July 20, 1975

To the Graduate Council:

I am submitting herewith a thesis written by George Takyi Owirodu entitled "Design, Construction, and Evaluation of a Parallel Belt Sheller for Mature Green Soybeans." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

Luther R Wilhelm

L. R. Wilhelm, Major Professor

We have read this thesis
and recommend its acceptance:

B. L. Bledsoe

J. L. Collins

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

DESIGN, CONSTRUCTION, AND EVALUATION OF A PARALLEL BELT SHELLER FOR MATURE GREEN SOYBEANS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

George Takyi Owirodu

August 1975

ACKNOWLEDGEMENTS

The author is heavily indebted to Dr. L. R. Wilhelm, Assistant Professor in Agricultural Engineering, for his supervision and encouragement throughout the undertaking of this work.

The support of Dr. B. L. Bledsoe and Dr. J. L. Collins who served on the author's committee and who provided help at various times is also appreciated.

A special note of thanks goes to Dr. Houston Luttrell for his incessant encouragement and for making the resources and facilities of the Agricultural Engineering Department available.

Thanks are also extended to Mr. Paul Elliott and Mr. Walker Garner and their assistants in the Agricultural Engineering Shop for their outstanding work in constructing the experimental machine.

Mrs. Alice Ballard deserves a special recognition for her excellent work in typing the manuscript.

The author also expresses his appreciation to the entire staff and students of the Agricultural Engineering Department for their unique fellowship.

The work reported herein was supported by the Government of Ghana, the African American Institute and the University of Tennessee.

ABSTRACT

Mechanization of mature green soybean (Glycine max (L) Merr.) shelling is needed to stimulate increased use of the green soybean as a vegetable and to enhance commercial processing. Existing shellers have feeding problems and low shelling rates. In an attempt to overcome these problems, an experimental parallel belt sheller was designed. The parallel belt sheller was chosen because it appeared to have potential for a high shelling rate and no difficulty in feeding. A shelling system using the shear force developed by the relative motion of two parallel belts was designed and constructed. The machine was tested in the laboratory and its performance compared to roller and paddle-type shellers. The results of the test indicated that shelling mature green soybeans by the parallel belt principle is possible. The shelling efficiency of the green soybeans was improved by preheating the green pods. Belt spacing and speed were found to have significant effects on shelling. Though the general performance of the parallel belt sheller was lower compared to the roller and paddle-type shellers, it produced the highest shelling rate. There was no difficulty in feeding pods to the machine.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

I. BACKGROUND AND STATEMENT OF THE PROBLEM

Soybeans rank high on the list of most valuable crops grown in the United States today. The substantial contribution made by soybeans to the agricultural economy is demonstrated by the annual increase in acreage cultivated to the crop. Approximately 46 million acres (20) of soybeans were harvested in 1972 compared to 23 million acres (20) in 1959. This shows a 50 percent increase in harvested acreage over the past 13 years.

The two types of soybean grown are the field soybean and vegetable (garden) soybean. The field soybean is commonly grown on a large scale and mechanically harvested for the industry. The vegetable soybean is grown in small acreages and harvested both green and dry for home consumption. The garden soybean usually has larger seeds and flatter pods than the field soybean.

Despite the high nutritive value of the soybean and the large quantities in which it is produced, only very small amounts of the product are consumed as a vegetable. One reason suggested (6) for the inappreciable use of the vegetable type of soybean is that it is not yet widely accepted as a vegetable crop. Another reason is that most varieties grown are the field type which are more suitable for the industry than for direct human consumption. Difficulty of removing the bean from the green pod for preservation is also accountable for the limited use of soybeans as a vegetable.

Growers of garden soybeans have found that the removal of the beans from the pods is facilitated by heating the mature green pods in water and then gently squeezing the pods between the thumb and forefinger. Though the hand shelling method is effective, it is slow and incompatible with commercial processing of the green soybean.

Mechanization of green soybean shelling is needed to stimulate increased use of the crop as a vegetable, to induce large scale production of vegetable-type soybeans, and to encourage commercial processing.

II. OBJECTIVES

The purpose of this study was to investigate the possibility of using the shear force developed by the relative motion of parallel belts in shelling green vegetable soybeans. To determine its effectiveness this method was compared with two existing shellers, roller and paddle-types. Specific objectives were:

1. To design, construct and test a parallel belt mechanism for shelling green vegetable soybeans.
2. To evaluate the performance of the system on the basis of shelling capacity and bean damage, and to study the effect of heat treatment of pods on efficiency of shelling.

The mechanism was to be designed with provisions for varying the vertical displacement between the belts, varying the surface speeds of the belts and varying the threshing length.

CHAPTER II

REVIEW OF LITERATURE

I. GENERAL CONSIDERATION

To enhance output for commercial processing, numerous attempts have been made to mechanize green vegetable soybean (Glycine max (L) Merr.) shelling. Shelling is the process of removing the bean from the pod. Threshing is another term often used to describe the same process.

Literature abounds in information on the trend of development of various shelling mechanisms that dealt with different kinds of beans, particularly in the dry state. Though each shelling method has its merits, the fundamental problem underlying almost all of the mechanisms is the damage they do to the shelled bean. Bean quality, thus economic value, is reduced by the damage. Bean damage as used in this study refers to any disfiguring of the physical state of the bean resulting from cracked seed coat, split seed and broken cotyledons.

Since the difference between green beans and dry beans is mainly due to their moisture content, it was presumed that methods that were employed in shelling dry beans could also be used, perhaps with little modification, in threshing green beans. These methods could also serve as source of ideas for the synthesis of new shelling methods for green beans. From this standpoint, it was necessary to begin this study with a thorough review and consideration of all bean shelling mechanisms formerly and currently in use.

Hand shelling is the oldest method used for shelling beans. The sheller applied pressure to the pods in different ways to remove the bean from the pod. Squeezing the bean out of the pods by the pressure of the finger tips was one such way. This method was mainly applied to heat treated green pods and to varieties of beans which were dry and had delicate pods.

In the case where the bean had tough pods, more severe methods were applied. Splitting the pod was suitable in such situations. Split-shelling was accomplished in many ways including making an incision at the pointed end of the pod by the finger nail or a pointed stick and pulling the two halves of the pods apart along the suture and midrib. For dry beans with tougher pods, split-shelling was accomplished by beating the pods in sacks with sticks or by continual hitting of the sack against a wall or tree. Another method of hand shelling was by twisting the pod open by the fingers and brushing the beans out by the tip of the fingers.

Clearly, man's traditional methods of shelling did establish the basic requirements of shelling. This has successfully stimulated the development of a series of mechanical systems to shell beans.

II. THEORY OF THRESHING

Lamp *et al.* (9) noted that a thorough understanding of the nature of threshing was an aid in developing threshing mechanisms. They outlined the theory of threshing as:

> Whenever the applied force on a kernel exceeds the sum of the forces which restrain it, threshing (or freeing of the kernel) occurs. If the force continues to be applied after threshing and accelerates the kernel relative to the pod, separation occurs.

Arnold *et al.* (1), while considering the development of a sheller for castor beans, described the problem of shelling as getting the bean out of its individual part of the pod without cracking or injuring the cover coat of bean. They found that when sufficient pressure was applied on the sides of the pod to break it loose, the bean was usually injured, but by applying pressure on the ends of the pods, most beans came out without cracking or injury.

III. DEVELOPMENT OF SHELLING MECHANISMS

Disc Sheller

Arnold *et al.* (1) reacted to the acute castor bean oil shortage caused by the world war situation by developing a castor bean sheller at the University of Tennessee to increase the production of the crop which grew well in the southern United States.

Their machine consisted of two vertical, rubber discs, one stationary and the other rotating at approximately 1000 rpm. The discs were spaced about one-half inch apart and the space could be adjusted so the beans would just fit endwise between the discs without being crushed. The pods were fed into the machine such that the shelling pressure was always applied on the ends to cause minimum damage to the beans. The mechanism was reported to have a shelling efficiency of over 94 percent, and a capacity of about one bushel per hour.

Arnold et al. (1), later in the same year, improved upon their machine by constructing one with 12 inch diameter rubber-faced discs instead of the six inch diameter discs which were originally used. The speed of the rotating disc was reduced to 525 rpm. The new machine gave a capacity of six bushels of shelled beans per hour with an overall efficiency of over 98 percent.

In 1943, Arnold (1) designed an improved castor bean sheller similar to the ones built earlier. The new machine had 24 inch diameter rubber-faced discs and a surprising average capacity of 1200 pounds of shelled beans per hour at an efficiency of over 96 percent. The results of the research conducted by Arnold and other researchers (1, 14) indicated a relationship among the shelling surface area, speed of rotation, and the capacity and efficiency of the sheller.

Schoenleber et al. (17) conducted a study on the performance of castor bean hulling plants designed by previous researchers. The results of the study indicated that the capacity of the disc hullers could be increased by increasing the diameter of the discs to 36 inches. It was also proposed that further research should be conducted on the disc surface nature and angle of disc which they believed could affect capacity and efficiency.

Porterfield et al. (14), in a similar study, conducted an investigation into the performance of a disc sheller with horizontal discs. The results of the tests indicated a direct relationship between the speed of rotation of the disc and the capacity of machine. However, it was noted that the percentage of unshelled beans and percentage of cracked beans increased with increase in speed.

The percentage of cracked beans decreased and the percentage of unshelled beans increased as the spacing between the discs increased. The hardness of the rubber which covered the discs was also found to affect the yield of the sheller. It appeared that a difference in hardness between the fixed and rotating disc of approximately 15 durometers gave the best performance considering the maximum capacity and the minimum unshelled and damaged beans collectively.

Schoenleber et al. (18) continued their study on the performance of castor bean shellers. The results of the investigation indicated that, for the horizontal disc shellers, increasing rubber thickness on the upper disc decreased the capacity while increasing lower rubber thickness increased both capacity and efficiency of the sheller. Increasing hardness differential between lower and upper rubber, from zero to 20 durometers, increased capacity and efficiency. The quality of the bean shelled also increased with increase in disc speed to 450 rpm but decreased with speed above 550 rpm. Efficiency and capacity of sheller decreased with increase in area of shelling surface.

Cylinder and Concave Thresher

Clay (5), in an effort to help solve the castor bean shortage problem left by the second world war, invented a castor bean thresher. The threshing device consisted of a 32 x 6, 10-ply truck tire slightly inflated and rotating at 50 to 100 rpm inside a segment (one-fifth of the circumference) of a 9.00 x 36 inch tractor tire casing. Castor bean pods placed inside the casing were shelled as a result of the relative motion of the tire and casing. The capacity of the machine was reported as over 200 pounds per hour. And with proper adjustment between tire and casing, about 90 percent of the beans were threshed.

Gordon (8) evaluated several types of experimental shellers in an attempt to build a sheller for castor beans. One such threshing device consisted of a horizontal cylinder 12 inches in diameter, studded with steel spikes which was rotated between a feeding hopper and a curved metal grate at about 250 rpm. The unshelled beans were fed into the hopper above the cylinder. Separation of chaff from beans was accomplished by the use of a screen and air blast. It was reported that the sheller worked satisfactorily with some varieties of castor beans. However, excessive breakage occurred with other varieties as a result of the beating caused by the rotating spiked cylinder on the shelled beans.

Another threshing device that was tested (8) consisted of an inverted conical rotor, mounted vertically and covered with rubber matting. The rotor turned inside a funnel-shaped housing at a closed distance which diminished toward the small end. The rotor was covered with rubber matting and the housing was lined with a smooth rubberized fabric underlain with sponge rubber. The rotor speed ranged from 125 to 150 rpm. The beans were fed into the top and discharged at the bottom or small end of the funnel. It was reported that the machine had a high shelling efficiency and did less damage to the beans. The capacity of the device was rather low.

Gordon (8) investigated the possibility of utilizing a small combine with a cylinder covered with heavy rubber matting for threshing castor beans. The cylinder was rotated at about 400 rpm. The test results indicated a high performance of the device with most of the varieties of castor bean. Gordon (8) continued his investigation by building a smaller shelling device. The machine consisted of a rubber-covered cylinder eight inches in diameter and 24 inches long rotating inside a rubber-covered concave. It was reported that the experimental results indicated a high shelling efficiency of the device on all varieties of castor beans. The capacity of the machine was, however, reportedly low.

The series of research conducted by Gordon _et al._ (8, 14) culminated in the development of the popular cylinder-concave principle for shelling castor beans, a principle which is widely used in various forms in threshing grains and other beans.

Roller Sheller

Mention of this type of thresher was first made in 1937 in California when Bainer _et al._ (2) were investigating the causes of poor stands of lima beans because of poor germination. Their early investigations (2) showed the cause to be mechanical injury during threshing. Additional preliminary studies verified this finding. These investigations therefore led to the conclusion that the standard bean thresher (cylinder-concave type) was unsatisfactory for threshing seed beans and that some new device should be developed. To satisfy this need the roller sheller was built. The principle underlying the roller shelling was simple. When beans were ready for threshing, slight pressure on the pods distorted them sufficiently to cause them to open along the suture and midrib. When the pressure was released the pod separated, throwing the beans out (2). This principle assumed thorough drying of the pod. The roller shelling unit consisted of a set of rubber-covered steel rolls approximately one foot in diameter. It was reported that the unit produced a total thresh of over 97 percent when the pods were passed through the shelling unit three times.

Bainer et al. (2), having observed that practically all the beans were threshed by passing the pods thrice between the rolls, built another machine having three sets of rolls. The rolls were of the same diameter as the original machine. All but two of the rolls were covered with 0.5 inch of soft rubber. The other two rolls had one inch of rubber vulcanized to them. The first and second set of rolls were driven at a peripheral speed of approximately 210 fpm, the third set at 250 fpm. These speeds were about 15 percent of the minimum cylinder speed found in the commercial cylinder and concave seed-bean threshers. The rolls were mounted in pairs on four feet centers. The lower roll of each pair was positively driven, whereas the upper rolls were driven by contact through the bean pods passing between them. The bearings on the upper rolls were mounted in guides that permitted them to rise sufficiently to give up to a three inch clearance between the two rolls. The upper rolls were loaded with compression springs to the pressure on the rolls increased as they were lifted by the pods. This machine was reported to have done a good work. Ninety-nine percent shelling was obtained with almost no visible and internal damage done to the beans.

Later results of the experimental tests (3) conducted on the roller seed bean thresher showed it to work satisfactorily on all varieties of lima beans and other small beans such as cowpeas and garden peas.

Notable of the results of the experimental tests run on the roller thresher (3) was the 91.9 percent shelling obtained with large limas (pacific) which had a high moisture percent of 17.7. Another important characteristic of the roller sheller was the lower power consumption compared to the regular cylinder-concave bean threshers.

In a similar study Schoenleber _et al._ (17) reported the roller thresher to work satisfactorily on castor beans.

Mitchell _et al._ (12) of Australia found the roller-squeezing procedure most promising of several methods examined for green peas. The yield of their machine was 94 percent of the yield from hand shelling when the pods of the green peas were heat treated in boiling water for 15 seconds. Untreated pods yielded only 55 percent. It was also reported (12) that best results were obtained when the peripheral speed of the roller was 75 fpm and when one roller was coated with hard rubber and the other with soft rubber.

Mitchell _et al._ (12), in a later study, reported the sheller to have merit because its utilization eliminated the need for most cleaning equipment as the shelled peas were clean and least damaged.

Collins _et al._ (6), in a similar study, found the roller sheller suitable for shelling mature, green soybeans. They reported the efficiency of the machine to be as good as that of hand shelling because all beans were removed from the pods. It was also observed that yield of shelled beans depended upon maturity of the pods at harvest and on the temperature of the preheated water for treating the green pods. A water temperature of 82°C was reported optimum. The experimental results also indicated that while the effect of temperature was significant, time of heat treatment from 30 to 120 seconds had no significant effect on the capacity of the machine. They attributed greater shelling yield at generally high temperature treatment to the weakening of the connective tissue that held the two sides of the pod together.

However, the roller sheller was found to have some serious limitations. It had to be hand fed and shelling was achieved only when the pods were fed into the device in a specific orientation (end-on presentation).

Parallel Belt Sheller

The old army huller used in 1918 was reported by Gordon (8) to operate on the parallel belt principle.

Gordon (8) investigating the possibility of mechanical shelling of dry castor beans built a small huller of the double-belt type. The machine consisted of two belts which travelled parallel to each other and in the same direction. The top belt travelled 38 percent slower than the bottom belt whose surface speed was 1200 fpm. The beans were shelled as a result of the abrasive action of the belt surfaces traveling at different speeds. The shelling efficiency of the device was reported to be 72 percent with 2 percent cracked beans. The capacity of the mechanism was 650 to 700 pounds of shelled beans per hour per foot of belt width. Though the belt type sheller showed promise as a threshing unit, considerable space would be required for such arrangement in addition to large capacity cleaning and separating device.

Walker et al. (24), while investigating the effectiveness of rub-threshing of soybeans, built a parallel belt mechanism for shelling dry soybeans. Their study indicated that threshing was affected by numerous factors including the moisture content of the pod and orientation of the pod with respect to the direction of belt travel. It was reported that the threshing unit produced a threshing percentage of over 99 percent with less than 0.1 percent total observed bean damage. Roller spacing and threshing length were found to be the controlling machine parameters of those investigated, with respect to threshing percentage. It was also observed that the top belt speed greatly influenced the threshing percentage. No matter what the speed of the bottom belt was, with the top belt stationary the threshing percentage remained constant and very high. At an idler roller spacing of 13.5 inches, threshing length of 40.5 inches and top belt speed of 100 fpm, the highest threshing percentage of 99 percent was obtained at a bottom optimum belt speed of about 800 fpm (24).

IV. CONCLUSIONS

A review of the numerous threshing mechanisms indicates that the force required for shelling beans or grain is provided by the relative motion of two surfaces. The effectiveness of shelling depends on the degree of contact between the pod and the shelling surfaces. The degree of contact, in turn, depends on the thickness of the pods, the shape of the beans in the pod, the speed of the shelling surfaces and the configuration of the shelling surfaces which normally may be flat, rough, or bear projections.

The nature of the shelling surface also determines, to a large extent, the type of threshing force that comes into play. Flat and rough surfaces normally exert rubbing and squeezing effects on the pod. These effects are described in the literature as rub threshing and squeeze threshing, respectively. Shelling surfaces with projections on one or both surfaces usually produce impact or beating effect on the pod causing twisting and splitting and subsequent release of the beans. This effect is best illustrated by a cylinder bar striking unthreshed grain. While research indicates that either method has relative merit in dry bean threshing, one method might be preferable to the other in green bean shelling because of the very tender nature of the product.

The impact-threshing method is most suitable for dry beans whose pods have developed stress imbalances as a result of drying and need a large force acting over a short period (impact) to deform the pod and release the beans they contained. The dry bean also has considerable strength to withstand the severe impact without damage. The impact method does not therefore look promising for green beans which have very little strength to withstand the large shelling force. Though by regulating the speed of the impact producing surface, gentle impacts could be produced which might not damage the green bean. But the magnitude of the impact might be insufficient to cause failure necessary in the green pod even with heat treatment.

The rub-threshing and squeeze-threshing methods appear more promising for green beans. They are more gentle because they bring to bear on the pod small forces which act over relatively long periods thus causing gradual shelling. However, too high speeds of and too little space between the shelling surfaces may cause severe bruises and coat damage to the bean which may reduce its quality. Literature provided evidence of the squeeze-threshing (roller shelling) method having been tried on dry beans. But no evidence existed regarding the application of the rub-threshing method (parallel belt principle) on green beans.

CHAPTER III

DESIGN OF THE PARALLEL BELT TYPE SHELLING UNIT

I. SELECTION OF OPERATING PARAMETERS

Initial consideration in designing the shelling unit was the selection of pertinent operating parameters to produce the desired shelling action.

Parallel belts moving in the same direction at different speeds (22) as opposed to parallel belts moving in opposite direction was chosen for the design. This design was chosen to ensure distinct feeding and recovery areas to the shelling unit and to avoid blending of input and output materials from the mechanism.

Since the effectiveness of the shelling unit was expected to depend significantly on the space between the belts, provision for varying the space over the selected range 3/32 - 7/32 inch was necessary. This range included the average thickness of the soybean pod, though the effective shelling space was expected to be slightly less than the average pod thickness.

Belt speed was also considered critical in the performance of the shelling unit. Provision for varying the surface speeds of belts over a range of zero to 850 fpm was therefore necessary. This speed range was cited (22) as being satisfactory for dry soybean shelling. The speed range was, however, extended from zero to 950 fpm to increase the probability of including the optimum speed at which the green soybean would shell.

Provisions were made for varying the shelling length or distance between the first and last rollers and the roller spacing between the rollers on the top belt.

Belt tension might affect shelling so provision was made for adjusting the tension.

The width of the shelling surface was maintained constant at 12 inches.

II. DESIGN OF THE SHELLING UNIT

The parallel belt shelling unit is shown in Figure 1, and a schematic of the mechanism is shown in Figure 2. The device is made up of two main parts, the upper and lower units. Each unit consists essentially of a belt and its drive mechanism. The entire device is mounted on a one and one-half inch angle iron frame 66 1/2 inches long, 54 inches high and 18 inches wide.

The belt on the upper unit will be referred to as the upper belt. The upper belt is made of neoprene and fabric and it is approximately a 151 inch loop, 12 inches wide and one-eighth inch thick. The belt runs on a 14 1/2 inch by eight inch diameter drive pulley and a 14 1/2 inch by four and one-half inch diameter aluminum idler drive. The pulley and idler drives are 56 inches apart. The drive pulley is mounted on two pillow blocks rigidly bolted to the frame. The idler drive is mounted on two side mounted, self aligning, take-up units firmly bolted to the frame. By means of the take-up unit the horizontal position of the idler drive can be adjusted to vary the

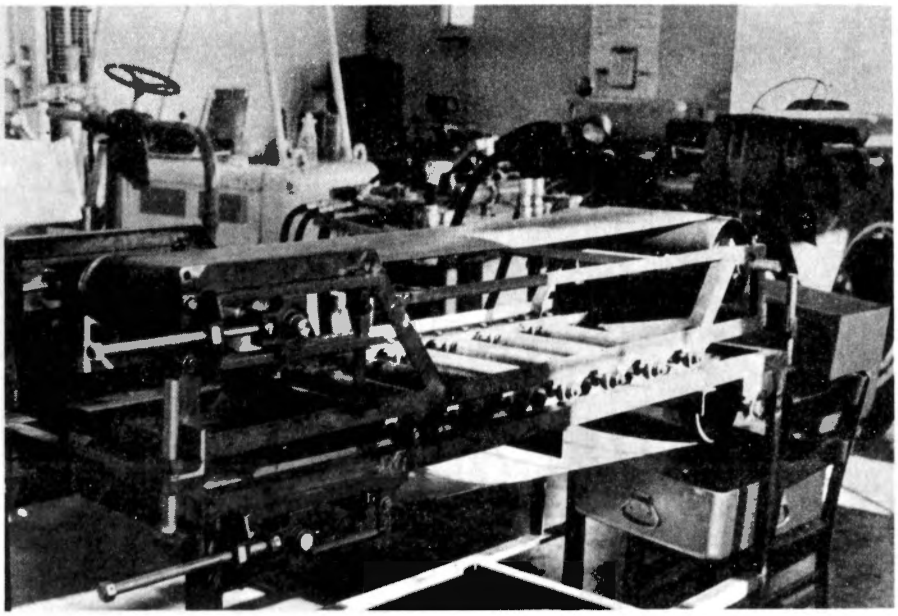

Figure 1. The parallel belt shelling mechanism.

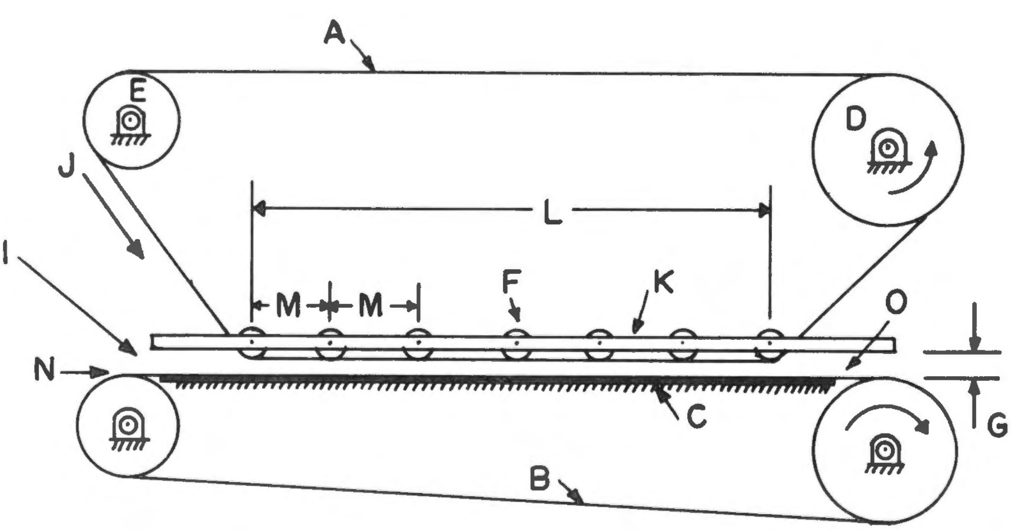

Figure 2. Schematic of the components and operation of the parallel belt sheller.

A.	Upper belt	I.	Inlet of sheller
B.	Lower belt	J.	Direction of upper belt travel
C.	Wooden board	K.	Rack bearing rollers
D.	Drive pulley	L.	Shelling length
E.	Idler drive	M.	Roller spacing
F.	Rollers	N.	Direction of lower belt travel
G.	Belt spacing	O.	Outlet of sheller

distance between it and the drive pulley by ten inches. This provides for varying the shelling length and adjusting the tension in the belt. The lower part of the upper belt runs on seven two-inch diameter idler rollers with one-half inch shafts installed in pillow blocks bolted to the frame. The idler rollers are spaced six inches apart. Shelling length is determined by the distance between the two extreme idler rollers. The length is decreased by removing one or more outermost idler rollers and changing the idler drive position to leave the belt in the proper tension. The rollers serve two main purposes. They keep the lower shelling surface of the upper belt flat and apply pressure to the pods to assist shelling.

The upper unit of the sheller is attached to the lower unit by means of a threaded rod-nut arrangement as shown in Figure 3. This comprises four long vertical threaded rods welded to the top four corners of the lower unit. They fit into slots in extensions welded to the upper unit. The upper unit is kept in position by eight large nuts. Two nuts screw on each treaded rod, one below and the other above the extension. The lower nut sets the level and the upper nut tightens to keep the unit firm. This arrangement allows up and down movement of the upper unit and thus makes provision for varying the vertical displacement between the upper and lower belts.

The lower unit has almost the same design as the upper unit. It consists of a lower belt of the same dimensions as the upper belt running on a drive pulley and an idler drive similar to the ones discussed. Like the upper unit, the drive pulley is mounted on pillow blocks and the idler is mounted on take-up units. The distance

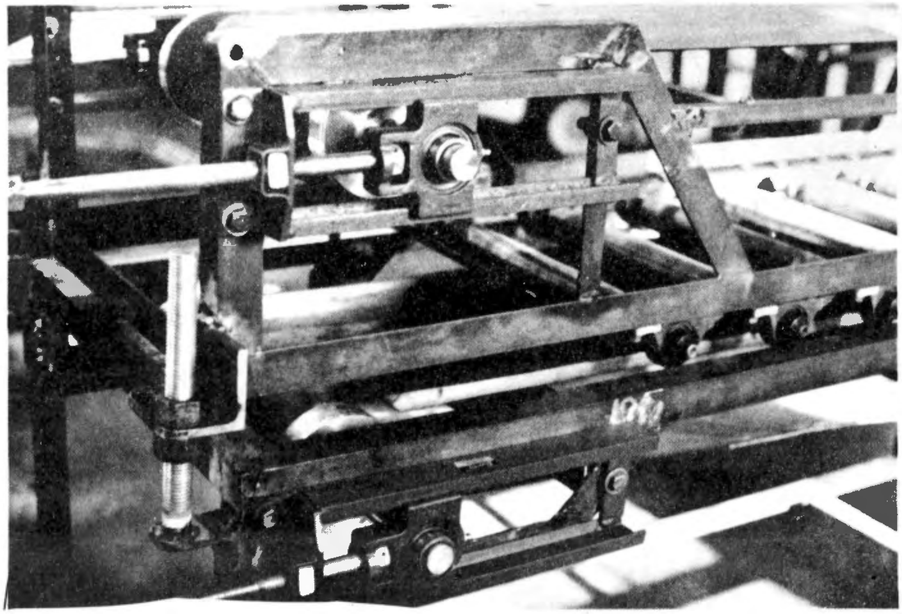

Figure 3. Attachment of the upper unit to lower unit.

between the drive pulley and idler drive is maintained constant at 56 inches. The upper part of the lower belt is maintained firm and flat by a 54 inch by 12 inch smooth oak board built under it.

The belts are driven independently by two variable speed hydraulic motors as shown in Figure 4. These motors are bolted to the right upper side of the sheller to connect the drive pulleys through jaw type couplings with neoprene insets. The surface speeds of the belts are changed by varying the speed of the hydraulic motors.

The hydraulic motors are powered by an independent hydraulic power supply which mounts on the three-point hitch of a tractor. The independent power supply consists of a hydreco model 19 P1 190036 hydraulic pump which is driven by the PTO of the tractor on which the power supply is mounted. Flow control valves which control the speed of each hydraulic motor are mounted above oil tanks of the power supply.

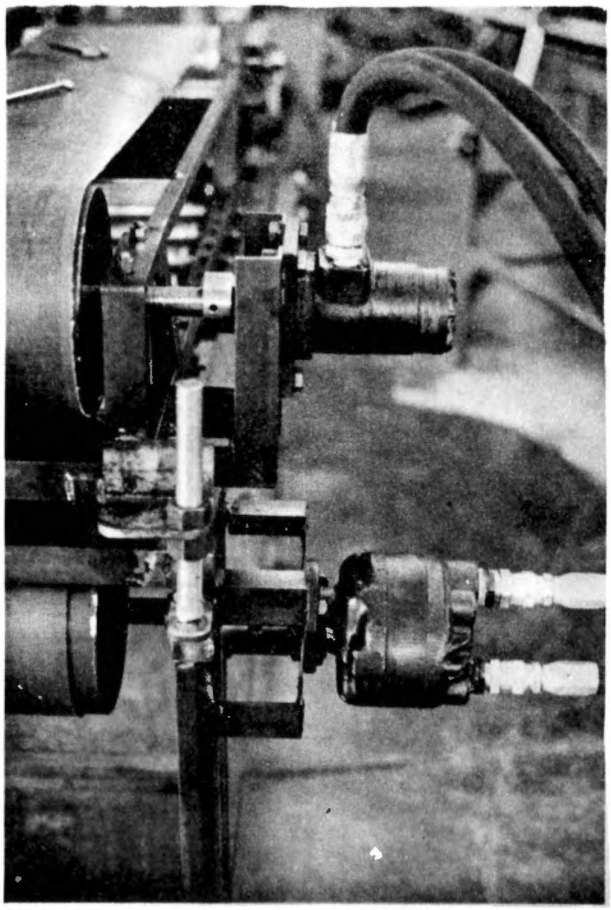

Figure 4. Variable speed hydraulic motors for driving pulleys.

CHAPTER IV

EXPERIMENTAL METHODS

I. DESIGN OF EXPERIMENT

The sheller was used to investigate the effects of belt speed, threshing length, distance between the upper and lower belt surfaces and orientation of pod during feeding on shelling percentage and quality of the shelled bean. The objectives of this laboratory study were to define which combination of upper and lower belt speeds, threshing length, distance between belts and pod orientation were optimal with respect to the performance of the parallel belt sheller and to compare the overall performance of the belt sheller with that of the roller-type and paddle-type bean shellers.

The literature indicated that most shellers would not perform on mature green beans unless the beans were given some heat treatment (6, 12). The result of a trial test performed on untreated green soybeans verified the above observation. It was therefore deemed necessary to investigate the effect of heat treatment of green soybeans on shelling as it appeared a determining non-machine parameter.

The effects of a total of three factors on shelling were investigated. There were two machine factors, namely belt speed and distance between belts, and a non-machine factor, heat treatment. All other factors were maintained constant. During the experiment five levels of each factor were studied in three replications.

Four response variables were measured during the tests. The capacity of the machine was measured. There were two main items of consideration under this: the percentage of pods that shelled and released all the beans they contained and the percentage of pods that shelled but did not release all the beans they contained.

The quality index of shelled beans was also measured. This included percentage of shelled beans with damaged seed coat and percentage of shelled beans with split cotyledons.

II. PREPARATION OF SOYBEANS

Approximately 20,000 pods of mature green vegetable soybean (variety unknown) were used for the tests. The soybean was a late maturing variety with physical characteristics similar to the Japanese variety, Hato. The beans were grown in one two-acre field at the University of Tennessee Experiment Station at Knoxville, Tennessee. They were considered of sufficient uniformity for test purposes.

The mature green pods were hand harvested by uprooting the plant, taking it to the laboratory and picking the pods in the laboratory just before the tests. Harvesting was done late in the morning and the beans were used the same day. Leftovers were discarded.

Samples of pods were taken at random from the lot and put in cotton bags ready for heat treatment. The pods were heated in water at the required temperature and for a specific period of time depending on the kind of test.

III. EQUIPMENT

Accessory equipment used during the tests consisted of a tractor, hydraulic power supply, tachometer, mercury thermometer, stove, stop watch, and an inch scale. The tractor was a 65-HP, gasoline Massey Ferguson Model 165. It was used to power the hydraulic power supply.

The hydraulic power supply consists of a Hydreco Model 19 PL 190036 hydraulic pump which was driven by the PTO of a tractor on which the unit was mounted. The hydraulic power supply was used to drive the hydraulic motors which operated the sheller.

The speed of the rotating parts of the sheller was measured with a 0-2000 rpm range tachometer. A 0-110°C range centigrade mercury thermometer was used to measure the temperature of the water in which the pods were treated. Water was heated by a portable gasoline stove.

Time of heat treatment and rate of shelling were measured by a stop watch. The distance between the two belts was measured with an inch-scale.

Two other important equipment items that were also used were the Taylor "Little Sheller" roller-type soybean sheller and the Dixie paddle-type pea and bean huller. Most of the heat treatment tests run on the parallel belt sheller were also run on these two shellers for comparison.

The Taylor "Little Sheller," as shown in Figure 5, consists of two small diameter rollers. One is 13/16 inch and the other is one inch. Each roller is covered with a relatively soft neoprene. The

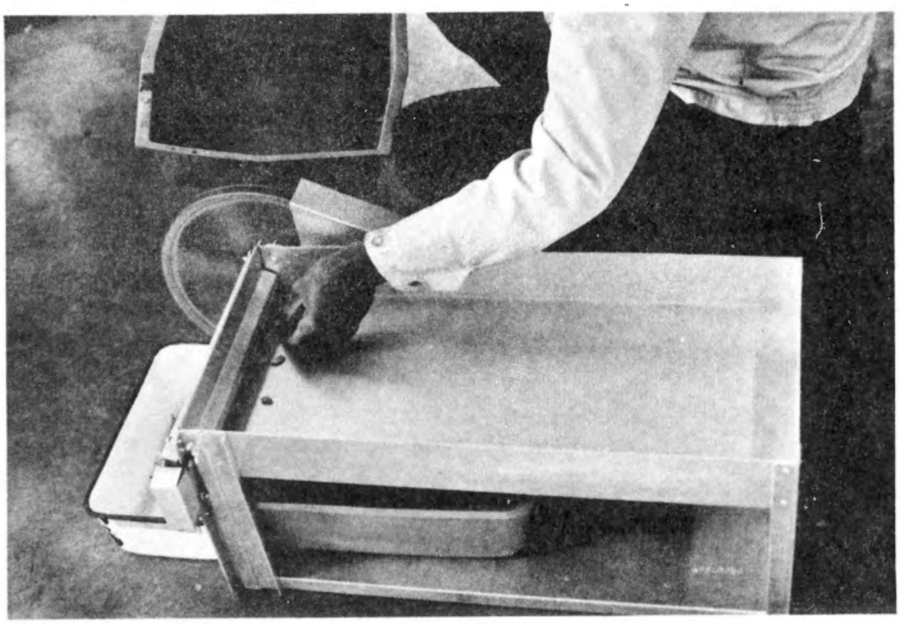

Figure 5. The Taylor "Little Sheller" (roller sheller).

space between the rollers, shown in Figure 6, is held constant during the operation and each roller is gear-driven by an electric motor.

The Dixie pea and bean huller is shown in Figure 7. It is made up of a feeder, a hulling unit and a separating unit. The hulling unit consists of a long shaft bearing paddles and rotating inside a perforated hexagonal drum which also rotates relative to the paddles. The separator is an inclined, slowly moving conveyor made of canvass with a coarse surface. During separation, the beans roll down the conveyor while the hulls move with the conveyor to discharge.

IV. TESTING PROCEDURE

The following procedure was used during the test.

1. Samples containing a specified number of soybean pods were taken at random and put in cotton bags (ham stocking). The pods were heated in water at required temperature and time and were then allowed to cool to room temperature.
2. The space between the top and bottom belts was adjusted to the desired distance.
3. The top and bottom belt speeds were adjusted to the desired speeds.
4. Samples of the heat treated pods were run through the sheller. Pod feeding was done by hand. Pods were fed one after another. The output material from the machine was collected. Shelled beans were separated from the hulls by hand and counted. Appropriate data were recorded.
5. Each test was replicated three times.

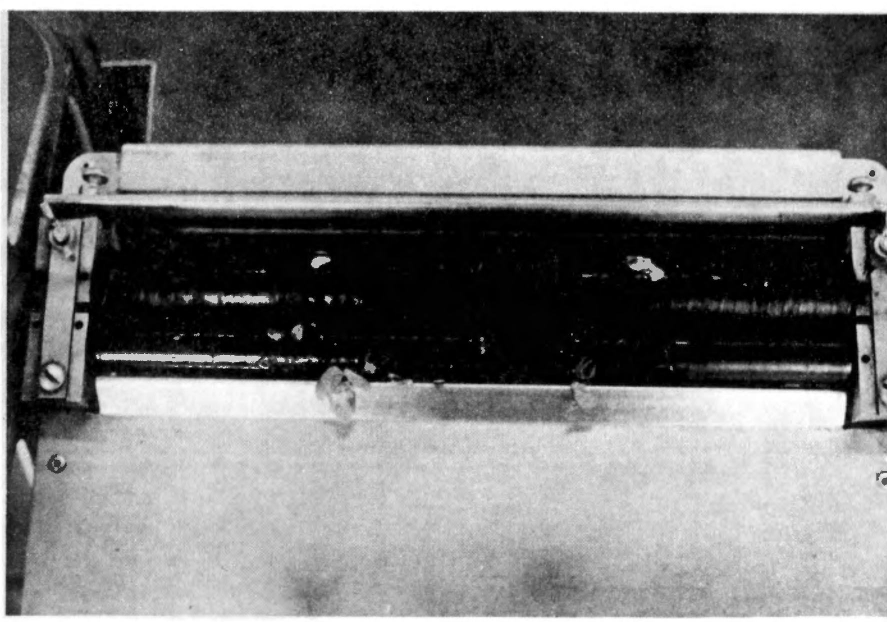

Figure 6. The Taylor sheller roller arrangement.

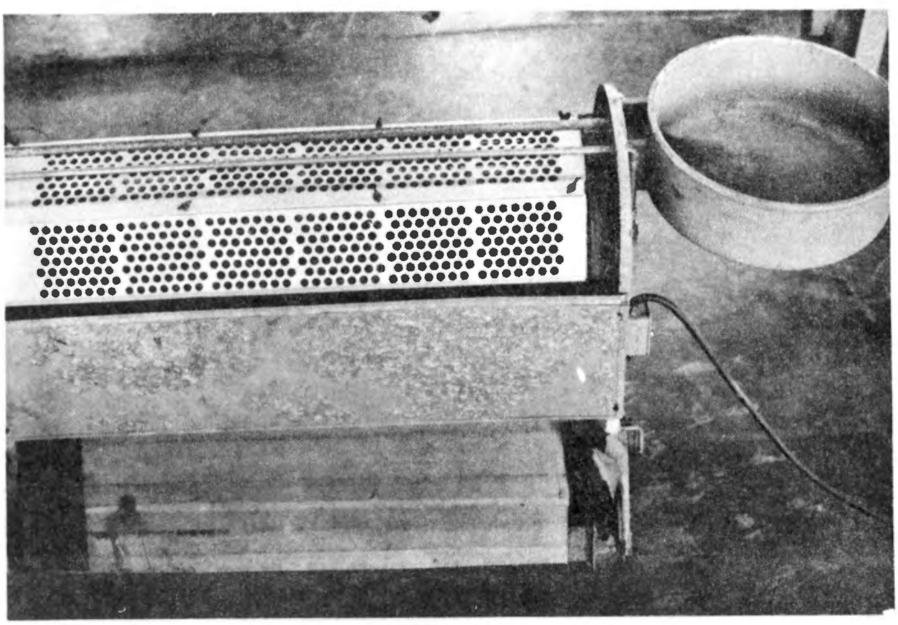

Figure 7. The Dixie pea and bean huller.

V. DESCRIPTION OF TESTS

Results of Preliminary Test

Initial tests were made on the parallel belt sheller to gain some idea about the effect of operating parameters on the performance of the sheller.

Orientation of pod during feeding showed little effect on the shelling percentage. No attention was therefore paid to pod orientation during subsequent tests. Pod feeding to the sheller was random.

Duration of heat treatment of pods showed only slight effect on shelling.

For heat treatment at temperatures below 100°C, treatment periods of one, two, and three minutes were ineffective. Treatment periods of four, five, and six minutes were equally effective. Heat treatment time of five minutes was therefore used for temperature treatments below 100°C. At 100°C heat treatment time of one-half minute was found effective. The half minute periods of heat treatment were used for 100°C temperature treatments.

The test results also indicated that the performance of the sheller depended more on the lower belt speed than the upper. The upper belt speed between 300-500 fpm was found most effective though the difference had only slight significance on shelling percentage. A working upper speed of 400 fpm was therefore used for the entire experiment.

Heat Treatment Test

One test made with the sheller was to determine the effect of heat treatment of green soybeans on shelling capacity and quality of shelled bean. Results of research conducted by Collins *et al.* (6) indicated that heat treatment had significant effect on the shelling percentage of green soybeans. In this test, the effect of five temperature treatments were investigated. Three samples of 100 pods each were heated for five minutes in water for each of the temperatures, 60°, 70°, 80°, and 90°C and for one-half minute for 100°C. The pods were run through the sheller and the output collected. During the tests, the belt speeds were held constant at 400 fpm for the upper belt and 220 fpm for the lower belt. The distance between belts was 9/64 inch and the shelling length was 36 inches. The roller spacing was also held constant at six inches.

Belt Speed Test

Another test consisted of the determination of the effect of belt speed on percentage shelling and bean quality. Three samples of 50 pods each were heat treated at 90°C for five minutes and shelled at each speed. The 90°C temperature was the one which yielded best results in the heat treatment test. The surface speed of the upper belt was held constant at 400 fpm and the speed of the lower belt was varied from 200 fpm to 440 fpm in increments of 60 fpm. Thus a total of five speed tests were made. The belt spacing, roller spacing and shelling length were the same as for the heat treatment test.

Belt Spacing Test

To investigate the effect of the distance between belts, results of the two previous tests were used. Three samples of 50 pods each were treated at 90°C for five minutes and shelled at each spacing. The spacings tested were: 4/32, 5/32, 11/64, 6/32, and 7/32 inch. The speeds of the upper and lower belts were held at 400 fpm and 200 fpm, respectively. Other factors were held constant.

Roller-type Sheller

Five samples of 50 pods each were heat treated at 90°C and shelled using the roller-type sheller. The rollers were driven by an electric motor through a belt arrangement. Feeding was made by hand and the pods were presented end-on to the rollers.

Paddle-type Sheller

Two samples of 1,200 pods each were heat treated at 90°C and run through the paddle-type sheller. The larger sample size was necessary to evaluate this type of sheller.

VI. DATA ANALYSIS

An analysis of variance was performed on the data collected for each of the response variables to determine if the independent factors (temperature, belt spacing, speed) had significant effects on them. The Statistical Analysis System (SAS) (21), as installed at the University of Tennessee Computing Center, was employed in the data analysis. Plots of observation points were also obtained from the same system.

The Duncan's multiple range test for each response variable was made to determine if the treatment means corresponding to the various treatments of the independent variables were significantly different. The tests were performed at 95 percent level of probability by the application of the DUNCAN procedure of the SAS package.

CHAPTER V

RESULTS AND DISCUSSION

I. HEAT TREATMENT

Data obtained in this test are summarized in Table 1. The results of these tests, as shown in Figures 8 and 9, indicated that as the temperature of heat treatment increased the percentage of pods shelled increased to a maximum at 90°C and then decreased with further increase in temperature. The effect of temperature on the percentage of pods incompletely shelled is shown in Figure 9. Generally, the percentage of incompletely shelled pods increased with temperature. The effect of temperature on bean coat damage, as shown in Figure 9, was inconsistent. The maximum coat damage occurred at 80°C. Quantity of beans with split cotyledons also increased with temperature but decreased above 90°C.

The results of the analyses of variance indicated that at a 95 percent level of probability temperature had a significant effect on all the response variables measured. This meant that the capacity of the sheller and the quality of the shelled bean depended on the temperature of treatment.

The results of the Duncan's multiple test, as shown in Table 1, indicated that there were significant differences between low temperature (60°C and 70°C as a group) and high temperature (80°, 90°, 100°C as a group) treatment means for shelling percentage and bean split.

Table 1. Effect of Heat Treatment on Shelling of Green Soybean Shelling and Results of Duncan's Multiple Range Test of Significance

Temperature* (°C)	Mean Values** Percent Pods Shelled	Percent Pods Incompletely Shelled	Number of Beans with Undamaged Coats***	Number of Beans with Split Seeds***
60	22.7[a]	6.3	18.3	9.0[a]
70	24.3[a]	8.7	25.0	11.0[a]
80	41.0[b]	8.7	13.0	26.6[b]
90	46.7[b]	9.7	17.3	27.0[b]
100	41.7[b]	12.3	27.0	25.6[b]

*All treatments were for five minutes at the temperature shown except one-half minute for 100°C.

**Based on a total of 100 pods.

***Based on quantity of beans shelled. Estimated average number of beans per pod was 2.07. Quanity of beans shelled is equal to the product of pods shelled and 2.07. There is significant difference, at 95 percent level of probability, between treatment means with dissimilar superscripts by Duncan's test.

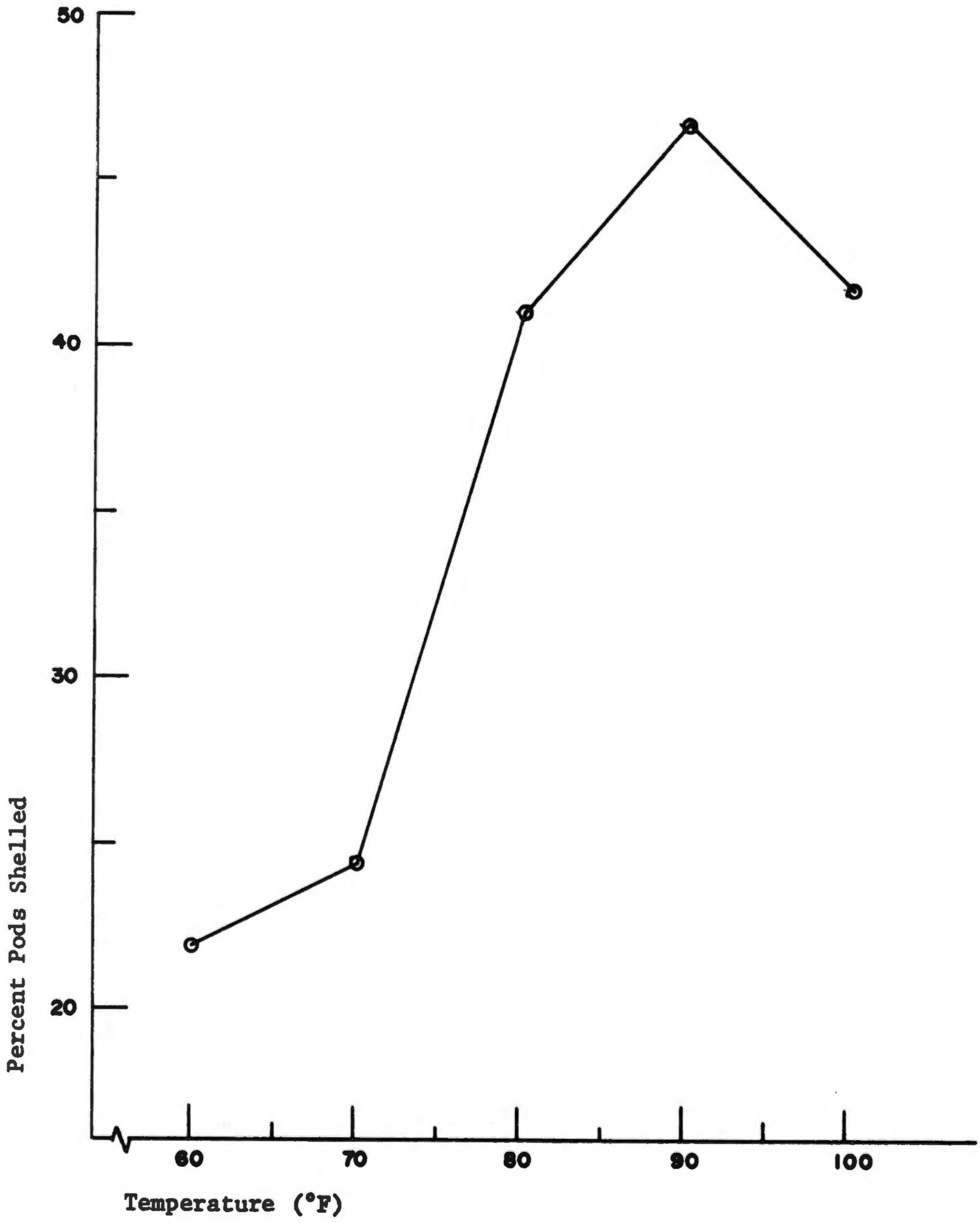

Figure 8. Graphical representation of the effect of temperature on shelling percentage of green soybeans.

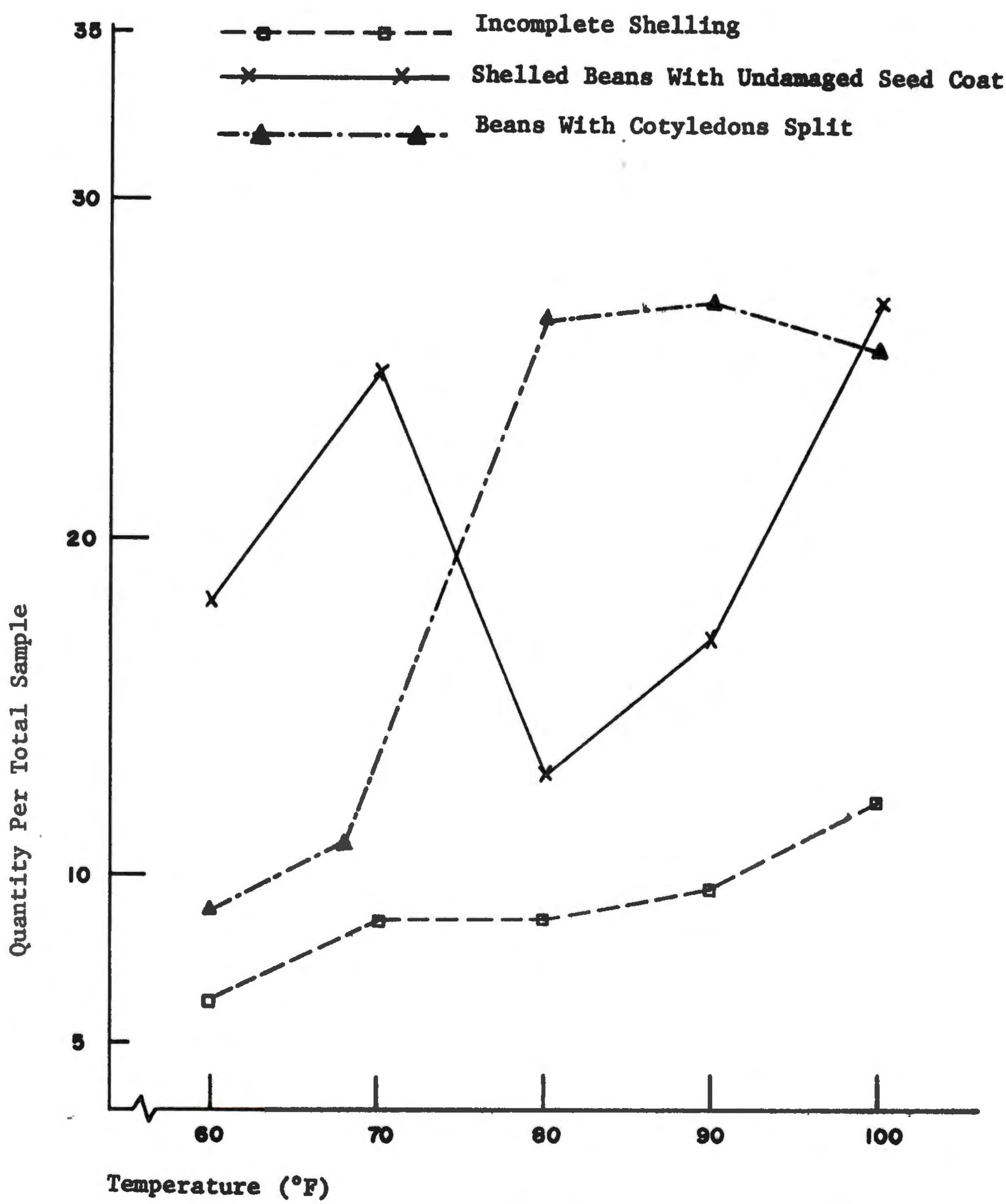

Figure 9. Graphical representation of the effect of temperature on incomplete shelling and bean damage of green soybeans.

This result indicated that shelling percentage and bean splitting were affected more by high temperatures (above 80°C).

II. BELT SPACING

Results of these tests are summarized in Table 2. Plots of response variables versus spacing, as shown in Figures 10 and 11, indicated that generally the shelling percentage decreased with increase in belt spacing. The highest shelling percentage was obtained at 4/32 inch spacing. Figure 11 shows that incomplete shelling increased with spacing but decreased for spacing larger than 11/64 inch. Quantity of beans with undamaged coat decreased with increase in spacing. Though bean splitting increased with increase in spacing from 4/32 to 5/32, as shown in Figure 10, it decreased with further increase in spacing.

Results of the analyses of variance indicated that belt spacing had a significant effect, at 95 percent level of probability, on the capacity of the sheller and the quality of shelled beans.

Results of Duncan's multiple test, as presented in Table 2, indicated significant difference between close spacing treatment means, 4/32, 5/32 and wide spacing means, 11/64, 6/32 and 7/32 inches for percentage of shelling. There was also significant difference between 4/32 spacing treatment mean and all other spacings for damaged bean coats. It could therefore be inferred that shelling percentage and extent of bean coat damage were greatly affected by belt spacing below 5/32 inch.

Table 2. Effect of Belt Spacing on Shelling of Green Soybean Shelling and Results of Duncan's Multiple Range Test of Significance

Belt Spacing (Inches)	Mean Values* Percent Pods Shelled	Pèrcent Pods Incompletely Shelled	Number of Beans with Undamaged Coats**	Number of Beans with Split Seeds**
7/32	10.0[a]	5.0	4.6[a]	2.6
6/32	14.6[a]	9.0	11.0[a]	6.3
11/64	12.6[a]	13.6	5.3[a]	17.0
5/32	72.6[b]	10.0	12.3[a]	64.6
4/32	100[b]	1.0	51.0[b]	44.6

*Based on a total of 50 pods.

**Based on quantity of beans shelled. Estimated average number of beans per pod was 2.07. Quantity of beans shelled is equal to the product of pods shelled and 2.07. There is a significant difference, at 95 percent level of probability, between treatment means with dissimilar superscript by Duncan's test.

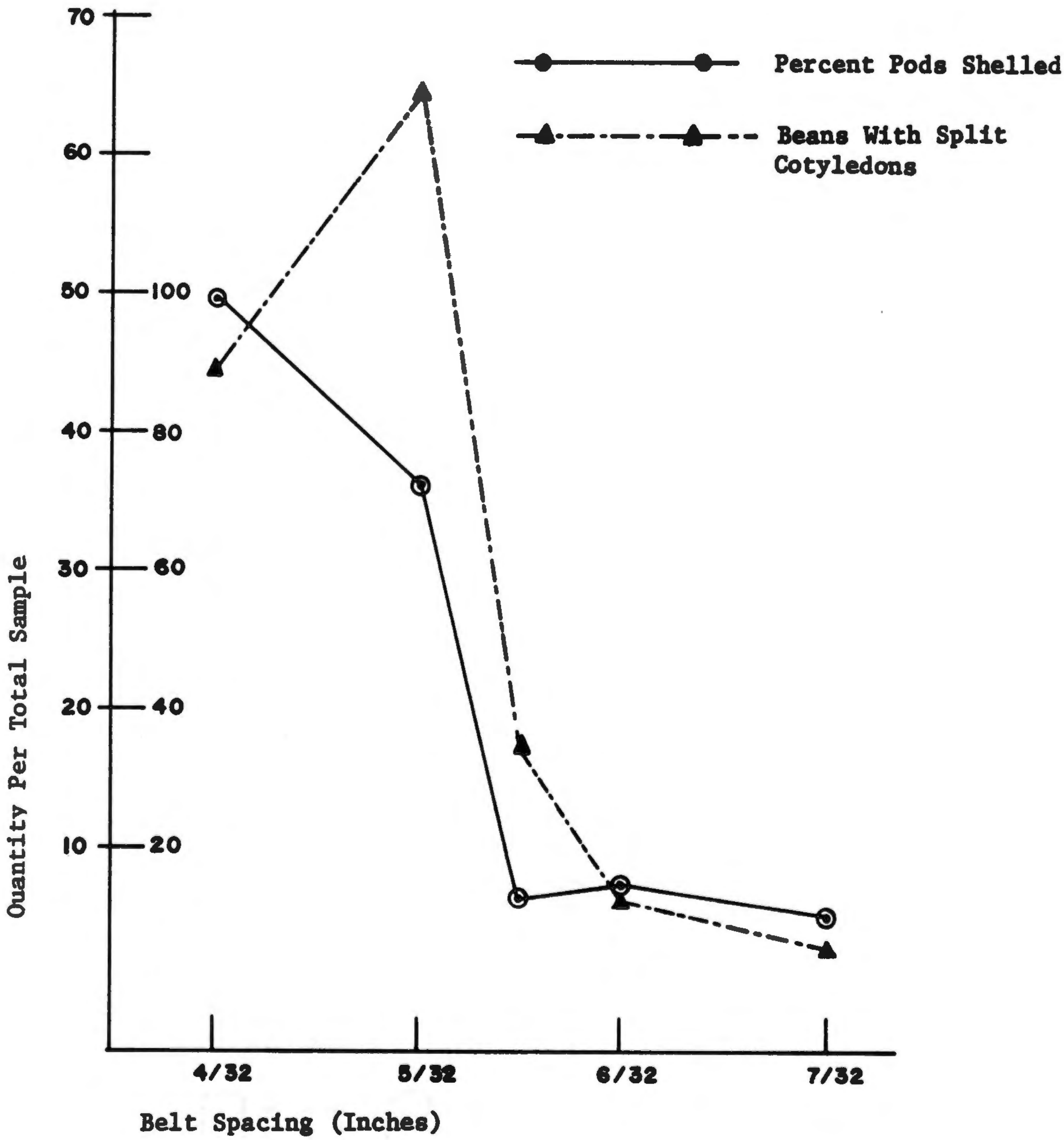

Figure 10. Graphical representation of the effect of belt spacing on shelling percentage and bean split of green soybeans.

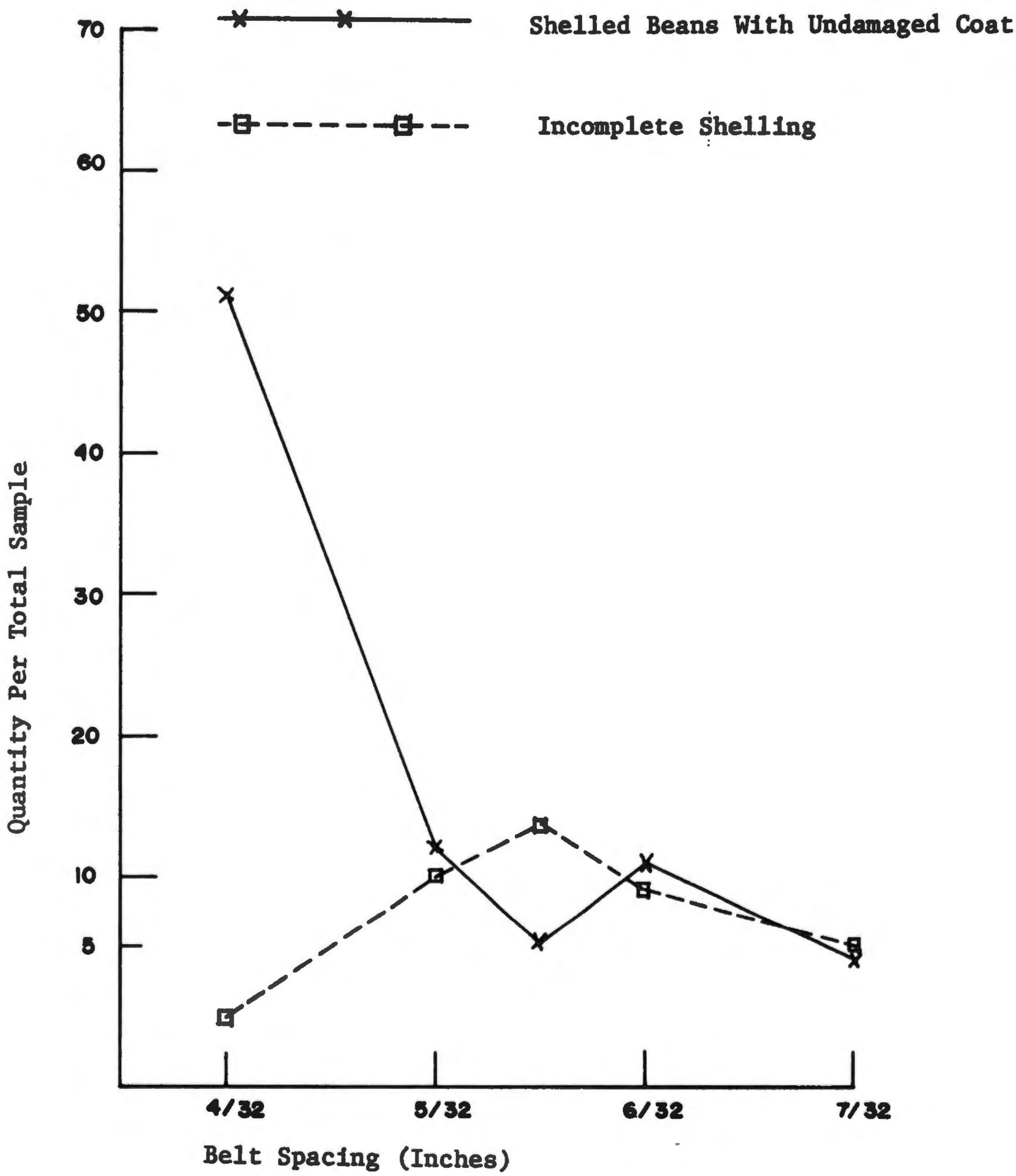

Figure 11. Graphical representation of the effect of belt spacing on incomplete shelling and seed coat damage of green soybeans.

III. BELT SPEED

Results of these tests are summarized in Table 3. With the speed of the upper belt held constant at 400 fpm, there was a decrease in shelling percentage with increase in lower belt speed. This is shown in Figure 12. This result indicated that the shear force available for shelling was proportional to the speed difference between the upper and lower belts. For this test the highest shelling percentage was obtained at a lower belt speed of 200 fpm. A plot of incompletely shelled pods versus speed, shown in Figure 13, yielded erratic results. This indicated that there appeared to be no relationship between incomplete shelling and speed. Figure 13 also indicates that there appeared to be no direct relationship between bean coat damage and speed. The effect of speed on bean splitting is shown in Figure 12. Generally, the quantity of bean split decreased with increase in belt speed. Most bean split occurred at 200 fpm. This was the speed at which most pods were shelled and at which the shelling force was greatest. It could be inferred that bean splitting tended to increase with shelling force for the speed range considered.

The results of the analyses of variance indicated that speed had significant effect on all response variables except incomplete shelling and bean coat damage.

A Duncan's multiple test, as presented in Table 3, indicated that there was significant difference between speed treatment mean for 440 fpm and all other speed treatment means for percentage of shelling. The test showed significant difference in treatment means for speed

Table 3. Effect of Belt Speed on Shelling of Green Soybean Shelling and Results of Duncan's Multiple Range Test of Significance

Lower Belt Speed* (Ft/Min)	Mean Values**			
	Percent Pods Shelled	Percent Pods Incompletely Shelled	Number of Beans with Undamaged Coats**	Number of Beans with Split Seeds***
200	72.0[a]	4.6	13.0	53.3[a]
260	62.6[a]	5.6	16.6	37.0[a]
320	50.0[a]	4.6	13.0	17.6[b]
380	47.3[a]	5.3	12.6	14.3[b]
440	19.3[b]	6.3	11.6	2.3[b]

*Upper belt speed was held constant at 400 feet/minute.

**Based on a total of 50 pods.

***Based on quantity of beans shelled. Estimated average number of beans per pod was 2.07. Quantity of beans shelled is equal to the product of number of pods shelled and 2.07. There is a significant difference, at 95 percent level of probability, between treatment means with dissimilar superscripts by Duncan's test.

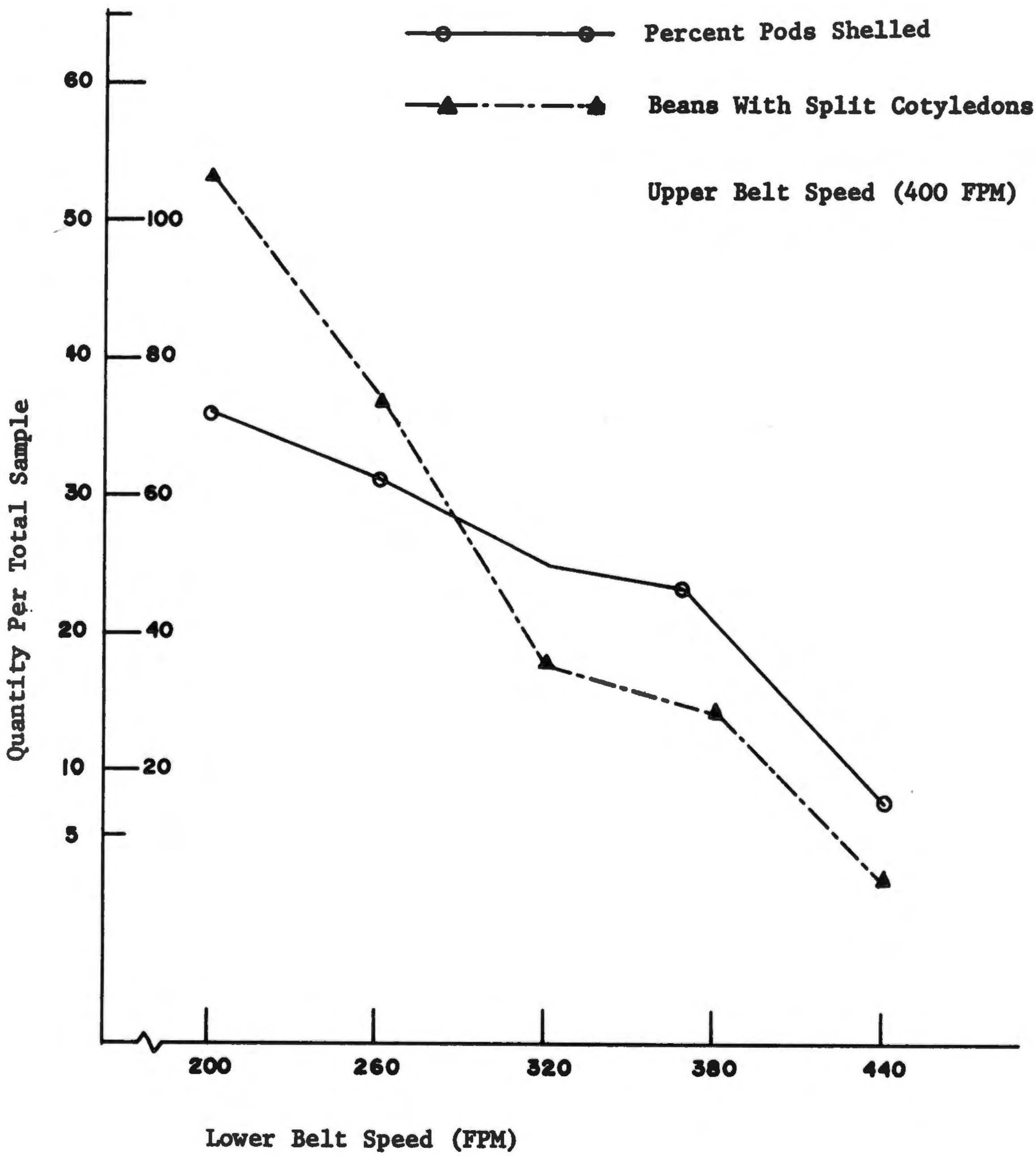

Figure 12. Graphical representation of the effect of belt speed on shelling percentage and bean split of green soybeans.

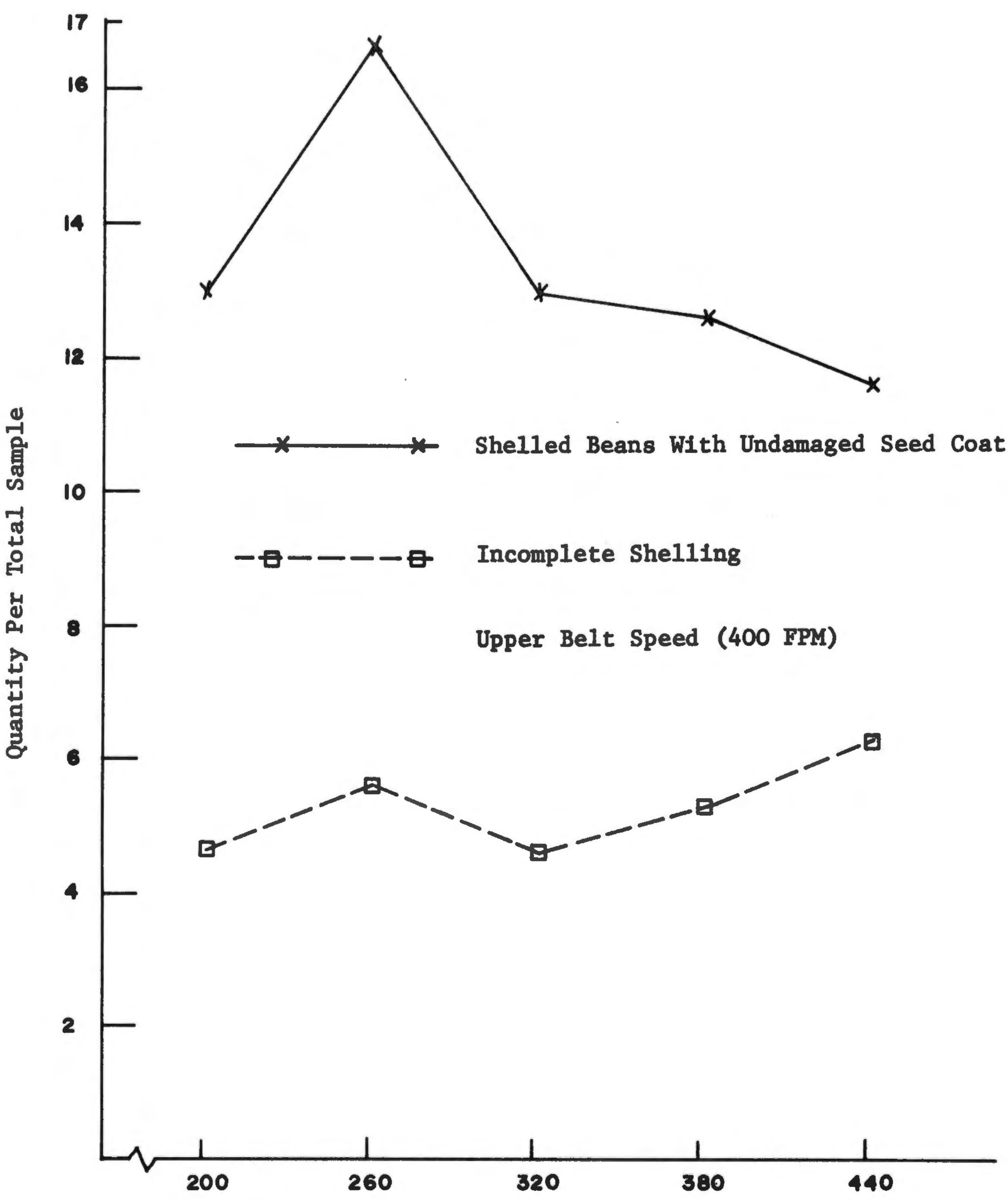

Figure 13. Graphical representation of the effect of belt speed on incomplete shelling and seed coat damage of green soybeans.

320 to 440 fpm and all other speed treatment means for bean splitting.

IV. COMPARISON OF SHELLERS

Overall performances and comparison of the three types of shellers are summarized in Tables 4 to 6 and Table 7, respectively.

The roller-type and paddle-type bean shellers performed better than the parallel belt type sheller. The roller sheller gave the best performance with respect to shelling percentage and quality of shelled beans. The parallel belt sheller, however, had the highest rate of shelling. It was noted through observation that feeding of pods to the parallel and paddle shellers presented no difficulty.

Feeding of pods to the roller sheller was a problem. Only one pod could be fed at a time as opposed to many pods in the other shellers. While pod orientation during feeding was an important factor to the roller sheller, it was not in the other two shellers. The roller sheller only accepted pods presented end-on to the rollers. This greatly restricts the capacity and usefulness of the roller sheller.

Table 4. Overall Performance of Parallel Belt Green Soybean Sheller at Optimum Conditions of Temperature, Spacing and Speed

Independent Variable	Overall Optimum Mean Values* Number of Pods Shelled	Number of Pods Incompletely Shelled	Number of Beans with Undamaged Coats	Number of Beans with Split Seed
Temperature	23.4	9.7	25.0	26.6
Spacing	36.3	10.0	12.3	17.0
Speed	36.0	4.7	13.0	53.3
Mean	31.9	8.1	16.8	32.3
Mean Percent Shelling	63.8%	16.3%	33.5%**	64.6%

*Based on sample size of 50 pods.

**66.5 percent coat damage.

Table 5. Overall Performance of Roller-type Sheller on Green Vegetable Soybeans

	Overall Mean Values*	
Number of Pods Shelled	Number of Beans with Undamaged Coats	Number of Beans with Split Seed
50	94.5	1
100%	91.3%	.01%

*Based on sample size of 50 pods at three replications. Heat treatment at 90°C, time five minutes.

Table 6. Overall Performance of Paddle-type Sheller on Green Vegetable Soybeans

	Overall Mean Values*	
Number of Pods Shelled	Number of Beans with Undamaged Coats	Number of Beans with Split Seed
850	1424	13
70%	80.96%	.01%

*Based on sample size of 1200 pods at three replications. Heat treatment at 90°C, time five minutes.

Table 7. Comparison of Shellers

	Parallel Belt Type	Roller-type	Paddle-type
Shelling Percentage %	63.8	100	70
Percent Bean Coat Damage %	66.5	8.7	19.0
Percent Bean Split %	64.6	.01	.01
Rate of Shelling Pods Shelled / Minute	150	55	105

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

Mechanization of mature green soybean shelling is needed to stimulate increased use of green soybean as a vegetable and to encourage its commercial processing. Recent researchers have found the roller-type sheller most promising among other mechanisms considered. The roller sheller was, however, found to have some serious limitations. It has a feeding problem and the rate of shelling is very low.

In an attempt to overcome these problems, a parallel belt type sheller was proposed. The parallel belt type sheller was chosen because it appeared to have high shelling rate and no difficulty in feeding.

An experimental green soybean sheller using the shear force developed by the relative motion of two parallel belts was designed and constructed in the Agricultural Engineering Research Shop of the University of Tennessee, Knowville. The performance of the parallel belt sheller was compared to that of the roller-type and paddle-type shellers.

The shelling mechanism was designed with provisions for varying the space between the belts, the speed of the belts, the threshing length and other variables. In the laboratory tests the parallel belt sheller was operated at belt speeds of 200, 320, 380 and 440 fpm with spacing of 4/32, 5/32, 11/64, 6/32, and 7/32 inches. The effect of heat treatment of pod on the efficiency of bean recovery was also tested. Response variables measured were percentage of shelling and quality of shelled beans.

II. CONCLUSIONS

Results of this study indicate that shelling mature green soybeans by the parallel belt principle is possible.

The sheller produced a shelling percentage of approximately 64 percent while causing 67 percent bean coat damage and 65 percent bean split. Though the general performance of the experimental parallel belt sheller was lower compared to the roller and paddle-type shellers, it produced the highest shelling rate. There was no difficulty in feeding pods to the machine as was encountered with the roller sheller.

Heat treatment did have a controlling effect on the efficiency of shelling. Increasing temperature of pod treatment up to 90°C raised the shelling percentage. However, higher temperatures decreased shelling percentage and increased bean damage.

Belt spacing was found to affect shelling significantly. Though the shelling percentage increased with decrease in belt spacing, percent bean damage increased.

Belt speed also had a significant effect on shelling. Percentage of pods shelled decreased when the lower belt speed was increased from 200 to 440 fpm and the upper belt speed held constant at 400 fpm. The effect of belt speed, however, had little influence on the quality of shelled beans.

III. RECOMMENDATIONS FOR FURTHER STUDY

The work reported in this thesis forms an initial part of a research directed toward the development of a green soybean sheller. The results obtained therefore show the effect of the basic design and operating factors on the performance of the experimental sheller. Other important factors which need to be studied are the effect of threshing length, roller spacing, roller size and roller shape. Round rollers were used for this study but oval rollers may also be tried. It may also be necessary to reduce bean damage by reducing the pressure on the pods during shelling. This can be achieved by spring loading the rollers so that they have slight up and down movement.

The effect of belt surface characteristics and hardness should also be studied.

The influence of bean shape on the effectiveness of the parallel belt sheller is also worth investigating. The flat bean variety of soybean was used in this study but better results may be achieved with a round bean variety.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Arnold, H. A., and M. A. Sharp. 1942. Shelling castor beans. Agricultural Engineering 23(1):11.

2. Bainer, R., and J. S. Winters. 1937. New principle in threshing lima bean seed. Agricultural Engineering 18(5):205-206.

3. Bainer, R., and J. S. Winters. 1938. Results of tests of a rubber roller seed bean thresher. Agricultural Engineering 19(6): 251-252.

4. Buelow, F. H. 1957. Creative engineering: what is it? Agricultural Engineering 38(8):587.

5. Clay, H. P. 1942. A homemade castor bean thresher. Agricultural Engineering 23(4):135.

6. Collins, J. L., I. E. McCarty, and H. D. Swingle. 1971. Shelling mature, green soybeans with a roller-type sheller. Tennessee Farm and Home Science, Progress Report 78:2-3.

7. Dickens, J. W. and D. D. Mason. 1962. A peanut sheller for grading samples: an application of statistics in design. Transactions of the ASAE 5(1):42-45.

8. Gordon, E. D. 1943. Castor bean hullers. Agricultural Engineering 24(6):189-190, 196.

9. Lamp, B. J., and W. F. Buchele. 1960. Centrifugal threshing of small grains. Transactions of the ASAE 3(2):24-28.

10. Lorenzen, Coby. 1954. Rationalizing analysis in design. Agricultural Engineering 35(3):303-306.

11. Mills, W. T., and D. D. Mason. 1958. Statistics help evaluate functional components of farm machinery. Agricultural Engineering 39(1):31-33.

12. Mitchell, R. S., L. J. Lynch, and D. J. Casimir. 1969. A new method of shelling green peas for processing. J. Food Technology 4:51-60.

13. Perry, J. S., and C. W. Hall. 1966. Evaluating and reducing mechanical-handling damage to pea beans. Transactions of the ASAE 9(5):696-701.

14. Porterfield, J. G., and F. J. Oppel, Jr. 1952. An experimental castor bean huller. Agricultural Engineering 33(11):713-716.

15. Silver, E. A., and G. W. McCuen. 1935. A study of power requirements and efficiency of threshing machines. Agricultural Engineering 16(4):137-141, 154.

16. Schoenleber, L. G., and L. F. Bouse. 1964. Mechanized harvesting of castor beans. Transactions of the ASAE 7(2):97-99.

17. Schoenleber, L. G., and W. M. Hurst. 1952. Performance of castor bean hulling plants. Agricultural Engineering 33(11): 708-710.

18. Schoenleber, L. G., and W. E. Taylor. 1954. Development of a portable castor bean huller. Agricultural Engineering 35(5): 327-333.

19. Stilwell, R. E. 1953. Procedure for the design of a farm machine. Agricultural Engineering 34(11):754, 758.

20. United States Department of Agriculture. 1973. Agricultural Statistics, 1972.

21. Barr, A. J., and J. H. Goodnight. 1972. User's Guide to the Statistical Analysis System.

22. Van Volkenburg, L. R. 1920. Thresher methods. Agricultural Engineering 13:117-124.

23. Vutz, W. 1966. Some applied design practices. Transactions of the ASAE 9(2):221, 224.

24. Walker, D. S., and C. E. Schertz. 1970. Soybean threshing by the relative motion of parallel belts. ASAE Paper No. 70-631. ASAE, Chicago, Illinois.

25. Wang, Jaw-Kai. 1963. Design of a ground husking machine. Transactions of the ASAE 6(4):311-312.

APPENDIXES

APPENDIX A

HEAT TREATMENT DATA

The experimental data used for determining the effect of heat treatment on shelling are given in Tables 8 through 11.

Table 8. Effect of Heat Treatment on Quantity of Soybean Pods Shelled

		Number of Pods Shelled*				
Temperature (°C)	Time (Minutes)	Sample 1	Sample 2	Sample 3	Average	Percent Per Total Pod Input
60	5	25	16	27	22.7	22.7
70	5	27	33	13	24.3	24.3
80	5	43	43	37	41.0	41.0
90	5	43	44	53	46.7	46.7
100	0.5	46	41	38	41.7	41.7

*Based on sample size of 100 pods.

Table 9. Effect of Heat Treatment on Quantity of Soybean Pods Incompletely Shelled

		Number of Pods Incompletely Shelled*				
Temperature (°C)	Time (Minutes)	Sample 1	Sample 2	Sample 3	Average	Percent Per Total Pod Input
60	5	7	4	8	6.30	6.30
70	5	10	7	9	8.70	8.70
80	5	10	7	9	8.70	8.70
90	5	10	9	10	9.70	9.70
100	0.5	8	14	15	12.30	12.30

*Based on sample size of 50 pods.

Table 10. Effect of Heat Treatment on Quantity of Shelled Beans with Undamaged Seed Coat

Temperature (°C)	Time (Minutes)	Number of Beans with Undamaged Seed Coat*				
		Sample 1	Sample 2	Sample 3	Average	Percent Per Bean Shelled
60	5	21	16	18	18.33	39.10
70	5	31	19	25	25.00	49.63
80	5	16	14	9	13.00	15.32
90	5	16	13	23	17.33	17.94
100	0.5	32	24	25	27.00	31.30

*Based on sample size of 50 pods.

Table 11. Effect of Heat Treatment on Quantity of Shelled Beans with Seed Cotyledons Split

Temperature (°C)	Time (Minutes)	Number of Beans with Cotyledons Split*				
		Sample 1	Sample 2	Sample 3	Average	Percent Per Bean Shelled
60	5	13	9	5	9.00	19.18
70	5	15	12	6	11.00	21.84
80	5	31	23	26	26.60	31.35
90	5	31	28	22	27.00	27.95
100	0.5	24	28	25	25.66	29.75

*Based on sample size of 50 pods.

APPENDIX B

BELT SPACING DATA

The experimental data used for determining the effect of belt spacing on shelling are given in Tables 12 through 15.

Table 12. Effect of Belt Spacing on Quantity of Soybean Pods Shelled

Belt Spacing (Inches)	Number of Pods Shelled*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Total Pod Input
7/32	5	4	6	5.00	10.0
6/32	7	7	8	7.33	14.7
11/64	6	7	6	6.33	12.7
5/32	30	37	42	36.33	72.7
4/32	49	50	50	49.66	99.3

*Based on sample size of 50 pods.

Table 13. Effect of Belt Spacing on Quantity of Soybean Pods Incompletely Shelled

Belt Spacing (Inches)	Number of Pods Incompletely Shelled*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Total Pod Input
7/32	6	5	4	5.00	10.00
6/32	8	9	10	9.00	18.00
11/64	10	17	14	13.67	27.34
5/32	16	7	7	10.00	20.00
4/32	1	1	1	1.00	2.00

*Based on sample size of 50 pods.

Table 14. Effect of Belt Spacing on Quantity of Shelled Beans with Undamaged Seed Coat

Belt Spacing (Inches)	Number of Beans with Undamaged Seed Coat*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Bean Shelled
7/32	5	3	6	4.67	45.03
6/32	10	11	12	11.00	72.37
11/64	5	5	9	5.33	41.64
5/32	14	15	8	12.33	16.40
4/32	45	67	41	51.00	49.61

*Based on sample size of 50 pods.

Table 15. Effect of Belt Spacing on Quantity of Shelled Beans with Seed Cotyledons Split

Belt Spacing (inches)	Number of Beans with Cotyledons Split*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Bean Shelled
7/32	2	3	3	2.66	25.65
6/32	6	7	6	6.33	41.64
11/64	21	19	11	17.00	73.45
5/32	62	65	67	64.67	86.00
4/32	46	36	52	44.67	43.45

*Based on sample size of 50 pods.

APPENDIX C

BELT SPEED DATA

The experimental data used for determining the effect of belt speed on shelling are given in Tables 16 through 19.

Table 16. Effect of Belt Speed on Quantity of Soybean Pods Shelled

Lower Belt Speed** (Ft/Min)	Number of Pods Shelled*				
	Sample 1	Sample 2	Sample 3	Average	Percent of Total Pod Input
200	36	33	39	36.00	72.00
260	30	35	29	31.33	62.66
320	25	18	32	25.00	50.00
380	35	16	20	23.67	47.34
440	4	13	12	9.67	19.34

*Based on sample size of 50 pods.

**Upper belt speed was constant at 400 ft/min.

Table 17. Effect of Belt Speed on Quantity of Soybean Pods Incompletely Shelled

Lower Belt Speed** (Ft/Min)	Number of Pods Incompletely Shelled*					
	Sample 1	Sample 2	Sample 3	Average	Percent Per Pods Shelled	Percent of Total Pod Input
200	3	5	6	4.67	13.00	9.34
260	3	7	7	5.67	18.10	11.34
320	4	8	2	4.67	18.68	9.34
380	5	4	7	5.33	22.52	10.66
440	4	7	8	6.33	65.50	12.66

*Based on sample size of 50 pods.

**Upper belt speed was constant at 400 ft/min.

Table 18. Effect of Belt Speed on Quantity of Shelled Beans with Undamaged Seed Coat

Lower Belt Speed** (Ft/Min)	Number of Beans with Undamaged Seed Coat*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Bean Shelled
200	12	13	14	13.00	17.44
260	8	16	26	16.67	25.70
320	16	8	15	13.00	25.12
380	19	8	11	12.67	25.86
440	9	15	11	11.67	58.35

*Based on sample size of 50 pods.

**Upper belt speed was constant at 400 ft/min.

Table 19. Effect of Belt Speed on Quantity of Shelled Beans with Seed Cotyledons Split

Lower Belt Speed** (Ft/Min)	Number of Beans with Cotyledons Split*				
	Sample 1	Sample 2	Sample 3	Average	Percent Per Total Bean Shelled
200	52	41	67	53.33	71.56
260	41	42	28	37.00	57.05
320	23	9	21	17.67	34.14
380	24	10	9	14.33	29.25
440	2	3	2	2.33	11.65

*Based on sample size of 50 pods.

**Upper belt speed was constant at 400 ft/min.

VITA

George Takyi Owirodu was born in Takoradi, Ghana (West Africa), on November 22, 1949. He graduated from Tema Secondary School, Ghana, in June 1968. In September of that year, he entered the University of Ghana, Legon, where he graduated in June 1972 with a Bachelor of Science degree in Agricultural Mechanization. He earned a Diploma in Journalism in July of the same year. In September 1972, he won an Elder Dempster shipping line fellowship award and re-entered the University of Ghana to start his graduate work in Agricultural Mechanization. Three months later he abandoned the program and left the University to work as a journalist with a local paper. He later served as a mathematics and physics teacher at the Ghana International School and then as an economics and logic teacher at another local school. In May 1973, he returned to the University of Ghana as a Graduate Research Assistant. In July 1973, he won two graduate fellowship awards simultaneously to do graduate work in Agricultural Engineering at the Guelph University, Canada under the University's support and also to pursue a similar program at the University of Tennessee under the support of the African American Institute. He chose the latter because of weather conditions.