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PROCESSING OF GREEN BEANS IN
RETORTABLE POUCHES

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Vicente de Paula Pereira

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PROCESSING OF GREEN BEANS IN RETORTABLE POUCHES

BY

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ABSTRACT

PROCESSING OF GREEN BEANS IN

RETORTABLE POUCHES

by

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Green beans were thermally processed in 7 x 10-inch pouches and in no. 303 cans. Quality comparisons were then carried out, using texture, color, and thiamine retention as criteria of quality.

Heat penetration studies were carried out using copper-constantan thermocouples, held at the middle plane of the pouch by steel wire spring. Lethality F_o was calculated by the Improved General Method.

Processing time requirements for different pouch treatments in water at 250^{o}F were found to vary from 10.24 to 12.91 minutes to give an $F_o \geq 3.5$ with 0.997 confidence coefficient. In order to give equal heat treatment, 303 x 406 cans were processed in steam at 250^{o}F for 12 minutes.

Green beans processed in pouches were firmer in texture and higher in thiamine value than canned beans that had received the same sterilization equivalent, but no statistically significant differences in color were found.

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

INTRODUCTION

The use of a flexible polymeric-foil laminate pouch to contain and maintain the wholesomeness of thermo-processed foods has been proved to be technically and commercially feasible over 16 years of research and over nine years of commercial experience in Japan, Europe, and more than two years in Canada.

Flexibly packaged, thermoprocessed, food items may be compared with items packed in the common three-piece steel plate or drawn aluminum sanitary can. In each instance, heat sterilization and the air tightness of the container assure sterility up to the point of use. However, the outward appearance of the flat pouch and the convenience of reheating by immersion of the unopened pouch in hot water invite a comparison with frozen "boil-in-bag" entree items.

Reduction in processing time of 30 to 50 per cent, may be achieved for equivalent sterilization treatments because the pouch has a thinner profile than the rigid can. Improved product quality is possible as the product around the periphery receives less overcooking.

Although overall production costs of retortable pouch products enclosed in paperboard cartons are currently slightly higher than those of canned and frozen foods, distribution and storage costs are basically lower for the pouched products. For these and other reasons, the retort pouch is a rapidly growing commercial reality.

Commercially, at this time, most foods in retortable pouches are entrees or sauce items. Only in Britain are there a number of flexibly-packaged vegetable products, and many of these are processed in semi-rigid containers. Further work is required to explore the potential for vegetable products in retortable pouches.

LITERATURE REVIEW

Retortable Pouch Material

Retort pouch wall is formed by three layers bonded by adhesive; an outer layer of polyester for strength, a middle layer of aluminum foil, as moisture, light, and gas barrier and an inner layer of polyolefin (high density modified polyethylene) or polypropylen ethylen copolymer which comes in contact with the food material and has heat sealing properties. In order to bond these three layers together an appropriate adhesive system should be used. The adhesive used must keep the layers together and not migrate through the inner layer to the product. Toluene diisocyanate (TDI), one of the reactants necessary for the adhesive, was found to be extracted by the food-simulating solvents. This extract revealed traces (0.3 to 3 parts per billion) of toluene diisocyanate. As described by Goldfarb (1973) a polyester-isocyanate is used to form the adhesive. First the polyester polymer is formed by the reaction of a dihydric alcohol with a dibasic acid. Thus the polymer is mixed with a coreactant diisocyanate (TDI sometimes called catalytic), and heated. The condensation product is an adhesive. This adhesive is specially applicable to retort pouches, since it has a strong affinity for foil and the isocyanate component reacts with surface hydroxyl and carboxyl groups of the polyester and available carboxyl groups of corona-treated polyolefins. Toluene diisocyanate although an irritant, is quite nontoxic, Lampi (1977) (LD_{50} of 5.8 mg/kg body weight).

Beyond the inherent low extractive property of retortable pouch films, suppliers and researchers (Duxbury et al., 1970; Torpe and Atherton, 1972) recognized from a practical production aspect that quality assurance surveilance is mandatory on roll stock and for preformed pouches to guarantee both freedom from odor and removal of solvent.

Film specifications of current suppliers (Duxbury et al., 1970), include retortability or sterilization resistance requirements. In Japan, cited by Lampi (1977), products are being commercially packed in a film described as 12-micron polyester/9-micron aluminum-foil/15 micron oriented Nylon 6/50-micron polypropylen and processed at temperatures up to 275°F for times ranging from 2.7 to 9 minutes.

The pouches discussed thus far have been retorted at temperatures in the range from 240° to 250°F. There are recent film developments that permit processing in the 275° to 293°F range. Studies reported by Komatisu and Yamaguchi cited by Lampi (1977) show that vegetables retain favorable color, and seafoods such as crab, shrimp, and whitefish, are good candidates.

Sealing

Sealing of pouch refers to forming of pouches from the roll stock, regardless of whether the food packing facility uses preformed pouches or roll stock with one side pouch fabrication. It also includes forming of the two side seals and a single bottom seal and the final sealing of the closure after filling and air removal. The reliability of the closure seal is directly affected by the ability of the filler operations, to leave the seal surface free of product contamination.

Until now there is not a definition of good seal and standard method to evaluate the performance of seal. For the retort pouch, this standard has been the sanitary can and its historically documented satisfactory performance. Burke and Schultz (1972) compared the resistance of metal can and retort pouch to a rough-handling cycle representative of the military distribution system. They found a 2% or less leaker after biotesting for both metal can and pouches.

Four different tests have been performed by different investigators, Brown and Keegan (1973); Duxbury et al. (1970); Pflug and Loong (1966); R.W.P. Flexible Packaging (1974); Shenkenberg (1975), in order to evaluate the pouch seal: (1) Fusion: Fusion is a requirement that is met when the opposing seal surfaces form a dual weld.

Such a weld is characterized by the inability to distinguish visually the inner opposing seal surface at the inner seal junction after seal tensioning. (2) Internal burst test: Pressure and time to burst at that pressure is recorded. (3) Tensile test: This is currently measured dynamically on Instron Universal Testing Machine or similar equipment. (4) Visual examination: To detect the absence or presence of fusion, heat creep, significant wrinkles, occluded matter in the seal area. Lampi et al. (1976) in their studies on retorting and storage effect on seal strength reported that seal strength was lower after retorting than before retorting and this effect was produced by temperature effect and not by the kind of product in the pouch. No differences were found in seal strength during storage.

Residual Gases Counterpressure Relationship

With the exception of bakery products where the dominant residual component is CO_2 from the leavening reaction it is generally recognized that residual gases in the retort pouches should be kept as low as possible to preclude chances of rupture during a retort cook cycle. Davis et al. (1960) devised apparatus and studied the pouch-retort pressure relationship during processing. They enumerated four causes of internal pressure increase as: (1) increase in the vapor pressure of the water in the processed food with increasing temperature; (2) increase in the pressure of air in the headspace with increasing temperature; (3) release of additional air from the product, due to a decrease in gas solubility with increasing in temperature; and (4) thermal expansion of the food itself. Yamano and Komatsu (1969) detailed the relationships among internal pressures, residual gas volumes, process temperatures, headspace expansion ratios and steam-air ratios. Their studies permitted calculations of required counterpressures to prevent failure. Rubinate (1964) in his studies concluded that an air pressure of 3 to 10 psig above the equilibrium pressure for water or steam at the process temperature over the total period of the cook is desirable; the reason is pouch restraint to prevent agitation and movement that could rupture the seals.

Aside from assurance of package integrity, superimposed air pressures, according to Keller (1959) and Nelson and Steinberg (1956), should be maintained to improve heat transfer. Japanese investigators cited by Lampi (1977) support this contention in relation to residual gases and offer data to indicate that the head space gas can also interfere with sterilization. Increasing head space gas volumes from 0 to 15 cc resulted in changes in f_h values from 6 to 7.2, and sterilization times at 250^{o}F from 6.7 to 7.1 minutes. When 20 cc of occluded air was incorporated into the product (but no head space gas, per se) the f_h increased to 9.4 and the sterilization time to 12.5 minutes.

Temperature Measurement

Temperature measurement for determining heat penetration rates generally have been by conventional copper-constantan thermocouples for preliminary heat penetration experiments and batch-production systems.

Where product characteristics, pouch-holding techniques, and pouch placement within the retort permitted, metal packing glands such as those used for conventional cans, Pflug et al. (1963) have been successfully employed to introduce wire and thermocouples into the pouch. Pflug et al. (1963) described a procedure whereby 30-gage thermocouple lead wire was introduced through the seal area. The section of wire that passed through the seal area was stripped of all insulation, cleaned with solvent, and coated with lacquer that is heat sealed to the innermost layer of the laminate. Torp and Atherton (1972) introduced thin, lacquered cooper-constantan wires through small holes made in the laminate about 0.75 inch above the bottom seal and sealed with a small amount of adhesive. Once the lead wire has been introduced into the package, positioning can be controlled by several means. Pflug et al. (1963) used a plastic saddle with the metal packing gland to orient the thermocouple tip to the geometric center of the pouch for liquid or semiliquid food under investigation. Pflug (1964) also reported using a piece of wood placed diagonally across the pouch with the thermocouple stapled onto the center. Torpe and Atherton (1972) used a rigid nylon spacer. With recipe packs, such as sweet and sour pork and beef stroganoff, the tip of the spacer-positioned thermocouple was secured in the center of a piece of meat of known size. Dewey Redesign (1975) described a disposable thermocouple/pouch arrangement where the lead wire enters through the pouch wall through an epoxy sealant and the thermocouple junction is suspended in the center of a conical coil spring.

When continuous retort is used, a different system should be used for heat penetration measurement. Goldfarb (1970, 1971) described and illustrated a temperature telemetry system in which a transistor sensor is inserted into the pouch through a packing gland similar to those used for conventional wire systems. The thermistor lead is connected to a battery-powered transmitter. The pouch transmitter combination, as it passes through the continuous retort, sends radio-frequency signals that are converted as temperature in a digital telemetry receiver. This system has been successfully used for temperature measurements on vegetables packaged in retort pouches using a continuous retort as reported by Lampi (1977).

Process Determination

Thermoprocessing conditions have been generally determined for pouches by methods proved satisfactory over decades of use for metal cans. Since the microbial history and growth environment (foods) are identical, the same concepts related to microbial survival have been fully accepted for direct applicability to retort pouches:

a. F_o - lethality in terms of minutes at 250°F required to destroy the specified spoilage organism in a specific medium assuming "Z" is equal to 18°F.

b. D - time in minutes to accomplish a 90% reduction in number of organisms (or spores).

c. Z - shape (slope) of the thermal death-time curve in degrees Fahrenheit required for the curve to transverse one log cycle (D versus °F).

Large-scale production tests such as those reported by Duxbury _et al_. (1970); Goldfarb (1970) indicated that F_o values suitable for commercially canned products are generally adequate for retort pouches. Lampi (1977) recommended that thermal-process parameters, as described by Ball and Olsen, can be established and should be confirmed using inoculated packs, but calculation techniques reduce time and permit translation of results from one set of conditions to another. These methods basically have consisted of integrating the desired lethality characteristics into the heat penetration curves of cans. Pflug _et al_. (1963); Thorne (1976); and Tung (1975), working with can and pouches using different products, found that center of retort pouches heat significantly faster than cans of equal net weight and concluded that processing time could be reduced from 30 to 44 percent. Similar comparison have been cited by Lampi (1977).

Heat penetration curves for cylindrical cans have been calculated and plotted on semilog paper and single or dual (broken) straight lines, can be obtained.

The time, in minutes, required for the straight line portion of the heat penetration curves to traverse one log cycle is termed f_h. It represents the slope of the curve. Another parameter used is j which is often referred to the heating lag factor. It is a factor which, when multiplied by the difference between retort temperature and initial food temperature, locates the intersection of the extension of the straight line portion of the heat penetration curve and a vertical line, representing the beginning of process or zero time, Stumbo (1973).

Pflug _et_ _al_. (1963) calculated the f_h value for a 0.75 inch slab and found that it agreed closely with experimental heating data, indicating that a calculated f_h can be useful in checking on experimental data for pouches.

Pflug (1964) and Pflug and Borrero (1967) in their extensive studies to compare various heating media (100% steam, water and steam-air) for applicability to commercial retort and to define specific heating characteristics of each medium using f_h, j, and F_o values as criteria for their comparison, concluded that usually f_h and j were adequate parameters to describe heat transfer in the laboratory. In their studies with a commercially sized retort, however, although they found that the three heating media gave predictable and reproducible results, they noted that some of the semilogarithmic plots were straight lines, some broke one time, and some actually were curves. This was especially true of water cooks, which exhibited a slow retort come-up time, with product temperature lagging 20° to 30°F behind water temperature. For those nonlinear heating situations, they recommend evaluations and design of thermal processes based on the general method.

Goldfarb (1970), Herndon (1971), in their studies, showed that predicted sterilization values for inoculated test packs would be closer to actual test values if the population distribution of the slope indices from a sample of heat-rise curves were used instead of the traditional slowest or mean single value of slope index in the sterilization calculations. Herndon (1971), to confirm his postulations, checked the accuracy of the proposed method with 240 gm retort pouches of whole kernel corn (180 gm of corn and 60 gram brine), first in a bath laboratory retort and then in a production prototype continuous retort (Hydrolok) using steam-air as the heat medium. The actual spoilage results from the inoculated test pack series on whole kernel corn closely correlated with the computer-calculated, predicted values, based upon population distribution of the heat-rise curves.

Yamano *et al*. (1975), reporting on studies using steam-air mixtures, found no appreciable differences among the heating rate parameters (f_h) for two types of film (12-micron polyester/50 micron polyethylene and 12-micron polyester/9 micron foil/50 micron polyethylene) and among processing temperatures from 105^{o}C to 120^{o}C.

As a whole, the reported experience indicated that heat penetration into retort pouches could usually be described by f_h and j and standard mathematical formulas for process calculations could be used. Frequent exceptions can occur (when the heat penetration curve shows no straight section) and then the general method becomes applicable. All researchers cautioned, and in his review, Lampi (1977) agrees, that calculations should be used only as means for assisting process calculations studies and not as a substitute for full process determination. Lampi (1977) pointed out that the significance of residual gas should not be discounted. Such dual approaches to process determination have been documented by Yamano *et al*. (1969a) with Chinese meat and soft spaghetti and for continuous steam air retort (Hydrolok) by Goldfarb (1970). Lampi (1977) cited investigations conducted by Schmidt and Robertson with inoculated-pack and heat penetration studies of vegetable products in which they concluded that: Heat penetration studies are a valid means for establishing processes, and that F_o values at cold point equal to those of cans would be sufficient to assure commercial sterility. Manson and Stumbo (1970) present a technique that evaluates the effects of thermal processes of conduction heating foods in rectangular-shaped containers. Bacterial lethality and the retention of any vulnerable factor that is degraded logarithmically upon subjection to moist heat may be determined by that digital computer program.

Processing Effect on Color

Tremendous effort has been aimed at stabilizing the color of green vegetables during processing, and/or storage. Heat processing, by far the most widely used method of preservation, causes very undesirable degradation of color in green vegetables. The major reason for this change is due to the formation of pheophytins from chlorophylls. Because of the commercial importance of heat processed green vegetables, stabilization of chlorophylls to maintain the green color has been the object of considerable research. The chlorophyll may be altered in many ways. In food processing, the most common alteration is the replacement of magnesium by hydrogen in the molecule and the consequent formation of the dull, olive-brown pheophytins. Chlorophyllides may be formed by the removal of the phytol chain. These compounds are green in color and have essentially the same spectral properties as chlorophylls, except they are water soluble, while the chlorophylls are ether soluble. If the magnesium in the chlorophyllides is replaced by hydrogen, the corresponding pheophorbides are formed which have the same color and spectral properties as the pheophytins, but are water soluble, Clydesdale and Francis (1970a). MacKinney and Joslyn (1940, 1941), Joslyn and MacKinney (1938), sought to define the kinetics of the conversion of chlorophyll to pheophytin. They used solution of chlorophyll in aqueous acetone containing various amounts of acid. The reaction rate was determined at several temperatures between 0 and 51^{o}C. Their results indicated that the reaction was first order with respect to both acid and chlorophyll. A number of methods have been developed to inhibit the degradation of chlorophyll in canned green vegetables during heat sterilization by reducing the concentration of acid in the tissue. On the basis of this principle several patents have been issued. The "Blair Process" (Blair, 1940 and 1940a) is probably the best, and the most successful alkalizing agent found was $MgCO_3$, Gupte (1964).

Still another approach, has been the use of High-Temperature Short-Time (HTST) processing. This method produces a very attractive product immediately after processing but the beneficial effects are quickly lost upon storage, Tom and Francis (1962), Luh et al. (1964). Gupte and Francis (1964) combined HTST processing in conjunction with $MgCO_3$. This produced a very attractive processed product, but the storage problem was not overcome. Clydesdale and Francis (1970), Gold and Weckel (1959) studying pigment degradation and methods of measurement found that the percentage of pigment chlorophyll lost correlates very well with certain color functions. The correlation coefficient, r, between the value -(a/b), a function of hue, and the percent of chlorophyll degradated was very high. The correlation coefficient, r, was -0.992 and highly significant as reported by Clydesdale and Francis (1970).

Clydesdale and Francis (1970) pointed out that instrumental color functions can be used to trace the percentage loss of chlorophyll, the pigment responsible for green color. Chemical pigment analyses are a great deal more difficult and time consuming than color measurements.

Thiamine Stability During Processing

The effect of heat and certain environmental factors on thiamine stability has been the subject of several comprehensive investigations. A number of food processing techniques have been involved which show promise of improving the quality of heat-processed foods. Many of these are based on achieving sterilization by high temperature-short time processing or by speeding up the rate of heating (thereby reducing the time required for sterilization) by means of agitation of container during processing. Feaster, Tompkins and Ives (1947) compared the influence of high temperature-short time with conventional processing methods on thiamine retention, in peas, carrots, green lima beans, green bean purees and cream style yellow corn. They showed that the high temperature-short time canning procedures resulted in increased thiamine retention over that obtained with conventional processing times and temperatures. It was found that increasing the rate of heat penetration through agitation of the cans during processing reduced the amount of thiamine loss by one-third.

Feliciotti and Esselen (1957), studying the thiamine degradation in buffered solutions and several foods, concluded that the thermal destruction of thiamine in foods may be dependent on the interrelationship of pH and the relative proportions of the free and combined forms of the vitamin. The data for carrots, green beans, peas and pork showed similar thermal destruction characteristics for thiamine.

Several methods of analysis have been used for thiamine determination. Recently, because of the increased need for routine analysis of vitamins in a variety of food products, semi-automated and automated methods have been developed.

Kirk (1974) described a semi-automated method for thiamine determination in milk with application to other selected foods.

Roy and Conetta (1976), using the Autoanalyser II analytical system, showed that chemical reactions occur in continuously flowing, air-segmented streams (air bubbles segment the flowing streams to maintain sample integrity and prevent cross mixing of sample) and every step of analysis is automatic from aspiration of sample, to detection, and finally to readout on a recorder and/or digital printer. Gregory and Kirk (1977) applied several methods of sample preparation for fluorometric analysis in order to maximize the removal of interfering compounds in green bean samples. They concluded that preparation chromatography using Decalso ion-exchanger columns provided lower apparent thiamine values than either direct analysis or pre-extraction with isobutanol of the green bean sample extract. They suggested that, for other foods, a preliminary testing of the effect of extract purification on each product be assayed to ensure accurary of routine chemical analysis.

Pelletier and Madere (1977) also described an automated method for thiamine and riboflavin determination in various foods and they recommended the addition of ethylene glycol monomethyl ether prior to separation of insoluble matter from certain fruits to prevent loss of those vitamins.

Texture Change During Processing

Texture of canned green beans can be affected by handling, blanching and retorting operations. Van Buren *et al.* (1960) concluded that the firmness of green beans and their resistance to sloughing and splitting can be greatly influenced by blanching treatment, by the time lapse between blanching and filling, and by the presence of calcium salts. Sistrunk and Cain (1960), working with pole snap beans, concluded that blanching at temperatures between 170^{o} and 180^{o}F for times of 1.5 to 5 minutes were the optimum for pole snap beans. Adjustments in the temperature of blanch or the time of blanch within this temperature range should be sufficient for controlling the sloughing and softening in pole snap beans for canning.

The pectic substances and pectin methylesterase (PME) are believed to be involved in changes occurring during the blanching and retorting. According to Van Buren *et al.* (1962) PME catalyses the removal of methyl groups from pectic substances, allowing calcium ions to react with exposed carboxyl groups. The insoluble calcium pectinates and pectates remain in the intracellular regions serving as cellular binding substances.

The specific effects of blanching and holding treatments and calcium additives have been determined largely on varieties of green beans common to the East and West cost of the United States, Kaezmarzyk *et al.* (1963).

Resistance to shear of green beans has been measured by the shear-press, Kramer *et al.* (1951); Sistrunk *et al.* (1960) and Kaezmarzyk *et al.* (1963). A sample of

150 grams of drained canned green beans is carefully put in a standard cell and the maximum-force for shearing the beans is recorded for each sample, and converted to pounds force per gram of product.

EXPERIMENTAL

Determination of Process Conditions

Process conditions were established through heat penetration studies of green beans in pouches. The use of a "goop" (Silicone glue - GE2562-01DP) enabled a hermetic seal to be obtained at the point of entry of the thermocouple that was required to monitor product temperature at the center of the package. 24-gauge, copper-constantan thermocouples covered with teflon were used in these experiments. The 7 by 10 inch flexible packages were constructed of 0.5 mil polyester (Mylar), 0.35 mil Al foil, 3 mil C-79 polyolefin (Continental Can Company).

In order to avoid the break of vacuum in the pouch and/or leak of brine or liquid from the product throughout the thermocouple cover, about 1.5 inches of the thermocouple cover was removed at a point about 6 $\pm$ 1 inches from the thermocouple junction. The 6-inch length of lead wire was passed through a hole made for the purpose in the exact center of the pouch wall. Silicone glue was used to attach the 1 1/2-inch, coverless section of thermocouple wire to the outer wall of the pouch at the point of entry of the wire into the pouch, at the same time sealing the hole with the silicone.

The extra six inches of thermocouple wire was needed so that placement of the thermocouple junction at the center of a piece of green bean pod could be accomplished outside of rather than within the pouch during the pouch-filling operation.

The thermocouple junction was placed in the green bean pod, and was then secured in the pouch's middle plane by positioning it in the center of a helical steel spring of a diameter of 0.75 in and 1.0 in, for pouches of 0.75 in and 1.0 in of thickness respectively, by 1.75 to 2 in long.

The rigid steel coil maintained package thickness of 0.75 and 1.0 in respectively and ensured that the thermocouple measured at point of greatest temperature lag.

Metal carriers of two different thicknesses were employed in order to keep the maximum desired thickness during the filling, sealing and retorting operation.

The pouches were filled with 8.0 and 9.5 ounces of green beans for 0.75 and 1.0 inch of thickness respectively. To some pouches a hot brine was added to the pouches as the experimental design.

The pouches were sealed in a Multivac vacuum seal machine. Type AGW Serial No. 969, with vacuum dial set to 2, which gives a vacuum of 0.95 kg/cm^2, and impulse seal dial set to 8.

Thermal processing was performed in a 45 cm diameter vertical retort using a water cook with superimposed air pressure. The retort was equipped with a water ball overflow valve with a capacity of 50 gallons/minute.

Steam, water and superimposed air inlet located at the bottom of the retort allowed a uniform distribution of heating and cooling during the process.

An automatic temperature and pressure control equipment from Foxboro was used in this experiment which gives a temperature $250^{o} \pm 1^{o}F$ and pressure in the range 30 ± 2 and 20 ± 1 psig. Cooling water was $15^{o}C$.

Pouches were placed vertically in the open shelf of a retort rack.

The retort rack was constructed of galvanized iron measuring 23 cm high, 29 cm wide, and 29 cm long. Between pouches a 0.25 inch apperture allowed a free circulation of heating and cooling medium. A wire screen was clipped over the pouch rack to prevent pouches flotation.

"Dummy" pouches were used in order to maintain a full rack load at all times. Thermocouples were used to monitor the retort temperature throughout each process run. The thermocouples were connected to a Honeywell strip chart recorder, Model No. K152X89-C-II-III-16.

Before the heat penetration study, the pouches were placed in water bath at $122^{o}F$ ($50^{o}C$) for 10 minutes in order to balance and equalize the initial temperature for the heat penetration study.

Water in the retort was preheated to $122^{o}C$. The loaded rack was immersed, the retort closed and brought up to the process temperature of 250°F in 5.00 ± .20 minutes. The initial product temperature was 122°F (50°C). A superimposed air pressure of 20 or 30 psig was maintained throughout the heating and cooling cycles, according to each treatment.

Test pouches, according to treatments in Table 2 were processed at three different times in order to make a regression analysis of the data and predict the time of processing (period of time from steam on to steam off) which gives a $F_o \geq 3.5$ with $0.997(\bar{X} \pm 3S)$ of confidence coefficient.

The process time for still cooked control cans was 12 minutes in steam at 250°F with water cooling system.

Green Beans

Green beans of unknown variety were bought at the Farmer Market in Lansing during the period from October 20, 1977 to January 20, 1978.

The raw product was washed and snipped to remove ends. It was then cut into pieces 1 inch long. The individual portions for each container were weighed and blanched separately by immersion in water at 180°F for 1.5 minutes, then cooled by immersion in cold water and packed.

In the case of brine-containing samples (Table 1) the amount of brine was equal to 30% of the weight of the

Table 1. Treatment notation with the levels used for each factor.

Treatment notation[1]				Factor		
				T (inches)	P (psig)	B (ml)
A	t_1	p_1	b_1	0.75	20	-
B	t_1	p_1	b_2	0.75	20	70
C	t_1	p_2	b_1	0.75	30	-
D	t_1	p_2	b_2	0.75	30	70
E	t_2	p_1	b_1	1.0	20	-
F	t_2	p_1	b_2	1.0	20	80
G	t_2	p_2	b_1	1.0	30	-
H	t_2	p_2	b_2	1.0	30	80
I	303 x 406 can					

[1] t_1, t_2 correspond to levels of thickness factor T.

p_1, p_2 correspond to levels of superimposed air pressure factor P.

b_1, b_2 correspond to levels of brine addition factor B.

Table 2. Time of processing[1] in minutes for test pouches and cans.

		Trials		
Treatments	notation[2]	1	2	3
A	$t_1p_1b_1$	8	10	12
B	$t_1p_1b_2$	9	11	13
C	$t_1p_2b_1$	9	11	13
D	$t_1p_2b_2$	9	11	13
E	$t_2p_1b_1$	10	12	14
F	$t_2p_1b_2$	11	13	15
G	$t_2p_2b_1$	11	13	15
H	$t_2p_2b_2$	11	13	15
I	303 can	12	--	--

[1] Time of processing corresponds to period of time from steam on to steam off.

[2] t_1, t_2 correspond to levels of thickness of factor T.
p_1, p_2 correspond to levels of superimposed air pressure of factor P.
b_1, b_2 correspond to levels of brine addition of factor B.

beans.

Experimental Design

A 2^3 factorial completely randomized design was used in this experiment, with three factors at two different levels, with ten repetitions for each treatment. Two notations will be used to label the treatments. One, a simple notation will be used for general comparison and a second one which gives factor levels will be used for specific comparison of main effect and interaction of factors.

Factors:

Thickness of the pouch which corresponds to the factor T with the following levels:

$t_1 \rightarrow$ 0.75 inch

$t_2 \rightarrow$ 1.00 inch

The superimposed air pressure in the retort which corresponds to the factor P with the following levels:

$p_1 \rightarrow$ 20 psig (which corresponds to 4 psig above the pressure corresponding to the water temperature in the retort)

$p_2 \rightarrow$ 30 psig (which corresponds to 14 psig above the pressure corresponding to the water temperature in the retort)

Brine addition which corresponds to the factor B with the following levels:

$b_1 \rightarrow$ no brine addition

b_2 → an amount of brine, which corresponds to 30% of the weight of the beans was added; 70 ml of 2% brine was added to treatments B and D and 80 ml of 2% brine to treatments F and H.

Quality Evaluation Methods

After heat penetration studies batches of pouches from each treatment were processed in order to evaluate the pouch and 303 products. Those evaluations were conducted within the three days after having been processed.

After being processed at 250^{O}F container contents were evaluated for thiamine, color, texture and moisture by the following methods:

Thiamine

The procedure employed for thiamine determination was the alkaline potassium ferricyanide oxidation of thiamine to thiocrome which is measured fluorometrically, using a Technicon AutoAnalyzer modules, Sampler II, 30 samples/hr; pump I, with modified plattered Technicon manifold No. 116-D207 (Kirk, 1974); and fluorometer with 360 nm primary filter, and 436 nm secondary filter, and recorder.

Extraction Procedures

After draining the processed green beans, a sample of about 14 grams weighed to the 4th decimal point, (macerated) ground, was washed with 50 ml of 0.1N HCl solution and transferred to a 250 ml flask, autoclaved for 30 minutes at 15 psig, and cooled to room temperature. After that the pH was adjusted to the range 4.0 to 4.5 with 2N Sodium Acetate, 4 ml 10% clarase solution added and incubated at 45 to 50°C for 3.5 hours. After refrigerating the samples overnight at 5°C they were diluted to 100 ml with 0.1N HCl solution. Using a Whatman #42 filter paper sample was filtered and 15 ml of the filtrate was mixed with 30 ml of isobutanol for pigment extraction prior to assay.

The recovery standard was prepared by adding 20 μg thiamine to duplicate samples of each treatment prior to extraction.

Analytical System for Thiamine Determination

Initially, water was pumped through all tubes and recorder base line adjusted to 5, using sample opening of 2 and reference opening of 1. Reagent lines were placed in appropriate reagents and system was purged 20-30 minutes before establishing the baseline reading of 5 with reagents. High standard is aspirated into the system and its maximum response is adjusted to 95 using a full scale recorder control. The sample test is then placed in water and the system is allowed to return to baseline before standards and samples are analyzed. The standard should be assayed after 10 to 15 samples to monitor any possible recorder drift. The blanks for each sample were determined by analyzing samples and standard substituting 15% sodium hydroxide for potassium ferricyanide oxidizer, Kirk (1974).

Texture

The texture of raw product and processed product was determined by Kramer Shear press unit, using a standard cell.

The Kramer Shear press unit with a stroke length of 8,84 cm, a time of 17 seconds and rate of speed of 0.52 cm/second lb. ring set to 3000 pounds.

Procedure Used

Processed green beans. A drained sample of 150 grams was carefully placed in the cup of the standard cell. The range sensitivity dial was set at 5 in order to get a good reading in the middle third of the chart paper.

Raw product. A 50 gram sample of raw product was placed in the cup of standard cell, the range sensitivity dial set to 50 in order to get a good reading in the middle third of the chart paper.

Calculations. The texture was expressed in pounds force/gram of product. By using the peak-height, the texture of the sample was calculated by the following formula:

$$\text{lb force/gram} = \frac{\text{lb ring} \times \frac{\text{peak height}}{100} \times \frac{\text{range sensitivity}}{100}}{\text{weight of sample (g)}}$$

where: lb ring = 3000 lb

peak height = read on the chart paper

range sensitivity = 5 for processed green beans

50 raw product

weight of sample = 150 grams for processed green beans

50 grams for raw product

Color

The color of the raw and processed green beans was determined by Hunter Lab Model 25 Color and Color Difference Meter using a Hunter Lab Standard Cell No. D33G-2060.

The samples of 50 grams of beans were put in a glass dish and two readings were taken from each sample. The first one with the dish in normal position, and the second one with the dish rotated 90^{o} on the horizontal plane.

Moisture Determination

Samples of the product were cut in 0.5 cm portions of about ten grams and dried at $100 \pm 2^{o}C$ for five hours, and were then reweighed for moisture calculation. This indirect method of moisture determination was checked at different times for constant weight. The chosen five-hour drying time was considered to be adequate since additional drying time (with just a few samples) was found to give no further weight loss.

RESULTS AND DISCUSSION

Heat Penetration Study

For each test pouch, process lethality (F_o) was calculated by the Improved General Method (Schlutz and Olson, 1940) based on measurements of center temperature at 0.5-minute intervals and a computer program to calculate the lethal rates (assuming Z value of 18°F) and total the interval lethalities. In the heat penetration study, 24 process lethalities were obtained, which constituted eight replications of each of the three process times that were used for a given treatment. A regression analysis procedure was applied to determine the process time which would assure an individual $F_o \geq 3.5$ minutes with a 0.997 ($\bar{X} \pm 3S$) confidence coefficient. With an initial product temperature of 122°F (50°C), the time of processing for all treatments considered in this experiment are given in Table 2.

The calculation of lethality was done using the method recommended by Schultz and Olson, 1940, where $L = \log^{-1} \frac{T - 250}{Z}$, T is the temperature in degrees Fahrenheit and Z is the slope of thermal death time curve. Data, average and standard deviations are presented in Table 3.

After F_o values were calculated at three different times with eight replications for each treatment (Table 3), a regression analysis was applied to the data, regression equations were determined and a predicted processing time to give a $F_o \geq 3.5$ minutes with 0.997 ($\bar{X} \pm 3S$) confidence coefficient was determined (Table 4).

Effect of Superimposed Air Pressure on Time of Processing

Pouches, unlike cans, do not have a rigid shape. During heat processing, some expansion of gases and of product occurs. As a consequence, pressure inside the pouch is increased. The use of superimposed air pressure counterbalances this effect and brings the pouch wall in closer contact with the food, thus improving the heat transfer rate, and consequently achieving a reduction in time of processing required for sterilization. On the other hand, the use of higher pressure results in more air entering the retort and this results in more air bubbles coming into contact with the pouch walls, thus reducing the heat transfer rate from the medium to the product because air has a smaller heat transfer coefficient than does water.

Effect of Pouch Thickness on Time of Processing

Quality retention during thermal processing becomes increasingly difficult with increases in container size. Shape of the container can also be important with respect

Table 3. Process lethality (F_o) calculated by Improved General Method, using center temperature at 0.5 minute intervals, and assuming Z = 18°F

Treat-ment	Time min	Replications 1	2	3	4	5	6	7	8	$\bar{X}$[1]	S[2]
A	8	1.69	1.79	1.26	1.35	1.55	1.83	1.35	1.36	1.55	0.21
$t_1p_1b_1$	10	3.94	3.69	4.41	3.75	3.70	4.00	3.59	3.47	3.82	0.29
	12	5.85	5.57	5.19	5.50	5.81	6.36	5.91	5.83	5.75	0.34
B	9	3.07	3.45	2.65	3.38	2.93	3.12	3.07	3.06	3.09	0.25
$t_1p_1b_2$	11	4.91	5.15	5.10	4.99	4.68	5.39	5.71	5.22	5.14	0.31
	13	6.86	-	6.58	6.63	7.17	6.61	7.02	7.17	6.86	0.26
C	9	2.55	2.73	2.29	2.23	1.97	1.66	2.47	1.88	2.22	0.36
$t_1p_2b_1$	11	4.74	4.46	4.48	3.39	4.62	4.13	4.40	4.80	4.38	0.45
	13	6.21	6.35	6.62	6.21	7.53	7.27	7.41	7.31	6.86	0.57
D	9	2.71	2.56	2.83	2.12	2.15	1.71	3.00	2.59	2.46	0.43
$t_1p_2b_2$	11	4.41	4.11	4.32	4.41	4.65	3.38	4.36	3.60	4.19	0.45
	13	7.46	6.97	6.52	5.91	6.64	6.12	5.69	6.65	6.62	0.54
E	10	2.07	2.07	3.10	1.93	1.46	1.94	2.10	1.79	2.06	0.47
$t_2p_1b_1$	12	4.56	4.45	3.41	3.79	4.14	4.14	3.37	3.71	3.95	0.45
	14	6.32	6.33	6.14	6.04	7.04	6.71	6.31	-	6.41	0.35
F	11	3.52	3.70	4.19	5.51	3.75	5.43	3.52	4.73	4.29	0.83
$t_2p_1b_2$	13	7.01	7.43	5.65	6.69	5.98	5.85	5.25	6.92	6.35	0.77
	15	7.59	8.43	6.93	8.00	8.02	8.49	7.76	7.18	7.80	0.55
G	11	2.51	3.70	2.96	3.62	3.20	2.12	2.80	2.46	2.93	0.56
$t_2p_2b_1$	13	4.55	4.54	5.58	5.34	4.46	4.44	-	-	4.82	0.51
	15	7.55	7.44	7.10	7.21	9.25	7.94	7.93	7.18	7.58	0.42
H	11	2.99	2.36	3.29	2.79	3.65	4.14	3.66	3.06	3.21	0.54
$t_2p_2b_2$	13	5.41	4.70	4.89	4.47	5.05	5.64	5.35	5.62	5.14	0.43
	15	7.10	6.97	7.90	7.56	7.63	6.16	7.35	8.00	7.46	0.38

[1] $\bar{X}$ - mean

[2] S - standard deviation

Table 4. Time of processing[1] required for pouches in water at 250°F to give a $F_0 \geq 3.5$ minutes.

Treatment	notation	Thickness (in)	Superimposed air pressure (psig)	Brine (g)	Time (min)
A	$t_1p_1b_1$	0.75	20	-	10.57
B	$t_1p_1b_2$	0.75	20	70	10.24
C	$t_1p_2b_1$	0.75	30	-	11.25
D	$t_1p_2b_2$	0.75	30	70	11.52
E	$t_2p_1b_1$	1.00	20	-	12.52
F	$t_2p_1b_2$	1.00	20	80	12.56
G	$t_2p_2b_1$	1.00	30	-	12.91
H	$t_2p_2b_1$	1.00	30	80	12.65
I	303 can	-	-	-	12.00[2]

[1]Correspond to period of time from steam on to steam off

[2] Processed in steam at 250°F

to quality loss during the sterilization process. The flat shape of the pouches and the fact that any desired thickness of product may be packed in them for thermal processing, gives them a distinct advantage over cans and jars. As the distance from the coldest point to the surface of the container is reduced, the time of processing can be reduced, consequently increasing nutrient retention and minimizing other undesirable changes in food characteristics like color, flavor, texture, etc.

The reduction in pouch thickness from 1.0 inch to 0.75 inches allowed the following reductions in time of processing, as shown in Table 4: At 20 and 30 psig of superimposed air pressure, the reductions in time of processing for pouches without brine were 1.95 and 1.66 minutes, respectively. The reductions in time of processing for the pouches with brine addition were 2.32 and 1.13 minutes at 20 and 30 psig, respectively.

Effect of Brine on the Processing Time

Heat penetration is faster by convection than by conduction. When a liquid is mixed with pieces of solid material, both convection and conduction will occur. The relative ratio of convection to conduction depends on several variables (density of liquid and of solid product, shape and size of pieces, shape of the container, ratio of liquid to solids pieces).

The brine addition did not greatly alter the time of processing. This small effect can be explained by the small amount of brine added to each pouch in proportion to the amount of beans and secondly, by the fact that the temperature of the thermocouple junction inserted was measured within the green bean pod, where conduction heating would be the major controlling factor.

The water cook with superimposed air pressure of 20 and 30 psig maintained throughout the heating and cooling cycles of the retort pouch processes was found effective in preventing vibration during the initial period of heating. The high external pressure also ensured that the pouch maintained contact with the product. Also, the high vacuum used before sealing the pouch made it very tight to the product, maximizing the heat transfer from medium to the product.

Quality Evaluation

Thiamine Retention

Table 5 shows the thiamine concentration in µg/gram of product (dry weight basis) for each treatment. Mean values followed by the same letter did not differ statistically at the 1% level, as calculated by Duncan's Multiple Range Test.

Table 5 results show all packed green beans, with exception of treatments D and H, to be significantly higher (at 1% level) in thiamine content than conventionally canned beans (Treatment I).

Effect of pouch thickness on thiamine retention

Analysis of variance (Table 6) indicated that thiamine retention was unaffected by any increase in pouch thickness from 0.75 to 1.0 inches. The addition of brine, on the other hand, did result in a statistically significant difference in thiamine retention. Variation in superimposed air pressure also produced a statistically significant change in thiamine retention.

Effect of brine addition on thiamine retention

The addition of brine to the pouch decreased the thiamine retention in the product as shown in Table 7. Some thiamine leaked from the product into the fluid,

Table 5. Thiamine content in μg/gram (dry weight basis) in processed green beans[1] from pouches and 303 cans

Treatment		Replicates												
		1	2	3	4	5	6	7	8	9	10	Total	$\overline{X}$[2]	S[3]
A	$t_1p_1b_1$	5.84	6.25	5.96	6.06	5.80	5.42	5.10	5.41	4.61	5.45	55.90	5.59[c]	0.49
B	$t_1p_1b_2$	7.11	6.25	6.11	5.20	3.80	3.67	4.46	3.98	4.63	4.27	49.58	4.96[bc]	1.17
C	$t_1p_2b_1$	5.77	5.41	5.05	4.82	4.60	5.33	4.79	4.57	4.82	4.44	49.60	4.96[bc]	0.42
D	$t_1p_2b_2$	3.86	4.42	4.35	4.51	3.52	3.65	4.58	4.93	4.36	5.02	43.20	4.32[ab]	0.50
E	$t_2p_1b_1$	3.83	4.71	5.79	5.71	5.91	5.62	5.27	5.78	6.24	5.61	54.47	5.45[c]	0.70
F	$t_2p_1b_2$	4.53	5.61	5.51	5.46	5.70	4.66	4.80	4.87	4.66	4.88	50.68	5.07[bc]	0.45
G	$t_2p_2b_1$	3.03	4.75	4.35	4.79	4.59	4.43	4.98	4.51	5.57	5.79	48.79	4.88[bc]	0.48
H	$t_2p_2b_2$	5.08	3.84	4.94	4.28	4.35	4.61	5.30	4.26	4.05	4.25	44.96	4.50[ab]	0.47
I	303 can	3.92	3.93	4.20	4.38	4.57	4.42	4.01	3.48	3.46	3.41	39.80	3.98[a]	0.42

[1] Liquid drained off before sampling for thiamine measurement

[2] $\overline{X}$ - Mean. Means with the same letter do not differ statistically at 1% level by the Duncan's Multiple Range Test.

[3] S - Standard deviation

Table 6. Analysis of variance of data in Table 17

	df[1]	SS[2]	MS[3]	F[4]
Thickness (T)	1	0.005	0.005	0.015
Brine (B)	1	5.266	5.266	13.256**
Superimposed-air pressure (P)	1	7.248	7.248	18.245**
<u>Interactions</u>				
TB	1	0.331	0.331	0.833
TP	1	0.008	0.008	0.020
BP	1	0.007	0.007	0.018
TBP	1	0.006	0.006	0.015
Error	72	28.602	0.397	
Total	79	41.447		

**Indicates significance at 0.01 level of probability

[1]df - degrees of freedom

[2]SS - square sum

[3]MS - mean square

[4] $F = \frac{MS}{MS\ (error)}$

Table 7. Effect of brine addition on thiamine retention µg/gram[1] in green beans processed in pouches in water at 250°F

Treatment T	P	Superimposed-air pressure b_1	b_2	Difference µg/g	Reduction %
t_1	p_1	5.59	4.96	0.63	11.27
t_1	p_2	4.96	4.32	0.64	12.90
t_2	p_1	5.45	5.07	0.38	6.97
t_2	p_2	4.88	4.50	0.38	7.79

[1]Average of 10 analyses, µg/g (dry weight basis)

reducing the thiamine content in the product. Values for the thiamine content of the raw, processed beans and liquid from each treatment are given in Table 8.

Considering the fact that packing liquid for vegetables is not normally consumed, reduction in the packing liquid added to the product will reduce the thiamine loss, and the loss of other soluble substances from the product. This loss can be avoided if the liquid is consumed or used to make up other types of foods.

Effect of superimposed air pressure on thiamine retention

Although superimposed air pressure made no difference in the processing time, it had an undesirable effect on thiamine retention. Table 9 shows the effect of superimposed air pressure on thiamine retention in processed green beans in pouches in water at 250^{o}F. It seems that thiamine degradation is accelerated by higher pressure during the processing. The data show that a change in superimposed air pressure from 20 to 30 psig gave a reduction of about 11% in thiamine.

No explanation was found in the literature relative to the effect of superimposed air pressure during processing on thiamine retention.

Table 8. Change in thiamine content in green beans during processing

Treatment notation	Thiamine Content[1] Raw Product	Thiamine Content[1] Processed Beans[2]	Thiamine Retention[3]	Drained liquid from containers Thiamine content[4]	Drained liquid from containers Total liquid	Total Thiamine loss in liquid
			%	μg/g	g	μg
A $t_1p_1b_1$	5.93	5.59	94.27	0.32	21.0	6.72
B $t_1p_1b_2$	5.93	4.96	83.64	0.24	64.5	15.48
C $t_1p_1b_z$	5.93	4.96	83.64	0.33	19.0	6.27
D $t_1p_2b_2$	5.93	4.32	72.85	0.23	72.0	16.65
E $t_2p_1b_1$	5.93	5.45	91.91	0.32	23.5	7.50
F $t_2p_1b_2$	5.93	5.07	85.50	0.32	77.3	24.73
G $t_1p_2b_1$	5.93	4.88	82.29	0.31	22.5	6.98
H $t_2p_2b_1$	5.93	4.50	75.89	0.24	84.2	20.25
I 303 can	5.93	3.98	67.00	0.14	215.8	30.21

1. μg/gram of product (dry weight basis) - average of ten determinations
2. Liquid drained off before measurement
3. It doesn't include thiamine content of drained liquid
4. Average of five determinations

Table 9. Effect of superimposed-air pressure (P) on thiamine retention μg/gram[1] in green beans processed in pouches in water at 250°F

Treatment T	B	Superimposed-air pressure P_1	P_2	Difference μg/g[1]	Reduction %
t_1	b_1	5.59	4.96	0.63	11.27
t_1	b_2	4.96	4.32	0.64	12.90
t_2	b_1	5.45	4.88	0.57	10.46
t_2	b_2	5.07	4.50	0.57	11.24

[1]Average of ten analyses, μg/g (dry weight basis)

Texture

The data, means and standard deviations of ten determinations of texture from each treatment of pouches and 303 cans are shown in Table 10.

The significance of differences among the means given in Table 10 was determined by the analysis of variance using Duncan's Multiple Range Test. Means followed by the same letter do not differ statistically from one another at the 1% level.

Table 10 results show all packed green beans, with the exception of treatments D and G, to have a significantly firmer texture (at the 1% level) than conventionally-canned beans (Treatment I), averaging 0.65 pounds of force/gram as compared with 0.39 pounds of force/gram for the can-packed product. Treatments D and F also exhibited higher shear force values than I (0.51 and 0.47, respectively) but the differences (from 0.39) were insufficient for 1% statistical significance.

In order to evaluate the main effect of each factor in this factorial experimental design as well as first and second order interactions, analysis of variance was done and the results are given in Table 11.

Only pouch thickness main effect had a statistically significant effect on green bean texture. The

Table 10. Texture of processed green beans[1] measured by the Shear press and converted to pounds force/gram.

Treatment notations		Replicates 1	2	3	4	5	6	7	8	9	10	Total Treat	$\overline{X}$[2]	S[3]
A	$t_1p_1b_1$	0.46	0.97	0.52	0.51	0.56	0.84	0.53	0.99	0.95	0.88	7.21	0.72^{ef}	0.22
B	$t_1p_1b_2$	0.65	0.63	0.62	0.69	0.66	0.65	0.65	0.62	0.47	0.47	6.11	0.61^{cde}	0.08
C	$t_1p_2b_1$	0.93	0.91	0.75	0.84	0.85	0.68	0.91	0.70	0.52	0.59	7.68	0.77^{f}	0.12
D	$t_1p_2b_2$	0.50	0.50	0.56	0.55	0.54	0.51	0.54	0.59	0.41	0.41	5.11	0.51^{abc}	0.06
E	$t_2p_1b_1$	0.52	0.50	0.53	0.52	0.50	0.41	0.65	0.68	0.56	0.61	5.49	0.55^{bcd}	0.08
F	$t_2p_1b_2$	0.55	0.55	0.53	0.55	0.57	0.57	0.65	0.73	0.70	0.53	5.93	0.59^{bcd}	0.07
G	$t_2p_2b_1$	0.50	0.44	0.45	0.42	0.45	0.47	0.45	0.58	0.53	0.42	4.71	0.47^{ab}	0.05
H	$t_2p_2b_2$	0.72	0.62	0.70	0.69	0.64	0.67	0.64	0.64	0.61	0.76	6.69	0.67^{def}	0.05
I	303 can	0.36	0.37	0.35	0.30	0.37	0.37	0.43	0.43	0.46	0.46	3.92	0.39^{a}	0.05

[1] Liquid drained off before measurement

[2] $\overline{X}$ - Mean. Means with the same letter do not differ statistically at 1% level by the Duncan's Multiple Range Test.

[3] S - standard deviation

Table 11. Analysis of variance of data in Table 18

	df[1]	SS[2]	MS[3]	F[4]
Thickness (T)	1	0.135	0.135	12.27**
Brine (B)	1	0.019	0.019	1.73
Superimposed-air pressure (P)	1	0.004	0.004	0.36
<u>Interactions</u>				
TB	1	0.464	0.464	42.18**
TP	1	0.003	0.003	0.270
BP	1	0.0002	0.000	0.017
TBP	1	0.245	0.245	22.27**
Error	72	0.806	0.011	
Total	79	1.545		

**Indicates significance at 0.01 level of probability

[1]df - degrees of freedom

[2]SS - Square Sum

[3]MS - Mean Square

[4] $F = \frac{MS}{MS\ (error)}$

green beans processed in pouches with 0.75 inches of thickness proved firmer than beans in 1.0-inch thick pouches. This result can be explained by the difference in time of processing, the thinner pouches having been processed for a shorter time than the thicker ones.

A first order interaction between thickness and brine addition was observed (Table 11 and Table 12), indicating that the significant reduction in shear-force value attributable to package thickness occured only in those samples to which brine had not been added. The statistically significant TB interaction also revealed the existence of a softening effect of brine addition, but only among 0.75-inch-thick samples.

A statistically-significant second order interaction (TBP) was also noted (Table 11), indicating that pressure variation influenced the effect of package thickness and brine addition on beans texture. The significantly firmer texture of treatment H beans, as compared with treatment D (Table 10), was opposite in direction to the textural change noted in the experiment as a whole (with respect to package thickness effect) and is indicative of the TBP interaction just referred to.

Within the range over which tested variables were studied, the use of a 0.75-inch-thick package to which no brine is added plus a superimposed air pressure during processing of 30 psig appears to provide optimum conditions for maximum firmness of final product.

Table 12. Examination of the TB interaction for the data from Table 18.

Brine = B	Thickness = T t_1	t_2	$t_1 - t_2$
b_1	14.89	11.22	+ 3.67
b_2	10.20	10.62	- 0.42
$b_1 - b_2$	4.69	0.60	

$$\text{B within } t_1\text{SS} = \frac{(b_1t_1 - b_2t_1)^2}{2 \times r \times p}$$

$$\frac{(14.89 - 10.20)^2}{2 \times 10 \times 2} = 0.550^{**}$$

$$\text{B within } t_2\text{SS} = \frac{(b_1t_2 - b_1t_2)^2}{2 \times r \times p}$$

$$\frac{(11.22 - 10.62)^2}{2 \times 10 \times 2} = 0.009$$

$$\text{T within } b_1\text{SS} = \frac{(b_1t_1 - b_1t_2)^2}{2 \times r \times p}$$

$$\frac{(14.89 - 11.22)^2}{2 \times 10 \times 2} = 0.337^{**}$$

$$\text{T within } b_2\text{SS} = \frac{(b_2t_1 - b_2t_2)^2}{2 \times r \times p}$$

$$\frac{(10.20 - 10.60)^2}{2 \times 10 \times 2} = 0.004$$

**Indicates significance at 0.01 level of probability

Color

The results of color measurements were analyzed and will be discussed in terms of the -a/b ratio since the conversion of chlorophyll to pheophytin is very well correlated with the ratio -a/b (Clydesdale, 1970a). Also, Hunter values L, a, b obtained were found to be very well correlated with visual rankings.

A plus value for a indicates redness; a minus value, greenness. A plus value for b indicates yellowness; a minus value, blueness. L measures lightness. The ratio -a/b, average and standard deviation values are in Table 13.

The significance of differences among the means given in Table 13 was determined by the analysis of variance using the Duncan's Multiple Range Test. Means with the same letter do not differ statistically at the 1% level.

The overall effect of treatments on color was small. There was little difference between green beans processed in pouches and 303 cans. The chlorophyll pigment is very sensitive to heat treatment and the reduction in time of processing for pouches did not make a big difference in the color of the processed green beans.

Data in Table 13 show a big variation among replicate readings, which gave large standard deviations. This variability may have resulted from variations of color in the part of the pod cut, and some differences

Table 13. Color measurement of processed green beans[1] with Hunterlab D25 Color and Color Difference Meter. Hunterlab standard cell No. D33 G20-60. Data transformed to -a/b.

	Treatment Notation								
Replication	A $t_1p_1b_1$	B $t_1p_1b_a$	C $t_1p_2b_1$	D $t_1p_2b_2$	E $t_2p_1b_1$	F $t_2p_1b_1$	G $t_2p_2b_1$	H $t_2p_2b_2$	I 303 can
1	-0.151	-0.249	-0.091	-0.203	-0.070	-0.202	-0.114	-0.050	-0.083
2	-0.037	-0.246	-0.019	-0.174	-0.100	-.062	-0.071	-0.005	-0.087
3	-0.070	-0.373	-0.085	-0.077	-0.065	-0.085	-0.084	-0.021	-0.082
4	-0.107	-0.260	-0.108	-0.168	-0.019	-0.063	-0.028	-0.092	-0.051
5	-0.051	-0.167	-0.073	-0.132	-0.067	-0.133	-0.095	-0.041	-0.117
6	-0.091	-0.265	-0.031	-0.062	-0.429	-0.007	-0.074	-0.036	-0.102
7	-0.070	-0.357	-0.034	-0.123	-0.033	-0.220	-0.057	-0.020	-0.057
8	-0.050	-0.275	-0.000	-0.139	-0.030	-0.050	-0.054	-0.022	-0.056
9	-0.086	-0.067	-0.061	-0.-02	-0.095	-0.063	-0.073	-0.025	-0.091
10	-0.039	-0.170	-0.016	-0.135	+0.033	-0.052	-0.168	-0.057	-0.114
Total	-0.752	-2.429	-0.518	-1.305	-0.575	-0.927	-0.818	-0.369	-.0570
X[2]	-0.075[b]	-0.293[a]	-0.052[b]	-0.131[b]	-0.058[b]	-0.093[b]	-0.087[b]	-0.037[b]	-0.084[b]
S[3]	0.035	0.091	0.037	0.044	0.047	0.070	0.038	0.025	0.024

[1]Liquid drained off before measurement.
[2]Means with the same letter do not differ statistically at the 1% level by the Duncan Multiple Range Test.
[3]Standard deviation.

in thickness of the layer of green beans on the plate during the readings. The two readings for each sample cut down somewhat on this variability, but in order to reduce it further, it might be a better idea to grind the samples before the reading.

All the factors considered in this experiment T, P and B, had statistically significant effects upon the change in color of the green beans during heat processing in pouches.

Effect of Pouch Thickness on Color

Higher average values of the ratio -a/b, which means greener color of beans, were obtained with thinner pouches, with brine addition, processed at lower superimposed air pressure ($t_1p_1b_2$). Lower average values of -a/b were obtained with higher levels of all factors considered ($t_2p_2b_2$) (Table 13).

The two first order interactions were determined between thickness x brine (TB) and brine x superimposed air pressure (BP) (Table 14).

These interactions were studied and Tables 15 and 16 summarize data for interactions TB and BP respectively.

Interaction of Thickness Versus Brine Addition (TB).

Reduction in pouch thickness had a significantly beneficial effect (i.e., higher -a/b value) on color

Table 14. Analysis of variance of data in Table 19.

	df[1]	SS[2]	MS[3]	F[4]
Thickness (T)	1	0.067	0.0670	28.54**
Brine (B)	1	0.070	0.0700	29.82**
Superimposed-air pressure (P)	1	0.035	0.0350	14.91**
Interactions				
TB	1	0.0818	0.0818	34.85**
TP	1	0.0134	0.0134	5.71*
BP	1	0.0355	0.0355	15.12**
TBP	1	0.0005	0.0005	0.21
Error	72	0.1690	0.0024	
Total	79	0.4720		

*Indicates significance at 0.05 level of probability

**Indicates significance at 0.01 level of probability

[1]df - degrees of freedom

[2]SS - square sum

[3]MS - mean square

[4] $F = \frac{MS}{MS\ (error)}$

Table 15. Examination of the TB interaction for data from Table 19.

Brine = B	Thickness = T t_1	t_2	$t_1 - t_2$
b_1	-1.270	-1.393	+0.123
b_2	-3.734	-1.296	-2.348
$b_1 - b_2$	+2.464	-0.097	

$$T \text{ within } b_1 SS = \frac{(b_1t_1 - b_1t_2)^2}{2 \times r \times p}$$

$$\frac{[-1.270 - (-1.393)]^2}{2 \times 10 \times 2} = 0.0004$$

$$T \text{ within } b_2 SS = \frac{(b_2t_1 - b_2t_2)^2}{2 \times r \times p}$$

$$\frac{[-3.734 - (1.296)]^2}{2 \times 10 \times 2} = 0.149^{**}$$

$$B \text{ within } t_1 SS = \frac{(t_1b_1 - t_1b_2)^2}{2 \times r \times p}$$

$$\frac{[-1.270 - (-3.734)]^2}{2 \times 10 \times 2} = 0.152^{**}$$

$$B \text{ within } t_2 SS = \frac{(t_2b_1 - t_2b_2)^2}{2 \times r \times p}$$

$$\frac{[-1.395 - (-1.296)]^2}{2 \times 10 \times 2} = 0.0002$$

**Indicates significance at 0.01 level of probability

Table 16. Examination of BP interaction for data from Table 19.

Brine = B	Superimposed-air pressure P p_1	p_2	$p_1 - p_2$
b_1	-1.327	-1.336	+0.009
b_2	-3.356	-1.674	-1.686
$b_1 - b_2$	+2.029	+0.338	

$$P \text{ within } b_1SS = \frac{(b_1p_1 - b_1p_2)^2}{2 \times r \times t}$$

$$\frac{[-1.327 - (1.336)]^2}{2 \times 10 \times 2} = 0.0002$$

$$P \text{ within } b_2SS = \frac{(b_2p_1 - b_2p_2)^2}{2 \times r \times t}$$

$$\frac{[-3.356\ 0\ (-1.674)]^2}{2 \times 10 \times 2} = 0.071^{**}$$

$$B \text{ within } p_1SS = \frac{(p_1b_1 - p_1b_2)^2}{2 \times t}$$

$$\frac{[-1.327 - (-3.356)]^2}{2 \times 10 \times 2} = 0.103^{**}$$

$$B \text{ within } p_2SS = \frac{(p_2b_1 - p_2b_2)^2}{2 \times r \times t}$$

$$\frac{[-1.336 - (1.674)]^2}{2 \times 10 \times 2} = 0.0003$$

**Indicates significance at 0.01 level of probability retention for treatments processed with added brine. Brine addition produced statistically significant color benefits only in the treatments involving the thinner pouches (t_1).

Differences in the amount of air trapped within the package may provide the explanation for the measured differences in color degradation of the various treatments. It was observed during these tests that beans could not be packed as tightly in the thicker pouches as in the thinner. This, apparently, resulted from the tendency of a greater proportion of beans in the thicker pouch to position themselves horizontally rather than vertically, thereby creating more air space (voids) in the package. This observation has no supporting data but, if correct, would mean that the thicker pouches contained a higher proportion of air space to liquid, thereby making them correspond more closely in this respect to the treatments without brine than did the thinner, brine-packed samples. Thus, if brine addition "protected" the color, the effect would theoretically be greatest in samples having the highest proportion of brine. The actual results reported in Tables 15 and 19 are in keeping with this line of reasoning, since beans in thinner pouches with brine added (t_1b_2) had better color than thicker pouches with brine added (t_2b_2) and were also better in color than either thickness of pouch without brine added (t_1b_1 and t_2b_1).

Interaction of Superimposed Air Pressure Versus Brine Addition (PB)

Overall, results of these tests suggest that low superimposed air pressure, some brine addition, and a thin-profile pouch will reduce the color change in pouch-packed green beans that are processed under conditions comparable to those used in these experiments.

SUMMARY AND CONCLUSIONS

The effects of pouch thickness, brine addition and superimposed air pressure on processing time requirements and product quality have been evaluated. Thiamine content, color, and texture were the parameters used to evaluate quality of product.

Process lethality (F_o) was calculated by the Improved General Method (Schultz and Olson, 1940) at three different processing times. Regression analysis procedures were applied to predict the time of processing needed to assure an $F_o \geq 3.5$ minutes with 0.997 confidence coefficient.

The processing time varied from 10.24 to 12.91 minutes with a come-up time to process temperature of 250^oF of 5.0 ± 0.2 minutes.

The process time for 303 x 406 cans in steam at 250^oF in order to give the same F_o value was 12 minutes, with a come-up time of 1.0 minute.

Overall comparison of beans processed in pouches with those processed in cans showed statistically significant superiority for the former with respect to thiamine retention and texture, but no statistically significant difference in color.

Studying the effect of each factor (thickness, brine addition, and superimposed air pressure) on pouch product quality, the following general conclusions can be drawn:

Texture - within the range over which tested variables were studied, the use of a 0.75-inch thick package to which no brine is added and a superimposed air pressure during processing of 30 psig appears to provide optimum conditions for maximum textural firmness.

Thiamine - within the range over which tested variables were studied, package thickness did not affect thiamine retention. However, thiamine retention was significantly improved by use of 20 psig superimposed air pressure during processing and by packing the product without brine.

Color - overall, results of these tests suggest that lower superimposed air pressure, the addition of some brine, and the use of thinner-profile pouches all reduce color change in pouch-packed green beans. Variability of replicate color readings might have been reduced by grinding the product before measurement.

The long come-up time during processing was unavoidable because of process equipment limitations. Reduced come-up time can be achieved by using a retort with high-capacity heating and circulation of hot water. Overall process time could thereby also be substantially reduced.

For overall product quality, the best combination of pouch thickness, brine addition and superimposed air pressure may depend on the relative importance of each quality factor (color, texture, and thiamine retention) since optimum processing conditions are not identical for each quality factor.

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APPENDIX A

APPENDIX

Statistical Analysis

Two distinct statistical analyses were performed in this work. The first one was done to evaluate the general effect of the pouch treatments and the 303 can treatment on quality of processed green beans.

The second one was performed in order to evaluate the main effect factors and their interactions on quality of the processed green beans.

General Analysis of Variance

k = 9 treatments n = 10 observations

1. Mean of observation in the ith sample (i = 1,2,...K).

$$\overline{X}_i = \frac{1}{n_1} \sum_{j=1}^{n_1} X_{ij}$$

2. Standard deviation of observation in the ith sample.

$$S_1 = [(\sum_{j=1}^{n_i} X^2_{ij} - n_1\overline{X}_1^2) / n_1 - 1]^{1/2}$$

3. $\text{Sum}_1 = \sum_{j=1} X_{ij}$

4. Total sum of squares

$$TSS = \sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij}^2 - \frac{(\sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij})^2}{\sum_{j=1}^{k} n_1}$$

5. Treatment sum of squares

$$TrSS = \sum_{i=1}^{k} \frac{\left(\sum_{j=1}^{n_1} X_{ij}\right)^2}{n_i} - \frac{\left(\sum_{i=1}^{k}\sum_{j=1}^{n_i} X_{ij}\right)^2}{\sum_{i=1}^{k} n_i}$$

6. Error sum of squares

$$ESS = TSS - TrSS$$

7. Treatment degree of freedom

$$df_1 = K - 1$$

8. Error degree of freedom

$$df_2 = \sum_{i=1}^{k} n_i - K$$

9. Total degree of freedom

$$df_3 = \sum_{i=1}^{k} n_i - 1$$

10. Treatment mean square

$$TrMS = \frac{TrSS}{df_1}$$

11. Error mean square

$$EMS = \frac{ESS}{df_2}$$

12. The F ratio

$$F = \frac{TrMS}{EMS} \quad \text{(with degrees of freedom } df_1,\ df_2\text{)}$$

Analysis of variance for pouch treatments

Step I

Compute -

Correction term = C

Total SS = TSS

Treatment SS = TrSS

Error SS = TSS - TrSS

Step II

The treatment sum of squares is partitioned into components attributable to main effects and interactions.

Factors -

T - Thickness levels $t_1, t_2, \ldots, t_i$

P - Superimposed air pressure-levels $p_1, p_2, \ldots, p_j$

B - Brine addition-levels $b_1, b_2 \ldots, b_k$

r - replication 10

$$SS(P) = \frac{\sum_j (p_j)^2}{rtb} - C$$

$$SS(T) = \frac{\sum_i (t_i)^2}{rpb} - C$$

$$SS(B) = \frac{\sum_k (b_k)^2}{rpt} - C$$

$$SS(TP) = \frac{\sum_{i,j} (t_i p_j)^2}{rb} - C - SS(T) - SS(P)$$

$$SS(TB) = \frac{\sum_{i,k} (t_i b_k)^2}{rp} - C - SS(T) - SS(B)\ ,$$

$$SS(BP) = \frac{\sum_{k,j} (b_k p_j)^2}{rt} - C - SS(B) - SS(P)$$

$$SS(TPB) = \frac{\sum_{i,j,k} (t_i p_j b_k)^2}{r} - C - SS(T) - SS(P) - SS(B) - SS(TP) - SS(TB) - SS(PB)$$

Linear Regression Analysis

$$b = \frac{\Sigma x_i y_i - \frac{\Sigma x_1 \ \Sigma y_1}{n}}{\Sigma x^2{}_i - \frac{(\Sigma x_i)^2}{n}}$$

$$a = \frac{\Sigma y_i}{n} - b\,\frac{\Sigma x_i}{n}$$

$$r = \frac{\Sigma x_i y_i - \frac{\Sigma x_i \ \Sigma y_i}{n}}{[\Sigma x^2{}_i - \frac{\Sigma x_i)^2}{n}]^{1/2} \ [\Sigma y^2{}_i - \frac{(\Sigma y_i)^2}{n}]^{1/2}}$$

APPENDIX B

Table 17. Thiamine concentration in μg/gram[1] (dry weight basis) of processed green beans in pouches

Thickness = T	S. Imposed air pressure = P	Brine = B b_1	b_2	Total $b_1 + b_2$
t_1	p_1	55.90 $t_1p_1b_1$	49.58 $t_1p_1b_2$	105.48 t_1p_1
	p_2	49.60 $t_1p_2b_1$	43.20 $t_1p_2b_2$	92.80 t_1p_2
	Total p_1+p_2	105.50 t_1b_1	92.78 t_1b_2	198.28 t_1
t_2	p_1	54.47 $t_2p_1b_1$	50.68 $t_2p_1b_2$	105.15 t_2p_1
	p_2	48.79 $t_2p_2b_1$	44.96 $t_2p_2b_2$	93.75 t_2p_2
	Total p_1+p_2	103.26 t_2b_1	95.64 t_2b_2	198.90 t_2
Total $t_1 + t_2$	p_1	110.37 p_1b_1	100.26 b_2p_1	210.63 p_1
	p_2	98.39 p_2p_1	88.16 p_2b_2	186.55 p_2
	Total p_1+p_2	208.76 b_1	188.42 b_2	397.18 G

[1]Each value is a total of ten replicates of each treatment. Data from Table 5

Table 18. Texture in pounds force/gram[1] of green beans processed in pouches.

Thickness = T	Superimposed air pressure = P	Brine = B b_1	b_2	Total $b_1 + b_2$
t_1	p_1	7.21 $t_1p_1b_1$	6.11 $t_1p_1b_2$	13.32 t_1p_1
	p_2	7.68 $t_1p_2b_1$	5.11 $t_1p_2b_2$	12.79 t_1p_2
	Total p_1+p_2	14.89 t_1b_1	11.22 t_1b_2	26.11 t_1
t_2	p_1	5.49 $t_2p_1b_1$	5.93 $t_2p_1b_2$	11.42 t_2p_1
	p_2	4.71 $t_2p_2b_1$	6.69 $t_2p_2b_2$	11.40 t_2p_2
	Total p_1+p_2	10.20 t_2b_1	12.62 t_2b_2	22.82 t_2
Total t_1+t_2	p_1	10.70 p_1b_1	12.04 p_1b_2	24.74 p_1
	p_2	12.39 p_2b_1	11.80 p_2b_2	24.19 p_2
	Total p_1+p_2	25.09 b_1	23.84 b_2	48.93 G

[1] Each value is a total of ten replicates of each treatment. Data came from Table 10.

Table 19. Color ratio -a/b[1] of green beans processed in pouches.

Thickness = T	Superimposed air pressure = P	Brine = B b_1	b_2	Total $b_1 + b_2$
t_1	p_1	-0.752 $t_1p_1b_1$	-2.429 $t_1p_1b_2$	-3.181 t_1p_1
	p_2	-0.518 $t_1p_2b_1$	-1.305 $t_1p_2b_2$	-1.823 t_1p_2
	Total p_1+p_2	-1.270 t_1b_1	-3.734 t_1b_2	-5.004 t_1
t_2	p_1	-0.575 $t_2p_1b_1$	-0.927 $t_2p_1b_2$	-1.502 t_2p_1
	p_2	-0.818 $t_2p_2b_1$	-0.369 $t_2p_2b_2$	-1.187 t_2p_2
	Total p_1+p_2	-1.393 t_2b_1	-1.296 t_2b_2	-2.689 t_2
Total $t_1 + t_2$	p_1	-1.327 p_1b_1	-3.356 p_1b_2	-4.683 p_1
	p_2	-1.336 p_2b_1	-1.674 p_2b_2	-3.010 p_2
	Total p_1+p_2	-2.663 b_1	-5.030 b_2	-7.693 G

[1]Each value is a total of ten replicates of each treatment. Data came from Table 13.