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The effect of gas plasma irradiation on the dehulling and resulting chemical and physical properties of soybeans

Chien-Ning Wang

To the Graduate Council:

I am submitting herewith a thesis written by Chien-Ning Wang entitled "The effect of gas plasma irradiation on the dehulling and resulting chemical and physical properties of soybeans." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Melvin R. Johnston, Major Professor

We have read this thesis and recommend its acceptance:

JImmie L. Collins, Woodrow W. Overcast, Ivon E. McCarty

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

March 18, 1969

To the Graduate Council:

I am submitting herewith a thesis written by Chien-Ning Wang, entitled "The Effect of Gas Plasma Irradiation on the Dehulling and Resulting Chemical and Physical Properties of Soybeans." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology.

Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice Chancellor for
Graduate Studies and Research

THE EFFECT OF GAS PLASMA IRRADIATION ON THE DEHULLING AND RESULTING CHEMICAL AND PHYSICAL PROPERTIES OF SOYBEANS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Chien-Ning Wang

March 1969

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ABSTRACT

A study was made to ascertain the chemical and physical changes and the amount of dehulling induced by varying the electrical current in the gas plasma irradiation of two varieties of soybeans.

Moisture content, the amount of cracked beans and the amount of dehulling were determined on samples treated with 0, 40, 80, and 120 milliampers (ma.) and on the control. Crude lipids, total and water soluble proteins, trypsin inhibitor activity of soybeans and the iodine and peroxide numbers of soybean oil were determined on samples treated with 40 and 120 ma. and on the control.

The results of the experiment showed that gas plasma irradiation increased the number of cracked beans and improved the dehulling effect of soybeans. The treatment resulted in a loss of moisture and weight in the soybeans. Gas plasma irradiation increased the water sorption of the soybean. However, deformation and fragility were found in the soaked beans. At the lower treatment level (40 ma.), no change was found in the extractability of lipids and total and soluble protein contents in the soybeans. No difference was found in iodine and peroxide numbers of the oil from the soybeans at the two treatment levels (40 and 120 ma.). Slight decrease in extractability of lipids and total protein content were found in beans treated with 120 ma. Higher treatment intensity (120 ma.) resulted in a destruction of protein; there was both a lower soluble protein content and less trypsin inhibitor in the soybean

extracts. The changes induced by the gas plasma irradiation in the Soylima beans were more manifest than that in the Lee soybeans, and the degree of changes increased as the treatment energy level was raised.

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CHAPTER I

INTRODUCTION

With the increase in population, an urgent need has arisen for greater quantities of the more nutritious foods. The principal food shortage is protein, although fat, carbohydrates and vitamins also are deficient in many areas. A low-cost source for high-quality protein has gained world-wide interest. The soybean has become tremendously important in recent years due to its high content of protein and fat. In 1967, the estimated world production of soybeans was 36,277,000 metric tons (2). The United States produced about 73 percent and mainland China furnished over 19 percent of the world production (2). In 1966, soybeans replaced cotton as the number one cash crop in the United States (35).

In the soybean processing industry dehulling is one of the important processing steps. Conventionally, it is done by cracking the beans and then removing the hulls by screening, aspiration or by other means. During the separation process some of the hulls adhere to the cotyledons and can not be separated. In some cases, some of the finely ground meat is removed with the hull.

Little work has been conducted on the improvement of the dehulling process of soybeans. This study was undertaken to determine the amount of dehulling induced by varying the electrical current in the gas plasma irradiation and to ascertain the chemical and physical changes of the irradiated soybeans.

CHAPTER II

REVIEW OF LITERATURE

I. HISTORY OF SOYBEAN UTILIZATION

The early history of the soybean, Glycine max (L.) Merrill, is not clear. Ancient Chinese literature reveals that the soybean was cultivated extensively and valued highly as a food centuries before written records were kept. The first written record of the soybean plant was dated 2838 B. C. and for many centuries the culture of soybeans was confined to the Asian countries. However, after World War II the production of soybeans spread rapidly into the Western World (26, 32).

According to old Chinese records, the soybean was used as food and a remedy for certain human ills. No mention has been found of soybean oil in ancient Chinese literature. Morse (26) concluded that the crushing of soybeans for oil originated comparatively in recent times.

The soybean has been utilized for many centuries by the oriental people in the preparation of a great variety of fresh, fermented and dried food products (25, 37, 42) which form an indispensable part of their diet.

According to Piper and Morse (26, 32), the earliest record about the soybean in the United States was written by Mease in 1804. Before World War II, the United States was a net importer of oil seed crops for its animal feed and oil uses. The greatest production increases occurred between 1941 and 1942 due to the impetus of the war. The acreage, yield, and production have moved upward continuously since that time (16). In recent years, mainly the United States and mainland China have produced the majority of the world's soybeans. Small production is centered in Brazil, Russia, Japan, Canada, and Korea (2).

Initially, soybeans were grown in the United States, primarily as a forage and pasture crop, over half of the acreage was used for hay, grazing and green manure. The soybean harvested for beans were used for seed and feed for livestock. After 1935, the soybean was used predominantly in the processing industry (16).

Between 1966 and 1967, 63 percent of the soybeans was used for oil, and 30 percent was exported. In 1966, over 90 percent of the domestic soybean oil was used in food products, such as margarine and shortening. A small percentage was used in paint, varnish and other non-food uses. About 79 percent of the total meal supply was utilized as feed (2). Soybean protein which was used in industry for glues, paper-coating adhesives, textile size plastics, textile fibers and other uses were of minor importance (10, 28).

The use of soy protein as flour, grits, flakes, concentrates, or isolates has become increasingly important in the food industry. Nowadays, many forms of soy protein are used widely in bakery products, breakfast cereals, macaroni and spaghetti products, soups, snack items, and baby foods. They are also incorporated into prepared mixes, meats, candies, and high protein drinks to improve the quality and the nutritional value of the products (9, 13, 36).

Products resembling different meat items are produced commercially from soy protein by many food companies under different trade names (13, 15, 17, 24, 36, 38, 43, 44, 45). Most of them provide flavor and texture similar to real meat products.

II. COMPOSITION OF THE SOYBEAN SEED

The composition of the soybean seed is very complex. It is modified by genetic factors and environment. In general, the soybean seed consists of proteins, lipids, carbohydrates and minerals.

Bailey _et al_. (6), using hundreds of samples, found that the soybean consists of 6 to 8 percent hull, 90 to 92 percent cotyledons and 1.5 to 2 percent embryo.

The composition of ten varieties of soybeans grown in five locations during 1936 to 1940 were studied by Catter and Hopper (1). The results, except for iodine number, are expressed as percentage of the dry weight and are shown in Table I.

An early study of the soybean protein by Osborne and Clapp (31) showed that the amino acids in the soybean protein are very similar to that of casein. Bondi and Birk (8) reported that no major differences existed between the animal and the plant protein in the rates of liberation of amino acids by _in vitro_ digestion with proteolytic enzymes. Many studies showed that the methionine was the limiting factor in the

TABLE I

COMPOSITION OF SOYBEAN SEED REPORTED BY CATTER AND HOPPER

Constituents	Low	High	Average
Protein (N × 6.25)	36.62	53.19	42.88
Oil (ether extract)	14.95	22.95	19.63
Ash	3.67	5.90	4.99
Crude fiber	4.34	7.67	5.52
Sugar (as sucrose)	2.70	11.97	7.97
Iodine number of the oil	103.9	143.2	128.6

nutritive value of the soybean protein. This defect can be overcome by the supplement of methionine in the soybean protein diet. Fomon (14) found that infants fed a soybean formula had the same rate of growth and as much retention of nitrogen as those of normal, full term infants of similar ages who were fed human milk.

Trypsin inhibitor in the raw soybean has been demonstrated as a growth-inhibiting factor in rats and chicks by many workers (1, 22). Studies on the extraction, separation, and the characteristics of soybean trypsin inhibitor have been carried out extensively. Since the soybean inhibitor was found to be relatively heat sensitive, the nutritional value of the soybean could be improved by heating. Van Buren et al. (40) found that the nutritional value of soybeans is inversely proportional to the trypsin inhibitor content and that heating resulted in a destruction of the inhibitor. They suggested that the level of trypsin inhibitor remaining in the soy product could serve as an index of adequacy of the heat treatment.

Markley and Goss (23) indicated that over 95 percent of the fatty material was found in the cotyledons and the remainder, in the germ and the hull. The lipids consist principally of the glycerides of saturated and unsaturated fatty acids. Other lipid materials include phosphatides, sterols, long chain hydrocarbons, alcohols and ketones, free fatty acids, pigments, vitamins, and an antioxidant. Small amounts of non-lipid, gummy or mucilaginous substances are present also.

Piper and Morse (32) reported that the soybean contains many different carbohydrates, which account for 22 to 29 percent of the bean. The forms of carbohydrates include celluloses, free sugars, pentosans, hexosans, glycosides, and probably other forms. Mature soybeans are practically free of starch.

The content of inorganic constituents compiled from various literature sources reported by Morse (27) showed that potassium, phosphorus, sulfur, sodium, calcium, magnesium, chlorine, iron, manganese, zinc, copper, aluminum, and iodine were present in soybean seeds.

Circle (12) indicated that urease, allatoninase, amylase, ascorbic acid oxidase, carboxylase, catalase, β-glycosidase, lipase, lipoxidase, phytase, protease, and uricase have been found in the soybean by different investigators.

Vitamins A, B-complex, D, E, and K have been found in the soybean by various workers as reported by Markley and Goss (23). Dry soybeans were reported to be relatively low in vitamin C.

III. GAS PLASMA TREATMENT OF SEEDS

Attempts have been made since the discovery of electricity to ascertain the effects of electrical treatment of biological materials. According to Andrew (3), Lingerfelt (21), and Lakshmanan (20), early experiments conducted by different workers showed that electrical treatment increased the production and improved the growth of many plants such as potatoes, strawberries, wheat, corn, beets and others. However, contradictory results were also reported (3, 20, 21).

In recent years, gas plasma has been used as a method of exposing biological materials to electrical radiation. The principle of the glow discharge as stated by Howatson (18) was based upon the ionization of a gas medium resulting from the current produced when an electrical current was applied between two electrodes. It was called glow discharge when the gas discharge carried a current from 10^{-6} to 10^{-1} amperes. The term plasma was used to denote gas which contained both positive and negative particles but had no net charge. The luminosity resulted from the excitation of the gas molecules. As reported by Nelson _et_ _al_. (29), seeds that were held in the gas plasma of an electric-glow discharge were subject to a wide variety of radiation, including radio-frequency, infrared, visible light and ultraviolet energy.

Experiments by Andrew (3) on corn, Lakshmanan (20) on four varieties of soybean, Lingerfelt (21) on the Ogden soybean and on corn, and Webb _et_ _al_. (41) on cotton seed, showed that gas plasma treatment of the respective seeds resulted in early germination and increased the water sorption. The response of different seeds varied.

Roseman _et_ _al_. (33) found that gas plasma treatment resulted in a marked increase in the amount of water sorption and a greater swollen appearance of the irradiated rice over the control when they were immersed in hot water. They also found that gas plasma irradiation resulted a less amount of oil and a smaller iodine number in the oil from the irradiated rice bran than that of the non-irradiated samples (34).

Lingerfelt (21) found that treated soybean seeds contained 10.2 to 27.4 percent more soluble amino nitrogen than untreated seeds.

Ark and Parry (5) reported that Frolov found that the electrical treatment decreased the amount of starch present in seeds and increased their sugar content. Unspecified changes also were reported in the albumin.

IV. DEHULLING OF SOYBEANS

Markley and Goss (23) and Burnett (9) mentioned that for human consumption it was necessary to separate the hull from the cotyledon in order to get an acceptable color in the oil and in the flour. Most commercial practices crack the bean by corrugated rollers. The hull is removed then by winnowing, screening, air suction or other means. In this operation, the initial cracking should be sufficiently coarse to produce a minimum of "fines" so that the finely ground meat would not be lost.

Very little work has been done on the dehulling process of soybeans. Bollens and Kruse (7) have patented a method of treating soybeans with a relative dry gaseous atmosphere having a temperature of above 300°F for a period of time sufficiently long enough to heat the hull without materially raising the internal temperature of the beans. The treatment improved the dehulling effect.

Another treatment of soybeans before dehulling was patented by Ueda (39) in Japan. The beans in a metal wire container less than 100 mm.

in thickness, were treated with 60°-100°C moisture-regulated air for less than 10 minutes. The treatment increased the amount of dehulled beans more than three times over untreated beans.

CHAPTER III

MATERIAL AND METHODS

Soybeans

Soylima. Mature seeds were obtained from Little Creek Sanitarium, Knoxville, Tennessee, in 1966. The variety of this soybean has not been identified. The name, Soylima, was derived from the fact that the green immature bean was similar to the small lima bean in appearance.

Lee variety. Mature seeds were received from The University of Tennessee Test Plot, Knoxville, in 1967. The crop was grown from certified seeds.

Gas Plasma Treatment

The apparatus used in the present experiment to treat the beans was the same one that was used by Webb *et al.* (41) to treat cotton seeds. The dimensions of the glass irradiation chamber was 24-inches in length and 48 mm. in diameter. Iron electrodes were used at both ends of the tube. Thirty grams of soybeans were treated at each time. The beans were leveled on the bottom of the glass tube. The treatment was carried out under a pressure of 5 mm. mercury for 5 minutes with a frequency of 60 cycles per second. The electrical currents were controlled at 0, 40, 80, and 120 milliamperes (ma.)for both varieties. At 0 ma., no electrical current was applied to the electrodes, the other treatment conditions were the same as the other level treatments. No treatment was conducted on the control samples. The treatment was carried out in the United States Department of Agriculture-operated Engineering Laboratory at The University of Tennessee, Knoxville.

Temperature Measurement

Immediately after the treatment, the soybeans were put into an insulated beaker and the temperature of the beans was measured. Four thermocouples placed at different locations were used to measure the temperature of each batch of samples (30 g). The average temperature of the beans was calculated from four thermocouple readings of five batches of soybeans.

Weight Loss

The weights of the soybean before and after treatment were recorded. The amount of weight decreased after the treatment was calculated as weight loss.

Preparation of Samples for Analyses

Samples which received four levels of electrical current and the control were used in the dehulling and moisture tests. Dehulled soybeans with 40 and 120 ma. treatments and the control beans were used in the oil extraction tests. Tests to determine the content of protein, amount of trypsin inhibitor activity and sorption of water were conducted on beans with hull that received the 40 and 120 ma. treatments and on the control beans. All samples, except for the whole beans used for the water sorption test, were ground in a Wiley Mill to pass through a number 20 mesh screen. For the moisture, the percentage of cracked beans and the dehulling effect, triplicate tests were made; for other determinations, duplicate tests were made.

Dehulling Test

Fifty grams of the treated soybeans were used for each dehulling test. Number of cracked beans were counted before dehulling. The dehulling tests were performed by the device shown in Figure 1.

To conduct the dehulling tests, fifty grams of beans were put on the sand paper (Garnet type, number 60 from Carborundum, Niagara Falls, New York) at area B'- B', and a 12 × 17 inch board covered with the same kind sand paper was placed on top of the soybeans such that points A - A on the board were in line with points B' - B'. Fifty pounds were put on the center area of the board and the board was moved slowly forward by use of a motor until points A - A on the board reached points A' - A' on the sand paper. The distance between A' and B' was one foot. The time required to move the board one foot was seven seconds. The weights were removed and the number of the completely dehulled soybeans were counted.

Moisture

The moisture of dehulled and ground samples was determined by the method in AOAC (4) for soybean flour.

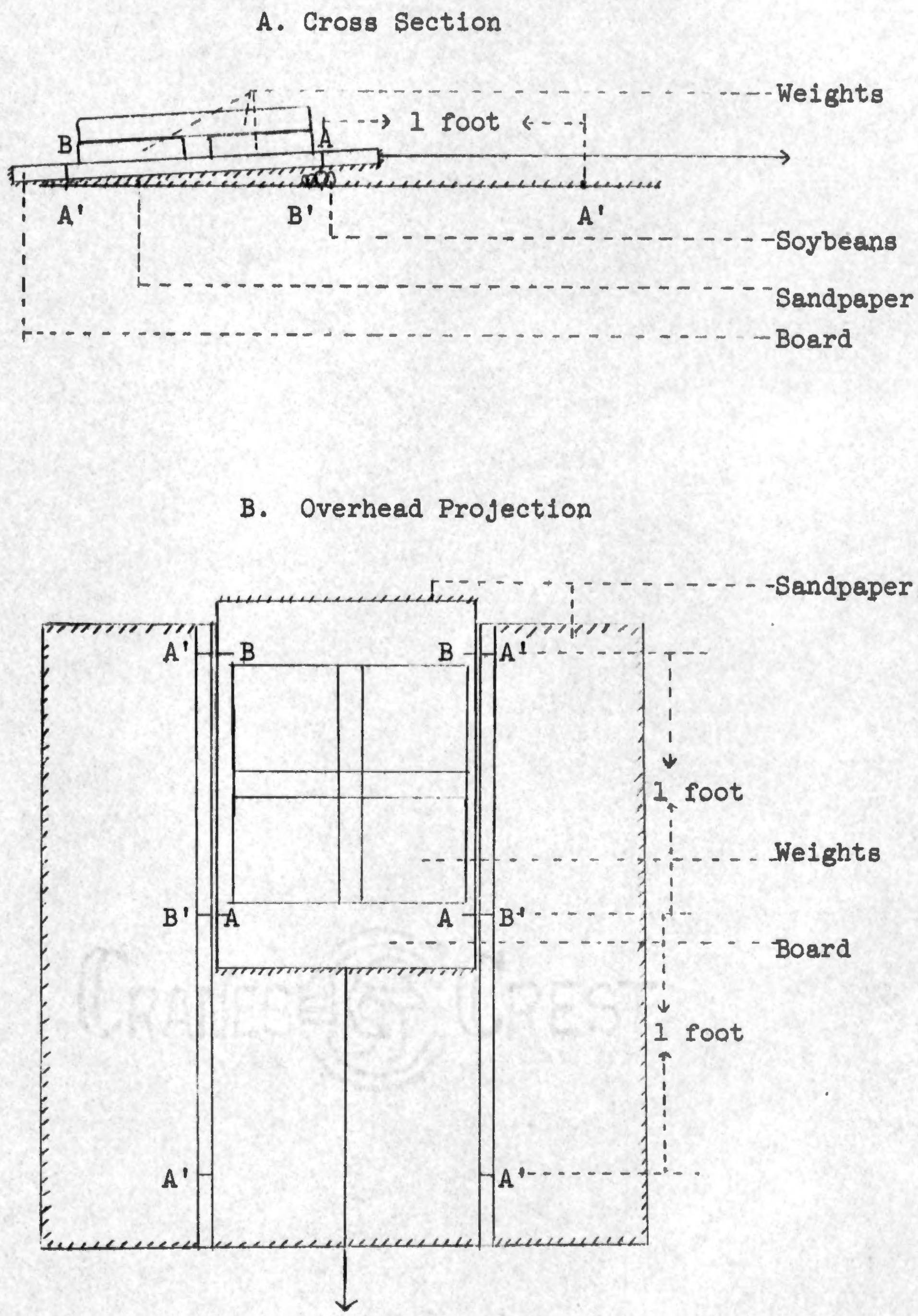

Figure 1. Device for Dehulling the Soybeans After Treatment in the Gas Plasma Discharge Tube.

Lipid Determination and Oil Extraction

A mixture of chloroform and methanol (2:1) was used as the extracting solvent for both lipid determination and oil extraction. About 2 g of dehulled and ground soybeans were extracted in a Goldfisch extractor for 20 hours. The extracted materials were dried to constant weight in the Goldfisch cups in a vacuum oven under 20 inches mercury partial vacuum at 65° - 70°C. The percentages of the lipids were then calculated.

For oil extraction, a Soxhlet extractor was used. Twenty-five to 30 g of dehulled and ground beans were extracted in each thimble for 20 hours. The extracted material was dried in an oven under a 20 inches mercury partial vacuum at 65° - 70°C for 12 hours. The clear oil was collected in brown bottles and stored under nitrogen for the determinations of the iodine number and peroxide number.

Iodine Number

The iodine number was determined by the Hanus method according to the procedure in AOAC (4) for oils and fats.

Peroxide Number

The procedure for determining the peroxide number was similar to the method in AOAC (4). About 0.5 g of oil was weighed into a 250 ml Erlenmeyer flask, into which 10 ml of glacial acetic acid and chloroform (2:1) mixture and 1 ml saturated KI were added. The flask was corked and heated in boiling water for 30 seconds. Fifty ml of distilled water were added and then the mixture was titrated with 0.002 N $Na_2S_2O_3$ to an end point by using 2 ml of a one percent starch solution as the indicator. The peroxide number was calculated according to AOAC procedure (4).

Total Protein

The total nitrogen was determined by use of the Kjeldahl method (4). The ground sample was dried in a vacuum oven at 65° - 70°C and 20 inches of mercury partial vacuum overnight before determination. The percentage of protein was calculated by multiplying the percentage of nitrogen by 6.25.

Water Soluble Protein

Samples were dried in a vacuum oven for 12 hours at 65° - 70°C before determination of the water-soluble protein content. The amount of water soluble nitrogen was determined by using the modified method in AOAC (4) for wheat flour. About 5 g of samples were weighed into a 300 ml plastic bottle, to which 200 ml of distilled water were added. The bottle was stoppered and shaken on a wrist-action shaker for an hour and then centrifuged at 1,200 rpm for 15 minutes. The supernatant was filtered through a pad of fine asbestos on a 2-inch Buchner funnel. The protein content in 50 ml of filtrate was determined by use of the Kjeldahl method as total protein.

Trypsin Inhibitor

The trypsin inhibitor activity of the soybean was determined by measuring the tryptic activity in a solution containing trypsin, the soybean extract and a gelatin substrate. The procedure for the determination of tryptic activity was similar to the Gelatin-Formol method used by Kunitz (19) and Northrop (30). A one-gram ground sample was placed in a 50 ml Erlenmeyer flask into which 20 ml of 0.0025 N HCl was added. The flask was stoppered and placed on a wrist-action shaker for 30 minutes, and centrifuged at 1,500 rpm for 15 minutes. The same amount of trypsin solution (100 mg of trypsin from Worthington in 100 ml of 0.0025 N HCl) was mixed with the supernatant of soybean extract. The tryptic activity in the mixture was determined as follows:

One ml of the mixture was placed into a 50 ml tube with 5.0 ml of 2.5 percent gelatin dissolved in 0.1 M phosphate buffer, pH 7.6, and held at 35°C for 20 minutes. One ml of formaldehyde, 0.5 ml of 0.1 percent phenolphthalein in 95 percent alcohol, and 1.0 ml of 0.1 N NaOH were added in this order. The mixture was titrated with 0.02 N NaOH to the color of the standard. The color standard which developed a maximum pink color was prepared by mixing 5 ml of 2.5 percent gelatin, 1 ml of formaldehyde, 3 ml of water, 1 drop of 0.1 percent phenolphthalein and several drops of 1.0 N NaOH.

The tryptic activity was expressed in $(\text{Trypsin Units})^{\text{Gelatin Formol}}$ or $(\text{T. U.})^{\text{Gel. F.}}$, which expressed the milliequivalents of acid formed per minute in 6 ml of digestion mixture.

Water Sorption

About 10 g of treated whole beans were used for each determination of water sorption. The weighed sample was placed into a 250 ml beaker and 100 ml of distilled water were added. The beans were allowed to soak for 10, 30, 60, and 120 minutes. After the soaking period, the beans were poured onto a number 20 seive and allowed to drain for 2 minutes. During draining, the water trapped between the hull and the cotyledon was removed by squeezing slightly. The increase in the weight of the soaked beans was calculated as the percentage of water absorbed.

CHAPTER IV

EXPERIMENTAL RESULTS

The summary of the analysis of variance of the effect of gas plasma treatment and variety on the physical properties of soybeans is shown in Table II, and that on the chemical properties of soybeans is shown in Table III. The summary of the analysis of variance of the gas plasma treatment, variety, and soaking time on the water sorption of soybeans is shown in Table IV.

The results showed that there were significant differences between the two varieties in both physical and chemical properties and water sorption. No difference was found among treatment levels in extractable lipids, the total protein of soybeans or the iodine and the peroxide numbers of the soybean oil. Differences among treatments in moisture content, weight loss, amount of cracked beans, dehulled beans, water soluble protein, tryptic activity and water sorption were significant.

Temperature

The temperature of the soybeans immediately after treatment (Table V) varied with the level of the gas plasma treatment. A higher temperature resulted at the higher intensity treatments. The temperature of the beans in the control was the same as the room temperature where the beans were treated. Within some of the treatments, the temperature was different between the two varieties.

TABLE II

SUMMARY OF ANALYSIS OF VARIANCE FOR THE EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PHYSICAL PROPERTIES OF SOYBEANS

Source of Variance	D.F.	Mean Squares			
		% Weight Lost	% Moisture	% Cracks	% Dehulled
Among Treatments	4	2.291**	1.170**	11378.110**	1197.017**
Between Varieties	1	0.069*	0.296*	1482.632**	40494.835**
Among Replications	2	0.008	0.500**	5.830	21.807
Residual Error	22	0.014	0.044	115.499	98.299

*Means significant at 0.05 level of probability.

**Means significant at 0.01 level of probability.

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE FOR THE EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE CHEMICAL PROPERTIES OF SOYBEANS

Source of Variance	D.F.	Mean Squares					
		% Lipids	Iodine Number	Peroxide Number	% Total Protein	% Soluble Protein	(T.U.)Gel.F. $\times 10^{-3}$ Trypsin Activity
Among Treatments	2	0.659	0.336	0.081	0.074	16.782**	0.065**
Between Varieties	1	7.120**	3.154*	39.457**	2.818**	4.805**	0.036*
Among Replications	2	4.012**	0.142	5.414**	0.145*	0.445	0.014
Residual Error	12	0.212	0.630	0.594	0.019	0.209	0.004

*Means significant at 0.05 level of probability.

**Means significant at 0.01 level of probability.

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE FOR THE EFFECT OF GAS PLASMA TREATMENTS, VARIETY, AND SOAKING TIME ON THE WATER SORPTION OF SOYBEANS

Source of Variance	D.F.	Mean Squares of Percentage of Water Absorbed
Among Treatments	2	10600.945**
Between Varieties	1	2636.655**
With Time	3	16846.592**
Among Replications	2	1.806
Residual Error	63	89.967

**Means significant at 0.01 level of probability.

TABLE V

MEAN TEMPERATURE OF THE SOYBEANS IMMEDIATELY AFTER GAS PLASMA TREATMENT

	Treatments									
	Control		0 ma.		40 ma.		80 ma.		120 ma.	
Replications	A	B	A	B	A	B	A	B	A	B
I	83.0	81.0	82.6	80.0	131.6	120.2	166.4	149.6	180.4	178.6
II	80.0	79.0	78.8	78.0	117.2	128.9	155.4	161.4	181.1	171.5
III	71.0	71.0	73.8	73.0	123.8	117.8	160.1	152.2	180.5	184.5

A is Soylima, B is Lee soybeans.

Each temperature (^{o}F) value is the mean of twenty readings.

Weight Loss

The weight loss of the soybeans (Table VI) by the gas plasma treatment was increased significantly as the treatment level was raised. The loss by the Soylima beans after treatment was significantly greater than the Lee soybeans. The highest weight loss was found in samples treated with 120 ma., with an average loss of 1.51 percent.

Moisture Content

The moisture content in the dehulled Soylima seeds was significantly higher than that in the dehulled Lee soybeans (Table VII). As the treatment level was increased, the moisture content decreased significantly. However, the moisture level was not different between 40 ma. and 0 ma. and the control. The moisture content in the third replication (III) was higher than that of the first (I) and the second (II) replications.

Cracks in Seed Coat

The count of cracked soybeans was increased significantly as the level of gas plasma treatment was raised (Table VIII). The percentage of cracked beans on the Soylima seeds was higher than that of the Lee soybeans. No difference was found between soybeans treated at the 120 ma. and 80 ma. levels, and between the control and 0 ma. level. At higher levels of treatment (120 and 80 ma.) the percentage of cracked beans on the Soylima seeds was lower than that of the Lee variety whereas at the lower levels, the situation was reversed.

TABLE VI

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT WEIGHT LOSS OF THE SOYBEANS IMMEDIATELY AFTER TREATMENT

Treatment	Mean	Variety	Mean
Control	0.00^{e}	Soylima	0.74^{m}
0 ma.	0.24^{d}	Lee	0.64^{n}
40 ma.	0.61^{c}		
80 ma.	1.10^{b}		
120 ma.	1.51^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE VII

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT MOISTURE CONTENT OF DEHULLED SOYBEANS

Treatment	Mean	Variety	Mean
Control	7.22^{a}	Soylima	6.86^{m}
0 ma.	7.06^{ab}	Lee	6.66^{n}
40 ma.	6.85^{b}		
80 ma.	6.55^{c}		
120 ma.	6.11^{d}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE VIII

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY
ON THE PERCENT CRACKED SOYBEANS

Treatment	Mean	Variety	Mean
Control	6.90^{c}	Soylima	62.32^{m}
0 ma.	13.20^{c}	Lee	48.26^{n}
40 ma.	63.32^{b}		
80 ma.	94.45^{a}		
120 ma.	98.58^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

The size of the Soylima seeds was not as uniform as that of Lee variety. Thirty grams of Soylima seeds consisted of 94 to 106 beans; for the Lee variety, 171 to 178. The cracked seed coats on the Soylima were found primarily on the larger seeds.

Dehulling

The dehulling effect was significantly increased by the gas plasma treatment (Table IX). The percentage of dehulled beans increased as the treatment level was raised. Dehulling of the Soylima seeds was more effective than that on Lee soybeans. The percentage of dehulled soybeans treated with 40, 80, or 120 ma. were significantly higher than that for the control and the soybeans treated with partial vacuum (0 ma.). No difference was found among samples treated at 40, 80, and 120 ma. and between samples treated with 0 ma. and the control.

Lipids

The extractable lipids in the Soylima beans was higher than that in Lee soybeans (Table X). No difference was found between samples treated with 40 ma. and 120 ma., and with 40 ma. and the control. Samples treated with 120 ma. contained 0.65 percent less extractable lipids than the control. The lipid content in the third replication was lower than that in the other two replications.

Iodine Number

No significant difference was found in the iodine number of the oil from different treatment levels, including the control samples

TABLE IX

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT DEHULLED SOYBEANS

Treatment	Mean	Variety	Mean
Control	24.92^{b}	Soylima	79.52^{m}
0 ma.	32.30^{b}	Lee	6.04^{n}
40 ma.	47.82^{a}		
80 ma.	52.78^{a}		
120 ma.	56.08^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE X

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT LIPIDS OF DEHULLED SOYBEANS

Treatment	Mean	Variety	Mean
Control	27.95^{a}	Soylima	26.97^{n}
40 ma.	27.55^{ab}	Lee	28.23^{m}
120 ma.	27.30^{b}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

(Table XI). The overall mean iodine number for Soylima bean oil was 133.40, and for Lee soybean oil, 132.56.

Peroxide Number

The peroxide number of the oil from the Soylima beans was higher than that from the Lee variety (Table XII). No difference was found among the treated samples and the control. The peroxide number for the second replication was lower than the other two replications.

Total Protein

The total protein content in the Lee soybeans was higher than that of the Soylima beans (Table XIII). Higher amounts of protein were found in samples treated with 120 ma. level than those treated with 40 ma. level. However, no difference was found between soybeans at 120 ma. and the control or between those at 40 ma. and the control.

Soluble Protein

The water soluble protein content in the Lee variety was higher than that of the Soylima beans (Table XIV). As the treatment intensity was increased the amount of water soluble protein in the beans was decreased. A significantly lower soluble protein content was found in samples treated with 120 ma. than in those treated with 40 ma. and the control. There was no difference in content of soluble protein between the control and 40 ma.-treated samples.

TABLE XI

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE IODINE NUMBER OF THE SOYBEAN OIL

Treatment	Mean	Variety	Mean
Control	132.74^{a}	Soylima	133.40^{m}
40 ma.	132.99^{a}	Lee	132.56^{n}
120 ma.	133.21^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE XII

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PEROXIDE NUMBER OF THE SOYBEAN OIL

Treatment	Mean	Variety	Mean
Control	4.06^{a}	Soylima	5.48^{m}
40 ma.	4.08^{a}	Lee	2.52^{n}
120 ma.	3.87^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE XIII

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT TOTAL PROTEIN OF SOYBEANS

Treatment	Mean	Variety	Mean
Control	44.01^{ab}	Soylima	43.60^{n}
40 ma.	43.88^{b}	Lee	44.39^{m}
120 ma.	44.10^{a}		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE XIV

EFFECT OF GAS PLASMA TREATMENTS AND VARIETY ON THE PERCENT SOLUBLE PROTEIN OF SOYBEANS

Treatment	Mean	Variety	Mean
Control	18.91[a]	Soylima	17.20[n]
40 ma.	18.44[a]	Lee	18.23[m]
120 ma.	15.80[b]		

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

Trypsin Inhibitor

The higher the tryptic activity in the mixture of the soybean extract and the trypsin was the lower the amount of trypsin inhibitor present in the soybean (Table XV). The tryptic activity in samples containing 120 ma.-treated soybean extract was higher than those containing 40 ma.-treated and the control soybean extracts. No difference existed between the latter extracts. A higher tryptic activity was found in the digestion mixture containing Soylima bean extract than that containing Lee soybean extract.

Water Sorption

The amount of water absorbed by soybeans of both varieties increased significantly with the time of soaking (Table XVI). The treated soybeans absorbed more water than beans of the control. In the Lee variety, the amount of water absorbed increased as the intensity of the treatment was increased. The amount of water absorbed in Soylima seeds treated at 120 ma. was not as great as the amount absorbed at 40 ma. level after soaking 30 minutes or longer. Soylima seeds absorbed more water than the Lee soybeans. No difference was found between samples treated at two different levels.

TABLE XV

EFFECT OF GAS PLASMA TREATMENTS ON THE ABILITY OF EXTRACTS FROM TWO VARIETIES OF SOYBEANS TO INHIBIT THE ACTIVITY OF TRYPSIN

Treatment	Mean	Variety	Mean
Control	0.60^{b}	Soylima	0.70^{m}
40 ma.	0.58^{b}	Lee	0.61^{n}
120 ma.	0.77^{a}		

The trypsin activity unit is $(\text{T. U.})^{\text{Gel.F.}} \times 10^{-3}$.

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

TABLE XVI

EFFECT OF GAS PLASMA TREATMENT, VARIETY AND SOAKING TIME ON THE PERCENT WATER ABSORBED BY THE SOYBEANS

Treatment	Mean	Variety	Mean	Time in Minutes	Mean
Control	42.94^{b}	Soylima	73.21^{m}	10	34.45^{k}
40 ma.	77.88^{a}	Lee	61.10^{n}	30	55.46^{j}
120 ma.	80.65^{a}			60	71.82^{i}
				120	106.90^{h}

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.

CHAPTER V

DISCUSSION

Due to the partial vacuum of the tube and the heat generated from the gas plasma irradiation, moisture loss occurred in the treated soybeans. The loss increased as the intensity of the treatment was increased. A decrease in weight and moisture content was found in the treated samples.

Gas plasma irradiation increased the number of cracked beans in the two varieties used. Loosening of the hull from the cotyledon was observed in the treated beans, and more hulls were loosened from beans receiving the higher levels of radiation. Webb et al. (41) reported that broken surfaces were found on the gas plasma-irradiated cotton fibers. They indicated that the broken surface area probably resulted from localized high temperature effects. This same effect could have caused the cracks to occur in the hulls of the soybeans.

The degradation of waxes, which had been found in the cotton fiber and cottonseeds (41), probably also occurred in the soybeans treated with gas plasma irradiation. The cracks on the hulls and the degradation of waxes may have been the explanation for the rapid water sorption in the treated soybeans.

The cotyledons of soybeans treated with gas plasma split into halves after they were soaked for 30 minutes. The majority of the treated beans appeared deformed and fragile after soaking for 60 minutes.

The deformation and fragility of the soaked beans increased as the length of soaking time and the intensity of treatment were increased. The deformation of the soaked beans was more serious in the Soylima than in the Lee variety. The untreated soaked beans were only swollen in size. This phenomenon indicated that unknown structural changes were induced by the gas plasma irradiation.

After the dehulling process, all of the hulls were loosened from the cotyledons on the Lee soybeans treated with 120 ma., and a majority of the hulls were loosened when the 80 ma. level treatment was applied. Most of the Soylima seeds which were not dehulled were the smaller seeds.

The difference in the shape of the two varieties of soybeans was the major cause of the significant difference in dehulling effects. The resistance of the flat-type Soylima seeds to the moving board during dehulling process (Figure 1, page 14) caused the separation of the hulls from the cotyledons. The round-shaped Lee soybeans rolled along with the board and less friction was available to remove the hulls from the cotyledons.

The amount of lipids extracted from the beans by the mixture of chloroform and methanol was much higher than the amount extracted by ether as reported by Catter and Hopper (11). Methanol may have extracted materials other than lipids from the soybean. The gas plasma irradiation in the experiment tended to reduce slightly the solubility of certain extractable material in the solvent. The reduction in the extractability of oil from soybeans was not as much as that reported by Roseman <u>et al.</u> (34) from rice bran.

The iodine number of the soybean oil was found to be within the range reported by Catter and Hopper (11). The result indicated that double bond breakage or polymerization in fatty acids were not induced by gas plasma irradiation. This is not in compliance with the report by Roseman et al. (34), who found reduction of iodine number in the oil from gas plasma-irradiated rice bran.

The observation on the peroxide number of soybean oil may indicate that the gas plasma treatment did not change the rancidity susceptibility of the oil from the treated soybean during the experimental period. No report of research concerning the effect of gas plasma irradiation on the peroxide number of lipids and oil could be found in the literature.

The amount of soluble protein, as determined by determining the total nitrogen, was reduced at high intensity treatment (120 ma.). No change was found at low intensity (40 ma.) level. These results were not in agreement with the result reported by Lingerfelt (21), who found that the soluble amino nitrogen, which amounted to over 90 percent of the total nitrogen in the soybean (12) was increased with a lower intensity (less than 40 ma.) and a pressure of 1 mm mercury.

The higher tryptic activities of the reaction mixture containing extracts from soybeans treated at the higher energy levels indicate that some of the trypsin inhibitor of the soybeans was inactivated. Van Buren et al. (40) suggested the use of trypsin inhibition as an index of heat treatment on the soybean. The gas plasma irradiation did not cause destruction of the soybeans protein at low intensity

(40 ma.). Some denaturation of the protein occurred in the soybean with higher intensity (120 ma.) treatment.

The results of the experiment showed that gas plasma irradiation could increase the number of cracked beans and improve the dehulling effect of soybeans. The treatment resulted in a loss of moisture and weight in the soybeans. Gas plasma irradiation increased the water sorption of the soybean; however, deformation and fragility were found in the soaked beans. At lower treatment level (40 ma.), no change was found in the extractability of lipids and total and soluble protein contents in the soybeans. No difference was found in iodine and peroxide numbers of the oil from soybeans at two treatment levels (40 and 120 ma). Slight decrease in extractability of lipids and total protein content were found in beans treated with 120 ma. Higher treatment intensity (120 ma.) resulted in a destruction of protein, which was shown in lower soluble protein content and less trypsin inhibitor in the soybean extracts. The changes induced by the gas plasma irradiation in the Soylima beans were more manifest than that in the Lee soybeans.

CHAPTER VI

SUMMARY

A study was made to determine the chemical and physical changes and the amount of dehulling induced by varying the electrical current in the gas plasma irradiation of two varieties of soybeans. Under the conditions of this study the following results were found:

1. The gas plasma treatment decreased the moisture content of the bean, increased the cracks on the hull, and increased the dehulling effect and water sorption of the bean. The degree of increase or decrease varied with the intensity level used.
2. The overall effect on the Soylima was more significant than on the Lee variety.
3. The radiation treatments tended to decrease slightly the amount of extractable lipids and total protein contents in the beans at 120 ma. treatment level. No change was found at 40 ma. level.
4. High intensity (120 ma.) energy reduced the solubility of soybean protein, and it also resulted in partial denaturation of the soybean inhibitor. No change was found at 40 ma. level.
5. No difference was found for the iodine number and peroxide number of soybean oil among the treated and control samples.

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APPENDIX

TABLE XVII

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE PERCENT WEIGHT LOSS OF THE SOYBEAN

	Treatments									
	Control		0 ma.		40 ma.		80 ma.		120 ma.	
Replications	A	B	A	B	A	B	A	B	A	B
I	0.00	0.00	0.33	0.20	1.04	0.47	1.30	1.00	1.40	1.47
II	0.00	0.00	0.27	0.20	0.53	0.53	1.07	1.13	1.47	1.47
III	0.00	0.00	0.25	0.17	0.58	0.50	1.17	0.92	1.67	1.58

A is Soylima, B is Lee soybeans.

Each value is the result of one determination on 150 g sample.

TABLE XVIII

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE PERCENT MOISTURE OF DEHULLED SOYBEANS

	Treatments									
	Control		0 ma.		40 ma.		80 ma.		120 ma.	
Replication	A	B	A	B	A	B	A	B	A	B
I	7.49	6.71	7.35	6.51	6.76	6.20	6.72	6.26	5.86	5.86
II	7.26	6.97	7.08	6.91	6.82	6.79	6.55	6.45	6.13	6.00
III	7.44	7.47	7.28	7.25	7.12	7.38	6.65	6.65	6.35	6.47

A is Soylima. B is Lee soybeans.

Each percent moisture value is the mean of three determinations.

TABLE XIX

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT
ON THE PERCENT CRACKED SOYBEANS

	Treatments									
	Control		0 ma.		40 ma.		80 ma.		120 ma.	
Replications	A	B	A	B	A	B	A	B	A	B
I	11.4	1.0	31.0	2.9	84.9	36.1	94.0	94.4	98.5	100.0
II	9.0	1.0	19.2	2.5	83.5	46.0	90.8	97.7	95.2	99.8
III	16.9	2.1	22.5	1.1	87.5	41.9	92.4	97.4	98.0	100.0

A is Soylima. B is Lee soybeans.

Each percent crack value is the mean of three determinations.

TABLE XX

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE PERCENT DEHULLING OF SOYBEANS

	Treatments									
	Control		0 ma.		40 ma.		80 ma.		120 ma.	
Replications	A	B	A	B	A	B	A	B	A	B
I	40.5	1.4	71.4	1.0	94.1	3.1	96.8	15.0	97.5	20.0
II	49.8	0.8	57.1	0.4	90.4	2.5	94.1	6.8	96.1	13.8
III	56.2	0.8	62.3	1.5	94.0	2.8	96.2	7.8	96.3	12.8

A is Soylima. B is Lee soybeans.

Each value for percent dehulled soybeans is the mean of three determinations.

TABLE XXI

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT
ON THE LIPID CONTENT OF DEHULLED SOYBEANS

	Treatments					
	Control		40 ma.		120 ma.	
Replications	A	B	A	B	A	B
I	28.06	28.63	27.96	28.64	27.99	28.15
II	27.36	29.31	27.25	28.08	27.04	28.26
III	26.07	28.29	25.78	27.59	25.23	27.11

A is Soylima. B is Lee soybeans.

Each value for percent lipid is the mean of two determinations.

TABLE XXII

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE IODINE NUMBER OF THE SOYBEAN OIL

Replications	Treatments					
	Control		40 ma.		120 ma.	
	A	B	A	B	A	B
I	133.50	132.11	133.19	132.59	133.83	133.68
II	134.13	131.43	133.17	132.30	133.63	132.82
III	133.54	131.74	132.44	134.26	133.15	132.13

A is Soylima. B is Lee soybeans.

Each value for iodine number is the mean of two determinations.

TABLE XXIII

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE PEROXIDE NUMBER OF THE SOYBEAN OIL

Replications	Treatments					
	Control		40 ma.		120 ma.	
	A	B	A	B	A	B
I	7.36	1.64	6.16	3.37	5.34	4.14
II	3.86	1.83	4.49	1.35	4.51	1.45
III	6.13	3.51	6.39	2.74	5.11	2.67

A is Soylima. B is Lee soybeans.

Each value for peroxide number is the mean of two determinations.

TABLE XXIV

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT
ON THE PERCENT TOTAL PROTEIN OF SOYBEANS

Replications	Treatments					
	Control		40 ma.		120 ma.	
	A	B	A	B	A	B
I	43.61	44.47	43.72	44.48	43.54	44.59
II	43.65	44.67	43.57	44.19	43.84	44.67
III	43.56	44.09	43.34	43.97	43.56	44.38

A is Soylima. B is Lee soybeans.

Each value for percent total protein is the mean of two determinations.

TABLE XXV

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE PERCENT SOLUBLE PROTEIN OF SOYBEANS

Replications	Treatments					
	Control		40 ma.		120 ma.	
	A	B	A	B	A	B
I	17.90	19.71	18.30	19.15	14.91	16.86
II	19.01	19.55	17.62	18.98	15.59	16.97
III	18.81	18.45	17.85	18.73	14.80	15.87

A is Soylima. B is Lee soybeans.

Each value for percent soluble protein is the mean of two determinations.

TABLE XXVI

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT ON THE TRYPSIN ACTIVITY INHIBITED BY SOYBEAN TRYPSIN INHIBITOR

	Treatments					
	Control		40 ma.		120 ma.	
Replications	A	B	A	B	A	B
I	0.74	0.54	0.66	0.52	0.85	0.86
II	0.65	0.54	0.76	0.52	0.75	0.76
III	0.63	0.52	0.53	0.51	0.71	0.71

A is Soylima. B is Lee soybeans.

The trypsin activity is expressed as $(T.\ U.)^{Gel.F.} \times 10^{-3}$ units.

Each trypsin activity value is the mean of two determinations.

TABLE XXVII

THE EFFECT OF DIFFERENT LEVELS OF GAS PLASMA TREATMENT AND DIFFERENT SOAKING TIMES ON THE PERCENT WATER ABSORBED BY THE SOYBEANS

Soaking Time in Minutes	Replications	Treatments					
		Control		40 ma.		120 ma.	
		A	B	A	B	A	B
10	I	22.4	14.3	41.7	41.1	42.0	47.1
10	II	21.6	13.6	38.3	42.4	40.6	48.7
10	III	20.5	13.6	40.2	40.6	42.9	48.5
30	I	39.0	29.2	71.0	58.0	65.4	68.0
30	II	41.5	31.7	67.8	63.4	64.1	67.0
30	III	41.5	28.9	67.2	59.1	66.4	69.1
60	I	54.2	42.8	92.2	71.1	87.5	82.7
60	II	49.8	41.8	92.1	73.1	85.4	81.3
60	III	57.8	43.7	99.3	68.2	86.2	83.5
120	I	79.9	56.7	148.4	104.8	148.8	110.7
120	II	87.8	60.4	143.6	101.1	132.1	117.2
120	III	77.6	60.3	143.0	101.4	135.7	114.7

A is Soylima. B is Lee soybeans.

Each value for percent water absorbed is the mean of two determinations.

VITA

The author was born July 11, 1939, in Sichang, Sikang, China. In 1961, she finished her undergraduate work in the Department of Agricultural Chemistry of Taiwan Provincial Institute of Agriculture, Pingtung, Taiwan. She worked in the Union Industrial Research Institute, Ministry of Economic Affairs, Hsinchu, Taiwan before she came to the United States. In September 1966, she entered The University of Tennessee Graduate School. Since that time she has been working to complete the requirements for the degree of Master of Science.