A STUDY OF THE EFFECT OF STORAGE AND ENVIRONMENTAL FACTORS UPON CHANGES IN QUALITY AND NUTRITIVE VALUE OF LIMA BEANS

By

John Lowry Bowers

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INTRODUCTION

The development and expansion of the processing industry in the United States is paralleled to some degree by the search for methods of measuring quality in food products. An over-all view of the trend of quality studies indicates that one of the most influential and universally operative factors responsible for variation in eating quality is the stage of development or the degree of maturity. Some vegetable products have their highest quality while they are quite young and others increase in quality as the product matures.

For many years the quality of canned lima beans has been largely based upon color and size. These factors were determined by human sight and by the use of sizing equipment. With varieties such as Henderson Bush the assumption that color and size were closely related to quality and maturity proved to be sound and useful. However, the introduction of "green seeded" varieties has altered this relationship between color and quality. The new "green seeded" types do not lose all their green pigment in the process of maturation; consequently, the color factor as an accurate means in evaluating quality is no longer reliable. Thus, the development of some other method is imperative. A very strong effort has been made by investigators to associate certain chemical changes in the seed with maturity.

Although a considerable amount of scientific data have been published on the nutritive value of the lima bean, little information is available on factors related to quality. How is a change in the nutritive value reflected in a change of quality? A considerable amount of information has been compiled on the influence of a delay in harvest and storage factors upon changes in nutritive value, but these changes have not been related to changes in quality based on actual taste testing studies.

Although a considerable amount of scientific information has been compiled on maturity and quality measurements of the lima bean, little is known about how such environmental factors as light intensity and temperature affect changes in maturity and quality. The information on how environmental factors affect the period of duration of the most desirable edible stage in the lima bean is very scanty. Thus, these investigations were undertaken to determine the rate of change in nutritive value as affected by storage under different temperatures and durations, to measure the relationship between these changes and those in quality of the frozen product, to compare the rate of physico-chemical changes of beans in the pods removed from plants and held in storage with those left on the plants and to show the effect of light intensity and night temperatures upon growth, maturity and nutritive value of the lima bean.

REVIEW OF LITERATURE

STORAGE

Several investigators have studied the effects of storage upon changes in the various carbohydrates, vitamins and mineral contents of the lima bean and other closely related crops. Most of the early investigations reported the effect of temperature and duration in storage upon changes in the sugars, both reducing and non-reducing, and in the more complex carbohydrates such as cellulose and hemicelluloses.

Carolus (18) conducted studies on the effect of normal and low temperatures for periods of 24 and 72 hours on the changes in shelled and unshelled lima beans exposed in open pans and enclosed in cellophane bags. He reported that for the first 24 hours total sugars decreased rapidly, soluble nitrogen decreased slightly, and starch and insoluble nitrogen increased slightly. The starch content began to decrease slowly after the first 24-hour storage period. With unshelled beans the normal temperatures decreased the starch content more rapidly than the other storage conditions.

Bisson, Jones and Robbins (10) carried out studies on the effect of storage temperature upon changes in dry matter, reducing substances (mostly sugars), total sugars and crude fiber in the marketable spears of asparagus. In general, they found that storage temperatures of 41, 56, and 77 degrees F. resulted in rapid decreases of reducing substances and in total sugars, whereas the crude fiber increased with each increment increase of the storage temperature.

Denny and co-workers (25) investigated the influence of carbon dioxide upon the changes in the sugar content of several vegetables in storage. They placed lima bean pods in large galvanized containers in which the following concentrations of carbon dioxide were maintained: 0, 2.5, 7.5 and 22.5 per cent by volume, and stored the containers in a room maintained at 5 degrees C. Under these conditions they found that carbon dioxide retarded the rate of decrease of sucrose in the shelled beans and maintained good color and condition in the green pods. In sharp contrast to the results of other investigators, no reducing sugars were present in the shelled beans.

Brown (14) presents data which show that high temperatures markedly decrease the sugar content of garden peas immediately after they are harvested. Peas with a sugar content of 18.6 per cent (as invert sugar on a dry weight basis) at the harvest and stored at high temperatures for a period of 7 days lost 36.8 per cent of the sugars, while those stored at 32 degrees F. lost only 30 per cent of the total sugars.

Eheart et. al. (26) determined the ascorbic acid content of shelled lima beans under various storage conditions. They found that the 48-hour shelled refrigerator-stored samples were higher in ascorbic acid, with an 84 per cent retention than the 48-hour shelled room-stored samples, with a 33 per cent retention; whereas, the 48- and 96-hour pod room-stored samples retained 61 and 28 per cent, respectively. The 96-hour pod refrigerator-stored samples were only exceeded in ascorbic acid content by the fresh sample, the 48-hour shelled and the 48-hour pod-stored refrigerated samples.

Tresseler and co-workers (81) found that shelled lima beans stored at 0 degrees C. for 4 and 11 days lost 29 and 58 per cent of their ascorbic acid respectively, and pod-stored lima beans at the same temperature lost 19 and 31 per cent, respectively. They found the greatest losses in ascorbic acid during the first 3 days of storage.

Fellers and others (27) compared the Sherman bioassay for Vitamin C with the 2, 6 dichlorophenol-indophenol dye titration values and found the former considerably higher. They state, however, that the titration dye method is useful in checking losses during handling or storage. Their results show that fresh lima beans pod-stored in iced hampers lost 30 per cent of the original ascorbic acid content in 2 days. In studies on the nutritive value of canned foods, Guerrant et al. (30) showed that the vitamin content of most canned vegetables, including lima beans, decreased with increased temperature and prolonged storage.

Cortner et. al. (29) found that quick-frozen snap beans lost 30 per cent of their ascorbic acid when held for 1 year at 0 degrees F. and 80 per cent at 10 degrees F. In comparison to quick-frozen snap beans, these workers found that quick-frozen peas did not lose any of their ascorbic acid content when held for one year at 0 degrees F.

Scott and Mahoney (73) studied quality changes in lima beans at different storage temperatures. Shelled beans were stored in consumer packages at 28, 32, 35, 38, 42 and 46 degrees F., and samples were removed at 2-, 4-, 6-, 8- and 11-day intervals to determine total solids, alcohol insoluble solids and ascorbic acid contents. Analyses were not made on samples held at 42 and 46 degrees F. because they were unmarketable after the first few days of storage. They found that shelled beans stored for a period of 4 days at any one of these temperatures, 28, 32 and 35 degrees F., whether from precooled or non-precooled lots retained approximately 2/3 of their original ascorbic acid content and were excellent in appearance and free from off odors. The shelled beans remained in an edible stage for 11 days when stored at 28 degrees F.

Jones and Allinger (38) studied the sugar and starch content of peas stored in the shelled and unshelled condition. The unshelled peas that were stored at 3.5 degrees C. for a period of 188 hours showed a rapid translocation of dry matter from the pods to the peas and a retention of 61 per cent of their original sugar content, while shelled peas that were stored at the same temperature for a period of 112 hours showed a retention of only 11.6 per cent of their original total sugar content.

Kertesz (39) measured the changes in reducing sugars, sucrose, starch and alcohol insoluble solids of peas after they had been removed from the plant. He found a striking reduction in the sucrose content. However, the reducing sugars and starch remained almost the same. The alcohol insoluble solid fraction increased very rapidly. In the immature peas, there was a 50 per cent increase in the first 24 hours, whereas, there was only 24 per cent increase in the mature peas.

Studies conducted by Scott and Tewfik (74) on atmospheric changes occurring in film-wrapped packages of vegetables and fruits showed a very rapid deterioration in flavor of the lima bean, and no impairment in flavor of the snap bean. Carbon dioxide accumulated and oxygen was depleted in all of the film-type wrappers these workers tested.

Wadsworth and Wilcox (83) found that unthawed frozen samples of lima beans held at 0 degrees F. for a period of 14 to 18 weeks contained 19.9 milligrams of ascorbic acid per 100 grams fresh weight as compared with the 27.9 milligrams per 100 grams found in fresh lima beans.

Williams et al. (85) carried out extensive investigations upon changes in the sugar content of raw green beans stored under ordinary room temperatures and iced in hampers. They found that storage in iced hampers resulted in no change in reducing sugars and an increase in sucrose from 0.4 to 0.85 grams per 100 grams of fresh tissue, and storage at ordinary room temperature resulted in a decrease in reducing sugars from 1.92 to 0.90 grams.

Appleman and Arthur (4) studied the rate of sugar loss in sweet corn held in storage. They found that the depletion of sugar does not proceed at a uniform rate. In general, the rate of sugar loss becomes slower until the initial total sugar content is decreased to approximately 62 per cent and the sucrose initial content to approximately 70 per cent. Their work shows that during the first 24 hours at 30 degrees C. the kernels lost 50 per cent of their original sugar content, while for the same period at 20 and 10 degrees C. the kernels lost 25 and 15 per cent, respectively, of the original sugar content.

ENVIRONMENTAL FACTORS

Several investigations have been made on the influence of shade or partial shade as compared with sunlight on the yield of vegetable crops. Halsted (31) tested spinach and lima beans under a shaded and non-shaded environment. He found that shading favored the growth of spinach, but strikingly reduced the yield of lima beans. The shaded plots of lima beans yielded an average of 28.87 pounds of pods as compared to the unshaded plots with a yield of 52.12 pounds. Andrews (2, 3) found that the Fordhook variety outyielded Henderson Bush when the two varieties were grown under shade. Under these conditions he observed little or no difference in stomatal behavior, leaf thickness or palisade cell length of the two varieties. However, when both varieties were grown in full sunlight, the chlorophyll content, stomatal opening, leaf thickness and yield of Henderson was greater than that of Fordhook.

Reid (68) studied the effect of light variations upon the growth of the cowpea plant. Plants grown under relatively weak light (184 gram-calories per day solar radiation) had thicker leaves, larger stems and smaller roots and a lower ascorbic acid content than those grown in strong light (344 gram-calories per day solar radiation). She concluded that a reduction in the light intensity increased the size of leaf but did not increase the green weight. In another investigation (69), Reid found a definite influence of light intensity on a "day to day" and even in a "time of day" effect upon the ascorbic acid content of the cowpea plants. In some cases ascorbic acid content increased throughout the day. She concludes that "concomitant increases in ascorbic acid and dry matter during the course of the day suggest a close relationship between synthesis of the carbohydrates and that of ascorbic acid."

Thut and Loomis (79) studied the relation of light to growth in Zea mays and found that maximal growth of stem axis and leaves occurred in full sunlight (10,000 foot-candles or more). They concluded that all the effects of day and night can be explained upon the basis of two indirect effects of sunlight, namely, temperature and water deficit. This conclusion was based upon the fact that the growth curves of shaded and unshaded plants were practically identical except during the drier parts of the day when the shaded plants made the greater growth.

Tanada (77) determined the effect of light intensity upon utilization of nitrates and upon the changes in hemicellulose, dry matter, soluble sugars, and starch by the coffee plant. He found that shading resulted in an increase in the different forms of nitrogen and hemicellulose, and in a decrease in dry matter, soluble sugars, and starch.

Arthur (5) found that photosynthesis takes place only in the visible and near ultra violet regions of the spectrum, and that the dry weight of plant tissue is closely correlated to the output of a lamp in the visible region. Panchaud (62) studied the production of dry substance in the root of the radish under different light intensities. His findings show that the ratio of water to dry substance tends to decrease as the light intensity increases.

Lubimenko (50, 51) studied the effect of light intensity upon chlorophyll production of many plants. He found that within limits chlorophyll increased rapidly with a decrease in light intensity. His studies also show that stem growth increases with illumination, whereas, root and leaf growth decrease with illumination.

Blackmon (11) grew duckweed at light intensities varying from 350 to 1400 foot-candles and at temperatures ranging from 15 to 30 degrees C. His findings show that light intensity and temperature are interrelated. In general, an increase in light intensity to which the plants were exposed resulted in a shift of the optimum temperature to a higher level.

Kohman and Porter (40) present data on the effect of solar rays upon ascorbic acid in the tomato. They kept tomato plants in a laboratory during the night and placed them on the roof exposed to sun rays during the day. The plants lost ascorbic acid when kept inside, but made more to replace the losses when exposed to the sun again. They found a positive correlation between ascorbic acid and sugars in the ripe fruit. McCollum (53), working with the same crop, found that fruits shaded by plants contained 31.1 milligrams ascorbic acid, whereas fruits unshaded by the plants contained 34.0 milligrams in 100 grams on the fresh weight basis. However, this investigator found no relationship between the ascorbic acid content and total solids nor with total sugars.

The interaction of light intensity and temperature upon frond multiplication of Lemna was studied by Ashley and Oxley (7). These investigators found that both light intensity and temperature have a significant effect upon frond multiplication and weight. They found that frond area was independent of temperature above 24 degrees C. and independent of light intensity above 350 foot-candles.

Popp (64) reports that the thickness of the stem of the soybean plant is proportional to the light intensity. He found that optimum elongation of the stem occurred at 500 foot-candles. Porter (65) studied the influence of light intensity upon photosynthetic activity of tomato plant leaves, as measured by the amount of growth, fruit production, and increases in fresh and dry weight. He found that with decreased light intensity stem elongation and leaf expansion increased. The percentages of dry matter, fresh weight and elaborated food materials correlate rather closely with light intensity.

Studies of different densities of shading as they affect growth and fruiting of the Henderson Bush variety of lima bean were carried out by Havis (32) in Ohio. In his experiment, 2, 3, and 4 layers of cheesecloth were employed. Leaves of plants grown under any of the shade treatments were larger and thinner than those of plants exposed to full sunlight. However, there were no significant differences between the leaves from plants of any two of the shading treatments. Plants under the 2 and 3 layers of cheesecloth flowered only 1 day later than plants in full sunlight, whereas the plants shaded with 4 layers of cheesecloth flowered 7 days later than plants in full sunlight. Shaded plants differed from those in full sunlight in the following respects: roots were less woody and had smaller diameter, stems were thinner, more succulent and much elongated, and the top-root ratio was greater.

Smith (75) studied the effect of various wave lengths of light upon the development of carotenoid pigments in the tomato. His data show that wave lengths of 5400 to 5800 A. U. were not conducive to maximum production of the carotenoid pigments, whereas some of the shorter and longer wave lengths tend to increase the carotene content. He concludes that fruit should be ripened in light to obtain the maximum carotenoid pigment development.

Arthur and Stewart (6) carried out shading experiments upon salvia, sunflower, buckwheat, dahlia and tobacco plants grown during June and July. Four plant cages were set up to permit 100, 78, 58 and 35 per cent transmission of the light available. They found that all plants, except salvia, produced greater dry and wet weight of tissue when shaded as compared to open sunlight. The optimum intensities found for tobacco, sunflower, buckwheat and dahlia were 35, 78, 58 and 58 per cent transmission of the total solar radiation, respectively. However, when the same experiment was repeated in August, the highest dry weight was made by plants grown in full sunlight.

Roberts (70) observed the effects of different temperatures and photoperiods on the behavior of 240 varieties and/or species of plants. In general, plants grown under high night temperatures were of a pale yellow color, especially those considered as warm-climate plants, while those grown under low night temperature did show discoloration of the foliage.

Andrews' work (1) on the effect of temperature on flowers of Crocus vernus brings out the extreme sensitivity of a plant to small changes in the temperature. Even a change of 0.5 degree C. resulted in perceptible opening of the petals.

Curtis and Herty (23) studied the effects of temperature upon translocation from leaves, and found that cooling a petiole between 0.5 and 4.5 degrees C. greatly retarded translocation from the leaf blade.

The greater rate of transport took place between 17 and 24 degrees C. These workers concluded that the increased carbohydrate content of receiving tissues as well as leaves is an indication that utilization through respiration and by growth are retarded more by low temperature than translocation.

Boswell (12, 13) investigated the relation of such environmental factors as rainfall and temperature to yield and several plant characters of the pea. He found an inverse relationship between temperature and weight of plant, number of pods and peas per plant. Under the climatic conditions of the experiment, he concludes that temperature is the most noticeable factor influencing yield and development of the garden pea.

Cordner made a study (19, 20) of the external and internal factors that affect blossom drop in the Henderson Bush variety of lima bean. He found that high temperatures and low atmospheric humidity favored the abscission of blossoms. Many racemes averaged 53 potential buds but only 2 pods set per raceme.

Several investigations have been reported which stress the important influence of site or location upon vitamin and mineral content of vegetables. Reder et. al. (67) found that the influence of place was 13.75 times as great as the most important average effect produced by a fertilizer treatment upon ascorbic acid content of turnip greens. Janes (36) reports little variation in carotene, ascorbic acid and dry matter content of collards, broccoli and carrots grown under different fertilizer treatments, but considerable variation in percentage of these constituents from one location to another. Eheart et. al. (26)

reported on the effects of location on the ascorbic acid, thiamine and riboflavin contents of lima beans. Highly significant location differences were obtained for all 3 vitamins and between years at the same location for ascorbic acid. Janes (35) compared the carotene of snap bean varieties at different locations in Florida. He found some differences between varieties but much greater differences between locations.

McGinty and Andrews (54) found that increases in nitrogen content of fertilizers increased the seed weight, but had no significant effect on pod or seed numbers in lima beans. They also report that the examination of blossoms showed that the anthers do not dehisce under ordinary conditions at Clemson College and some of the pollen grains germinate within anthers. Wolf (86) states that Henderson Bush plants which have set a good crop of pods contained significantly more nitrate nitrogen, available calcium and less available phosphorous than poorly-set plants. Rapid soil tests for organic matter content of the soil showed a positive correlation between seed set and soil organic matter content.

MATURITY, QUALITY AND VARIETIES

During the last 10 year period many investigators have directed their efforts to measuring maturity and quality objectively. These 2 factors are so closely interrelated that most studies are reported on both factors. Kramer and Smith (44) studied the relationship between tenderometer readings on the raw lima beans and alcohol insoluble solids content of the canned product. The correlation coefficient between these 2 factors was +.91. They found very little varietal difference in this relationship but distinctively different ranges for different varieties. They conclude that the maximum yield stage is reached when the largest portion of beans has reached the maximum size. However, maximum size can only be obtained by means of several successive harvests. In the Henderson Bush variety this point was reached when approximately 40 per cent of the beans had turned white and the tenderometer reading was 300. In another phase of their work they showed that the use of brine solutions was quite satisfactory for the small size beans but decidedly unsatisfactory for the large sizes. Another study conducted by Kramer (41) brings out the relationship between maturity and yield in the lima bean. It is pointed out that shelled beans increase in maturity as they increase in size until the "medium size" is reached; at this time individual beans of Henderson Bush variety weigh slightly over 1 gram, but, if they are allowed to remain in the field beyond this stage they shrivel back to the tiny size.

Lee (46) reports the employment of a tenderometer capable of measuring shearing forces up to 550 pounds per square inch as compared with the standard which measures up to 250 pounds. The grade estimates made over 2 seasons and based upon per cent of white beans in the Henderson Bush variety and the per cent of wrinkled beans after blanching of Clark's Allgreen did not correlate very well with tenderometer reading.

The specific gravity principle has been employed by several investigators as an objective measure of maturity in peas and lima beans. Lee (47) concludes that the determination of specific gravity as a measure of maturity is more reliable than the determination of alcohol insoluble solids, or total solids of frozen lima beans. Lee (48, 49) employed the specific gravity factor in maturity studies on peas. From these results on blanched peas he concludes that the specific gravity of the Fancy grade should be under 1.084, for the standard grade from 1.085 to 1.094, and for the sub-standard grade above 1.095. The specific gravity measurements on raw peas were unsatisfactory.

Culpepper and Magruder (22) made determinations on the specific gravity of the raw seeds of 4 types of lima beans at several stages of development and at dry ripeness. They found that the specific gravity of the entire green seeds was very poorly correlated with their age. This appeared to be due to the presence of air spaces between the seed coats, largely between cotyledons. After removal of seed coats, specific gravity of seeds was fairly closely correlated with the age of seeds. In the small-seeded varieties, the specific gravity of entire seeds increased fairly consistently with increasing age and was consequently a more reliable measure of maturity than the same measurement on whole seeds of the large-seeded types.

Culpepper and Caldwell (21) investigated the development of different parts of the lima bean pod in relation to maturity and eating quality. The parts studied were, namely, fresh weight of seed, ratio of fresh weight of seed to fresh weight of pericarp and ratio of fresh weight of cotyledons to fresh weight of seed coat. They conclude that relations between the fresh or dry weights of different parts are less affected by environmental conditions than the weight of the individual parts. They found that the ratio of fresh weight of the cotyledons to that of the seed coat and the ratio between the dry weights of the same parts to be more reliable indices of stage of development and especially of usable maturity, than the weights themselves or any other relationships that exist between them.

Eheart et. al. (26) separated beans by eye on the basis of immature greens, mature greens and mature whites and determined the ascorbic acid, thiamine, riboflavin and moisture contents. They found a significant decrease in each vitamin and moisture content with an increase in maturity. Tresseler et. al. (81, 82) found that the rate of loss of ascorbic acid in lima beans was greater for the small sizes, but the amount retained was about the same for all sizes, and that ascorbic acid decreased with bean maturity.

Studies on the relationship between starch content and maturity of lima beans were made by Nielsen and Gleason (61). Starch content correlated very well with the brine flotation and organoleptic rating for maturity. Nielsen et al. (60) state that 80 to 85 per cent of the observed variance in starch content of the pea can be attributed to maturity. Furthermore 90 per cent of the variance in the cotyledon texture as determined by the starch content can be accounted for by differences in maturity. These same workers report no correlation between sugar content and maturity in the pea.

Mitchell and Roderick (57) studied changes in ascorbic acid of lima beans harvested at 10 to 14 day intervals. Three harvests on the Henderson Bush variety were made: early, medium and late. Although each harvest included immature, mature and over mature pods, the results of the analyses indicate that beans harvested in relatively early stages of maturity are likely to have the highest ascorbic acid content.

Woodroof and Tankersley (87) consider the color of the lima bean to be one of the important quality factors. They consider that 3 colors, namely, blue, green and yellow, exist in the seed, and that the bean seed loses these colors upon shelling in the order they are listed. After the beans were shelled, the blue color was lost in 24 hours; the green and yellow were lost after 48 hours. At the end of 2 days all beans were white regardless of maturity at harvest.

Kramer and Mahoney (43) found that semi-quantitative determinations of catalase and peroxidase activity and pigment content were unsuitable as quality indices for frozen and canned lima beans. These workers found that iodine threshold value (iodo-colorimetric test for ascorbic acid) and organoleptic tests on the frozen and canned material were very closely correlated when the interval between harvest and processing and varieties were the variable factors. Their work also shows that over blanching reduced the iodine threshold value more than it did the organoleptic value. Kramer (42) reported in another study that tin containers had no detrimental effect on quality. He also found that the optimum cooking period for frozen beans was 17 minutes after the beans and water come back to a boil. In this study frozen-dry samples were no better; neither were they inferior to the brine-frozen pack of beans.

Lutz (52) concludes that chemical and physical determinations can not always be relied upon to give accurate information on characteristics such as color, texture and flavor of certain vegetables after cooking when after harvest treatments were the variables. However, Schrader (72) reports that ascorbic acid of lima beans was very closely correlated with organoleptic tests under several variations, experimentally produced.

Several investigators have shown the close relation of tenderometer values of the raw product to organoleptic values on the canned product. Walls et. al. (84) obtained tenderometer and organoleptic readings on 632 samples of peas. They report a very high degree of correlation between tenderometer readings and the standard methods of grading. Jenkins and Lee (37) obtained a close correlation coefficient (0.90 ± 0.054) between the tenderometer values for raw asparagus and organoleptic tests of the canned products.

Wadsworth and Wilcox (83) investigated changes in the ascorbic acid content of lima beans that were frozen and stored at 0 degrees F. and the effect of thawing and cooking frozen samples upon ascorbic acid values. The raw lima beans contained 27.9 milligrams per 100 grams fresh weight, unthawed frozen beans, 19.9 milligrams per 100 grams and cooked samples, 9.9 milligrams per 100 grams. Thompson and Mahoney (78) found that the ascorbic acid content of lima bean samples, which had been previously separated into sieve sizes and further separated by brine flotation, 60 degrees salometer, varied from 15 to 36.6 milligrams per 100 grams on a fresh weight basis. As the sieve size decreased the moisture and ascorbic acid content increased. Ascorbic acid was markedly reduced by blanching with hot water as compared to blanching with steam. Increasing the blanching period in both water and steam reduced the ascorbic acid content.

Although lima beans are considered a poor source of carotene, several investigators have studied the changes in this compound in the seed. The seed used by Zscheile et. al. (89) contained from 0.32 to 5.70 gammas per gram of carotene, with 53 to 79 percent in the form of beta carotene. Both total and beta carotene decreased during frozen storage, and small young beans contained more carotene than the large old beans. Zimmerman et. al. (88) found that the carotene content of frozen lima beans of the Henderson Bush variety did not change during 5 months of frozen storage at 0 degrees F and at -40 degrees F. They found that 2/3 of the yellow pigment was beta carotene and 1/3 was alpha carotene.

Davis and co-workers (24) found that the protein content, 6.65 per cent, of frozen lima beans was only slightly lower than protein content of raw beans, 7.27 per cent. They found an inverse but highly significant ratio between both protein and water content, and sulfur and water content. Water blanching and color sorting only slightly lowered the protein and sulfur percentages.

Many investigators have determined the differences in vitamin content between strains and varieties of lima beans. McWhirter (55) measured the Vitamin C content of the marketable pods of Henderson Bush and the Carolina Sieve pole varieties before and after cooking. The raw beans contained 37 and 40 milligrams per 100 grams, respectively, and the cooked beans contained 30 and 37 milligrams per 100 grams, respectively. In another report this same investigator (56) states that the differences in ascorbic acid content between any 2 of the 7 bush varieties tested were of no more importance nutritionally than the differences in the Vitamin C content of 1 variety at the varying stages of maturity. This investigator also found the Peerless variety to be exceptionally high in carotene.

Caldwell, et. al. (16) made comparative studies of varietal suitability for freezing on several vegetable crops. Their test on lima beans included 8 varieties, 6 bush types and 2 pole types. They found that the pole types retained their color well until the beans reached full size, and rated excellent in texture and very good in flavor. Although the shelled beans of the Dreer's Bush variety were considered superior to those of any other variety in the test, these investigators found that shelled beans of Henderson Bush required hand picking to obtain a comparable type pack with Dreer's Bush or the pole varieties, namely, King of Garden and Giant Podded. In another report on their studies these investigators (17) state that younger beans of all varieties retain their appearance when frozen but older beans yellowed, and found that dry packs were equal in all respects to those in the brine. Caldwell and co-workers (15) also tested the suitability of 19 varieties for dehydration. They rated only 1 bush type as superior, selection 403A, and several as fair, such as Henderson Bush, Cangreen, Clark's Bush, Supergreen and Woodruff. Fordhook, Fordhook 242 and Early Market were placed in a second rating. Small sizes of these varieties were excellent, whereas the large sizes were inferior.

Helm and Troole (34) and Tompkins (80) caution that tasting panels should be carefully selected and trained before evaluations are made.

Tompkins (80) states that the aggregate score for the various characteristics should not be recommended, since failure to meet a standard in any one characteristic may render a product unacceptable.

MATERIAL AND METHODS

STORAGE STUDIES

The 3 varieties used in these studies to determine the effect of storage temperature and duration upon the physico-chemical changes in shelled lima beans were Concentrated Fordhook, Peerless, and Fordhook 242. These varieties were selected because they are suitable for the fresh market and the frozen food trade, and may also be used for canning.

Crop production and harvest. These varieties were planted on a sandy loam soil in 4 complete randomized blocks on May 25, 1948 at the Plant Research Farm, College Park, Maryland. Each plot consisted of 12 rows 100 feet long, each row spaced 3 feet apart. The 12-row plots were divided into sub-plots of 4 rows each. This permitted the harvest of a sub-plot of each variety at 3 successive intervals.

The Concentrated Fordhook variety was harvested on September 11, 16 and 23, whereas the Peerless and Fordhook 242 varieties were harvested on September 13, 17 and 23. The plants of 3 of the 4 rows in each sub-plot were harvested by means of bean knives attached to a row-crop tractor and vined at the Plant Research Farm vinery, and the plants of the remaining row were harvested by means of stripping all pods from the plants. The shelled beans and pod samples were transported on a truck to the Horticulture Department's processing laboratories.

Preparation and storage of samples. The yield of pods by sub-plots at each harvest was obtained at the processing laboratory. Then each sample was washed to remove the trash and dirt, drained and divided into 3 equal lots by weighing into open hampers on scales that weighed to the 1/10 pound. This division of the pods of 1 variety from each harvest into 3 equal lots permitted pod-storage at 3 temperatures, namely, 35, 50 and 70 degrees F. These temperatures were maintained within a ± 0.5 degree F. range. At the same time a sample of pods was placed in storage, another sample of shelled beans of the same variety was taken for the physical and chemical measurements and for the processing phases. The sampling of beans held in storage was carried out as follows: 4 pounds of pods were taken from each storage lot on the first day after storage, third day after storage and the sixth day after storage. Each sample removed from storage was shelled in the Junior Bean and Pea Huller in order that the physico-chemical measurements and processing phases of the study could be carried out on the shelled beans.

Processing of the samples from storage studies. This process consisted of washing to remove pieces of hull and other trash, blanching for 2 minutes in boiling water, immediately cooling under a stream of cold water, drying to remove excess water, placing the seed in 1/2 pint cellophane bags and sealing the bags with an electric sealer, and placing the sealed bags in a quick-freezer temperature at -20 degrees F. for overnight, then removing to 0 degrees F. storage.

Processing of samples at harvest. Shelled beans of each variety on each harvest date were washed in a riffle washer in the horticultural processing laboratories. The washed beans were then sized into 3 sieve grades, namely, small, medium and large.[1] A sample out of each size grade was carried through the same procedure as described under processing of the storage samples for the frozen pack. Another sample out of each size grade was weighed into a No. 2 size tin can. Three cans properly labelled were filled out of each sample if the quantity of beans was sufficient. The cans were then filled with a 2 per cent brine solution and sealed immediately on an automatic sealer. The sealed cans were placed in a cooking retort and cooked under steam pressure at 240 degrees F. for a period of 45 minutes. The cans were then removed and cooled immediately. They were then placed under room storage until they were graded organoleptically in February.

BIOPHYSICAL AND CHEMICAL DETERMINATIONS

The samples taken at harvest and at each storage sampling were divided into 2 lots: those employed in the physical measurements and those employed in the chemical analyses. Tenderometer, per cent white, ascorbic acid, color and moisture determinations were made immediately, whereas another portion of the sample was stored in alcohol for the chemical analyses which were carried out later.

Tenderometer measurements: The standard tenderometer which is capable of measuring shearing force up to 250 pounds per square inch

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[1] Size specifications presented in the National Canners' Association Manual for Canned Food Labels, 1942.

and a hydraulic tenderometer which was adapted to measure a shearing force of 500 pounds per square inch were employed in these measurements. A reading on 2 representative lots of shelled beans from each sample was made on the standard tenderometer, whereas 3 reading were made on each sample with the hydraulic tenderometer. Each reading on each instrument was recorded at the time of the measurement. These readings on each sample were later averaged for each respective instrument. A miniature tenderometer which measured the force in pounds per square inch required to shear 1 individual bean was employed on 38 samples. In order to obtain accurate sampling for this test, 20 shelled beans were taken from each sample tested and a reading obtained on each bean. These 20 readings for each sample were later averaged and recorded in this manner. Either before or immediately after the tenderometer readings were made, a representative lot was taken from 55 different samples for the percentage of white counts. Each representative lot was composed of 100 shelled beans and the percentage of beans with no green color in the cotyledon among this group was recorded. These counts were recorded as percentage of whites for each respective sample.

Moisture and color determinations. The shelled beans of a sample taken on each harvest date and from each storage sampling were thoroughly mixed and a 100-gram sample weighed out on a triple beam balance to ± 0.1 gram. The weighed sample was placed in a Waring Blender and 100 cc of tap water added. The bean and water mixture was blended for a period of 3 minutes. An approximately 20-gram sample of the blended mixture was weighed accurately to 1 milligram into a tared porcelain moisture dish on a chainomatic analytical balance. These samples were placed in a vacuum oven maintained at a temperature of 70 degrees C. and dried for a period of 24 hours. The dried samples were then removed from the oven and placed in a desiccator to cool for 30 minutes. The dried samples were weighed to 1 milligram on a chainomatic analytical balance. Another 20 ± .01-gram sample of the bean-water-blend was weighed on the analytical torsion balance and this was transferred into a clean Waring Blender with 70 cc of acetone. This mixture was blended for a period of 3 minutes. The blender cup was immediately removed from the base and the contents poured carefully into a hundred milliliter graduated cylinder. The blended solution was made up to 100 ml. volume by adding acetone. The contents of the graduated cylinder were mixed and a portion of the blended mixture poured into a glass test tube to fill the latter approximately 2/3 full. The test tube and contents were centrifuged for 15 minutes at 2000 r.p.m. Transmission readings on each sample were made on the Beckman Spectrophotometer at wave lengths of 665 mu and 450 mu.

Nutritive value determinations. The 2-6 dichloro-phenol-indophenol dye method (71) was used in determining the ascorbic acid content of each sample. A 0.5 per cent solution of oxalic acid was used as the extracting agent in place of the 3 per cent metaphosphoric acid because the former is more stable. The dye was standardized on each day that samples were analyzed. The results of each determination are reported in milligrams per 100 grams based upon the titration factor for each respective determination.

The carotene determinations could not be made on the same day as harvested or when a sample was removed from storage; thus, it was necessary to preserve a sample for later analyses. This was accomplished by weighing (on a triple beam balance) 100 ± .1 grams of fresh shelled beans of each sample. This weighed sample was transferred to a No. 1 tin can and a 2 per cent solution of potassium hydroxide (in ethanol) was added to cover the sample. The cans were sealed and stored at 32 degrees F. until the analyses could be made. The method outlined by Moore and Ely (58) was followed in making the beta-carotene determination on each sample. It was found that duplicate determinations checked much more closely if 20-gram samples of the beans were used instead of 10-gram samples. The transmission readings of the petroleum ether extract from each sample were made on the Beckman Spectrophotometer at 450 mu wave lengths. The transmission readings for each sample were converted into gammas of beta-carotene per gram.

Alcohol insoluble solids, sugar and starch determinations. These demonstrations could not be made at the time of sampling; consequently, it was necessary to preserve a sample for the analyses. These samples were prepared by weighing a 100-gram sample of shelled beans on a triple beam balance to within a ± .1 gram. The weighed sample was placed in a No. 1 tin can and covered with 95 per cent ethyl alcohol. The cans were sealed and placed in storage until the analyses could be made. The method used in determining the alcohol insoluble solids was essentially the same as outlined in the Association of Official Agricultural Chemists Journal (8). The 10-gram bean sample was refluxed in 150 ml. of 85 per cent ethyl alcohol for a 2-hour period. The refluxed sample was filtered through a weighed No. 1 Whatman filter paper on a Buchner funnel which had been placed on a Fisher filtrator. The filtrate was caught in a No. 1 tin can and stored for sugar analyses. The filter paper and residue were placed in weighed tin containers and dried in an electric oven at 100 degrees C. for a period of 30 minutes. The containers and dried residue were then cooled and weighed accurately to within 1 milligram on a chainomatic analytical balance. The weight of each dried sample was obtained by subtracting the weight of tin container plus filter paper from the dried weight of the residue, container and paper. These weights were converted into percentage alcohol insoluble solids by shifting the decimal point in the dry weight of each sample 1 place to the right.

The reducing and total sugar determinations were made on the filtrate obtained in the alcohol insoluble solids determinations. For both determinations the Heinze and Murneek (33) modification of the Shaffer-Somogyi method was used. This method is based upon the principle that sugar in a monosaccharide form will reduce copper. The reduced copper is in turn oxidized by iodine in a solution of known iodine value, and the iodine not used in the oxidizing process is titrated against a .02 N sodium thiosulfate solution. The difference in the amount of .02 N sodium thiosulphate required to titrate the unknown samples and the blank sample expressed in milliliters multiplied by 0.4444 gives the quantity of glucose present in the sample. Total sugars were determined by following essentially the same procedure as outlined by Heinze and Murneek after the sucrose had been hydrolyzed. The hydrolysis was accomplished by pipetting 50 ml. of the lead free sugar filtrate into a hundred milliliter volumetric flask. Then 20 ml.

of distilled water and 5 ml. of concentrated hydrochloric acid were added. The volumetric flasks and contents were placed in a rack and then lowered into a water bath held at 70 degrees C for 10 minutes. The flasks were then removed and cooled with tap water to 20 to 25 degrees C. The sample was made to 100 ml. volume by adding distilled water. A 10 ml. aliquot of each sample was pipetted into sugar test tubes. This solution in the test tube was neutralized by adding 15 per cent sodium hydroxide. From this point on the procedure was the same as outlined by Heinze and Murneek for the determination of reducing sugars.

The method employed in determining the starch content of each sample was essentially the same method as that employed by Nielsen (59) on peas and lima beans. One-tenth of the finely ground alcohol insoluble fraction of each sample was weighed out on the analytical balance, and solubilized with a 72 per cent perchloric acid solution which had been previously diluted with water in these proportions, 2 parts water, 2.7 parts 72 per cent perchloric acid. The solubilized mixture was permitted to stand for 10 minutes with occasional stirring, and made up to 50 ml. volume with distilled water. A 1 ml. aliquot of the supernatant liquid was pipetted into a hundred milliliter beaker and then 6 ml. of water added. The sample was then neutralized with a 2 N sodium hydroxide solution. After this the sample was made slightly acid by adding 2.5 ml. of 2 N acetic acid. The iodine starch color was developed by adding 0.5 ml. of 10 per cent potassium iodide solution and 5 ml. of .01 N potassium iodate solution and permitting the solution to stand at least 5 minutes. This bluish-green, starch-iodine solution was made up to 50 ml. volume and a transmission reading made on the Beckman Spectrophotometer at a wave length of 670 mmu. These transmission readings were converted to milligrams of starch by establishing the transmission curve for standard solution of a known amount of raw potato starch. The results, as interpreted from the potato starch curve are relative but should afford opportunity for studies on the trend of starch changes in the bean.

Organoleptic grading. The canned samples which had all been taken at harvest were graded in the raw form. Each sample was scored, individually, on the basis of color, tenderness and flavor by a panel of 6 judges. Color was scored in this manner on a numerical value range of 1 to 10; 1 being for the poorest color and 10 for the brightest green samples, 8 for tender succulent samples, 9 for samples too young and watery but still good and 10 for samples too young and watery. The flavor numerical ratings were made in this manner: excellent 10, very good 8, good 6, fair 4 and poor 2. Each sample was rated on over-all grade, ranging from 1 through 4.

ENVIRONMENTAL STUDIES

This phase of the study was conducted in the late fall and winter months of 1948-49 in the horticultural greenhouses at College Park, Maryland. In this way environmental factors could be controlled and varied within certain limits.

Establishment of the planting. A well composted soil mixture consisting of 3 parts sandy loam and 1 part well rotted manure was screened through 1/4 mesh hardware cloth, thoroughly mixed, weighed in 20 pound lots and placed into each of 81 coffee-urn jars. On November 13, 1948, 9 seeds of the Peerless variety were planted in the soil in each jar, and the seedlings were thinned to 3 plants per jar. A wire stake was inserted by each plant to give it support. The plants were grown under uniform conditions of moisture, temperature and light until the "first heavy wave" of pods was set. At this time the light and night temperature treatments were set up and the plants subjected to the 9 different light-night temperature treatments.

Plot design. This experiment was set up as a 3 x 3 x 3 factorial in which the variables were light intensities, night temperatures and times of harvest. Eighty-one plants, 3 plants in each of 21 jars were subjected to each of these 3 light intensities: (1) full sunlight plus three 200 watt bulbs, (2) full sunlight plus three 200 watt bulbs reduced by 1/3 by means of shading cloth, and (3) full sunlight plus three 200 watt bulbs reduced by 2/3 by means of shading cloth. The 3 bulbs were spaced 2 feet apart and 30 inches above the plant tops in each light treatment as shown in Figure 1. A Weston illuminator meter was used to check the relative light intensity of the 3 treatments. Under each light intensity treatment 3 separate lots, 27 plants, 3 in each of 9 jars, were held at 3 different night temperature ranges, namely, 40 to 45 degrees F., 60 to 65 degrees F., and 80 to 85 degrees F. The plants subjected to night temperatures of a low range and to night temperatures of a high range were placed at sunset in rooms maintained from 40 to 45 degrees F. and from 80 to 85 degrees F., respectively,

Figure 1. A general view of the light intensity and night temperature experiment on the Peerless variety of bush lima bean.

and returned to the light treatments the following morning; and the plants subjected to the medium range were allowed to remain in the greenhouse at 60 to 65 degrees F. A recording thermograph was placed in each room and in the greenhouse as an aid in checking the desired temperature range. In general, there were 3 light treatments within each of which there were 3 night temperature treatments, and within each night temperature treatment there were 3 times of harvest. For each harvest the entire crop of pods was removed from the 3 plants in each of 3 jars from each treatment combination and weighed to within ± 0.1 gram on a triple beam balance. The pods were shelled by hand and the shelled beans from plants in each jar in each treatment were weighed and the data recorded. It was necessary to pool the shelled beans from the plants in 3 jars of each treatment combination in order to afford a sufficient sample for the various chemical determinations.

Chemical determinations. The alcohol insoluble solids, sugar, moisture and starch determinations were made on a sample from each of the 27 treatments. The shelled bean samples from the different combinations of light intensity and the 80 to 85 degrees F. night temperature range were not sufficient to make the ascorbic acid, color and carotene determinations. These determinations were made on the other samples. The analytical methods have been described in a foregoing section.

Statistical methods. The data were analyzed according to Fisher's (28) method for the analysis of variance and Snedecor's (75) tables of

F values and method of calculating L.S.D.[2] were used to determine the significance of the differences between treatments. The machine method of calculating correlation coefficients as described by Snedecor (75) was employed.

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[2] Least significant difference

RESULTS

STORAGE STUDIES

The storage studies were set up in such a manner so that the data could be statistically analyzed to measure the effect of storage temperature and duration and time of harvest upon changes in the various physico-chemical determinations, and to determine the degree of some important first-order interactions.

The data presented in Table 1 show how each delay in harvest significantly increased the yield of shelled beans, whereas there was no significant change in the yield of pods when harvest was delayed. When the pod yield as affected by delay in harvest is considered for each variety, it is noted that there was a considerable increase in yield of pods in the second harvest over the first harvest in the Concentrated Fordhook variety. In the other 2 varieties, namely, Fordhook 242 and Peerless, the pod yields from different harvests differed by only insignificant amounts. When comparisons are made strictly on a varietal basis, it is noted that the differences in yield between either Concentrated Fordhook or Peerless as compared to the yield of Fordhook 242 are significant, but yield differences on either pod or shelled bean basis between the two leading varieties are not significant.

The data presented in Table 3 show the effect of storage temperature and duration and times of harvest upon changes in the tenderometer values. The effect of a delay in time of harvest upon the shearing force required was far greater than either temperature or duration

Table 1. Effect of time of harvest upon the yield expressed in pounds per acre[1] of shelled beans and fresh pods of three varieties of lima beans.

Times of Harvest	Concentrated Fordhook		Peerless		Fordhook 242	
	Shelled Beans	Fresh Pods	Shelled Beans	Fresh Pods	Shelled Beans	Fresh Pods
First Harvest	1340	4760	2003	6598	849	3479
Second Harvest	2126	6489	1939	5796	1089	3422
Third Harvest	2752	6969	2405	5730	1313	3517
Varietal Mean	2072	6073	2116	6011	1083	3473
Times of Harvest	First Harvest		Second Harvest		Third Harvest	
	Shelled Beans	Fresh Pods	Shelled Beans	Fresh Pods	Shelled Beans	Fresh Pods
Mean	1397	4946	1718	5206	2157	5404

[1] The acre yield factors for shelled bean and pod yields are 48.40 and 145.20, respectively.

L.S.D. at 5-percent level:		
	Varieties, shelled beans	293
	Varieties, pods	1046
	Harvests, shelled beans	227

Table 3. Effect of storage temperature and duration, and times of harvest on changes in the tenderometer readings, expressed as shearing force in pounds per square inch of three varieties of lima beans.

Factors	Concentrated Fordhook			Peerless			Fordhook 242			
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	Temperature Mean
Temperature:										
35°F	159.3	182.3	229.5	174.7	200.0	226.3	149.1	188.8	207.3	190.3
50°F	161.0	186.9	244.8	174.9	193.5	222.0	161.3	190.0	215.0	192.15
70°F	169.5	192.0	228.3	182.2	201.8	223.8	175.8	187.3	216.1	197.40
Durations:										Duration Mean
At harvest	154.0	190.0	236.0	171.7	189.0	216.0	152.3	190.0	205.0	189.33
1 day after	161.0	182.0	226.0	174.3	200.3	216.3	155.3	183.7	207.7	189.63
3 days after	172.2	188.8	215.3	186.0	193.3	235.0	162.3	182.7	225.7	195.70
6 days after	165.8	187.3	232.7	177.0	211.0	228.7	178.3	198.3	212.8	199.11
Varietal Mean	192.6			199.89			187.84			
Times of Harvest	First Harvest			Second Harvest			Third Harvest			
Mean	167.53			191.38			221.43			

L.S.D. at 5-percent level, varieties .59
harvests .59
temperatures .59
harvests, duration interaction 1.17
varieties, duration interaction 1.17

effects of storage, even though the effect of each factor is significant statistically. The influence of storage temperature upon changes in the tenderometer values is less than that from period of storage. The significant interactions between harvest and duration and between varieties and duration indicate that the effect of duration upon changes in the tenderometer values was not the same on the beans stored from each harvest period, nor the same for each variety in storage.

The effect of time of harvest, storage temperature and duration on the moisture content of shelled beans are presented in Table 4. As with tenderometer readings, a delay in harvest had more influence on moisture content than either storage temperature or duration. In fact, no significant differences occurred between the moisture content of beans held at any 2 of the 3 storage temperatures, or between shelled beans from any 2 storage periods. The moisture content of the shelled beans of the Peerless variety was significantly lower than that of either Concentrated Fordhook or Fordhook 242.

Data presented in Table 6 show the effects of harvests, varieties, durations and temperatures on changes of the alcohol insoluble solids fraction of the shelled beans. As in the case of the tenderometer readings and moisture content, the effect of times of harvest upon changes in the alcohol insoluble solids was greater than the effect of either storage temperature or duration. For example, the alcohol insoluble solids changed from 21.54 to 28.45 per cent from the first to the third harvest, from 24.23 to 25.22 per cent with storage temperature of 70 degrees F., and from 23.34 to 25.27 per cent for the first day of

Table 4. Effect of storage temperature and duration, and times of harvest upon changes in percentage moisture in three varieties of lima beans.

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	73.46	70.82	66.11	72.85	67.61	64.66	77.58	70.94	68.21	70.25
50°F	74.38	71.32	67.33	72.78	67.25	63.52	76.20	71.31	69.02	70.35
70°F	74.69	70.70	65.87	71.59	66.44	63.86	76.57	72.04	68.82	70.06
Durations:										Duration Mean
At harvest	75.67	72.23	67.13	76.04	66.68	65.21	80.42	71.78	69.80	71.66
1 day after	73.26	70.45	67.00	72.18	67.06	62.59	77.20	70.21	69.11	69.89
3 days after	73.17	70.81	66.03	70.46	67.48	64.60	74.60	72.48	67.74	69.71
6 days after	74.61	70.31	65.57	70.95	67.18	63.65	74.92	71.24	68.09	69.61
Varietal Mean		70.52			67.84			72.30		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		74.46			69.82			66.38		

L.S.D. at 5-percent level: between varieties 2.56
between harvests 2.56

Table 6. Effect of storage temperature and duration, and times of harvest upon the changes in alcohol insoluble solids percentage in raw shelled beans of three varieties of lima beans.

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	19.28	22.69	27.81	23.61	25.39	30.08	19.44	23.07	26.78	24.23
50°F	20.33	23.73	27.94	23.59	26.42	30.01	20.30	22.83	27.24	24.71
70°F	20.02	22.82	28.98	24.72	26.47	29.50	22.56	24.14	27.76	25.22
Durations:										Duration Means
At harvest	18.18	21.29	29.87	21.78	23.76	27.94	19.21	21.61	26.45	23.34
1 day after	20.37	23.19	26.90	24.89	27.60	30.82	21.39	25.20	27.12	25.27
3 days after	21.24	23.80	27.23	24.74	24.60	30.12	21.32	23.71	28.00	24.97
6 days after	19.70	24.04	28.97	24.46	28.41	30.54	21.14	22.86	27.45	25.29
Varietal Mean		23.73			26.64			23.79		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		21.54			24.17			28.45		

L.S.D. at 5-percent level:

temperatures	0.66
durations	0.76
varieties	0.66
harvests	0.66
harvest, variety interaction	1.15
Harvest, duration interaction	1.32
variety, duration interaction	1.32

storage. The differences in the A. I. S.[1] fraction between any 2 of the 3 storage periods, namely, 1 day after, 3 days after, or 6 days after, are not significant. As shown in Appendix Table 8, significant interactions occurred between harvests and varieties, between harvests and durations, and between varieties and durations. Thus, the effect of time of harvest upon alcohol insoluble solids is not always the same for each variety, is not always the same for each harvest, and differs with each variety.

Data on the effect of storage temperature and duration and times of harvest upon changes in the percentage of starch in the raw beans are presented in Table 7. These data show that each factor studied with the exception of duration in storage had a significant effect upon the starch content of the raw bean. The greatest change in the starch content resulted by a delay in the harvest, 13.76 per cent in raw beans from the first harvest as compared with 16.45 and 20.09 per cent for the second and third harvest, respectively. There is a difference between the starch content of samples held at 35 degrees F. and the 50 degrees F. storage, but it is not statistically significant. However, there is a significant increase in starch content when beans are held at 70 degrees F., 17.32 per cent as compared to 16.16 per cent starch found in the raw beans held at 35 degrees F. These data also show that the Peerless variety contains less starch than either Fordhook 242 or Concentrated Fordhook varieties, and the latter variety is considerably

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[1] Alcohol insoluble solids

Table 7. Effect of storage temperature and duration, and times of harvest on changes in the percentage starch in raw shelled beans of three varieties of lima beans

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	15.97	17.92	21.87	10.95	15.10	18.12	11.87	15.60	18.00	16.16
50°F	16.30	19.45	23.57	11.77	14.85	18.07	13.62	14.80	18.95	16.82
70°F	17.02	19.52	24.87	11.77	14.57	19.47	14.52	16.22	18.80	17.32
Durations:										Duration Mean
At harvest	13.20	16.60	20.80	11.50	15.10	20.00	16.50	16.90	19.00	16.62
1 day after	17.00	19.57	22.63	11.43	14.50	17.17	12.73	16.57	18.20	16.64
3 days after	18.03	19.60	23.03	11.80	15.03	17.73	10.83	15.13	18.30	16.61
6 days after	17.50	20.10	25.97	11.27	14.70	19.47	13.30	13.57	18.83	17.19
Varietal Mean		19.50			14.98			15.82		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		13.76			16.45			20.09		

L.S.D. at 5-percent level:

L.S.D. at 5-percent level:	between temperatures	.87
	between varieties	.87
	between harvests	.87
	between varieties, durations interaction	1.74

higher in starch than Fordhook 242. The significant interaction between varieties and durations as shown in the Appendix Table 8 means that duration of storage did not consistently affect changes in the starch value of each variety. Note that in Table 7 with Concentrated Fordhook there was a continual increase in the starch content due to duration in storage, whereas with Peerless and Fordhook 242 there was no increase in starch content. The data presented in Table 9 show the percentages presented in Table 7 transformed to angles. The alcohol insoluble solids and starch content of the raw lima beans were affected by the same factors with the exception of storage duration. This similarity in behavior is to be expected since the alcohol insoluble solids consist mainly of starch. Polysaccharides other than starch included in the alcohol insoluble solids fraction are cellulose and hemicellulose. The differences between starch and alcohol insoluble solid fractions in shelled beans of the Peerless and Fordhook 242 varieties were much greater than those for the Concentrated Fordhook variety.

The data on the effect of time of harvest, storage temperature and duration on the changes in ascorbic acid content of raw lima beans are presented in Table 11. The data show that each of these three factors significantly influenced ascorbic acid content. The 50 degrees F storage temperature was equally as effective as 35 degrees F. in preventing losses of ascorbic acid from pod-stored beans.

The ascorbic acid content of pod-stored beans decreased rapidly when duration of the storage period was prolonged. At some time

Table 9. Effect of storage temperature and duration, and times of harvest upon changes in the starch content of three varieties of lima beans (percent starch data transformed to angles)

Factors	Concentrated Fordhook			Peerless			Fordhook 242			
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	Temperature Mean
Temperature:										
35°F	23.52	25.04	27.88	19.32	22.87	25.14	20.06	23.17	25.09	23.57
50°F	23.77	26.15	29.01	20.06	22.67	25.15	21.63	22.61	25.81	24.09
70°F	24.31	26.18	29.23	20.07	22.44	26.25	22.32	23.74	25.69	24.47
Durations:										Duration Mean
At harvest	21.30	24.04	27.13	19.82	22.87	26.56	23.97	24.27	25.84	23.98
1 day after	24.34	26.24	28.40	19.76	22.38	24.41	20.86	23.95	25.25	23.96
3 days after	25.11	26.25	28.67	20.07	22.81	24.90	19.21	22.86	25.31	23.91
6 days after	24.72	26.62	30.62	19.61	22.57	26.18	21.30	21.60	25.72	24.33

Varietal Mean	26.12	22.66	23.35
Times of Harvest	First Harvest	Second Harvest	Third Harvest
Mean	21.67	23.87	26.58

L.S.D. at the 5-percent level:

harvests	0.67
temperatures	0.67
varieties	0.67
V x D, interaction	1.34

Table 11. Effect of storage temperature and duration, and times of harvest upon ascorbic acid losses in three varieties of lima beans. (Ascorbic acid expressed in mgm. per 100 gm.)

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	21.13	23.87	19.99	21.93	23.32	19.94	22.52	23.21	22.03	21.97
50°F	21.26	21.33	20.26	22.72	24.27	20.70	22.91	23.29	20.99	21.96
70°F	21.06	21.36	18.41	21.43	22.12	17.67	21.63	21.71	18.12	20.39
Durations:										Duration Mean
At harvest	22.39	24.63	20.12	24.68	25.33	22.16	23.17	25.69	21.31	23.28
1 day after	20.59	23.54	20.78	23.82	25.00	20.98	24.62	25.30	22.77	23.04
3 days after	21.29	19.29	19.58	20.28	21.92	17.18	21.32	19.82	18.78	19.94
6 days after	20.35	21.01	17.73	19.34	20.71	17.42	20.30	20.00	18.65	19.50

Varietal Mean	20.94	21.57	21.81
Times of Harvest	First Harvest	Second Harvest	Third Harvest
Mean	21.85	22.69	19.79

L.S.D. at the 5-percent level, temperatures 0.88
durations 1.01
harvests 0.88
temperature, duration interaction 1.74

between 1 day and 3 days after storage the rapid losses of ascorbic acid in the beans were incurred. Although there was a slight decrease in ascorbic acid in the beans after the first day of storage, the amount present did not differ significantly from that in the fresh beans. The effect of time of harvest upon changes in ascorbic acid content show that beans from the second harvest were higher than those from the first harvest. This difference between these two harvests approaches significance. However, a further delay in the harvest brought about a significant decrease in this vitamin, from 22.69 milligrams to 19.79 milligrams per 100 grams on the fresh weight basis. The variance for varieties was not significant as shown by the analysis of variance data on ascorbic acid presented in Appendix Table 13. The data show that the effect of temperature upon ascorbic acid content was not the same at different storage durations as is indicated by the significant interaction between these two factors. Very little effect occurred when the duration period was short, but very great effects took place when the duration was long.

Data on beta carotene are presented in Table 12. Unlike the data in Table 11 on ascorbic acid, the beta carotene content of beans in the pod was not affected significantly by the storage temperature but decreased in beans rapidly between the first and third day after storage similar to the manner that ascorbic acid decreased. In general, the delay of harvest resulted in a loss in beta carotene content of shelled beans; especially is this true when the 1.40 micrograms per gram content found in beans from the third harvest is compared to the 1.97

Table 12. Effect of storage temperature and duration and times of harvest upon changes in the beta carotene of three varieties of lima beans. (Beta carotene expressed in micrograms per gram on fresh weight basis.)

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	2.04	1.82	1.27	2.22	2.13	1.61	1.83	1.92	1.40	1.80
50°F	2.05	1.47	1.27	1.98	2.07	1.54	1.94	1.90	1.60	1.76
70°F	1.73	1.75	1.13	1.95	1.72	1.46	2.04	1.70	1.29	1.64
Durations:										Duration Mean
At harvest	1.78	1.13	1.25	2.63	1.88	2.13	2.25	2.05	1.65	1.86
1 day after	1.94	2.08	1.37	2.27	2.29	1.67	2.53	1.47	1.70	1.92
3 days after	1.98	2.10	1.28	1.63	1.97	1.28	1.68	1.92	1.40	1.69
6 days after	2.06	1.41	1.01	1.66	1.75	1.07	1.27	1.93	0.97	1.46
Varietal Mean		1.62			1.85			1.73		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		1.97			1.83			1.40		

L.S.D. at the 5-percent level, durations 0.22
varieties 0.19
harvests 0.19
varieties, durations interaction 0.38

micrograms per gram of beans from the first harvest. The difference between beta carotene content of beans from the first and second harvest is not significant. The beta carotene content of shelled beans of the Concentrated Fordhook variety is significantly lower than that of the Peerless variety but does not differ significantly from that of the Fordhook 242 variety. Neither is the difference in the beta carotene content between Peerless and Fordhook 242 significant. The effect of duration upon changes in the beta carotene content of raw beans is not the same for different varieties as indicated by the significant interaction between these 2 factors and presented in Appendix Table 13.

Data on the total sugar content of the raw beans are presented in Table 14. The significant factors that influenced changes in the total sugar content of the raw bean were temperature, duration and varieties. There are 2 significant interactions, namely, between harvest and duration and between duration and temperature. There was a tremendous loss in the total sugars due to the higher storage temperature 70 degrees F. as compared with either the 50 degrees or 35 degrees F. storage. The difference in the total sugar content of beans held at 50 degrees F. (1.51 per cent) and those held at 35 degrees F. (1.63 per cent) approaches a significant difference. There was a continual decrease in the total sugar content of raw beans when the duration of storage was prolonged; however, the greatest decrease occurred during the first day in storage. The total sugar content decreased from 1.87 to 1.42 per cent. Holding the samples in storage after this 1 day period resulted in a slower rate of loss as the period of storage increased. The total

Table 14. Effect of storage temperature and duration, and times of harvest upon changes in the percentage of total sugars in fresh shelled beans of three lima bean varieties.

Factors	Concentrated Fordhook			Peerless			Fordhook 242			Temperature Mean
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	
Temperature:										
35°F	1.53	1.60	1.58	1.88	1.97	1.86	1.37	1.33	1.53	1.63
50°F	1.41	1.38	1.55	1.84	1.80	1.84	1.14	1.11	1.53	1.51
70°F	1.07	1.02	1.28	1.39	1.21	1.29	1.02	0.72	0.92	1.10
Durations:										Duration Mean
At harvest	1.99	1.98	1.93	2.15	2.11	1.69	2.02	1.27	1.73	1.87
1 day after	1.42	1.36	1.33	1.71	1.62	1.89	1.25	1.01	1.21	1.42
3 days after	1.02	0.95	1.36	1.78	1.51	1.58	0.66	0.98	1.21	1.23
6 days after	0.91	1.05	1.26	1.17	1.41	1.50	0.76	0.96	1.16	1.13
Varietal Mean	1.38			1.68			1.19			

Times of Harvest	First Harvest	Second Harvest	Third Harvest
Mean	1.40	1.35	1.49

L.S.D. at the 5-percent level,

temperatures	.12
durations	.14
varieties	.12
H x D	.25
D x T	.25

sugar content of the Peerless variety was significantly higher than that of either Concentrated Fordhook or Fordhook 242. The total sugar content of Concentrated Fordhook, 1.38 per cent, is significantly higher than that of the Fordhook 242, 1.19 per cent. The effect of delaying harvest upon changes in the total sugars in raw shelled beans is not significant as shown in Table 14. The lima beans from the first harvest lost sugar much faster than those from the second or third harvest. The effects of storage duration upon sugar losses were much greater under high storage temperatures than under the low storage temperatures.

Data on the effects of the storage treatments and times of harvest upon changes in the green and yellow pigment of raw beans are presented in Tables 16 and 17, respectively. It will be noted from the data in these two tables that the same factors, namely, time of harvest, storage temperature and duration, had a significant influence upon changes in the 2 respective pigments in the raw beans. There was no significant varietal difference when either pigment is considered. It is apparent that storage at 35 degrees F is much superior to the 50 degrees F. storage in the retention of either pigment. The 70 degrees F. storage resulted in even greater losses of the pigments than the 50 degrees F. storage but the difference between these 2 storage temperatures is not significant. When beans were held in storage more than 3 days, there was a tremendous loss in both the green and yellow pigments as is shown in Tables 16 and 17, respectively. Each delay in harvest resulted in a tremendous loss of the green and yellow pigments and the proportional

Table 16. Effect of storage temperature and duration and times of harvest upon changes in the green pigment, expressed as chlorophyll in parts per million of three varieties of lima beans

Factors	Concentrated Fordhook			Peerless			Fordhook 242			
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	Temperature Mean
Temperature:										
35°F	59.62	49.62	50.25	59.75	55.00	46.37	66.87	58.12	49.75	55.04
50°F	51.50	47.25	50.62	60.75	51.92	40.62	58.50	55.75	48.07	51.67
70°F	55.25	48.00	44.62	54.50	46.37	34.62	63.50	51.37	39.37	48.63
Durations:										Duration Mean
At harvest	60.00	48.00	70.00	62.00	49.00	41.50	64.00	56.00	46.00	55.17
1 day after	50.33	53.00	44.83	68.00	60.66	38.00	67.33	62.66	51.33	55.13
3 days after	62.17	45.17	43.17	60.33	52.40	42.33	73.33	51.67	44.80	52.81
6 days after	49.33	47.00	36.00	43.00	42.33	40.33	47.17	50.00	40.83	44.00
Varietal Mean	50.75			49.99			54.56			
Times of Harvest	First Harvest			Second Harvest			Third Harvest			
Mean	58.92			51.49			44.93			

L.S.D. at the 5-percent level, harvests 4.28
durations 4.94
temperatures 4.28
harvests x durations 8.55

Table 17. **Effect of storage temperature and duration, and times of harvest upon changes in the yellow pigments, expressed as B-carotene in micrograms per gram of three varieties of lima beans.**

Factors	Concentrated Fordhook			Peerless			Fordhook 242			
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	Temperature Mean
Temperatures:										
35°F	10.82	8.72	9.52	10.10	10.72	8.92	11.20	10.05	9.22	9.92
50°F	10.20	8.40	9.17	10.30	9.50	7.67	9.95	9.60	8.27	9.23
70°F	10.17	8.57	8.60	9.15	8.30	6.62	10.50	8.45	7.50	8.65
Durations:										Duration Mean
At harvest	11.50	8.30	12.30	9.50	8.30	7.40	10.0	8.80	8.50	9.40
1 day after	10.50	9.20	8.50	12.13	12.40	7.40	12.20	10.87	8.97	10.24
3 days after	11.03	7.97	8.50	10.67	9.33	7.80	12.00	8.37	7.83	9.21
6 days after	8.57	8.80	7.10	7.70	8.00	8.37	8.00	9.43	8.03	8.22
Varietal Mean	9.36			9.03			9.42			
Times of Harvest	First Harvest			Second Harvest			Third Harvest			
Mean	10.27			9.15			8.39			

L.S.D. at the 5-percent level,		
	harvest	0.59
	temperatures	0.59
	durations	0.68
	H x D, interaction	1.17
	V x D, interaction	1.17

losses with each successive delay in harvests were approximately the same for each pigment. The analysis of variance of the data on pigment content is presented in Appendix Table 18. Significant interactions were obtained between time of harvest and duration for the green pigment and between time of harvest and duration and between varieties and duration for the yellow pigment. These interactions indicate that the effect of duration upon changes in both pigments was not the same for different harvest periods and for different varieties in the yellow pigment.

The data presented in Tables 19, 20, 22 and 23 show the effect of temperature and duration of storage and times of harvest upon changes in the organoleptic values for tenderness, flavor, over-all grade and color, respectively. As shown in Tables 19 and 20, although time of harvest had no significant effect on flavor, a delay in harvest significantly decreased tenderness. On the other hand, both storage temperature and duration significantly decreased tenderness and flavor. The numerical value of tenderness and flavor both decreased as the storage temperature increased. For example, the highest storage temperature resulted in a very marked change in tenderness and flavor as shown by the change in numerical values from 6.60 to 5.77 and from 6.14 to 5.20, respectively. Even a change of only 15 degrees F. in the storage temperature, from 35 degrees F. to 50 degrees F., resulted in a significant change in the tenderness value, from 6.60 to 6.08. The period of time that beans were held in storage had a very significant effect upon changes in the tenderness value, from 6.78 to 5.49, and even a more significant effect upon flavor since the value of this factor

Table 19. Effect of storage temperature and duration, and times of harvest upon the organoleptic rating of tenderness[1] of three varieties of lima beans.

Factors	Concentrated Fordhook			Peerless			Fordhook 242			
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	Temperature Mean
Temperature:										
35°F	7.12	6.71	5.87	7.04	6.54	6.06	7.21	6.67	6.17	6.60
50°F	6.58	6.25	5.69	6.75	5.10	6.06	6.67	6.05	5.54	6.08
70°F	6.66	5.92	4.71	6.75	4.16	5.54	6.56	5.62	6.00	5.77
Durations:										Duration Mean
At harvest	6.67	6.67	6.33	7.50	6.83	6.83	7.17	7.00	6.00	6.78
1 day after	6.93	7.22	5.22	7.22	5.44	5.89	7.11	6.23	6.50	6.42
3 days after	7.00	5.67	5.06	6.44	4.67	5.69	6.67	5.94	6.00	5.90
6 days after	6.55	5.61	5.08	6.22	4.12	5.13	6.31	5.28	5.11	5.49
Varietal Mean	6.17			6.00			6.28			
Times of Harvest	First Harvest			Second Harvest			Third Harvest			
Mean	6.82			5.89			5.74			

L.S.D. at the 5-percent level, harvests .36
durations .42
temperatures .36
harvests, varieties interaction .62

[1] Score 1 for hardest, starchiest samples...to 8 for best quality tender succulent samples, 9 for samples too young and watery but still good, 10 for samples that are poor because they are too watery.

Table 20. Effect of storage temperature and duration, and times of harvest upon the organoleptic rating of flavor[1] of three varieties of lima beans.

Factors	Concentrated Fordhook			Peerless			Fordhook 242			Temperature Mean
	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	First Harvest	Second Harvest	Third Harvest	
Temperature:										
35°F	6.26	6.33	5.83	7.33	6.71	4.67	5.91	5.83	6.33	6.14
50°F	5.42	5.83	5.75	6.75	5.98	5.50	5.21	5.79	5.42	5.74
70°F	5.08	5.04	5.14	6.75	4.92	4.58	5.03	4.83	5.42	5.20
Durations:										
At harvest	5.67	6.67	7.33	8.67	7.67	5.67	6.33	7.00	6.00	6.78
1 day after	5.79	7.33	4.38	7.11	6.45	6.00	6.08	6.50	6.22	6.21
3 days after	5.67	4.44	6.00	6.22	4.91	3.67	5.50	5.00	5.56	5.22
6 days after	5.22	4.50	4.59	5.78	4.46	4.33	3.63	3.44	5.11	4.56
Varietal Mean		5.63			5.91			5.53		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		5.97			5.70			5.41		

L.S.D. at the 5-percent level, durations 0.66
temperatures 0.57
harvests, varieties interaction 0.98

[1] Score of 2 is for poor, 4 for fair, 6 for good, 8 for very good, and 10 for excellent.

Table 22. Effect of storage temperature and duration, and times of harvest upon the organoleptic color grade[1] of three varieties of lima beans.

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	7.17	5.37	3.88	5.83	5.34	3.15	6.50	6.07	4.25	5.28
50°F	5.75	5.13	3.75	5.63	4.71	3.42	5.04	5.50	3.83	4.75
70°F	5.75	4.38	3.17	5.58	4.19	2.69	5.22	4.42	3.34	4.30
Durations:										Duration Mean
At harvest	7.33	5.83	4.33	7.33	6.00	3.50	6.83	6.67	4.67	5.83
1 day after	6.67	6.50	3.83	6.50	5.19	3.67	6.06	5.75	4.39	5.40
3 days after	6.11	3.89	3.44	4.89	4.28	2.64	5.22	4.94	3.67	4.34
6 days after	4.78	3.61	2.78	4.00	3.50	2.53	4.25	3.94	2.50	3.54
Varietal Mean		4.93			4.50			4.91		
Times of Harvest		First Harvest			Second Harvest			Third Harvest		
Mean		5.83			5.01			3.50		

L.S.D. at the 5-percent level,		
	temperatures	.36
	durations	.42
	varieties	.36
	harvests	.36

[1] Score of one for poorest, pale or yellowish samples....to 10 for best deepest brightest green samples.

Table 23. Effect of storage temperature and duration, and times of harvest upon organoleptic over-all grade[1] of three varieties of lima beans.

Factors	Concentrated Fordhook First Harvest	Concentrated Fordhook Second Harvest	Concentrated Fordhook Third Harvest	Peerless First Harvest	Peerless Second Harvest	Peerless Third Harvest	Fordhook 242 First Harvest	Fordhook 242 Second Harvest	Fordhook 242 Third Harvest	Temperature Mean
Temperature:										
35°F	2.80	2.70	2.32	2.95	2.32	1.95	2.70	2.75	2.50	2.56
50°F	2.40	2.40	2.10	2.60	2.08	2.05	2.38	2.40	2.15	2.28
70°F	2.35	2.10	1.80	2.50	1.88	1.80	2.28	2.20	2.20	2.12
Durations:										Duration Mean
At harvest	2.60	2.80	2.60	3.40	3.00	2.40	3.00	3.20	2.60	2.84
1 day after	2.60	3.13	2.30	2.93	2.30	2.07	2.63	2.63	2.47	2.56
3 days after	2.67	1.87	2.07	2.33	1.60	1.60	2.23	2.13	2.13	2.07
6 days after	2.20	1.80	1.33	2.07	1.47	1.67	1.93	1.[illegible]	1.93	1.80
Varietal Mean	2.33			2.24			2.39			
Times of Harvest	First Harvest			Second Harvest			Third Harvest			
Mean	2.55			2.31			2.10			

L.S.D. at the 5-percent level, harvests 0.17
durations 0.20
temperatures 0.17
varieties, harvests interaction 0.30

[1] Score of one through four, from poorest to excellent in over-all appearance and grade.

changed from 6.78 to 4.56. Each successive prolongation of the storage period resulted in a decrease in the tenderness and flavor values with the exception of the samples removed 1 day after the storage. Samples held in storage in the pods only 1 day after harvest differed from those taken at harvest, but this difference is not of sufficient magnitude to be significant. The organoleptic value of tenderness on beans from the second harvest of 5.89 is significantly lower than the corresponding value of beans taken from the first harvest of 6.82. The tenderness value on shelled beans from the third harvest as compared with those from the second harvest is not significantly different. The significant interaction between harvest and varieties on each factor, namely, tenderness and flavor, as shown in Appendix Table 21 indicates that the time of harvest did not affect the value of each respective factor in the same way for each variety.

The data on time of harvest, duration of storage, and storage temperatures as they affected color values, determined organoleptically, of the 3 varieties are presented in Table 22. The effects of time of harvest and duration in storage are extremely striking. Each successive delay in the harvest brought about a significant decrease in the color value. For example, this decreased from 5.83 for the first harvest to 3.01 for the third harvest. The magnitude of change in color values due to duration in storage was comparable to that of time of harvest. In other words, as the storage period increased from 1 day to 3 days to 6 days the color values correspondingly decreased. Although the effect of storage temperature was not as great as that of duration or of times of harvest the differences between storage temperature are significant. For each increment increase in storage temperature there was a corresponding decrease in color value. No significant interactions were found between any 2 of the variables tested in this phase of the work. These are presented in Appendix Table 24.

The data presented in Table 23 show that each of the 3 individual factors, namely, harvest, duration and temperature, had a significant effect upon the over-all grade given each sample. The data obtained in these studies indicate that the mean effect of duration in storage was greater than either temperature or harvest. Holding the beans in storage for a 6 day period lowered the over-all grade from 2.84 to 1.80. Each successive prolongation of storage resulted in a comparable decrease in the over-all grade. The effect of temperature and times of harvest on the over-all grade appears to be comparable. A change in storage temperature from 35 degrees F. to either 50 degrees or 70 degrees F. lowered the over-all grade from 2.56 to 2.28 and to 2.12, respectively. Each successive delay in harvest resulted in a decrease in the over-all grade. The significant interaction between varieties and harvest indicates that the effect of delaying the harvest upon over-all grade was not the same for each variety.

<u>Correlation studies on storage data.</u> The data obtained on the storage studies was of such magnitude that it permitted the correlation studies on objective and subjective measurements as presented in Tables 25, 26, 27 and 28. The correlation coefficients as presented in Table 25 are between possible combinations of the 16 factors listed.

It was not deemed necessary to make correlation coefficient determinations between all the possible combinations. However, where it was at all possible the correlation coefficient was determined between the objective and the corresponding subjective test. For example, the degree of relationship between tenderometer readings and organoleptic tenderness, inclusive of the data on 3 varieties, is expressed in the correlation coefficient (r) as -.66. Even though the correlation coefficient is highly significant, it is not possible to employ the regression coefficient in estimating organoleptic grade of tenderness from the tenderometer readings.

It will be noted under vertical column 11 in Table 25 that the following factors are correlated with organoleptic tenderness: moisture .61, tenderometer as mentioned above, individual bean tester -.63, ascorbic acid .64; organoleptic color .81, organoleptic flavor .51, and organoleptic over-all grade .61. These factors were found to be correlated with organoleptic color under column 12: per cent whites -.83, green pigments .63, organoleptic over-all grade .67, yellow pigments .48, beta carotene .67. Only a few factors showed any degree of correlation with flavor. These are as follows: ascorbic acid .48, total sugars .37, starch - total sugar ratio -.35, organoleptic tenderness .51, organoleptic color .49, and over-all grade .83. The organoleptic over-all grade is correlated with these factors: moisture .38, tenderometer -.35, per cent whites -.67, ascorbic acid .59, alcohol insoluble solids -.56.

Table 25. Correlation coefficients, showing relationship between several objective and subjective measurements on three varieties of lima beans.

No.	Factors / Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Moisture	—	-.84*			+.78*	+.49*	-.78*				+.61*		+.15	+.38*		
2	Tenderometer	-.84*	—	+.86*	+.78*		-.52*	+.89*	+.13	+.85*		-.66*		-.11	-.35*		
3	Individual Tester		+.86*	—								-.63*			+.06		
4	Percent Whites		+.78*		—	-.66*	-.79*	+.69*					-.83*		-.67*		
5	Green Pigment	+.78*			-.66*	—	+.57*		+.28*				+.63*	+.18			
6	Ascorbic Acid	+.49*	-.52*		-.79*	+.57*	—	-.42*	+.40*	-.41*	-.55*	+.64*		+.48*	+.59*		
7	Alcohol Insoluble Solids	-.78*	+.89*		+.69*		-.42*	—		+.89*		-.60*		-.06	-.56*		
8	Total Sugars		+.13			+.28*	+.40*		—					+.37*			
9	Starch		+.85*				-.41*	+.89*		—				-.10	-.28*		
10	Starch/Total Sugar						-.55*				—			-.35*			
11	Organoleptic Tenderness	+.61*	-.66*	-.63*			+.64*	-.60*				—	+.81*	+.51*	+.61*		
12	Organoleptic Color				-.83*	+.63*				-.10		+.81*	—	+.49*	+.71*		
13	Organoleptic Flavor	+.15	-.11			+.18	+.48*	-.06	+.37*	-.28*	-.35*	+.51*	+.42*	—	+.83*		
14	Organoleptic Average Grade	+.38*	-.35*	+.06	-.67*		+.59*	-.56*				+.61*	+.67*	+.83*	—		
15	Yellow Pigments												+.48*			—	
16	B-Carotene												+.67*			+.61*	—

* Correlation coefficients significant at the 1-percent level

Two correlation coefficients, namely, that between tenderometer and alcohol insoluble solids content of the raw product, .89, and between tenderometer and starch, .85, are considered to be sufficiently high to use the regression coefficient in an equation in predicting the alcohol insoluble solids and starch values, respectively, on the basis of tenderometer readings.

The data on correlation analysis, presented in Table 26, show that the relation of flavor to sugar content, and flavor to ascorbic acid content varied with the variety. For example, as between flavor and sugar content Concentrated Fordhook and Fordhook 242 showed a close relationship between these factors while Peerless showed no relation. On the other hand, as between flavor and ascorbic acid content, Peerless and Fordhook 242 showed a high relationship while Concentrated Fordhook showed a low relationship.

The correlation coefficients in Table 27 also show that the relationship of tenderometer readings to organoleptic tenderness is much closer in Peerless (-.77) and in Fordhook 242 (-.74) than in Concentrated Fordhook (-.54), and that no relationship exists between green pigment and organoleptic color in the Concentrated Fordhook. However, the correlation coefficients show a highly significant relationship between these 2 factors in Peerless and Fordhook 242. The correlation between beta carotene and yellow pigment values is between 2 objective types of measurements. A highly significant correlation was found between these 2 factors when data from the Peerless or Fordhook 242

Table 26. Correlation coefficients on several objective and subjective measurements on each of three varieties.

Varieties	Concentrated Fordhook			Peerless			Fordhook 242		
Factors	Ascorbic Acid	Flavor	Sugar	Ascorbic Acid	Flavor	Sugar	Ascorbic Acid	Flavor	Sugar
Ascorbic Acid	—	+.3166	+.3391	—	+.5259**	+.3252*	—	+.5996**	+.6696**
Flavor	+.3166	—	+.6948**	+.5259**	—	+.0614	+.5996**	—	+.5578**
Sugar	+.3391	+.6948**	—	+.3252*	+.0614	—	+.6696**	+.5578**	—

* Significant at the 5-percent level

** Significant at the 1-percent level

Table 27. Correlation coefficients on several objective and organoleptic measurements on each of three varieties of lima beans.

Varieties	Concentrated Fordhook			Peerless			Fordhook 242		
Factors	Tenderometer	Green Pigment	Beta Carotene	Tenderometer	Green Pigment	Beta Carotene	Tenderometer	Green Pigment	Beta Carotene
Organoleptic Tenderness	-.541**			-.767**			-.737**		
Organoleptic Color		+.203			+.815**			+.786**	
Yellow Pigment			+.411			+.825**			+.724**
Starch	+.92**			+.87**			+.89**		
Alcohol Insoluble Solids	+.91**			+.85**			+.91**		

* Significant at the 5-percent level.

** Significant at the 1-percent level.

varieties are considered. This offers the possibility of estimating beta carotene content from an acetone extract of ground beans.

The data on multiple correlations, presented in Table 28, show that the variation of these factors, namely, ascorbic acid, alcohol insoluble solid and moisture are concomitant with variations in the over-all grade. Each multiple correlation coefficient with the exception of that between flavor, tenderometer, alcohol insoluble solids and starch was highly significant. The highest multiple correlation coefficient obtained on flavor, which included data on all varieties, was with these factors, namely, sugar, ascorbic acid and starch/sugar ratio. When data on each variety was considered separately a very good relationship was obtained for Concentrated Fordhook between flavor, and sugar, and ascorbic acid (.70). A multiple correlation coefficient of .639 and .529 was found between these same factors when data of the Fordhook 242 and the Peerless varieties, respectively, are considered. The highest multiple correlation coefficient, .854, was obtained between over-all grade and the objective measurements of ascorbic acid, alcohol insoluble solids and starch. Another high degree of relationship was found in the data between organoleptic over-all grade and tenderometer, alcohol insoluble solids and starch, .751.

The graphs presented in Figures 2, 3 and 4 show a very good relationship between the tenderometer values and the alcohol insoluble solids content for each of the 3 varieties, namely, Concentrated Fordhook, Peerless and Fordhook 242. It can be observed in Figure 2 and Figure 4 that the dots lie fairly close to the regression line for

Table 28. Multiple correlation coefficients between dependant and independant factors in three varieties of lima beans.

Dependant Factors	Independant Factors									Multiple Correlation Coefficients	Multiple Correlation Coefficients Significant at:	
	Sugar	Ascorbic Acid	Chlorophyll	Starch/ Sugar	Tender-ometer	A. I. S.	Moisture	Starch	% Whites		05	01
Flavor	x	x	x							.538	.254	.312
Flavor	x	x		x						.580	.233	.287
Flavor	x	x						x		.446	.233	.287
Flavor		x			x		x			.511	.219	.270
Flavor					x	x		x		.146	.233	.287
Flavor of Peerless [1]	x	x								.539	.316	.408
Flavor of Fordhook 242 [1]	x	x								.639	.361	.463
Flavor of Concentrated Fordhook	x	x								.700	.349	.449
Organoleptic Ave. Grade		x			x	x				.680	.230	.283
Organoleptic Ave. Grade					x	x	x			.651	.230	.283
Organoleptic Ave. Grade					x	x		x		.751	.233	.287
Organoleptic Ave. Grade		x				x		x		.854	.233	.287
Organoleptic Ave. Grade		x				x	x			.714	.233	.287
Organoleptic Ave. Grade		x			x				x	.725	.177	.232
Organoleptic Ave. Grade		x				x			x	.699	.230	.283
Organoleptic Tenderness		x			x					.749	.230	.283

[1] Multiple correlation coefficients computed for each variety, individually.

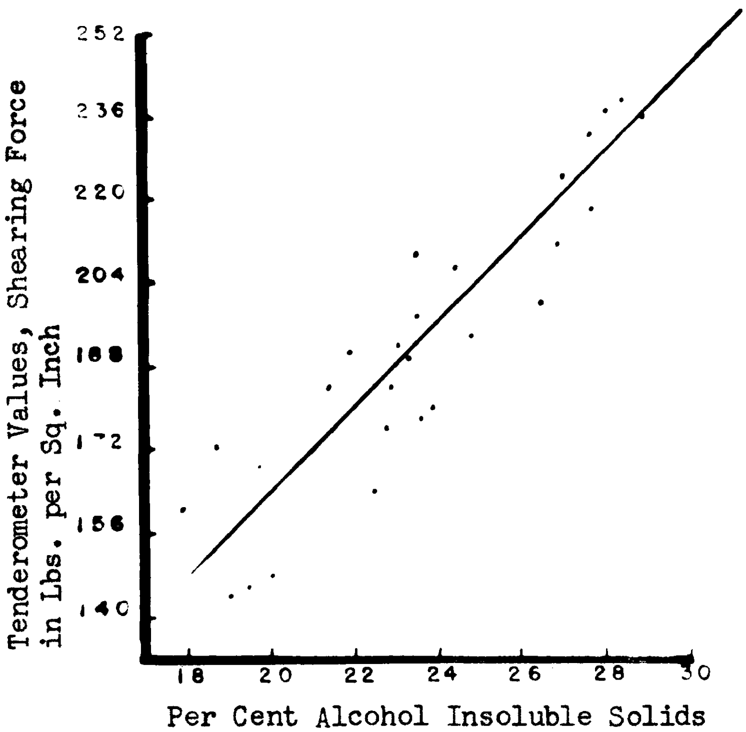

Figure 2 - The relationship between the tenderometer values and the per cent alcohol insoluble solids in raw shelled beans of the Concentrated Fordhook variety.

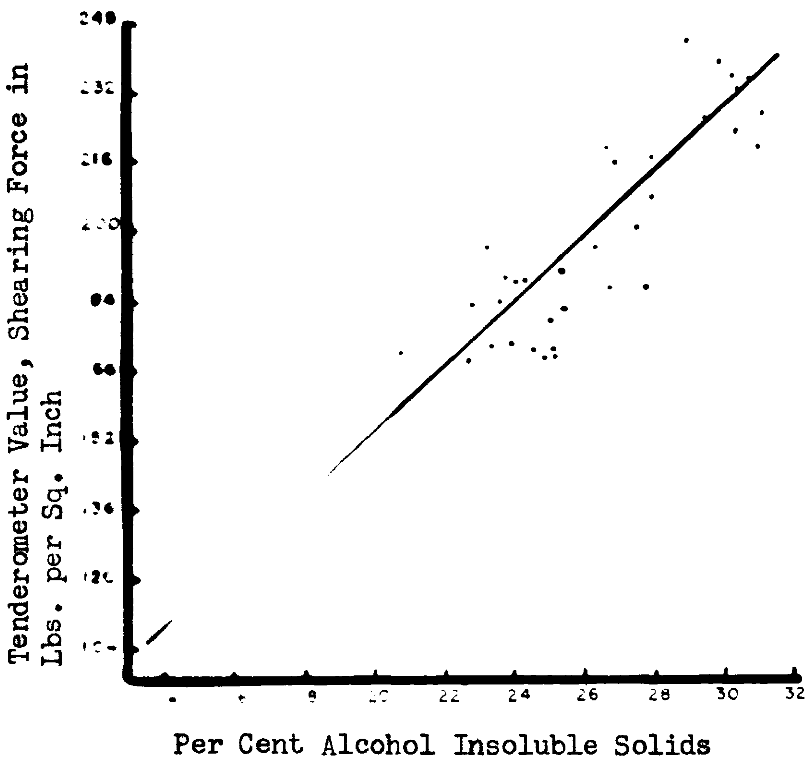

Figure 3 - The relationship between tenderometer values and the per cent alcohol solids in raw shelled beans of the Peerless variety.

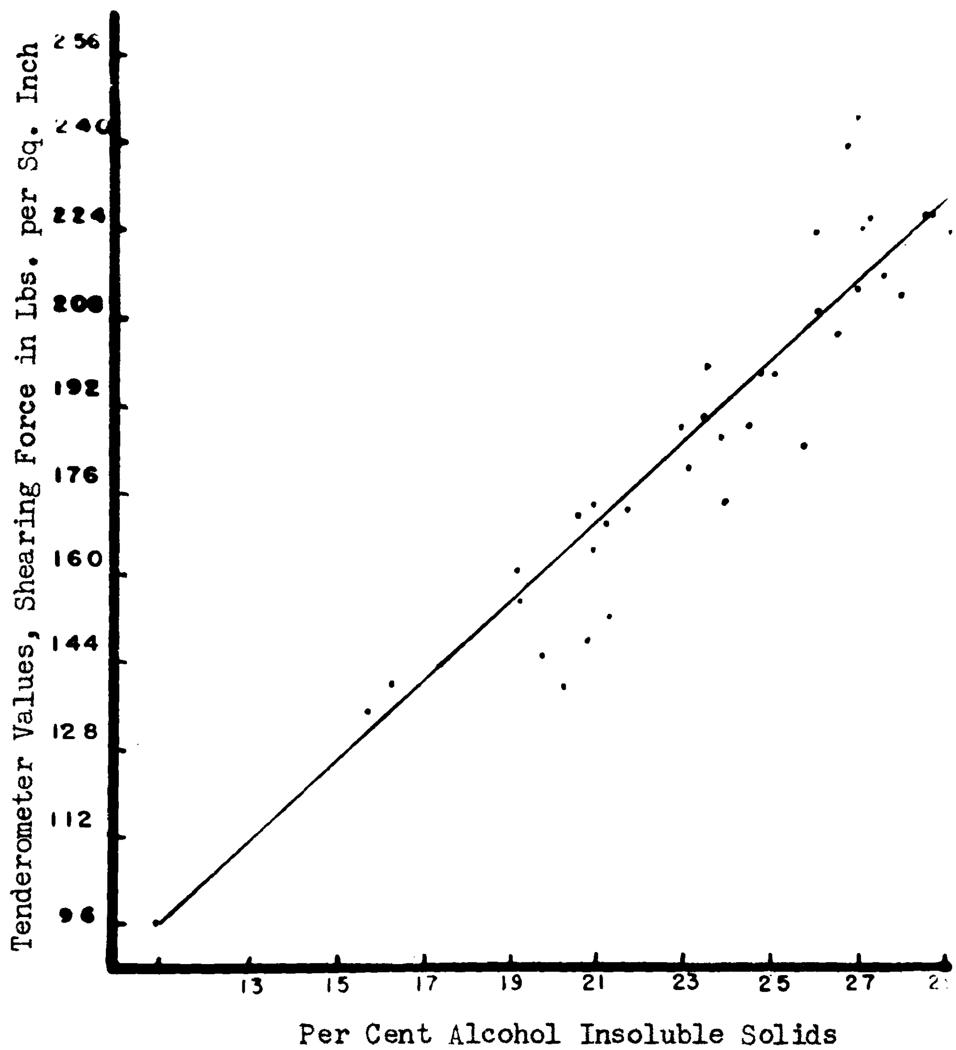

Figure 4 - The relationship between tenderometer values and per cent alcohol insoluble solids in raw shelled beans of the Fordhook 242 variety.

the Concentrated Fordhook and the Fordhook 242 varieties, whereas they are slightly more widely dispersed about the regression line in the case of the Peerless variety.

The graphs, presented in Figures 5, 6 and 7, show the relation of the tenderometer readings to the starch content in per cent in the shelled beans of the 3 varieties: Concentrated Fordhook, Peerless and Fordhook 242. A much closer relationship between tenderometer and starch determinations was obtained with Concentrated Fordhook and Fordhook 242 varieties than with Peerless.

The relationship of the green pigment, expressed as chlorophyll in parts per million, to the organoleptic color values for 2 varieties: Fordhook 242 and Peerless, is presented graphically in Figures 8 and 9, respectively.

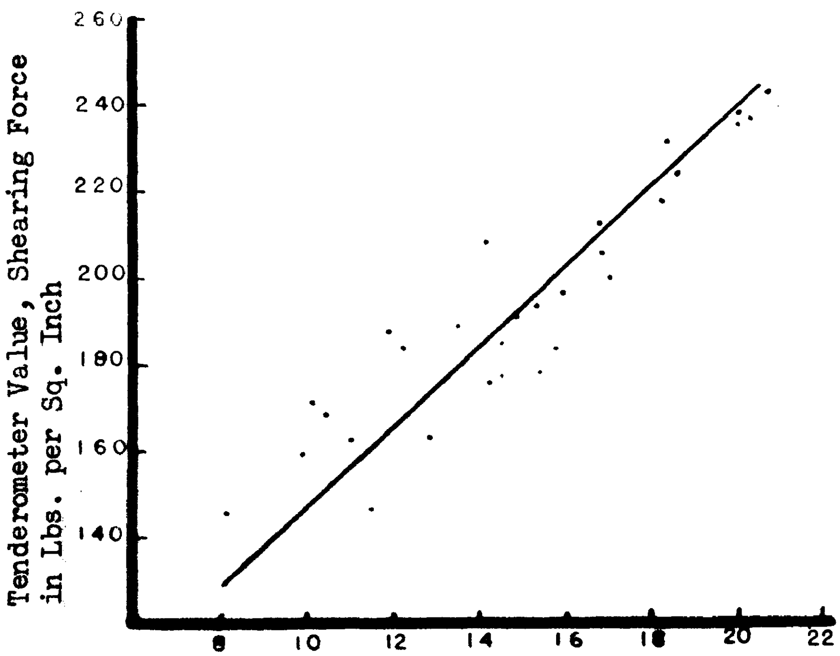

Figure 5 - The relationship between tenderometer values and per cent starch in raw shelled beans of the Concentrated Fordhook variety.

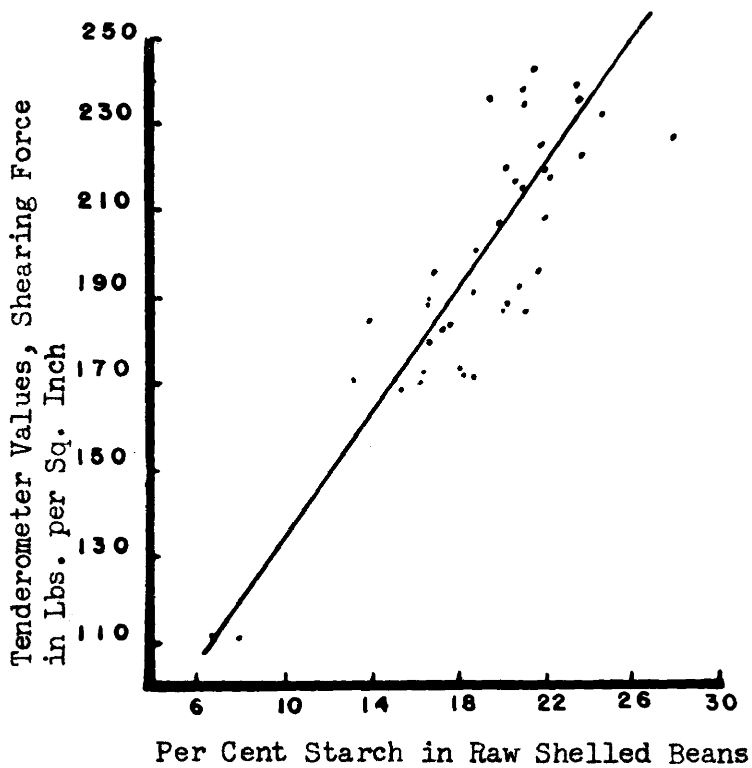

Figure 6 - The relationship between tenderometer values and per cent starch in raw shelled beans of the Peerless variety.

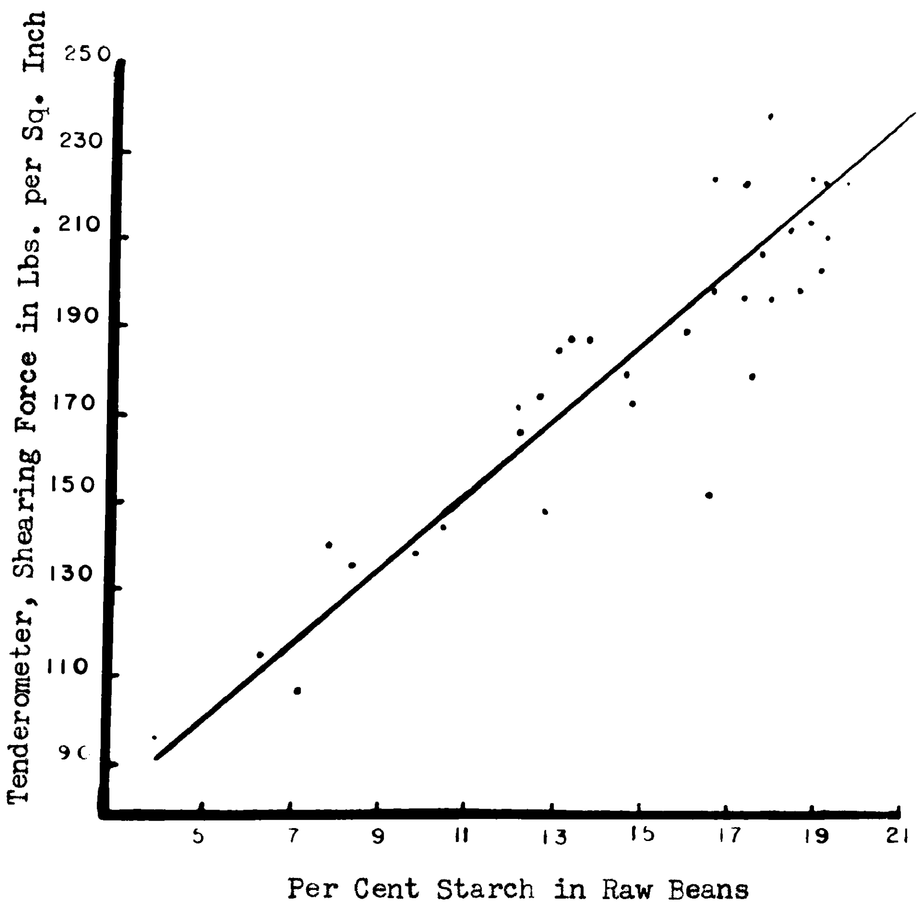

Figure 7 - The relationship between tenderometer values and per cent starch in raw shelled beans of the Fordhook 242 variety.

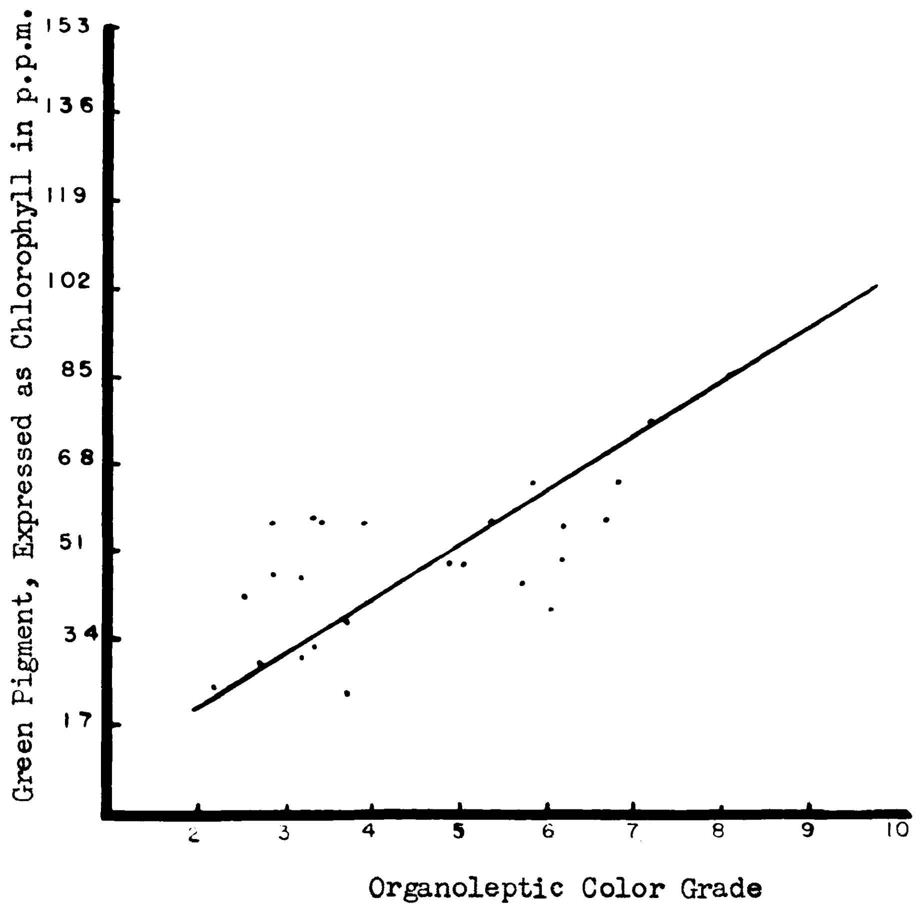

Figure 8 - The relationship between green pigment values on the raw bean and organoleptic grade on the frozen beans of the Fordhook 242 variety.

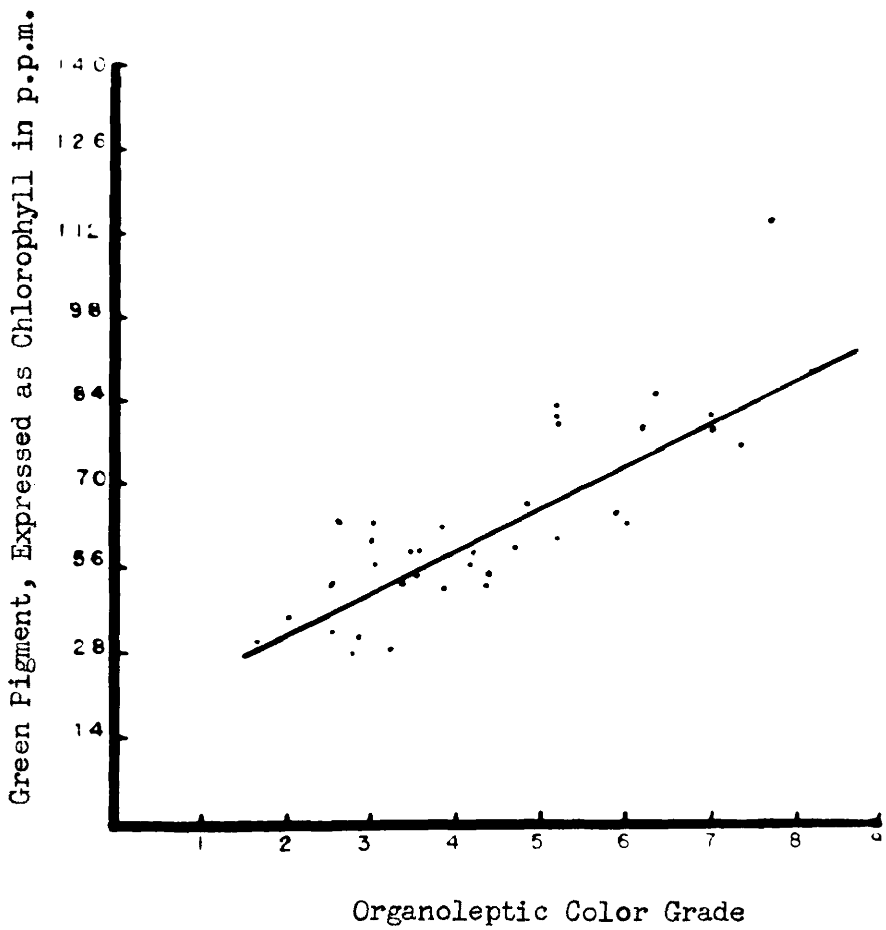

Figure 9 - The relationship between green pigment values of the raw bean and organoleptic color grade on the frozen beans of the Peerless variety.

ENVIRONMENTAL STUDIES

This phase of the investigations was designed to measure the effect of light intensity, night temperature and time of harvest on yield and development of the plant and on changes in the nutritive value of the shelled beans. The Peerless variety was used.

The data, presented in Table 29, show that light intensity, night temperature, and time of harvest significantly influenced the yield of fresh pods. The optimum night temperature range based on these data was 60 degrees to 65 degrees F. Raising or lowering the temperature from this range resulted in a tremendous decrease in the yield. When the light intensity of light treatment 1 was reduced by 2/3 the yield was significantly reduced. Each successive delay in the harvest resulted in a decrease in the yields as shown by these data. There were no significant first order interactions in the analysis of variance as shown in Appendix Table 31.

The data, presented in Table 30, show the effect of the 3 environmental factors on the yield of shelled beans. Only 1 factor, night temperature, significantly influenced the yield of shelled beans. Yields were very low for high night temperatures (80 to 85 degrees F.) and for the low night temperatures (40 to 45 degrees F.). On the other hand, reducing light intensity and delaying the time of harvest had much more effect in reducing yields of the pods than in reducing yields of the shelled beans.

Table 29. Effect of different light intensities, night temperatures and times of harvests upon the yield of fresh pods of the Peerless lima bean variety. (Yields expressed in grams from nine plants.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	265.5	447.1	52.5	255.0
three 200 watt	2-15-49	196.0	347.7	47.8	197.2
bulbs.	2-21-49	37.8	224.4	26.4	96.2
Temperature x Light Mean		166.4	339.7	42.2	---
2. Light intensity:	2-10-49	185.8	363.5	49.9	199.7
of Treatment 1	2-15-49	133.4	240.6	36.4	136.8
reduced by 1/3.	2-21-49	72.9	287.4	29.1	129.8
Temperature x Light Mean		130.7	297.2	38.5	---
3. Light intensity:	2-10-49	204.5	254.1	50.1	169.6
of Treatment 1	2-15-49	117.0	262.2	29.8	136.3
reduced by 2/3.	2-21-49	82.5	169.8	12.5	88.3
Temperature x Light Mean		134.7	228.7	30.8	---
Temperature Mean		143.9	288.5	37.2	

Light Intensities	First Treatment	Second Treatment	Third Treatment
Mean	182.8	155.4	131.4

Harvests	2-10-49	2-15-49	2-21-49
Mean	208.1	156.8	104.8

L.S.D. at the 5-percent level,		
	temperatures	37.5
	lights	37.5
	harvests	37.5

Table 30. Effect of different light intensities, night temperatures and dates of harvest upon yield of shelled lima beans of the Peerless variety. (Yield expressed in grams from nine plants.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	33.2	130.8	15.8	59.9
three 200 watt	2-15-49	35.2	114.0	9.2	52.8
bulbs.	2-21-49	4.5	92.4	10.5	35.8
Temperature x Light Mean		24.3	112.4	11.8	—
2. Light intensity	2-10-49	23.3	109.9	9.1	47.4
of Treatment 1	2-15-49	21.3	94.0	7.7	41.0
reduced by 1/3.	2-21-49	15.6	137.7	9.0	54.1
Temperature x Light Mean		20.1	113.9	8.6	—
3. Light intensity	2-10-49	24.6	87.6	16.9	43.0
of Treatment 1	2-15-49	20.1	103.8	7.8	43.9
reduced by 2/3.	2-21-49	21.6	87.3	6.8	38.6
Temperature x Light Mean		22.1	92.9	10.5	—
Temperatures Mean		22.2	106.4	10.3	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	49.5	47.5	41.8
Harvests	2-10-49	2-15-49	2-21-49
Mean	50.1	45.9	42.8

L.S.D. at the 5-percent level, temperatures 15.5

The data on the effect of light intensity, night temperature and times of harvest upon beta carotene content are expressed on the fresh weight basis in Table 32 and on the moisture-free basis in Table 33. Night temperature range was the only factor that had a significant effect on the beta carotene content of shelled beans on either the fresh or dry weight basis. Beta carotene accumulated in the beans when plants were grown under a low night temperature range (40 to 45 degrees F.). The effect of a low night temperature upon the beta carotene content is even more pronounced when the data is expressed on a moisture-free basis. Even though the light-temperature interaction is not significant as presented in Table 34, the effect of a low night temperature upon beta carotene content appears to be greatest under a slight reduction of the light intensity, since data in Tables 32 and 33 show greater differences in beta carotene content between the 40 to 45 degrees F. and the 60 to 65 degrees F. night temperature ranges under light treatment 2.

The data in Table 35 on the acetone extract of yellow pigments show that light intensities and night temperatures had a significant effect on the yellow pigment content of shelled beans. There was no significant difference between the yellow pigment content in shelled beans grown under full sunlight and those grown under this light intensity reduced by 1/3. However, a further decrease in light intensity resulted in a decrease in the yellow pigments. Shelled beans from plants grown under light intensity treatment 3 contained only 9.49 micrograms per gram as compared to 13.17 micrograms per gram of the beans grown

Table 32. Effect of different light intensities, night temperatures and dates of harvest upon changes of the Beta Carotene in shelled lima beans of the Peerless variety. (Beta Carotene expressed in micrograms per gram on fresh weight basis.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	Night Temperatures 60-65°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	1.40	1.15	1.27
three 200 watt	2-15-49	1.80	0.70	1.25
bulbs.	2-21-49	2.20	1.60	1.90
Temperature x Light Mean		1.80	1.15	—
2. Light intensity	2-10-49	3.80	1.10	2.45
of Treatment 1	2-15-49	1.75	0.90	1.33
reduced by 1/3.	2-21-49	3.70	0.65	2.17
Temperature x Light Mean		3.08	0.88	—
3. Light intensity	2-10-49	1.10	1.50	1.30
of Treatment 1	2-15-49	1.75	1.20	1.47
reduced by 2/3.	2-21-49	2.53	0.90	1.71
Temperature x Light Mean		1.79	1.20	—
Temperature Means		2.23	1.08	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	1.47	1.98	1.50
Harvests	2-10-49	2-15-49	2-21-49
Mean	1.67	1.35	1.93

L.S.D. at the 5-percent level, temperatures .87

Table 33. Effect of different light intensities, night temperatures and dates of harvest upon changes of the Beta Carotene in shelled lima beans of the Peerless variety. (Beta Carotene expressed in micrograms per gram on a moisture-free basis.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	Harvest x Light Mean
1. Sunlight plus	2-10-49	7.17	4.42	5.79
three 200 watt	2-15-49	7.00	2.20	4.60
bulbs.	2-21-49	8.18	4.16	6.17
Temperature x Light Mean		7.45	3.59	—
2. Light intensity	2-10-49	16.30	4.33	10.31
of Treatment 1	2-15-49	5.22	2.94	4.08
reduced by 1/3	2-21-49	11.30	1.74	6.52
Temperature x Light Mean		10.94	3.00	—
3. Light intensity	2-10-49	6.49	5.78	6.13
of Treatment 1	2-15-49	6.47	4.38	5.42
reduced by 2/3	2-21-49	8.45	2.18	5.31
Temperature x Light Mean		7.14	4.11	—
Temperature Means		8.51	3.57	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	5.52	6.97	5.62
Harvests	2-10-49	2-15-49	2-21-49
Mean	7.41	4.70	6.00

L.S.D. at the 5-percent level, temperatures 3.02

Table 34. Analysis of variance of data presented in Tables 32 and 33.

Source of Variance	d. f.	Mean Square: Beta Carotene, Fresh Weight Basis	Mean Square: Beta Carotene, Moisture-free Basis
Total	17		
Lights	2	0.49	3.92
Temperatures	1	**5.93	**109.76
Harvests	2	0.51	11.05
L x T	2	1.25	10.37
L x H	4	0.54	5.22
T x H	2	0.42	4.80
L x T x H, error	4	0.44	5.33

**Significant at the 1-percent level

Table 35. Effect of different light intensities, night temperatures and times of harvests upon changes of the yellow pigment in shelled lima beans of the Peerless variety. (Pigment expressed as Beta Carotene in micrograms per gram.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	14.60	9.60	12.10
three 200 watt	2-15-49	14.40	6.80	10.60
bulbs.	2-21-49	18.30	12.00	15.15
Temperature x Light Mean		15.77	9.47	---
2. Light intensity	2-10-49	21.00	10.00	15.50
of Treatment 1	2-15-49	14.00	6.00	10.00
reduced by 1/3.	2-21-49	22.40	5.60	14.00
Temperature x Light Mean		19.13	7.20	---
3. Light intensity	2-10-49	16.80	6.80	11.80
of Treatment 1	2-15-49	9.50	6.45	7.98
reduced by 2/3.	2-21-49	13.30	4.10	8.70
Temperature x Light Mean		13.20	5.78	---
Temperature Means		16.03	7.48	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	12.62	13.17	9.49
Harvests	2-10-49	2-15-49	2-21-49
Means	13.13	9.53	12.62

L.S.D. at the 5-percent level, temperatures 2.97
lights 3.64

under the light intensity of treatment 2. The low night temperature range (40 to 45 degrees F.) brought about an accumulation of the yellow pigments, expressed as micrograms per gram of beta carotene on a fresh weight basis.

The temperature and harvest factors had a significant effect upon the development of chlorophyll as shown in Table 36. The lima beans grown under the higher temperature range (60 to 65 degrees F.) had slightly over 1/2 the green pigments contained by the shelled beans grown at night temperatures of 40 to 45 degrees F. Shelled beans from the first harvest contained significantly more green pigment than the beans from either of the 2 later harvests. There was no significant difference between the green pigment content of beans harvested on February 15 as compared with those harvested on February 21.

The data presented in Tables 38 and 39 show that light intensity had insignificant effects on the ascorbic acid content of the shelled beans and that night temperatures and time of harvest had significant effects. Ascorbic acid content of shelled beans expressed on a fresh weight basis produced under the low night temperature range (40 to 45 degrees F.) was almost 1½ times that found in beans from plants grown under the night temperature range, 60 to 65 degrees F., whereas on the moisture-free basis this proportion was increased to 1-3/4 times the content of beans at the higher range. The influence of time of harvest is less pronounced than that of night temperature. For example, the shelled beans of the first harvest had 35.58 milligrams of ascorbic acid per 100 grams and those of the second and third harvest had 24.96

Table 36. Effect of different light intensities, night temperatures and times of harvests upon changes in the green pigment of shelled lima beans of the Peerless variety. (Pigment expressed as parts per million of Chlorophyll.

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	Night Temperatures 60-65°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	77.00	54.00	65.50
three 200 watt	2-15-49	76.00	36.00	56.00
bulbs.	2-21-49	72.50	41.00	56.75
Temperature x Light Mean		75.00	43.67	—
2. Light intensity	2-10-49	108.00	57.50	82.75
of Treatment 1	2-15-49	60.00	33.50	46.75
reduced by 1/3.	2-21-49	60.00	19.50	39.75
Temperature x Light Mean		76.00	36.83	—
3. Light intensity	2-10-49	92.00	41.50	66.75
of Treatment 1	2-15-49	40.00	34.50	37.25
reduced by 2/3.	2-21-49	54.30	16.00	35.15
Temperature x Light Mean		62.10	30.67	—
Temperature Means		71.09	37.06	
Light Intensities	Treatment One	Treatment Two	Treatment Three	
Mean	59.42	56.42	46.38	
Harvests	2-10-49	2-15-49	2-21-49	
Mean	71.67	46.67	43.88	

L.S.D. at the 5-percent level, temperatures 14.88
harvests 18.22

Table 38. Effect of different light intensities, night temperatures and times of harvests upon changes in the ascorbic acid in shelled lima beans of the Peerless variety. (Ascorbic acid expressed in milligrams per 100 grams on fresh weight basis.)

Light Treatment and Number	Harvest Date	Night Temperatures 40-45°F	60-65°F	Harvest x Light Mean
1. Sunlight, plus three 200 watt bulbs	2-10-49	37.61	30.51	34.06
	2-15-49	30.82	24.20	27.51
	2-21-49	36.50	14.52	25.51
Temperature x Light Mean		34.98	23.08	---
2. Light intensity of Treatment 1 reduced by 1/3.	2-10-49	43.40	30.96	37.18
	2-15-49	23.43	21.40	22.42
	2-21-49	32.91	26.18	29.54
Temperature x Light Mean		33.25	26.18	---
3. Light intensity of Treatment 1 reduced by 2/3.	2-10-49	43.13	27.88	35.50
	2-15-49	30.16	19.78	24.97
	2-21-49	37.21	19.72	28.47
Temperature x Light Mean		36.83	22.46	---
Temperature Means		35.02	23.91	

Light Intensity	Treatment One	Treatment Two	Treatment Three
Mean	29.03	29.71	29.65

Harvests	2-10-49	2-15-49	2-21-49
Mean	35.58	24.96	27.84

L.S.D. at the 5-percent level, temperatures 4.84
harvests 5.92

Table 39. Effect of different light intensities, night temperatures and dates of harvest upon changes of the ascorbic acid in shelled lima beans of the Peerless variety. (Ascorbic acid expressed in milligrams per 100 grams, dry weight basis.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	Night Temperatures 60-65°F	Harvest x Light Mean
1. Sunlight, plus three 200 watt bulbs.	2-10-49	192.48	117.21	154.85
	2-15-49	119.88	76.01	97.94
	2-21-49	135.78	37.71	86.74
Temperature x Light Mean		149.38	76.98	—
2. Light intensity of Treatment 1 reduced by 1/3.	2-10-49	186.27	121.89	154.08
	2-15-49	69.88	69.96	69.92
	2-21-49	100.46	70.24	85.35
Temperature x Light Mean		118.87	87.36	—
3. Light intensity of Treatment 1 reduced by 2/3.	2-10-49	254.30	107.44	180.87
	2-15-49	111.49	72.27	91.88
	2-21-49	124.32	47.69	86.01
Temperature x Light Mean		163.37	75.80	—
Temperature Means		143.87	80.05	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	113.18	103.12	119.59

Harvests	2-10-49	2-15-49	2-21-49
Mean	163.27	86.58	86.03

L.S.D. at the 5-percent level, temperatures 23.32
harvests 28.57
T x H 40.39

and 27.84 milligrams of ascorbic acid per 100 grams of fresh weight, respectively. In the analysis of variance data presented in Table 40, it will be observed that on the dry weight basis the interaction between temperature and harvest is significant. The data in Table 39 show that the effect of delaying the harvest upon ascorbic acid values was not the same under the 2 night temperature ranges.

Of the various environmental factors studied, only night temperature affected the total sugar content of lima beans as shown in Table 41. The highest total sugar content was observed in beans grown under the lowest night temperature range, 40 to 45 degrees F. There was no significant difference between the total sugar content of lima beans grown at 60 to 65 degrees F. range and those grown at the 80 to 85 degreesF. range. Delaying the harvest resulted in successive decreases of the total sugars but these reductions are not significant.

The data, presented in Table 43, show that light intensity and night temperatures produced significant effects on the percentage of alcohol insoluble solids in the shelled beans. Plants grown under the highest light intensity or under the highest night temperature (80 to 85 degrees F.) had a significantly higher percentage of alcohol insoluble solids than those grown under the lower light intensities or under the lower night temperatures, respectively. On the other hand, time of harvest had no significant effect upon the percentage of alcohol insoluble solids even though there was some increase in the percentage of alcohol insoluble solids with each delay in the harvest.

Table 40. Analysis of variance of data presented in Tables 38 and 39.

Source of Variance	d. f.	Mean Square: Ascorbic Acid, Fresh Weight Basis	Mean Square: Ascorbic Acid Dry Weight Basis
Total	17		
Temperatures	1	**555.77	**18332.29
Lights	2	0.86	413.49
Harvests:			
1st vs(2nd + 3rd)	1	**337.02	**23689.82
2nd vs 3rd	1	24.80	0.91
T x L	2	20.72	1261.41
T x H	2	31.03	*1748.09
L x H	4	12.86	243.74
T x L x H	4	13.65	317.69

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 41. Effect of different light intensities, night temperatures and times of harvests upon changes in the percentage of total sugars in shelled lima beans of the Peerless variety.

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	2.44	2.40	2.80	2.55
three 200 watt	2-15-49	2.72	2.00	3.10	2.61
bulbs.	2-21-49	1.45	1.32	1.57	1.45
Temperature x Light Mean		2.20	1.91	2.49	—
2. Light intensity	2-10-49	3.11	2.12	1.78	2.34
of Treatment 1	2-15-49	4.23	1.18	1.35	2.25
reduced by 1/3.	2-21-49	2.48	2.36	2.10	2.31
Temperature x Light Mean		3.27	1.89	1.74	—
3. Light intensity	2-10-49	3.24	2.19	2.24	2.56
of Treatment 1	2-15-49	2.68	2.18	2.11	2.32
reduced by 2/3.	2-21-49	2.62	2.00	1.91	2.18
Temperature x Light Mean		2.85	2.12	2.09	—
Temperature Mean		2.77	1.97	2.11	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	2.20	2.30	2.35

Harvests	2-10-49	2-15-49	2-21-49
Mean	2.48	2.39	1.98

L.S.D. at the 5-percent level, temperatures 0.58

Table 43. Effect of different light intensities, night temperatures and times of harvests upon changes in the percentage of alcohol insoluble solids in shelled lima beans of the Peerless variety.

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus three 200 watt bulbs.	2-10-49	13.26	20.70	57.88	30.61
	2-15-49	17.00	24.41	63.20	34.87
	2-21-49	24.25	35.30	42.56	34.04
2. Light intensity of Treatment 1 reduced by 1/3.	2-10-49	16.52	19.75	36.99	24.42
	2-15-49	21.50	23.16	28.30	24.32
	2-21-49	17.60	29.21	23.04	23.28
3. Light intensity of Treatment 1 reduced by 2/3.	2-10-49	12.00	20.83	31.36	21.40
	2-15-49	15.40	28.70	41.13	28.41
	2-21-49	18.17	31.30	48.40	32.62
Temperature Mean		17.30	25.93	41.43	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	33.17	24.01	27.48

Harvests	2-10-49	2-15-49	2-21-49
Mean	25.48	29.20	29.98

L.S.D. at the 5-percent level, temperatures 7.21
lights 7.21

The data in Table 44 present the results on the influence of light intensity, night temperatures, and times of harvest on the starch content of raw beans. In general, plants grown under the highest light intensity and highest night temperature had a higher starch content than those grown under the medium and low light intensity and under the moderately high and low night temperatures, respectively. The differences are significant between the highest night temperature and the lowest night temperature and they approach significance between the highest night temperature and the moderately high night temperature. They are significant between the highest light intensity and the medium light intensity, but they are insignificant between the highest light intensity and the low light intensity. Even though the differences in time of harvest in starch content are not significant, a very definite trend is evident toward the accumulation of starch with each successive delay in the harvest. The significant interaction between temperature and light is shown by the fact that high night temperatures did not affect the starch content of raw beans in the same manner under each different light intensity.

The findings on the effect of the 3 environmental factors upon total growth as expressed on the fresh and the dry weight basis are presented in Tables 46 and 47, respectively. Night temperature range was the only factor that affected growth significantly when the data on a fresh weight basis are considered; whereas the data on plant growth based on dry weight basis shows that 2 factors, namely, night temperature and light intensity had a significant effect on total growth.

Table 44. Effect of different light intensities, night temperatures and times of harvests on percentage starch in shelled lima beans of the Peerless variety.

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus three 200 watt bulbs.	2-10-49	8.90	15.20	41.80	21.97
	2-15-49	10.50	22.81	35.40	22.90
	2-21-49	11.41	31.00	30.87	24.43
Temperature x Light Mean		10.27	23.00	26.02	---
2. Light intensity of Treatment 1 reduced by 1/3.	2-10-49	10.10	14.50	11.00	11.87
	2-15-49	9.72	16.50	12.60	12.94
	2-21-49	7.56	18.15	19.44	15.05
Temperature x Light Mean		9.13	16.38	14.35	---
3. Light intensity of Treatment 1 reduced by 2/3.	2-10-49	5.00	13.90	19.10	12.67
	2-15-49	9.11	21.00	22.99	17.70
	2-21-49	21.25	25.90	28.55	25.23
Temperature x Light Mean		11.79	20.27	23.55	---
Temperatures Mean		10.39	19.88	24.64	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	23.10	13.29	18.53

Harvests	2-10-49	2-15-49	2-21-49
Mean	15.50	17.85	21.57

L.S.D. at the 5-percent level,	temperatures	5.16
	lights	5.16
	temperature, light interaction	8.94

Table 46. Effect of light intensity, night temperature and dates of harvest upon total plant growth of the Peerless lima bean variety. (Growth expressed in grams fresh weight per nine plants.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus three 200 watt bulbs.	2-10-49	438.0	540.3	521.3	514.9
	2-15-49	473.9	515.3	537.1	508.8
	2-21-49	487.0	553.5	610.6	550.4
Temperature x Light Mean		481.3	536.4	556.3	---
2. Light intensity of Treatment 1 reduced by 1/3.	2-10-49	413.5	553.2	623.7	530.1
	2-15-49	422.0	480.4	494.4	465.6
	2-21-49	351.9	581.4	375.9	436.4
Temperature x Light Mean		395.8	538.3	498.0	---
3. Light intensity of Treatment 1 reduced by 2/3.	2-10-49	477.8	545.9	554.4	526.0
	2-15-49	346.6	509.7	517.3	457.9
	2-21-49	417.3	489.6	469.5	458.8
Temperature x Light Mean		413.9	515.1	513.7	---
Temperatures Mean		430.3	529.9	522.7	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	524.7	477.4	480.9

Harvests	2-10-49	2-15-49	2-21-49
Mean	523.7	477.4	481.9

L.S.D. at the 5-percent level, temperatures 58.7

Table 47. Effect of light intensity, night temperature and dates of harvest upon total plant growth in the Peerless variety of lima beans. (Growth expressed in grams of dry weight per nine plants.)

Light Treatment and Number	Harvest Dates	Night Temperatures 40-45°F	60-65°F	80-85°F	Harvest x Light Mean
1. Sunlight, plus	2-10-49	89.6	76.3	87.8	84.6
three 200 watt	2-15-49	84.6	74.6	93.0	84.1
bulbs.	2-21-49	107.8	103.5	100.3	103.9
Temperature x Light Mean		94.0	84.8	93.7	—
2. Light intensity	2-10-49	68.9	72.5	105.6	82.3
of Treatment 1	2-15-49	77.4	60.0	81.8	73.1
reduced by 1/3.	2-21-49	70.9	81.7	57.6	70.1
Temperature x Light Mean		72.4	71.4	81.7	—
3. Light intensity	2-10-49	78.3	66.9	81.8	75.7
of Treatment 1	2-15-49	60.3	58.9	79.5	66.2
reduced by 2/3.	2-21-49	75.7	60.6	65.4	67.2
Temperature x Light Mean		71.4	62.1	75.6	—
Temperatures Mean		79.3	72.8	83.6	

Light Intensities	Treatment One	Treatment Two	Treatment Three
Mean	90.8	75.2	69.7

Harvests	2-10-49	2-15-49	2-21-49
Mean	80.9	74.5	80.4

L.S.D. at the 5-percent level, temperatures 10.07
lights 10.07

The data on the effect of night temperature upon total growth, on the fresh weight basis, show that plants grown under the low night temperature range (40 to 45 degrees F.) was much less than the total growth made by plants under either the 60 to 65 degrees F. range or 80 to 85 degrees F. range. There were differences in the total growth made by plants under different light intensities but they are not of sufficient magnitude to be significant.

The data in Table 47 show that the dry matter content of plants grown under the low night temperature range was not significantly different from that of the high night temperature range (80 to 85 degrees F.), but the plants under the latter temperature range had made more growth than plants under the 60 to 65 degrees F. range. The data in this table also show that reducing the light intensity reduced the dry matter content of the plants even when the light intensity was reduced by 1/3. The difference in dry matter content of plants grown under light treatment 2 as compared with that of plants grown under light treatment 3 was not statistically significant.

DISCUSSION

The test of significance used in evaluating the data reported in these studies was the F value as presented by Snedecor (76). Since this test is valid only when the mean and variance of the varieties are independent, the nature of the relationship between these 2 factors was determined on the starch data. The most accurate test of this type is carried out by analyzing percentage data before and after its transformation. The starch data were analyzed by following this procedure and it was found that the interpretation of the data based on percentages and upon angles was the same. Since it was found that transformation of the data on starch from percentages to angles did not change the interpretation of the results, it was not deemed necessary to transform other data in these studies before completing the statistical analysis.

Considerable variation existed between varieties in the tenderometer readings. For instance, the range was from 154 to 236 units[1] for Concentrated Fordhook, from 171.3 to 216 units for Peerless and from 152.3 to 205 units for Fordhook 242. For the latter 2 varieties there was a spread of 10 days between the first and last harvest, whereas for Concentrated Fordhook there was a spread of 12 days between the first and last harvest. Kramer and Smith (46) found that the tenderometer range on the Henderson Bush variety extended from 165 to 336 + units. These comparisons show that the large seeded types do not become hard or as tough as quickly as the small seeded types do.

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[1]Units are in pounds per square inch surface required to shear shelled beans.

Although the tenderometer ranges determined for each of the 3 varieties were narrow, there was a very close relationship between this factor and the alcohol insoluble solids content of raw beans. The data obtained on this phase of the study indicated that maturity grades based upon tenderometer units could be established, provided adequate samples of wide ranges of maturity were used in setting up the grade standard.

The investigations (46, 48) on the alcohol insoluble solids fraction of the lima bean have been reported on the canned or frozen product and not upon the fresh beans. However, these investigations show there is very close relationship between this factor and tenderometer units of the fresh bean. The changes in the alcohol insoluble solids content of the fresh bean due to delay in the harvest were similar to the findings of Kramer and Smith (46) on the canned product. Fresh beans of Peerless had a much higher alcohol insoluble solids content than canned beans when the 2 are compared at comparable stages of maturity based upon tenderometer readings on the raw beans. This difference in the alcohol insoluble solids content between fresh and canned beans can be explained by the fact that during the blanching process, the moisture content of the bean increases approximately 2.5 per cent and the bean also loses carbohydrates during the blanching process. These changes in moisture content and carbohydrate losses which occur during the blanching process were reported by Kramer and Smith (45).

The rapid method for starch analyses employed in these studies has several advantages over the official A. O. A. C.[2] method. These advantages are, mainly, speed and the inexpensive equipment required. Pucher and Vickery (66) first reported the use of the starch iodine reaction as a means of determining starch quantitatively. Nielsen (62) made several modifications of their method which speeded up the analytical procedure considerably. Nielsen compared the starch iodine method with the official starch method on lima bean samples and found very close agreement between the 2 methods. The rapid starch method could be used in a canning factory establishment to determine the maturity grade on fresh samples.

Data on the various carbohydrate fractions and their relative proportion in each variety are presented in Table 49. It will be noted that Peerless was higher in total solids and alcohol insoluble solids than either of the other 2 varieties. Peerless was also higher in total soluble solids and alcohol insoluble solids and lower in starch than Concentrated Fordhook. Thus, Peerless contained a much higher percentage of polysaccharides such as cellulose, hemicellulose and pentosans other than starch than the latter variety. The relationship between tenderometer values and the starch content of the Peerless variety was not as close as the relationship between the same 2 factors for the Concentrated Fordhook variety. This difference between the carbohydrate fractions for these 2 varieties may explain in part the difference found

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[2]Association of Agricultural Chemists

Table 49. Effect of storage temperature and duration, and times of harvest upon changes in the percentage of total solids, alcohol insoluble solids, starch and sugars in three varieties of lima beans.

Factors	Concentrated Fordhook				Peerless				Fordhook 242			
	Total Solids	A.I.S.[1]	Starch	Total Sugars	Total Solids	A.I.S.	Starch	Total Sugars	Total Solids	A.I.S.	Starch	Total Sugars
Times of Harvest:												
First Harvest	25.82	19.87	16.43	1.34	27.59	23.97	11.56	1.70	23.21	20.77	13.34	1.17
Second Harvest	29.05	23.08	18.97	1.33	32.90	26.09	14.84	1.66	28.57	23.34	15.54	1.06
Third Harvest	35.57	28.24	23.11	1.47	35.99	29.85	18.60	1.66	31.31	27.26	18.58	1.33
L.S.D.[2] at .05 level	1.57	1.15	1.51	0.22	1.57	1.15	1.51	0.22	1.57	1.15	1.51	0.22
Durations:												
At Harvest	28.32	23.11	16.87	1.97	30.69	24.49	15.53	1.98	26.00	22.42	17.47	1.67
1 day after	29.76	23.48	19.73	1.31	32.73	27.77	14.37	1.74	27.83	24.57	15.83	1.16
3 days after	30.00	24.09	20.22	1.11	32.49	26.49	14.85	1.62	28.39	24.35	14.76	0.95
6 days after	29.84	24.24	21.18	1.07	32.74	27.80	15.16	1.36	28.58	23.82	15.23	0.96
L.S.D. at .05 level	1.84	1.32	1.74	0.24	1.84	1.32	1.74	0.24	1.84	1.32	1.74	0.24
Temperatures:												
35°F	29.87	23.26	18.59	1.57	31.63	26.35	14.73	1.91	27.75	23.09	15.16	1.41
[illegible]°F	28.99	23.99	19.78	1.45	32.15	26.67	14.90	1.82	27.82	23.46	15.79	1.26
70°F	29.58	23.94	20.14	1.12	32.71	26.89	15.31	1.30	27.52	24.82	16.52	0.89
L.S.D. at .05 level	1.57	1.15	1.51	0.22	1.57	1.15	1.51	0.22	1.57	1.15	1.51	0.22

1 Alcohol insoluble solids

2 Least significant difference

in the relationship between tenderometer units and starch value for the 2 varieties.

After pods had been removed and were held in storage, ascorbic acid and total sugars were found to be indicators of freshness. Each of these factors decreased in the bean as storage was prolonged. The ascorbic acid content of the beans did not decrease during the early part of the storage period, but it did decrease rapidly after the third day in storage. Since there was a progressive decrease in total sugars as storage duration was prolonged, total sugar content was a more reliable index of freshness than ascorbic acid content. These findings on total sugar changes in stored beans are in agreement with those of Denny and co-workers (25).

The determinations for reducing substances on several samples which had been stored in cold alcohol showed that small amounts of reducing sugars were present. However, identical samples stored in a 2 per cent potassium hydroxide solution of ethyl alcohol yielded only slight traces of reducing substances. The latter findings are in agreement with those of Denny and co-workers (25) and Carolus (17) on reducing substances in lima beans. Parker and Stuart (63) found that the bean separated from the pod in the snap bean did not contain any reducing sugars. Boswell (13) found only traces of reducing sugars when peas were dropped into boiling alcohol; whereas those dropped into cold alcohol that had 0.2 gram of calcium carbonate added, showed varying amounts of reducing sugars present when analyzed.

These studies were planned to correlate specific objective measurements with closely associated organoleptic values. It was reasoned that such relationships would permit more accurate grade predictions. The findings in this study indicate that is is necessary to consider the relationships by individual varieties. For instance, the correlation coefficient for total sugars and flavor for the 3 varieties was only .37 or about the same as no correlation at all. However, the relationship between these 2 factors was found to be significant by varieties because a correlation coefficient of .69 and .56 were obtained from the data on Concentrated Fordhook and Fordhook 242 varieties, respectively. The data on the Peerless variety indicated no relationship between total sugars and flavor as shown by a correlation coefficient of .06. These findings clearly show that the total sugar determination, as an objective test, would have somewhat limited practical application because the flavor grades could only be predicted from a scale based upon data from 1 variety. The best relationships between flavor and total sugars obtained were only correlation coefficients of .69 and .56 and these are too low to be used in a regression equation for predicting grades. These very poor relationships indicate that other possible objective tests which might have a greater specific association with flavor than was found between the 2 factors studied should be investigated. A study of the relationship between flavone pigments and flavor might reveal a better objective test for flavor.

These studies have revealed several valuable objective measurements. The relationship between green pigment content of the raw bean and organoleptic color is a very good example. These 2 factors were found to be very closely related in data for the Peerless variety. Color grades of the frozen product could be predicted from raw beans. Another very close relationship was found to exist between tenderometer units and organoleptic tenderness. The correlation coefficients between these 2 factors were -.54, -.77 and -.74 for data on the Concentrated Fordhook, Peerless and Fordhook 242 varieties, respectively. Although these correlation coefficients are not satisfactory for prediction purposes, they indicate a fairly close relationship which merits further study. This relationship was found to be closer for those varieties that contain smaller starch fractions but a higher content of polysaccharides other than starch. A further breakdown of the polysaccharides into hemicelluloses might provide a better picture as to the factors contributing to the tenderness or toughness of a lima bean.

Multiple correlation coefficient determinations afforded a measuring stick of the effect of any 1 objective test upon organoleptic grade when 2 or more factors are considered to determine the grade. For example, the multiple correlation coefficients between the objective tests, total sugars and ascorbic acid, with flavor for the Concentrated Fordhook variety was .70 as compared to the correlation coefficient between sugar and flavor of .69. These 2 comparisons show that total sugar rather than ascorbic acid variations accounted for most of the variation in flavor in this variety; whereas ascorbic acid rather than the total sugars accounted for the flavor variations in the Peerless variety. Although multiple correlation analysis did not reveal any group of factors that could be used in predicting flavor grades, it did reveal 1 very significant relationship between over-all grade, ascorbic acid, alcohol insoluble solids and starch. The multiple correlation coefficient for this relationship was .85 which means that 72 per cent of the total variation in organoleptic over-all grade can be attributed to these factors.

The studies of the effect of environmental factors revealed that night temperature exerted a very strong influence upon the plant processes, yield and composition. For example, the optimum night temperature range (60 to 65 degrees F.) produced approximately 5 times the yield of the low night temperature range (40 to 45 degrees F.) and approximately 10 times the yield of the high night temperature range (80 to 85 degrees F.). On the basis of these findings it appears that lima beans should be grown during a season in the year when the mean night temperature range is between 60 and 65 degrees F. Temperatures lower than this range slowed up the maturation process and were responsible for an increased sugar and vitamin content of the bean. On the other hand, night temperatures above the optimum range hastened maturation and starch accumulation. Under a high night temperature environment some of the pods even began to shrivel before the seed reached maximum size.

The data, also, showed that reduction of light intensity tended to slow up maturity in plants held under the 80 to 85 degrees F. night temperature range. This response was reflected in the starch content of beans under the high night temperature - low light intensity treatment. The very close relationship between night temperatures and maturity indicates that heat summation units may be used to explain the rate of maturity of the lima beans. If heat summation units were directly related to the rate of maturity, their application to the timing of plantings would facilitate the regulation of supplies for the cannery for any 1 period.

Night temperatures have a pronounced effect upon the nutritive value of the lima bean. In this study beans grown at a night temperature range of 40 to 45 degrees F. contained approximately $1\frac{1}{2}$ times as much ascorbic acid expressed on a fresh weight basis as the beans grown under night temperature range of 60 to 65 degrees F. The beans grown at the low night temperature range contained slightly over twice as much beta carotene on the fresh weight basis as did the beans from the 60 to 65 degrees F. range. The highest quality beans based upon nutritive value were grown under the low night temperature range (40 to 45 degrees F.). This range could not be recommended because yields were extremely poor as compared to the yield from the optimum night temperature range (60 to 65 degrees F.) based on yield performance.

These studies have revealed several useful relationships between the objective tests on raw beans and organoleptic evaluations of the cooked frozen bean. These useful relationships are: between green pigment and organoleptic color, and between tenderometer readings and tenderness. It is hoped that their close association will stimulate further investigation. With some varieties total sugars were correlated with flavor and in others it was ascorbic acid that was correlated with flavor. The relationships between objective tests such as sugar determinations and flavor are not close enough to be used in predicting grades. Further study on objective tests, other than those employed in the studies, must be made before much light can be thrown upon flavor.

SUMMARY AND CONCLUSIONS

Studies were made to determine the effect of certain storage and environmental factors on changes in physico-chemical processes and in nutritive value of shelled lima beans. The investigations were divided into 2 phases: (1) the effect of 3 times of harvest, 3 varieties, 3 storage temperatures and 4 storage durations on changes in beans grown under field conditions, and (2) the effect of 3 times of harvest, 3 night temperatures and 3 light intensities on changes in beans of the Peerless variety grown under greenhouse conditions. The storage tests were conducted on the beans grown under field conditions and the physico-chemical determinations were made on both phases of the study in the laboratories of the horticultural department of the University of Maryland. The storage experiment was planned on a 3 x 3 x 3 x 4 factorial design. The variables were varieties, times of harvest, storage temperatures and storage durations, respectively. Data were secured on the yield of the plants and on moisture, alcohol insoluble solids, beta carotene, green and yellow pigments, total sugars, starch content, tenderometer readings and organoleptic values of shelled beans both before and after storage and on organoleptic values of the frozen product.

In general, the data show that delay in harvest significantly increased the yields of plants, as measured by the weight of shelled beans, and significantly increased tenderometer readings, alcohol insoluble solids and starch content of the shelled beans. On the other hand, delay in harvest significantly reduced moisture, carotene and organoleptic values, with the exception of flavor, pigments, and significantly reduced ascorbic content between certain harvests and not between others.

These findings show that increasing the storage temperature from 35 degrees F. to 70 degrees F. significantly increased tenderometer readings, alcohol insoluble solids, and starch, whereas higher storage temperatures decreased organoleptic values, green and yellow pigments, ascorbic acid, and total sugars. Variation of the storage temperature did not affect the moisture and beta carotene content of shelled beans.

Prolongation of the storage period was accompanied by increases in tenderometer values and alcohol insoluble solids content and decreases in the organoleptic values, ascorbic acid, beta carotene, green and yellow pigments and total sugars. Moisture and starch content were not affected significantly by storage duration.

In some cases, significant differences between varieties were established. Concentrated Fordhook and Peerless produced significantly greater yields of shelled beans than Fordhook 242. Peerless had a significantly lower moisture content than either Concentrated Fordhook or Fordhook 242, and a significantly higher alcohol insoluble solids, beta carotene and total sugar content than the latter 2 varieties.

The following significant first order interactions were found: (1) between time of harvest and duration of storage for tenderometer values, alcohol insoluble solids, total sugars and pigments, (2) between variety and duration for tenderometer values, alcohol insoluble solids, starch, beta carotene and yellow pigments, (3) between harvest and varieties for alcohol insoluble solids, organoleptic tenderness, organoleptic flavor and organoleptic over-all grade, (4) between temperature and duration for ascorbic acid and total sugars.

Useful correlation coefficients were obtained with tenderometer values and alcohol insoluble solids content, and with tenderometer values and starch content for each of the 3 varieties. The multiple correlation coefficients failed to reveal any close relation of any 3 or more variables to be useful for the evaluation of flavor.

For the greenhouse studies, a 3 x 3 x 3 factorial design was employed. The variables were light intensity, night temperature and time of harvest, respectively. Seed were planted in a fertile soil mixture in coffee-urn jars on November, 1948. Seedlings were thinned to 3 per container. Data were secured on the yield of plants and on moisture, alcohol insoluble sloids, starch, ascorbic acid, beta carotene, green and yellow pigments and total sugars.

Of the 3 environmental factors studied, night temperature had the more significant effect on the chemical composition of shelled beans. In general, the lowest night temperature (40 to 45 degrees F.) was favorable to the formation of relatively high contents of carotene, green and yellow pigments, ascorbic acid and total sugars, while the highest night temperature (80 to 85 degrees F.) was favorable to accumulation of alcohol insoluble solids and starch. Both starch and alcohol insoluble solids increase with an increase in the light intensity.

These studies revealed that 8 correlation coefficients were sufficiently high to be used in predicting the value of the dependent factor from that of the independent. The relationship between alcohol insoluble solids and tenderometer and between starch and tenderometer for each of the 3 varieties are considered to be sufficiently close to use for prediction purposes. The multiple correlation determinations did not reveal any relationship that could be used in evaluating flavor. However, this phase of the investigation did show the factors that influence over-all grade. The objective tests on ascorbic acid, alcohol insoluble solids and moisture could be used in a multiple regression equation for the prediction of over-all grade on lima bean samples.

The phase of the study on environmental factors shows that nutritive value of the lima bean can be increased by growing plants under low night temperatures and decreased by high night temperatures. The environmental factors, light intensity and times of harvest had very little effect upon the nutritive value under the conditions that prevailed in this study.

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Table 2. Analysis of variance of data presented in Table 1.

Source of Variance	d. f.	Mean Square	
		Shelled Beans	Fresh Pods
Total	35		
Varieties	2	**1745.95	**11276.74
Harvests	2	**744.78	271.99
Replicates	3	*297.71	**2462.30
V x H	4	155.48	1238.94
V x R	6	*272.08	*2281.31
H x R	6	56.69	501.75
Error	12	67.49	590.10

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 5. Analysis of variance of data presented in Tables 3 and 4.

Source of Variance	d. f.	Mean Square	
		Tenderometer	Moisture
Total	82		
Varieties	2	**1325.40	**181.47
Harvests	2	**26264.90	**591.67
Durations	3	**617.93	25.34
Temperatures	2	*439.90	0.72
V x H	4	346.92	4.95
V x D	6	112.70	0.69
V x T	4	100.48	2.75
H x D	6	123.03	9.35
H x T	4	155.80	0.23
D x T	6	110.53	1.88
Error	43	134.47	0.29

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 8. Analysis of variance of data presented in Tables 6 and 7.

Source of Variance	d. f.	Mean Square: Alcohol Insoluble Solids	Mean Square: Starch
Total	84		
Harvests	2	**438.38	**364.04
Varieties	2	**99.41	**208.42
Durations	3	**23.30	3.17
Temperatures	2	*8.26	*12.27
H x V	4	*5.81	3.19
H x D	6	*4.99	2.93
H x T	4	1.47	.94
V x D	6	*4.68	**21.33
V x T	4	2.30	1.11
D x T	6	1.80	2.15
Error	45	1.93	3.36

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 10. Analysis of variance of data presented in Tables 9 and 7.

Source of Variance	d. f.	Mean Square: Transformed Starch Data	Mean Square: Percent Starch Data
Total	84		
Harvests	2	**217.84	**364.04
Varieties	2	**120.81	**208.42
Durations	3	0.98	3.17
Temperatures	2	*7.46	*12.27
H x V	4	1.95	3.19
H x D	6	1.83	2.93
H x T	4	0.65	0.94
V x D	6	**12.86	**21.33
V x T	4	0.55	1.11
D x T	6	1.52	2.15
Error	45	2.00	3.36

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 13. Analysis of variance of data presented in Tables 11 and 12.

Source of Variance	d. f.	Mean Square: Ascorbic Acid	Mean Square: Beta Carotene
Total	82		
Harvests	2	**80.02	**3.29
Varieties	2	7.26	* 0.51
Durations	3	**107.58	**1.18
Temperatures	2	**29.77	0.25
H x V	4	2.16	0.03
H x D	6	3.36	0.33
H x T	4	4.20	0.008
V x D	6	5.19	0.47
V x T	4	2.81	0.06
D x T	6	**12.92	0.17
Error	43	3.60	0.16

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 15. Analysis of variance of data presented in Table 14.

Source of Variance	d. f.	Mean Square Total Sugars
Total	79	
Harvests	2	1.68
Varieties	2	**21.92
Durations	3	**29.36
Temperatures	2	**27.53
H x V	4	0.65
H x D	6	*1.87
H x T	4	0.56
V x D	6	1.15
V x T	4	0.38
D x T	6	**3.31
Error	40	0.68

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 18. Analysis of variance of data presented in Tables 16 and 17.

Source of Variance	d. f.	Mean Square	
		Green Pigment	Yellow Pigments
Total	85		
Harvests	2	**1764.09	**32.04
Varieties	2	218.94	1.53
Durations	3	**758.59	**18.55
Temperatures	2	*370.89	**14.54
H x V	4	144.28	4.38
H x D	6	*204.12	**9.30
H x T	4	47.70	0.66
V x D	6	119.84	*5.51
V x T	4	27.29	1.50
D x T	6	130.29	2.91
Error	46	81.18	1.90

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 21. Analysis of variance of data presented in Tables 19 and 20.

Source of Variance	d. f.	Mean Square	
		Tenderness	Flavor
Total	69		
Harvests	2	**12.27	2.89
Varieties	2	0.70	1.39
Durations	3	**8.64	**26.49
Temperatures	2	**6.35	**7.93
H x V	4	*1.91	*4.96
H x D	6	0.62	1.93
H x T	4	0.83	0.84
V x D	6	0.65	1.36
V x T	4	0.25	0.16
D x T	6	0.83	1.35
Error	30	0.56	1.39

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 24. Analysis of variance of data presented in Tables 22 and 23.

Source of Variance	d. f.	Mean Square: Organoleptic Color Grade	Mean Square: Organoleptic Over-all Grade
Total	67		
Varieties	2	*2.05	0.23
Harvests	2	**50.50	**1.85
Durations	3	**28.86	**5.97
Temperatures	2	**8.69	**1.73
V x H	4	1.03	*0.38
V x D	6	0.18	0.18
V x T	4	0.43	0.04
H x D	6	0.85	0.21
H x T	4	0.99	0.05
D x T	6	1.25	0.23
Error	28	0.57	0.13

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 31. Analysis of variance of data presented in Tables 29 and 30.

Source of Variance	d. f.	Mean Square: Pod Yield (in grams)	Mean Square: Shelled Bean Yield
Total	26		
Temperatures	2	**143240.33	**24699.73
Lights	2	*5955.14	142.78
Harvests	2	**24035.67	121.27
T x L	4	2355.78	39.78
T x H	4	3367.45	43.48
L x H	4	2406.08	246.59
T x L x H, error	8	1188.34	204.40

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 37. Analysis of variance of data presented in Tables 35 and 36.

Source of Variance	d. f.	Mean Square: Yellow Pigments	Mean Square: Green Pigments
Total	17		
Temperature	1	**328.96	**5212.20
Lights:			
Tr 1 vs(Tr 2 ≠ Tr 3)	1	6.63	257.07
Tr 2 vs Tr 3	1	*40.52	302.01
Harvests:			
1st vs(2nd ≠ 3rd)	1	17.02	**2786.09
2nd vs 3rd	1	28.67	23.24
T x L	2	13.34	29.64
T x H	2	7.78	121.07
L x H	4	6.17	170.10
T x L x H (error)	4	5.15	129.27

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 42. Analysis of variance of data presented in Table 41.

Source of Variance	d. f.	Mean Square Total Sugars
Total	26	
Lights	2	5.33
Harvests	2	64.38
Temperatures:		
45°F vs(65°F + 85°F)	1	**323.31
60-65°F vs 80-85°F	1	8.25
L x H	4	37.38
L x T	4	64.32
H x T	4	25.25
L x H x T (error)	8	24.24

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 45. Analysis of variance of data presented in Tables 43 and 44.

Source of Variance	d. f.	Mean Square: Alcohol Insoluble Solids	Mean Square: Starch
Total	26		
Temperatures	2	**1345.37	**473.35
Lights	2	192.74	**217.03
Harvests	2	52.15	84.31
T x L	4	150.47	*88.30
T x H	4	53.19	13.59
L x H	4	30.40	24.09
T x L x H(error)	8	44.04	22.55

*Significant at the 5-percent level

**Significant at the 1-percent level

Table 48. Analysis of variance of data presented in Tables 46 and 47.

Source of Variance	d. f.	Mean Square: Plant Growth on Fresh Weight Basis	Mean Square: Plant Growth on Dry Weight Basis
Total	26		
Temperatures:			
40-45°F vs (60-65°F ≠ 80-85°F)	1	**55263.98	6.82
60-65°F vs 80-85°F	1	235.44	*531.31
Lights:			
Tr 1 vs (Tr 2 ≠ Tr 3)	1	11436.65	**2031.36
Tr 2 vs Tr 3	1	1055.82	133.39
Harvests	2	5864.17	114.57
T x L	4	1538.03	25.53
T x H	4	1356.94	214.28
L x H	4	3567.67	235.52
T x L x H	8	3364.29	85.74

*Significant at the 5-percent level

**Significant at the 1-percent level