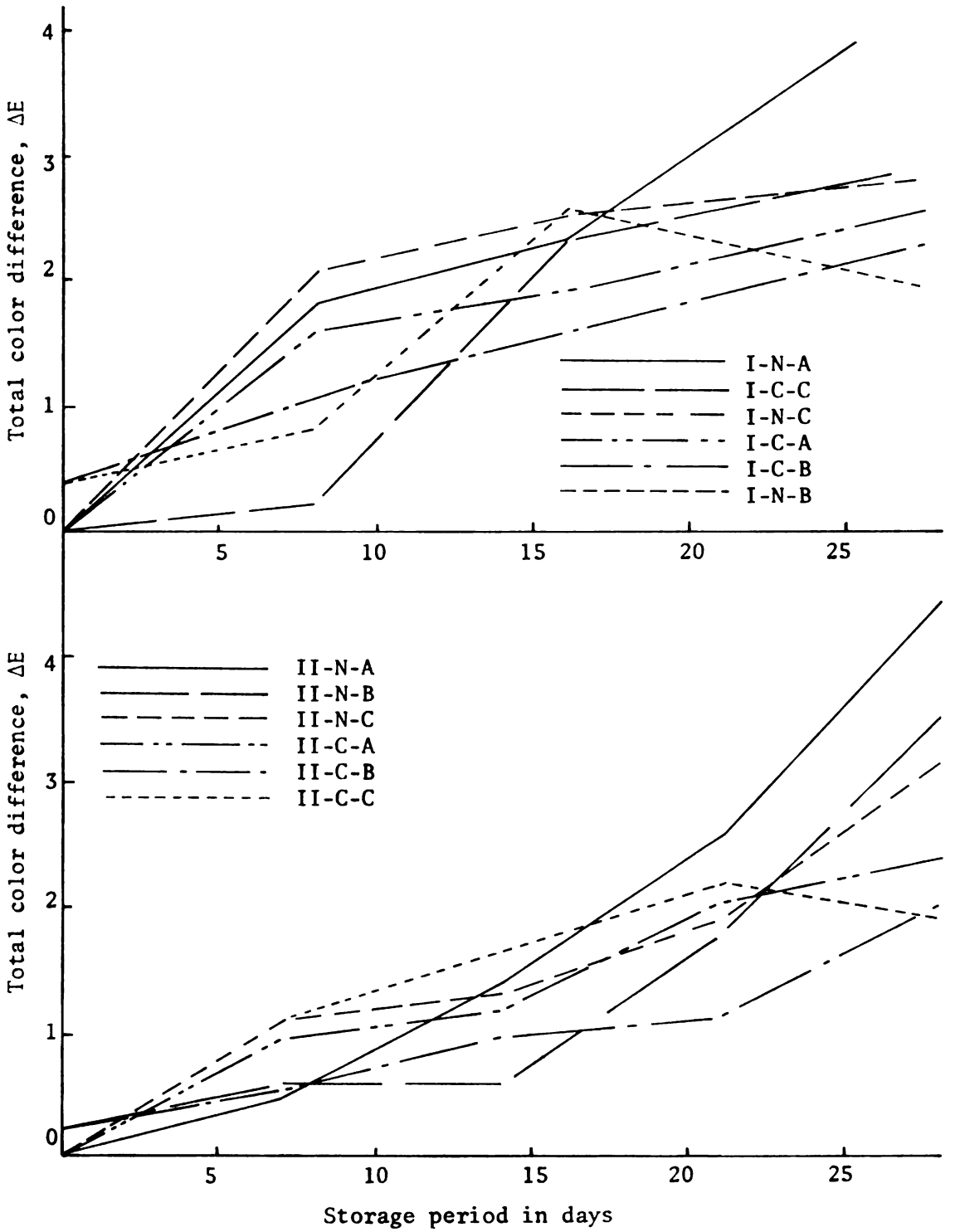

Figure 7.--Changes in total color difference in canned asparagus.

Table 17.--Visual color score of canned asparagus.

Test Series I (Martha Washington Variety)						
Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
			score			
0 day	5.5	5.5	5.5	5.5	5.5	5.5
8	5.3	5.2	5.0	5.2	5.2	4.6
16	5.0	5.1	4.7	4.6	4.7	4.6
24	4.0	4.8	4.6	4.6	4.7	4.8
mean	5.0	5.2	4.9	4.9	5.0	4.9
Duncan's multiple range test at 5% level:			N-B, C-B, N-A, N-C, C-A, C-C			
			B, A, C			

Test Series II (Viking Variety)						
Storage period	Normal Atmosphere			Controlled Atmosphere		
	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C
			score			
0 day	4.5	4.6	4.5	4.5	4.6	4.5
7	4.3	4.5	4.0	4.3	4.5	4.4
14	4.4	4.2	4.4	4.5	4.3	4.5
21	3.6	3.2	4.1	3.8	3.7	4.1
28	2.4	2.6	3.4	3.3	3.3	3.0
mean	3.8	3.8	4.1	4.1	4.1	4.1
Duncan's multiple range test at 5% level:			C-C, C-A, N-C, C-B, N-A, N-B			
			C, A, B			

of controlled atmosphere, storage method, or interaction on visual color score in Test Series I. Only time effect was highly significant (Table 38). Therefore, visual color scores among 6 batches were not statistically different, though slightly higher score was obtained from canned asparagus of "Chlorinated" (B). All visual color scores were above 4.0 in Test Series I (Table 17), signifying that the panel judged there to be no more than a slight difference in color between the reference and any of the test samples.

Effect of controlled atmosphere on visual color score of canned asparagus was significant in Test Series II (Table 38 in Appendix). Effects of storage method and interactions were not found. Lowest color score of 2.4, which indicated large color difference between reference and test sample, was shown in fourth week sample of "Control" stored in normal atmosphere.

Correlations between reflectance color measured by Hunter Color and Color Difference Meter and visual color score were examined and the results are given in Table 18. There were highly significant correlations between visual color score and L, $\sqrt{a^2 + b^2}$, and ΔE in Test Series I. These findings were clearly confirmed in Test Series II. The main difference between Test Series I and II was correlation between visual color score and -a/b. A highly significant correlation between visual color and -a/b obtained in Test Series II was not shown in Test Series I. Negative correlation coefficients indicated that visual color score decreased as L, $\sqrt{a^2 + b^2}$, and ΔE increased. These results stated that color changes

Table 18. Correlation between reflectance color and visual color score.

Test Series I (Martha Washington Variety)			
Reflectance color versus visual color score		Linear regression equation	Correlation coefficient
L	vs. visual color	$y = -0.267x + 14.205$	$r = -0.633^{*}$
-a/b	vs. visual color	$y = -8.103x + 6.195$	$r = -0.236^{N.S}$
$\sqrt{a^2+b^2}$	vs. visual color	$y = -0.484x + 14.738$	$r = -0.683^{**}$
ΔE	vs. visual color	$y = -0.265x + 5,380$	$r = -0.690^{**}$
Test Series II (Viking Variety)			
Reflectance color versus visual color score		Linear regression equation	Correlation coefficient
L	vs. visual color	$y = -0.513x + 23.136$	$r = -0.753^{**}$
-a/b	vs. visual color	$y = 40.318x - 2.450$	$r = 0.626^{**}$
$\sqrt{a^2+b^2}$	vs. visual color	$y = -0.772x + 21.115$	$r = -0.756^{**}$
ΔE	vs. visual color	$y = -0.456x + 4.602$	$r = -0.637^{**}$

in canned asparagus, from green towards yellow, which was detected by the Hunter instrument, were also distinguished very well by panelists.

Table 19 shows reflectance color values corresponding to certain visual color scores. These were calculated from linear regression equations in Test Series II (Table 18). For example, visual color score 5 which was corresponding to upper A grade of commercially canned whole spear asparagus, had L value 35.4, -a/b 0.19, and $\sqrt{a^2 + b^2}$ 20.9. Therefore, it was demonstrated that L, $\sqrt{a^2 + b^2}$, and ΔE could be used as good objective methods for measuring visual color of canned asparagus.

Table 19. Visual color score and its corresponding reflectance color values calculated from linear regression equation (Test Series II).

Visual color score	L	-a/b	$\sqrt{a^2 + b^2}$	$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$
1	43.2	0.09	26.1	7.9
2	41.2	0.11	24.8	5.7
3	39.3	0.14	23.5	3.5
4	37.0	0.16	22.2	1.3
5	35.4	0.19	20.9	---
6	33.4	0.21	19.6	---

Dietrich et al. (1957) reported that the ratio of a/b, which showed a change in hue from green to yellow, best represented changes in green beans, compared with the quantity $\sqrt{a^2 + b^2}$ best represented changes in peas. Sistrunk and Frazier (1963) found that -a/b for measuring color changes in canned snap beans correlated well with

visual judgments. Clydesdale and Francis (1969) conducted a study on the correlation of raw and reduced tristimulus values with visual ranking for processed spinach puree and found that L, a, b, -a/b, tan -a/b, and $\sqrt{a^2 + b^2}$ correlated very well with visual rankings. These findings implied that there might be product to product variation to best describe color changes in green vegetables by tristimulus values. L and $\sqrt{a^2 + b^2}$ were more reliable than -a/b or ΔE in representing meaningful visual color of canned asparagus, though all 4 parameters had highly significant correlation with visual color scores (Table 18).

Twenty-one samples of canned asparagus from Test Series II were evaluated for visual color by U.S.D.A. inspector at the Battle Creek, Michigan laboratory of the U.S.D.A. All samples were graded as A in terms of color scores, which varied from 17- to 20. The correlation between color scores by U.S.D.A. inspector and visual color scores by selected panelists from department by screening test was examined. The results are shown in Table 39 in Appendix. The correlation coefficient calculated was statistically significant at 5% level. This indicated that visual color scores of canned asparagus evaluated were meaningful.

Color of Frozen Asparagus

Reflectance color and visual color of frozen asparagus were studied in Test Series II. Frozen asparagus was thawed in refrigerator at 40°F overnight and reflectance color was measured on triplicate samples. Visual color evaluations were made on duplicate

samples. Mean values of measurements are given in Tables 20, and 22, and summaries of analysis of variance in Tables 40 and 41.

As it was observed in reflectance color of fresh as well as canned asparagus, L, b, and $\sqrt{a^2 + b^2}$ increased as storage period of fresh asparagus was prolonged. Changes in -a or -a/b were comparatively small. Effect of controlled atmosphere on L value of frozen asparagus was highly significant, as it was on L of canned asparagus (Table 40). This, in turn, indicated that frozen asparagus from normal atmosphere storage had more lightness, mostly due to having more yellow color.

"Control" (A) had significantly higher L value than others (B and C) and "Chlorinated" stored in normal atmosphere (N-A) had markedly higher lightness (L) than all others (C-A, N-C, C-C, N-B, and C-B) and "Chlorinated" stored in controlled atmosphere (C-B) lower lightness than others (N-A, C-A, N-C, C-C, and N-B). Asparagus stored in normal atmosphere had statistically higher lightness than that stored in controlled atmosphere, except "Butts standing in water.

Effect of atmosphere and storage method on -a/b of frozen asparagus were not found. These were in disagreement with the findings in fresh and canned asparagus. However, "Chlorinated" (B) had slightly higher -a/b than others (A and C). There was highly significant effect of storage method on $\sqrt{a^2 + b^2}$ of frozen asparagus, and "Control" (A) and "Butts standing in water" (C) had markedly higher $\sqrt{a^2 + b^2}$ than "Chlorinated" (B) (Tables 20 and 21). Since increase of $\sqrt{a^2 + b^2}$ was generally due to increase of b, this result

Table 20. Changes in reflectance color of frozen asparagus due to preprocessing storage conditions: Test Series II (Viking Variety).

Storage period	Normal Atmosphere														
	Control (II-N-A)					Chlorinated (II-N-B)					Butts in water (II-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	28.0	10.2	14.8	0.69	17.9	26.5	10.3	13.8	0.75	17.3	28.0	10.2	14.8	0.69	17.9
7	28.3	10.3	14.8	0.70	18.1	27.4	10.6	14.3	0.74	17.8	27.4	10.5	14.1	0.74	17.6
14	29.0	10.5	15.1	0.70	18.4	26.7	10.4	13.8	0.76	17.3	28.7	10.9	15.0	0.73	18.6
21	31.6	9.9	16.6	0.60	19.3	29.6	10.5	15.2	0.69	18.5	19.6	10.6	15.8	0.67	19.0
mean	29.2				18.43	27.6				17.70	28.4				18.27

Storage period	Controlled Atmosphere														
	Control (II-C-A)					Chlorinated (II-C-B)					Butts in water (II-N-C)				
	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$	L	-a	b	-a/b	$\sqrt{a^2+b^2}$
0 day	28.0	10.2	14.8	0.69	17.9	26.5	10.3	13.8	0.75	17.3	28.0	10.2	14.8	0.69	17.9
7	27.9	11.0	14.7	0.75	18.3	24.8	9.9	13.2	0.75	16.5	27.4	11.0	14.3	0.77	18.0
14	27.8	10.8	14.6	0.74	18.2	25.8	9.9	13.7	0.72	16.9	27.4	11.2	14.3	0.78	18.1
21	30.5	10.5	15.8	0.66	19.0	29.1	10.5	15.1	0.69	18.4	29.8	11.3	15.6	0.72	19.3
mean	28.6				18.35	26.5				17.25	28.2				18.33

Table 21. Duncan's multiple range test at 5% level to compare means of reflectance color of frozen asparagus among 6 batches.

Color	Difference among 6 means	Difference among 3 treatments
L	N-A, C-A, N-C, C-C, N-B, C-B	A, C, B
-a/b	No significant difference	No significant difference
$\sqrt{a^2+b^2}$	N-A, C-A, C-C, N-C, N-B, C-B	A, C, B

indicated that "Chlorinated" asparagus (B) had more green color than other two (A and C). "Chlorinated" asparagus stored in controlled atmosphere and normal atmosphere (C-B and N-B) had significantly lower $\sqrt{a^2 + b^2}$ than other batches (N-A, C-A, C-C and N-C). These findings indicated that "Control" (A) had more yellowish green color than other batches after storage and "Chlorinated" (B) had obviously greener color with less lightness than others. Controlled Atmosphere had a significant effect on lightness (L) of frozen asparagus by reducing chlorophyll destruction (Table 33), but did not significantly affect reduced color function, like -a/b, and $\sqrt{a^2 + b^2}$ of frozen asparagus.

Visual color of frozen asparagus was very much dependent on time factor (Table 41). Significantly higher color score was given to asparagus stored in controlled atmosphere. Effect of storage method on visual color score was highly significant and "Butts standing in water" (C) had markedly higher visual color score than others (A and B) (Table 22). There was no statistical difference between

"Control" (A) and "Chlorinated" (B) in terms of visual color. "Butts standing in water" stored in controlled atmosphere (C-C) had markedly higher visual color score than "Chlorinated" stored in normal or controlled atmosphere (N-B, C-B) and "Control" stored in normal atmosphere (N-A), but there was no significant difference among "Butts standing in water" stored in controlled atmosphere (C-C), normal atmosphere (N-C), and "Control" stored in controlled atmosphere (C-A) (Table 22).

Table 22. Changes in visual color score of frozen asparagus due to preprocessing storage condition: Test Series II.

Storage period	Normal Atmosphere			Controlled Atmosphere		
	II-N-A	II-N-B	II-N-C	II-C-A	II-C-B	II-C-C
0 day	5.0	4.7	5.0	5.0	4.7	5.0
7	4.8	4.6	4.8	4.8	4.5	4.9
14	4.6	4.4	4.0	4.8	4.5	4.9
21	2.2	3.8	4.1	3.5	3.5	4.5
mean	4.1	4.4	4.5	4.5	4.3	4.8
Duncan's multiple range test 5% level:			C-C, C-A, N-C, N-B, C-B, N-A			
			C,	B,	A	

It was found that frozen asparagus from asparagus stored for 3 weeks as "Control" in normal atmosphere had too much yellow color and did not hold market value. Frozen asparagus processed from 3 week-stored asparagus in controlled atmosphere maintained good visual color.

Correlations among visual color score, reflectance color values, and total chlorophyll content of frozen asparagus were evaluated, and the results are shown in Table 23.

Good correlations between visual score and L, -a/b, $\sqrt{a^2 + b^2}$, and ΔE were found. Correlation coefficients between visual color score and L, -a/b and ΔE were significant at 1% level, and correlation coefficient between visual score and $\sqrt{a^2 + b^2}$ was significant at 5% level. Negative correlation coefficients indicated that visual color score of frozen asparagus decreased as L, $\sqrt{a^2 + b^2}$, and ΔE increased. Therefore, reflectance color, such as L, -a/b, and ΔE could be used for objective color measurements which would represent visual color of frozen asparagus. -a/b was the most reliable one among them. These results agreed with findings of Kramer (1954) and Dietrich (1957). Kramer correlated tristimulus values of Hunter instrument with panel scores and the result showed that Hunter L value correlated well ($r = -0.836$) with panel scores.

Total chlorophyll content in frozen asparagus was correlated with reflectance color (Table 23). Correlation coefficient only between total chlorophyll and ΔE (total color difference) was significant, but not others. Poor correlation was also found between total chlorophyll content and visual color score. These results indicated that neither reflectance color nor visual score was markedly associated with total chlorophyll content in frozen asparagus samples studied.

Table 23. Correlation among visual color score, reflectance color, and chlorophyll content of frozen asparagus.

Reflectance color versus visual color	Linear regression equation	Correlation coefficient
L vs. visual color	$y = -0.275x + 12.085$	$r = -0.674^{**}$
-a/b vs. visual color	$y = 11.970 - 4.247$	$r = 0.782^{**}$
$\sqrt{a^2+b^2}$ vs. visual color	$y = -0.467x + 12.795$	$r = -0.527^{*}$
ΔE vs. visual color	$y = -0.422x + 5.004$	$r = -0.647^{**}$

Chlorophyll content vs. visual color	Linear regression equation	Correlation coefficient
Total chlorophyll vs. visual color	$y = 0.167x + 0.108$	$r = -0.407^{N.S.}$

Chlorophyll content vs.	Reflectance color	Linear regression equation	Correlation coefficient
Total chlorophyll vs.	L	$y = -0.251x + 35.147$	$r = -0.363^{N.S.}$
Total chlorophyll vs.	-a/b	$y = -0.001x + 0.739$	$r = -0.042^{N.S.}$
Total chlorophyll vs.	$\sqrt{a^2+b^2}$	$y = -0.158x + 22.484$	$r = -0.550^{N.S.}$
Total chlorophyll vs.	ΔE	$y = -0.355x + 10.482$	$r = -0.623^{*}$

Organoleptic Evaluation of Flavor

Canned asparagus was subjected to organoleptic evaluation for flavor. The flavor evaluation were performed on duplicate samples in Test Series II and on single sample in Test Series I. The results are shown in Table 24 and summaries of analysis of variance are given in Table 42 in Appendix.

Effect of controlled atmosphere on flavor of canned asparagus was highly significant in Test Series I (Table 42), but was not significant in Test Series II. Lower flavor score on "Chlorinated" asparagus (B) was expected due to high concentration of chlorine used. This was not detected by panelists in Test Series I. In Test Series II, effect of storage method on flavor of canned asparagus was highly significant, and "Chlorinated" asparagus (B) had significantly lower flavor score than "Control" (A) and "Butts standing in water" (C) (Table 24). This indicated that off-flavor due to high concentration of chlorine was detected in canned asparagus by panelists. Mercer (1957) reported that chlorine concentration used over 50ppm gave off-flavor in asparagus.

In Test Series II, "Control" stored in controlled atmosphere (C-A) had significantly higher flavor score than "Chlorinated" stored either in normal or controlled atmosphere (N-B, or C-B), but not significantly higher than "Butts standing in water" stored in normal or controlled atmosphere (C-C, N-C) and "Control" stored in normal atmosphere (N-A) (Table 24). "Chlorinated" stored in controlled atmosphere (C-B) had significantly lower flavor score than all others.

Table 24. Organoleptic evaluation for flavor of canned asparagus.

Test Series I (Martha Washington Variety)						
	Normal Atmosphere			Controlled Atmosphere		
Storage period	Control (I-N-A)	Chlori-nated (I-N-B)	Butts in water (I-N-C)	Control (I-C-A)	Chlori-nated (I-C-B)	Butts in water (I-C-C)
0 day	4.7	4.7	4.7	4.7	4.7	4.7
8	3.5	3.5	3.5	3.8	3.9	4.1
16	3.9	3.5	3.3	3.7	3.9	3.7
24	3.5	3.5	3.2	3.7	4.1	3.5
mean	3.9	3.8	3.7	4.0	4.2	4.0
Duncan's multiple range test at 5% level:			C-B, C-A, C-C, N-A, N-B, N-C			
			B, A, C			

Test Series II (Viking Variety)						
	Normal Atmosphere			Controlled Atmosphere		
Storage period	Control (II-N-A)	Chlori-nated (II-N-B)	Butts in water (II-N-C)	Control (II-C-A)	Chlori-nated (II-C-B)	Butts in water (II-C-C)
0 day	4.5	4.2	4.5	4.5	4.2	4.5
7	4.2	3.6	3.7	3.9	3.0	3.4
14	3.9	3.8	4.1	4.3	2.1	3.9
21	3.4	3.2	3.4	3.8	3.5	3.7
28	2.5	3.0	2.9	3.2	2.8	3.2
mean	3.7	3.5	3.7	3.9	3.1	3.7
Duncan's multiple range test at 5% level:			C-A, C-C, N-C, N-A, N-B, C-B			
			A, C, B			

Objectionable off-flavor was detected in canned asparagus which was processed from "Chlorinated" asparagus stored for 1-4 weeks in controlled atmosphere, "Control" and "Butts standing in water" stored in normal atmosphere (N-A and N-C) maintained fairly good asparagus flavor until 2 week of storage and then objectionable off-flavor was detected (Table 24, Test Series II). These storage methods (A and C) stored in controlled atmosphere had fairly good asparagus flavor until 3 weeks of storage, and then objectionable off-flavor was detected in canned asparagus. A few panelists stated that asparagus stored in controlled atmosphere was lacking in characteristic asparagus flavor

This study indicated that asparagus could be stored for 3 weeks in controlled atmosphere and for 2 weeks in normal atmosphere without objectionable off-flavor being developed in processed asparagus. One hundred ppm of chlorine obviously gave off-flavor in asparagus.

Microbial Spoilage of Fresh Package

Asparagus stored for various storage periods in Test Series II was packed in tray after removing all spoiled spears, and held at 55°F to evaluate shelf life of fresh package for fresh market. Observations on microbial spoilage of fresh package are shown in Table 42. Bacterial soft rot was the major disease which deteriorated quality of fresh packaged asparagus. Mold growth was also involved but not severely. "Chlorinated" and "Butts standing in water" stored in controlled atmosphere (C-B and C-C) had less microbial spoilage

Table 25.--Microbial spoilage of fresh packaged asparagus stored at 55°F which was prepared from asparagus stored for various periods.

samples \ shelf life	2 day	4 day	6 day	8 day
			Percent	
II-N-A-0	c: 1.8	c : 1.8	a : 15.2 c : 3.6	a : 24.1 c : 12.1
II-N-A-2	a : 7.1	a : 70.9 c : 1.8	a : 92.3 c : 44.2	--
II-N-A-3	a : 44.7	a : 88.5 a : 1.8	--	--
II-N-A-4	a : 41.7 c : 41.7	a : 83.3 c : 72.2	--	--
II-N-B-0	a : 9.0	a : 9.8	a : 63.1 c : 1.5	all spoiled
II-N-B-2	a : 6.6	a : 55.2	a : 77.4 b : 41.5	--
II-N-B-3	a : 93.8 c : 6.3	a :100 c : 40	--	--
II-N-B-4	--	a : 88.2 b : 11.8	--	--
II-N-C-0	c : 1.8	c : 1.8	a : 15.2 c : 3.3	a : 24.1 c : 12.1
II-N-C-2	a : 7.8	a : 65.4	a : 92.7 c : 54.5	--
II-N-C-3	a : 57.5 c : 17.5	a : 95.5 c : 52.3	--	--
II-N-C-4	a : 55.8 c : 46.2	a : 86.7 c : 77.8	--	--
II-C-A- 0	c : 1.8	c : 1.8	a : 15.2 c : 3.6	a : 24.1 c : 12.1

Table 25.--Continued.

shelf life / samples	2 day	4 day	6 day	8 day
			Percent	
II-C-A-2	a : 10.6	a : 30.4 c : 1.8	a : 59.6 c : 27.1	--
II-C-A-3	a : 67.4 c : 8.7	a : 91.9 c : 27.0	--	--
II-C-A-4	a : 47.8 c : 52.2	a : 91.4 c : 74.3	--	--
II-C-B-0	a : 9.0	a : 9.8	a : 63.1 c : 1.5	all spoiled
II-C-B-2	a : 7.7	a : 63.3 c : 2.0	a : 94.0 c : 6.0	--
II-C-B-3	a : 71.9 b : 2.7	a :100 c : 11.1	--	--
II-C-B-4	a : 64.7 c : 11.8	a :100 c : 25.0	--	--
II-C-C-0	c : 1.8	c : 1.8	a : 15.2 c : 3.6	a : 24.1 c : 12.1
II-C-C-2	a : 3.8	a : 50.8	a : 91.4 c : 22.4	--
II-C-C-3	a : 11.4 c : 4.5	a : 85.0 c : 40.0	--	--
II-C-C-4	a : 13.0 c : 10.9	a : 87.2 c : 63.8	--	--

a : bacterial soft rot on tip of asparagus

b : bacterial soft rot on butt end

c : mold spoilage

-0 : initial sample which was not stored
-1 : asparagus stored for 1 week
-2 : asparagus stored for 2 weeks
-3 : asparagus stored for 3 weeks
-4 : asparagus stored for 4 weeks

during first 2 days than those stored in normal atmosphere, this controlled atmosphere effect disappeared. In case of fresh asparagus which was not stored at all, shelf life of fresh package at 55°F was about 1 week, except chlorinated asparagus. Bacterial soft rot on chlorinated asparagus was more after 6 days' storage at 55°F. Package prepared from asparagus stored for 2 weeks had shelf life of about 2 days. Asparagus stored for 3 or 4 weeks could not be used for fresh package at all, because fresh packaged asparagus was severely spoiled after 2 days at 55°F.

SUMMARY AND CONCLUSIONS

Two varieties of green asparagus (Martha Washington and Viking) were stored in controlled atmosphere and in air at 35°F to study effects of post harvest storage conditions on the quality of asparagus. Fresh samples were taken at one week intervals to examine bacterial soft rot, off-odor development, texture, fiber content, chlorophyll content and reflectance color of fresh asparagus. Canned and frozen asparagus processed after various storage periods were used to evaluate effects of storage conditions on chlorophyll content, fiber content, reflectance color, visual color, and flavor.

Chlorination and butts standing in water were employed as storage methods to reduce microbial spoilage during storage, and their effects on quality of stored asparagus were compared.

The effect of controlled atmosphere in reducing bacterial soft rot was highly significant. Among storage methods, "Butts standing in water" was the most effective method to reduce bacterial soft rot. "Butts standing in water" stored in controlled atmosphere was the best combination of conditions to retard bacterial soft rot.

Off-odor development during storage of asparagus was closely associated with bacterial soft rot. "Butts standing in water" plus

controlled atmosphere was the best method to reduce off-odor development in asparagus during storage.

Shear force increased as storage period was extended in all samples, except "Butts standing in water." Asparagus stored in controlled atmosphere developed significantly less fiber than that stored in normal atmosphere. Fiber content significantly decreased in asparagus stored with "Butts standing in water" in controlled atmosphere. Previously-published results cited elsewhere in the thesis, suggest that the above-mentioned decrease in shear force and fiber content were at least partially due to stem elongation and partially due to a breakdown of intercellular components.

Asparagus stored in controlled atmosphere retained significantly higher chlorophyll than that in normal atmosphere. "Butts standing in water" was better than "Control" to maintain higher chlorophyll content in asparagus.

These findings indicated that harvested asparagus stored with butts standing in water in controlled atmosphere maintained tender texture and better color, and had significantly less microbial spoilage.

Asparagus stored in controlled atmosphere had significantly higher -a/b and lower $\sqrt{a^2 + b^2}$ than that stored in normal atmosphere. However, atmospheric condition did not affect L value of fresh asparagus. "Butts standing in water" stored in controlled atmosphere had more glossy and greener appearance than others. It was found that L, $\sqrt{a^2 + b^2}$, and ΔE were closely associated with chlorophyll content in fresh asparagus, each of them increasing as chlorophyll

content decreased. Higher chlorophyll retention observed in fresh asparagus stored in controlled atmosphere completely masked by blanching and freezing process. About 22% of total chlorophyll was destroyed by freezing.

Effect of controlled atmosphere, in general, on visual color of canned and frozen asparagus and on reflectance color of canned asparagus was significant. It was found that visual color score coorelated significantly with L, $\sqrt{a^2 + b^2}$, and ΔE, each of them increasing as visual color score decreased. These findings stated that L, $\sqrt{a^2 + b^2}$, and ΔE could be used as good objective methods for measuring visual color of canned and frozen asparagus.

More research on relationships between visual color score and L, -a/b, $\sqrt{a^2 + b^2}$, and ΔE of a large number of processed asparagus samples are required to extend these findings to industrial applications.

Chlorinated asparagus had significantly lower flavor score than "Control" and "Butts standing in water." Asparagus could be stored for 3 weeks in controlled atmosphere and for 2 weeks in normal atmosphere without objectionable off-flavor developed in processed asparagus.

Generally, beneficial effects of controlled atmosphere-storage found in fresh asparagus were also revealed in processed asparagus. "Butts standing in water" plus controlled atmosphere was the best storage condition to improve quality of fresh as well as processed asparagus.

REFERENCES

REFERENCES

Arnon, D. I. 1949. Copper enzymes in isolated chloroplasts. Plant Physiology, 24:1.

Aczel, A. 1971. Data on the color change of green peas. Lebensmittel-Wissenshaft und Technologie, 4(5):167.

Barker, J., and T. N. Morris. 1936. The storage of asparagus. Gt. Brit. Dept. of Sci. and Ind. Res., Food Investigation Board, 172.

Biale, J. B., R. E. Young. 1962. The Biochemistry of fruit maturation. Endeavour, 21 (Nr. 83-84): 1964.

Bisson, C. S., H. A. Jones, and W. W. Robbins. 1926. Factors influencing the quality of fresh asparagus after it is harvested. Cal. Agr. Exp. Sta. Bull. 410.

Bitting, A. W. 1915. Methods followed in the commercial canning of foods. U.S.D.A. Dept. Bull., 196:79.

Brennan, J. R. 1958. Anatomical and respiration studies of the asparagus stem and the development of fibrousness during storage. Hort. Abstr., 30:617.

Carolus, R. L., W. J. Lipton, and S. B. Apple. 1953. Effects of packaging on quality and market acceptability of asparagus. Mich. Agr. Exp. Sta. Ouart. Bull., 35:330.

Capellini, R. A. 1960. Post harvest quality control of asparagus. Hort. News, 41(4): 4060.

Clydesdale, F. M., and F. J. Francis. 1968. Chlorophyll changes in thermally processed spinach as influenced by enzyme conversion and pH adjustment. Food Tech., 22:135.

Clydesdale, F. M., and F. J. Francis. 1969. Colorimetry of foods. I. Correlation of raw, transformed, and reduced data with visual rankings for spinach puree. J. Food Science, 34:349.

Czukor, B., and A. Aczel. 1970. Physiochemical changes during the processing of peas. Chem. Abst., 73:250.

Dietrich, W. C., and F. E. Lindquist. 1957. Objective tests to measure adverse changes in frozen vegetables. Food Tech., 11:109.

Dietrich, W. C., R. L. Olson, Marvel-Dare Nutting. 1959. Time-temperature tolerance of frozen foods. Food Tech., 13:258.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics, 11:1.

Ehlert, G. R., and R. A. Seelig. 1966. Asparagus. Fruits and vegetable facts and pointers, Third revision.

Emanuelle, F., and G. Mauri. 1951. Determining the color of tomato concentration. Chem. Abst., 27:1414.

Franklin, E. W., A. Zitmok, and B. Barabas. 1960. Some effects of modified atmosphere on stored asparagus. Rept. Comm. Hort. Res.; Can. Hort. Council Ottowa 85.

Gilpin, G. L., J. P. Sweeney, V. J. Chapmen, and J. N. Eisen. 1959. Effects of cooking methods on broccoli. J. Am. Dietet Assoc., 35:359.

Gold, H. J. and K. G. Weckel. 1959. Degradation of chlorophyll to pheophytin during sterilization of canned green peas by heat. Food Tech. 13:281.

Groeschel E. C., A. I. Nelson, and M. P. Steinburg. 1966. Changes in color and other characteristics of green beans stored in controlled refrigerated atmospheres. J. Food Science. 31: 488.

Guyer, R. B., and A. Kramer. 1950. Factors affecting the quality measurements of raw and canned green and wax beans. Proc. Amer. Soc. Hort. Sci., 56:303.

Huang, I-lo, F. J. Francis, and F. M. Clydesdale. 1970. Colorimetry of foods. 2. Color measurement of squash puree using the Kubelka-Munk equation. J. Food Science, 35:315.

Isherwood, F. A. 1955. Texture in fruits and vegetables. Food Manuf., 30:399.

James, W. O. 1953. Plant respiration. Oxford at the Clarendon Press, Great Britain.

Joslyn, M. A. 1950. Methods of food analysis. Academic Press. New York, 137.

Kramer, A. 1950. This meter gives better color evaluation. Food Ind., 22:1897.

Kramer, A. 1954. Color dimensions of interest to the consumer. Quartermaster Food and Container Institute, Symposium color in foods, 39.

Kramer, A., A. Kornetsky, and N. Elehwany. 1956. A procedure for sampling and grading raw green asparagus. Food Technology, 10:212.

Kramer, A., I. C. Haut, L. E. Scott, and L. E. Ide. 1949. Objective methods for measuring quality factors of raw, canned, and frozen asparagus. Proc. Amer. Soc. Hort. Sci., 53:411.

Kramer, A., and K. Aamlid. 1953. The shear press, an instrument for measuring the quality of foods. Proc. Amer. Soc. Hort. Sci., 61:417.

Lee, F. A. 1943. Determination of toughness of frozen asparagus. Food Research, 8:249.

Lee, F. A., and C. B. Sayer. 1940. Tenderometer readings as index of quality of fresh asparagus. Food Research, 5:161.

Lieberman, M., and R. E. Hardenburg. 1954. Effect of modified atmospheres on respiration and yellowing of broccoli at 75°F. Proc. Amer. Soc. Hort. Sci., 63:409.

Lipton, W. J. 1957. Physiological changes in harvested asparagus as related to temperature and handling. Ph.D. thesis. University of Calif., Davis.

Lipton, W. J. 1958. Effect of temperature on asparagus quality. Transport of perishables conf. Proc., Davis, Calif., 147.

Lipton, W. J. 1960. Effect of atmosphere composition on quality. U.S. Dept. Agr. Marketing Res. Rept., 428:26.

Lipton, W. J. 1965. Post-harvest responses of asparagus spears to high carbon dioxide and low oxygen atmosphere. Proc. Amer. Soc. Hort. Sci., 86:347.

Lougheed, E. C. 1964. Some physiological responses of excised asparagus shoots to water, temperature, and atmospheres of oxygen and carbon dioxide. Ph.D. thesis. Michigan State University.

Lougheed, E. C., and D. H. Dewey. 1966. Factors affecting the tenderizing effect of modified atmospheres on asparagus spears during storage. Proc. Amer. Soc. Hort. Sci., 89:336.

Lyons, J. M., and L. Rappaport. 1962. Effect of controlled atmospheres on storage quality of Brussel sprouts. Proc. Amer. Soc. Hort. Sci., 81:324.

MacGillivray, J. H. 1933. Seasonal variation in the tenderness of asparagus. Proc. Amer. Soc. Hort. Sci., 30:558.

MacGillivray, J. H. 1938. Spectrophotometric and Colorimetric analysis of tomato pulp. Proc. Amer. Soc. Hort. Sci., 35:360.

Mackinny, G. 1940. Criteria for purity of chlorophyll preparations. J. Biol. Chem., 132:91.

Mendenhall, W. 1968. Introduction to Probability and Statistics. 2nd ed. Wadsworth Publishing Co., Inc.

Mercer, W. A., and I. I. Somers. 1957. Chlorine in Food Plant Sanitation. Advances in Food Research, 7:129.

Michael, G. 1935. Z. Botan., 29:385.

Mitchell, J. S. 1935. Comparative composition and color of commercial tomato juice. J. Assoc. Offic. Agr. Chemists, 18:128.

Morse, F. E. 1917. Experiment in keeping asparagus after cutting. Mass. Agr. Exp. Sta. Bull., 172:297.

Newhall, S. M. 1929. A method for determining the color of agricultural products. U.S. Dept. Agr. Tech. Bull., 154.

Parker, M. W., and N. W. Stuart. 1935. Changes in the chemical composition of green snap beans after storage. Maryland Univ. Agr. Exp. Sta. Bull., 383.

Pentzer, W. T., R. L. Perry, and G. C. Hanna. 1936. Precooling and shipping California asparagus. California Agr. Exp. Sta. Bull., 600:45.

Platenius, H. 1939. The effect of temperature on the rate of deterioration of fresh vegetables. J. Agr. Res., 59:41.

Platenius, H. 1942. Effect of temperature on the respiration rate and the respiratory quotient of some vegetables. Plant Physiology, 17:179.

Platenius, H. 1943. Oxygen concentration and respiration. Plant Physiology, 18(4):671.

Ramsey, G. B., and J. S. Wiant. 1941. Market disease of fruits and vegetables. U.S.D.A. Misc. Publ., 440:70.

Robinson, W. B., J. R. Ransford, and D. B. Hand. 1951. Measurement and control of color in the canning of tomato juice. Food Technology, 5:314.

Robinson, W. B., T. Wishnetsky, J. R. Ransford, W. L. Clark, and D. B. Hand. 1952. A study of methods for the measurement of tomato juice color. Food Technology, 6:269.

Ryall, A. L. 1963. Effect of modified atmosphere from liquified gases on fresh produce. 17th Nat. Conf. Handling perishable. Agr. Commodities, Purdue University, 21.

Scott, L. E., and A. Kramer. 1949. Physiological changes in asparagus after harvest. Proc. Amer. Soc. Hort. Sci., 54:357.

Segerlind, L. J. 1971. Private communication. Michigan State University.

Sistrunk, W. A., and W. A. Frazier. 1963. Changes in canned snap beans during serving table exposure. Proc. Amer. Soc. Hort. Sci., 83:476.

Smith, H. R., and A. Kramer. 1947. The fiber content of canned green asparagus. The Canner, 104(18):14.

Smith, W. H. 1963. The use of carbon dioxide in the transport and storage of fruits and vegetables. Advance in Food Research, 12:98.

Snedecor, G. W. 1956. Statistical methods. Iowa State College press Ed. 5.

Sweeney, J. P., and M. E. Martin. 1958. Determination of chlorophyll and pheophytin in broccoli heated by various procedures. Food Research, 23:635.

Tewfik, S., and L. E. Scott. 1954. Vegetables storage. Respiration of vegetables as affected by post harvest treatment. J. Agr. Food Chem., 2:415.

Thornton, N. C. 1931. The effect of carbon dioxide on fruits and vegetables in storage. Contribution Boyce Thompson Institute, 3:219.

Thornton, N. C. 1933. Carbon dioxide storage III. The influence of carbon dioxide on the oxygen up-take of fruit and vegetables. Contribution Boyce Thompson Institute, 5:371.

Vernon, L. P. 1960. Spectrophotometric determination of chlorophylls and Pheophytins in plant extracts. Anal. Chem., 32:114.

Wang, S. S., N. F. Haard, and G. R. Dimarco. 1971. Chlorophyll degradation J. Food Science, 36:657.

Wilder, H. K. 1948. Instructions for use of the fiberometer in the measurement of fiber content in canned asparagus. Res. Lab. Rep. No. 12313-C. Natl. Canners Assoc.

Wiley, R. C., N. Elehwany, A. Kramer, and F. G. Hager. 1956. The shear press. An instrument for measuring the quality of food. Food Research, 10:439.

Wood, J. G., D. H. Chuickshank, and R. H. Kuchel. 1943. The metabolism of starving leaves. Australian J. Exptl. Biol. Med. Sci., 21:37.

Wright, R. C., D. H. Rose, and T. M. Whiteman. 1954. The commercial storage of fruits, vegetables, and florist and nursery stocks. U. S. Dept. Agr. Handbook No. 66.

Younkin, S. G., 1950. Application of the Hunter Color Difference Meter to a tomato color measurement problem. J. Optical Soc. Amer., 40:265.

APPENDIX

APPENDIX

Preliminary Studies

These studies were performed to develop storage methods for principal tests which could reduce microbial spoilage during storage and after storage as fresh package. As preliminary studies were conducted in April and May when Michigan asparagus was not available, all green asparagus shipped from California was used for tests. Therefore, asparagus received was presumed to be about 5 days old after harvest because of transit time from California, but the quality was good enough for test purpose. As soon as asparagus was received, it was held at 35°F until used for test.

Asparagus was sorted and then graded according to diameter of stalk at 6 inches from the tip. Asparagus spears ranging from 3/8 to 6/8 inch in diameter were chosen for tests. All injured, misshapen, or otherwise undesirable spears were discarded. After grading, asparagus was washed with tap water for 2 minutes and then divided into lots, each weighing 6 to 8 pounds. Each lot was subjected to treatment according to test designs.

The treated asparagus was then packaged in plastic tray with water-vapor and gas permeable polyethylene film overwrapped (film;

VF-71, Borden Inc.) with 6 to 8 packages per treatment, each weighing 1 pound ± 1 ounce, and were held at 55°F. Microbial spoilage was observed over a 1 week storage period.

Test 1[1]

A. Control--washed with tap water (about 55°F) and surface water dried with fan at 60°F for 20 minutes.

B. Chlorinated (100ppm of chlorine, 2 minutes) in diluted "Oxine" solution and surface water removed as A.

C. Immersed in potassium sorbate solution (0.26%, 2 minutes) and dried as in A.

D. Chlorinated (100ppm of chlorine, 2 minutes) and then immersed in potassium sorbate solution (0.26%, 2 minutes) and dried as in A.

The results of microbial spoilage observed during test period are shown in Table 27. Percent spoilage was calculated as $\frac{\text{spoiled spears}}{\text{Total No. of spears}} \times 100$. However, the degree of spoilage of spoiled spear was not considered.

Test 2[2]

A. Control--washed and surface water dried under fan at 60°F for 20 minutes.

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[1]Temperature of solutions in treatments A through D was about 55°F.

[2]Temperature of tap water used for washing in treatments was about 55°F.

Table 26. Effect of chlorination and potassium sorbate treatment on microbial spoilage of packaged asparagus.

Treatment \ Observation		Percent spoilage				
		3 day	4 day	5 day	6 day	7 day
A)	mold	18.2	23.8	23.8	57.0	71.4
	bacteria	22.3	23.8	23.8	28.6	71.4
B)	mold	3.3	10.0	47.8	60.0	73.0
	bacteria	10.0	20.3	21.7	33.3	80.0
C)	mold	2.6	4.5	17.0	23.7	45.9
	bacteria	21.1	26.3	26.3	28.9	68.8
D)	mold	0	0	4.8	23.6	42.8
	bacteria	3.7	14.8	14.7	21.4	57.2

B. Washed spears were arranged on tray and 100gr of Silica Gel in smaller tray was added on top of spears without direct contact and then wrapped in film.

C. Immersed asparagus in hot water at 125 ± 3°F for 2 minutes, cooled immediately in running water, and then dried as in A.

The results obtained from this test are shown in Table 2. This test indicated that hot water treatment was effective in controlling mold. Packaging with desiccant could reduce mold growth fairly effectively for 4 days, but surface of asparagus spear was shriveled badly due to excessive water loss.

Test 3

A. Control--washed and surface water dried under fan at 60°F for 20 minutes.

B. Immersed in hot water (125°F, 2 minutes) and then cooled immediately in running water and dried as in A.

C. Chlorinated in 200ppm of chlorine solution (oxine) at 125°F for 2 minutes and then cooled immediately in running water and dried as in A.

D. Butts standing in water--bundle of washed asparagus was immersed in 2 inches water in a stainless pan.

These results clearly indicated that "Butts standing in water" reduced bacterial as well as mold spoilage very effectively. It was found that chlorination at 125°F was more effective than hot water treatment at the same temperature, or chlorination alone at the same chlorine concentration.

Table 27. Effect of desiccant and hot water treatment on microbial spoilage of packaged asparagus.

Observation / treatment		Percent spoilage			
		2 day	4 day	6 day	7 day
			(percent)		
A)	mold	0	2.9	8.8	40.7
	bacteria	0	47.1	52.9	55.6
B)	mold	0	0	29.4	--
	bacteria	3.3	29.4	50.1	--
C)	mold	0	3.4	5.0	
	bacteria	0	24.1	37.9	44.8

Table 28.--Effect of hot water treatment, chlorination, and butts standing in water on microbial spoilage of packaged asparagus.

Observation / treatment		Percent spoilage			
		2 day	3 day	4 day	5 day
		(percent)			
A)	mold	9	14.3	14.3	42.8
	bacteria	47.6	52.3	52.6	52.6
B)	mold	0	0	9.0	9.0
	bacteria	5.0	5.0	23.8	33.3
C)	mold	0	0	0	4.7
	bacteria	5.0	14.3	19.0	19.0
D)	mold	0	0	3.0	3.0
	bacteria	0	0	0	3.3

Table 29.--Summaries of analysis of variance for bacterial soft rot of Test Series I and II.

Source of variance	Degree of freedom	F test	
		Test Series I	Test Series II
atmosphere	1	15.832**	52.247**
storage method	2	127.198**	64.887**
time	3	401.096**	247.087**
atm. x stor.	2	4.377*	6.721**
atm. x time	3	$2.268^{N.S.}$	12.439**
stor. x time	6	21.930**	20.280**
atm. x stor. x time	6	$2.376^{N.S.}$	$1.771^{N.S.}$
error	24	--	--

Table 30.--Summaries of analysis of variance for off-odor development during storage in Test Series I and II.

Source of variance	Degree of freedom	F test	
		Test Series I	Test Series II
atmosphere	1	36.014**	5.885*
storage method	2	57.960**	20.651**
time	3	415.083**	47.145**
atm. x stor.	2	1.313$^{N.S.}$	0.412$^{N.S.}$
atm. x time	3	6.669**	1.961$^{N.S.}$
stor. x time	6	12.109**	3.315*
atm. x stor. x time	6	0.980$^{N.S.}$	0.960$^{N.S.}$
error	24	--	--

Table 31.--Summaries of analysis of variance for texture change during post harvest storage.

Source of variance	Degree of freedom	F test			
		Test Series I		Test Series II	
		7.5 inches	6 inches	7.5 inches	6 inches
atmosphere	1	1.080$^{N.S.}$	1.958$^{N.S.}$	0.215$^{N.S.}$	0.675$^{N.S.}$
storage method	2	6.182*	4.548*	0.046$^{N.S.}$	0.053$^{N.S.}$
time	3	0.306$^{N.S.}$	1.394$^{N.S.}$	2.672$^{N.S.}$	2.434$^{N.S.}$
atm. x stor.	2	0.679$^{N.S.}$	0.705$^{N.S.}$	0.321$^{N.S.}$	0.937$^{N.S.}$
atm. x time	3	0.410$^{N.S.}$	0.392$^{N.S.}$	0.097$^{N.S.}$	1.409$^{N.S.}$
stor. x time	2	0.679$^{N.S.}$	0.705$^{N.S.}$	0.321$^{N.S.}$	0.937$^{N.S.}$
error	10	--	--	--	--

Table 32.--Summaries of analysis of variance for changes in fiber content in fresh asparagus during post-harvest storage and in frozen asparagus due to pre-processing storage of asparagus.

Source of variance	Degree of freedom	F test		
		Fresh asparagus		Frozen asparagus
		Test Series I	Test Series II	Test Series I
atmosphere	1	34.778**	32.000**	43.700**
storage method	2	12.111**	19.000**	21.000**
time	4	17.778**	22.900**	8.600**
atm. x stor.	2	3.222$^{N.S.}$	2.450$^{N.S.}$	5.900**
atm. x time	4	7.222**	3.300*	7.500**
stor. x time	8	6.667**	7.700**	4.900**
atm. x stor. x time	8	0.889$^{N.S.}$	2.500*	4.900**
error	30	--	--	--

Table 33.--Summaries of analysis of variance for changes in total chlorophyll content during post-harvest storage of asparagus.

Source of variance	Degree of freedom	F test		
		Fresh asparagus		Frozen asparagus
		Test Series I	Test Series II	Test Series I
atmosphere	1	4.126$^{N.S.}$	36.100**	7.411*
storage method	1	1.295$^{N.S.}$	13.385**	0.368$^{N.S.}$
time	4	236.992**	313.056**	76.593**
atm. x stor.	1	13.561**	0.877$^{N.S.}$	0.611$^{N.S.}$
atm. x time	4	6.641**	3.997*	4.118*
stor. x time	4	3.540*	1.272$^{N.S.}$	4.583**
atm. x stor. x time	4	1.678$^{N.S.}$	1.111$^{N.S.}$	3.496*
error	20	--	--	--

Table 34.--Summaries of analysis of variance for changes in reflectance color of asparagus during storage: Test Series I.

Source of variance	Degree of freedom	F test		
		L	-a/b	$\sqrt{a^2 + b^2}$
atmosphere	1	$0.937^{N.S.}$	$1.478^{N.S.}$	$2.914^{N.S.}$
storage method	2	29.728**	5.902**	3.493*
time	4	45.587**	25.883**	46.293**
atm. x stor.	2	4.200*	6.562**	16.579**
atm. x time	4	$1.082^{N.S.}$	$2.244^{N.S.}$	2.934*
stor. x time	8	$1.095^{N.S.}$	3.430**	2.821**
atm. x stor. x time	8	7.136**	3.881**	5.095**
error	60	--	--	--

Table 35.--Summaries of analysis of variance for changes in reflectance color of asparagus during storage: Test Series II.

Source of variance	Degree of freedom	F test		
		L	-a/b	$\sqrt{a^2 + b^2}$
atmosphere	1	$1.896^{N.S.}$	38.413**	7.163**
storage method	2	17.075**	$1.476^{N.S.}$	11.987**
time	4	7.582**	8.014**	26.527**
atm. x stor.	2	3.436*	18.240**	13.173**
atm. x time	4	$2.058^{N.S.}$	8.207**	$0.770^{N.S.}$
stor. x time	8	6.281**	$1.370^{N.S.}$	6.514**
atm. x stor. x time	8	4.193**	2.755*	4.073**
error	60	--	--	--

Table 36.--Summaries of analysis of variance for changes in reflectance color of canned asparagus: Test Series I.

Source of variance	Degree of freedom	F test		
		L	-a/b	$\sqrt{a^2 + b^2}$
atmosphere	1	$3.805^{N.S.}$	$0.595^{N.S.}$	9.349**
storage method	2	$1.308^{N.S.}$	10.238**	$2.532^{N.S.}$
time	3	17.479**	6.071**	43.653**
atm. x stor.	2	$0.120^{N.S.}$	$0.845^{N.S.}$	4.044*
atm. x time	3	$0.363^{N.S.}$	3.190*	$1.880^{N.S.}$
stor. x time	6	$0.698^{N.S.}$	3.405**	3.499**
atm. x stor. x time	6	$1.995^{N.S.}$	$0.405^{N.S.}$	3.613**
error	48	--	--	--

Table 37.--Summaries of analysis of variance for changes in reflectance color of canned asparagus: Test Series II.

Source of variance	Degree of freedom	F test		
		L	-a/b	$\sqrt{a^2 + b^2}$
atmosphere	1	12.190**	5.389*	12.278**
storage method	2	3.979*	5.156**	5.970**
time	4	78.577**	23.333**	80.188**
atm. x stor.	2	$0.402^{N.S.}$	$0.889^{N.S.}$	$0.401^{N.S.}$
atm. x time	4	10.122^{**}	$0.844^{N.S.}$	8.411**
stor. x time	8	2.947**	3.111**	4.706**
atm. x stor. x time	8	$1.735^{N.S.}$	$0.533^{N.S.}$	$1.252^{N.S.}$
error	60	--	--	--

Table 38.--Summaries of analysis of variance for visual color score of canned asparagus.

Source of variance	Test Series I		Test Series II	
	Degree of freedom	F test	Degree of freedom	F test
atmosphere	1	$0.346^{N.S.}$	1	5.742*
storage method	2	$0.741^{N.S.}$	2	$1.682^{N.S.}$
time	3	18.352**	4	63.351**
atm. x stor.	2	$0.241^{N.S.}$	2	$1.119^{N.S.}$
atm. x time	3	$1.454^{N.S.}$	4	$0.874^{N.S.}$
stor. x time	2	$0.241^{N.S.}$	8	$1.947^{N.S.}$
error	10	--	30	--

Table 39.--Comparison of visual color scores by selected panelists with color scores by U.S.D.A. inspector.

Sample code	Visual color score	U.S.D.A. inspector	*** score	Linear regression equation
II-N-A-0	4.5	20		y = 0.304 x -1.442
II-N-B-0	4.6	18		
II-N-A-1	4.3	18		r = 0.483
II-N-C-1	4.0	18		
II-C-A-1	4.3	18		
II-C-B-1	4.5	18		
II-N-A-2	4.4	19		
II-N-B-2	4.2	18		
II-N-C-2	4.4	18		
II-C-A-2	4.5	18.5		
II-C-B-2	4.3	18.5		
II-C-C-2	4.5	18.5		
II-N-A-3	3.6	17		
II-N-B-3	3.2	18.5		
II-N-C-3	4.1	16.5		
II-C-A-3	3.8	17.5		
II-C-B-3	3.7	17.5		
II-C-C-3	4.1	18		
II-N-C-4	3.4	18		
II-C-A-4	3.3	18		
II-C-C-4	3.0	16.5		

***+ or - mark given by inspector was counted as half mark (0.5) in this table for calculation purpose.

Table 40.--Summaries of analysis of variance for changes in reflectance color of frozen asparagus: Test Series II.

Source of variance	Degree of freedom	F test		
		L	-a/b	$\sqrt{a^2 + b^2}$
atmosphere	1	16.091**	$0.023^{N.S.}$	$3.842^{N.S.}$
storage method	2	43.911**	$3.043^{N.S.}$	27.630**
time	3	63.897**	3.583*	31.207**
atm. x stor.	2	$1.907^{N.S.}$	$2.234^{N.S.}$	$1.221^{N.S.}$
atm. x time	3	$2.588^{N.S.}$	$0.851^{N.S.}$	$0.262^{N.S.}$
stor. x time	6	$1.609^{N.S.}$	$0.872^{N.S.}$	$1.346^{N.S.}$
atm. x stor. x time	6	$2.215^{N.S.}$	$0.936^{N.S.}$	2.301*
error	48	--	--	--

Table 41.--Summaries of analysis of variance for visual color score of frozen asparagus: Test Series II.

Source of variance	Degree of freedom	F test
atmosphere	1	5.027*
storage method	2	5.803**
time	3	45.099**
atm. x stor.	2	$2.885^{N.S.}$
atm. x time	3	$1.716^{N.S.}$
stor. x time	6	6.651**
atm. x stor. x time	6	$2.262^{N.S.}$
error	24	--

Table 42.--Summaries of analysis of variance for organoleptic evaluation of flavor of canned asparagus.

Source of variance	Test Series I		Test Series II	
	Degree of freedom	F test	Degree of freedom	F test
atmosphere	1	15.625**	1	$0.339^{N.S.}$
storage method	2	$1.667^{N.S.}$	2	9.220**
time	3	68.917**	4	25.843**
atm. x stor.	2	$1.917^{N.S.}$	2	4.622*
atm. x time	3	$2.333^{N.S.}$	4	3.252*
stor. x time	2	$1.917^{N.S.}$	8	$2.047^{N.S.}$
atm. x stor. x time	-	--	8	$1.654^{N.S.}$
error	10	--	30	--