EFFECTS OF PRE-HULLING TREATMENTS ON MUNG BEAN DEHULLING EFFICIENCY

BY

YANLING CHENG

Bachelor of Science

Henan Agricultural University

Zhengzhou, Henan

The People's Republic of China

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Bobby L. Clary

Thesis Adviser

Richard W. Whitney

[redacted]

[redacted]

[redacted]

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CHAPTER I

INTRODUCTION

Among the numerous species of legumes, mung beans are widely available and commonly consumed as an important food in many countries. It is an excellent source of protein and many other nutrients. Mung bean seeds contain approximately 50% starch, 25-30% protein, almost three times that of cereals, and supply the essential amino acid, lysine in which most cereal proteins are deficient (Wrenshall et al., 1974). They also provide substantial quantities of minerals and vitamins to the diet. Studies showed that among the legumes, mung beans were the least flatulent and most easily digestible (Payumo, 1978). There is an increasing need for processing and utilization of the beans in formulated foods. Therefore the processing of mung beans has become more attractive.

In general, the major disadvantage in the utilization of mung beans is the extended cooking time needed to achieve desired palatability and digestibility. In order to alter the image of the beans as well as to increase its overall acceptance, the green hull of the beans must be removed before it can be used for various food preparations. Many cereal grains, legumes and other seeds are dehulled during processing for food use or for home consumption (Shyeh et al., 1980). The process of dehulling involves the removal of the fibrous seed coat by various techniques, thereby improving the culinary properties and palatability of the beans. In many countries of the world, grain legumes are initially processed by dehulling and splitting. Dehulling increases the percent protein content (Reichert et al., 1984) while reducing fiber and tannin content. Dehulling also produces refined cotyledons with good appearance, texture, and cooking quality (Deshapande et al., 1982). In addition, dehulling also helps digestion and aids effective utilization of nutrients by the body. Dehulled grains require shorter cooking time and are especially used in a variety of foods (Kurien, 1984).

The mung bean has a tightly bound seed coat and is more difficult to dehull than many other grain legumes. The dehulling characteristics of mung beans are generally poor, and improvement in dehulling quality is warranted. Since the mung bean hull adheres to the cotyledons firmly, it is not easily removed unless suitably loosened by pre-hulling treatments. Dehulling of grain legumes is normally done after pre-hulling treatments to loosen the hull from the cotyledons. Suitable methods of "conditioning" the grain to loosen the mung bean hull effectively for dehulling should be developed.

Therefore, there is a need to develop an efficient method for dehulling mung beans. It is apparent that considerable attention should be given to the pre-hulling treatments before dehulling since mung bean hull adheres very firmly to the cotyledons. Under appropriate processing conditions, adequate loosening of the hull may be achieved, and the hull can be effectively removed from the beans with little damage to the cotyledons. It is desirable to remove the hull as completely as possible with minimum breakage of cotyledons and minimum loss of cotyledon tissue.

In this study, water soaking treatments were applied to the mung bean samples before dehulling to obtain satisfactory dehulling efficiency. Three factors -- final moisture content, soaking time and drying temperature -- were investigated to determine their effects on dehulling efficiency.

Objectives

The objectives of this study were:

1. To determine the effect of water soaking time on mung bean dehulling efficiency.
2. To determine the effect of drying temperature on mung bean dehulling efficiency.
3. To determine the effect of final moisture content on mung bean dehulling efficiency.

CHAPTER II

LITERATURE REVIEW

Grain legumes, before they are used in different food preparations, are usually dehulled. Dehulling of grain legumes is usually done after some kind of pre-hulling treatments to break the bond between the skin and cotyledons. A substantial portion of grain legumes is consumed after having been milled for removal of the hull or some other form of processing (Kurien, 1984). The dehulling process of grain legumes involves abrasive removal of the outer skin of the kernel followed by air separation (Ramarkrishnaian and Kurien, 1982). Removal of the seed coat reduces the crude fiber and increases the protein content of the whole bean value (Payumo, 1978). While removing the hull, a part of the edible kernel is also removed. The extent of removal depends on the grain processed and the techniques used. The technology used for dehulling should be such that the kernel losses are minimized. Unfortunately, the literature contains very little information on dehulling of mung beans, though there is some information available about the process for other grain legumes.

Traditionally mung beans are cooked, either whole or sprouted, as a vegetable dish in combination with meat, shrimp or fish. Snacks and desserts are also prepared from boiled beans. Mung bean starch is also prepared into traditional oriental noodles (Payumo, 1978). However, the length of time required for cooking mung beans influences the attitude of people towards its use.

Dehulling of grain legumes is accomplished traditionally with a mortar and pestle or mechanically with attrition-type dehullers (disc shellers) and abrasive-type roller dehullers (Kurien, 1984) or disc dehullers (Reichert et al., 1984). Attrition-type dehullers with their emery or stone surface are particularly suitable for dehulling and splitting legume grains with loose seed coats. Abrasive-type dehullers, which employ a carborundum or emery surface to gradually abrade the seed coat from the cotyledons, are more suitable for dehulling grains with more tightly adhering seed coats (Reichert et al., 1984). After dehulling, the hull is separated from the cotyledon pieces by air aspiration. Complete dehulling is usually achieved only after repeated passes through the dehulling machine. This results in more surface scouring of dehulled grains and causes high loss of surface proteins (Kurien, 1984). The methods followed in the home or village industry or in commercial dehulling are usually similar in principle but differ in the use of techniques for better yield, higher dehulling efficiency and large scale application. Since the hull tightly envelopes the cotyledons, the primary step in dehulling involves labor intensive procedures. Most of the commercial technologies available for dehulling are either obsolete or inadequate, and result in heavy losses due to breakage and powdering of the bean (United Nations University, 1979).

Traditional Technologies

The dehulling process of grain legumes in home-scale methods, village level processes or commercial operations consists mainly of two steps. The first step is for loosening the hull by some pre-hulling treatments. The second step is removal of the outer hull and cleaning by using suitable machines. In India, for example, the first step is achieved by sun-drying cleaned grains in thin layers for one or two days after the pre-hulling treatment, usually steeping the grains in water for several hours, or sometimes treating the grains with oil and/or water. The steeping technique to loosen the hull is also practiced in several Southeast Asian and African countries. This step is completely dependent on the climatic conditions. In some areas, grain varieties whose hulls are tightly attached to the cotyledons are soaked in water and then coated with red-earth paste before being sun-dried. In some varieties of legumes, mere sun-drying is sufficient to loosen the hull (Kurien, 1984).

In village industries, the techniques employed for loosening the hull are the following: (a) prolonged sun-drying until the hull is loosened; (b) application of small quantities of oil and water, followed by hours or even days of sun-drying and tempering; (c) soaking in water for several hours, followed by coating with red-earth slurry and sun drying; (d) soaking in water for several hours to loosen the hull before processing; or (e) a combination of these techniques (United Nations University, 1979). These methods are often inadequate, laborious, prolonged and dependent on climatic conditions.

The second step of dehulling is done by hand or power operated abrasion mills. Dehulling and splitting usually take place simultaneously (Kurien and Parpia, 1968). The hull is aspirated off and the dehulled grains are separated from cotyledons by sieving. Residual undehulled whole grains are again passed through the mills for complete dehulling and splitting. In the process, excessive breakage and powdering of grains may occur because of repeated splitting and dehulling operations. Germ from the split grains is generally lost in the powder or in the broken fractions. Although the hull forms only 11-15 percent of the grain, yield of the dehulled grain is usually about 20 percent less than the theoretical yield, because it is dependent mostly on the ease of dehulling and splitting. It also depends on the number of times the grains have to be passed through the machines (Kurien and Parpia, 1968). It is observed that legumes such as pigeon pea, mung bean and black gram are more difficult to dehull and require more prehulling treatments followed by prolonged sun-drying, while grains such as chickpea, soy bean etc. are more easily dehulled and require fewer prehulling treatments and shorter periods of sun-drying.

The abrasive roller machines have tapered or cylindrical emery-coated rollers and are more suitable for removal of the hull by abrasion (Kurien, 1984). Removal of the hull is usually completed in several passes and involves the risk of scouring portions of cotyledons in each pass. About 15-20 percent of powder formed in the roller is due to scouring of dehulled whole grains. The edges of cotyledons are also rounded which adds to the losses. The millers usually use a very coarse emery so that the hull is removed by shear. Splitting of dehulled whole grain helps in its separation from undehulled grains, but results in loss of the germ which forms 2-5 percent of the grains (Kurien and Parpia, 1968).

The oldest and most common household dehulling is accomplished by pounding the grain in a mortar with a pestle, or grinding in a hand-operated wooden or stone sheller. The hull is then separated by winnowing (Kurien and Parpia, 1968).

The commercial methods involve the same operation as in household methods and they are mostly mechanized. Removal of the loosened hull from grain legumes is commonly done by small machines followed by aspiration of the hull. Hand or power-operated grinders with emery-coated or stone contact surface are used. The complete hull removal from grain legumes usually can not be achieved through a single operation (Kurien and Parpia, 1968). After separation of dehulled cotyledons, the process is repeated several times, which involves the risk of scouring greater portions of cotyledons in each pass, until almost all the grain is dehulled. During the process, excessive breakage with powdering of grain occurs because of splitting and dehulling operations. Complete removal of hull from the grain is not always achieved, particularly with some varieties, such as black gram, mung bean and pigeon pea.

Improved Technologies

Dehulling grain legumes by traditional methods is laborious, time-consuming, dependent on climatic conditions, and there are considerable losses as brokens and powder due to scouring. Therefore, there is a great need to develop new technologies for efficient and economic milling of legumes. Some successful efforts have been made to develop improved technologies to reduce dehulling losses and improve product quality.

The improved technologies and machinery for economic dehulling of some grain legumes developed at Central Food Technological Research Institute, Mysore, India, made some efforts in this direction. The aim of the new method was to minimize difficulties and wastage often found in traditional methods. The method involved moisture conditioning to a critical level in order to loosen the hull. In the first step, the grain was exposed to heated air at specific temperatures for a predetermined time, and equilibrated to the critical moisture level with gradual aeration in tempering bins. The optimum air temperature, grain temperature and tempering time to loosen the hull were specific to each legume and made the hull brittle and loose. The second step, removal of the hull, was done in an improved abrasion-type dehulling machine. An almost complete removal of the hull could be achieved in a single pass with little scouring or breakage of the cotyledons. The new technique was independent of climatic conditions. These improved technologies were shown to increase the yield by 5 - 10 percent and improved product quality. Cost and time of processing were also reduced considerably. This technique was originally developed to dehull the pigeon pea. It was also successfully used for dehulling some other grain legumes such as chickpea and black gram by making suitable modifications in pre-hulling treatments and machinery (Kurien et al., 1974). However, this approach has not been widely implemented to date (Reichert et al., 1984). There is no report of critical moisture levels and temperature levels for the legumes, though they may well vary from one legume seed to another.

At The National Research Council of Canada, Prairie Regional Laboratory, Saskatoon, Canada, the Hill grain thresher, an abrasive type dehuller consisting of carborundum stone discs mounted on a horizontal shaft (Reichert and Youngs, 1976), was successfully used for dehulling cowpeas at low carborundum stone speeds. The dehulling efficiency was high with short dehulling time (Reichert et al., 1979). The hull was removed by the abrasive action of the rotating stones. The amount of kernel removed as fine material was dependent on the retention time in the machine which, in turn, was dependent on the rate at which grains were fed into the machine (Reichert et al., 1979).

Dehulling Characteristics

Different varieties of grain legumes may have different dehulling characteristics, yield and efficiency. It is observed that larger grain varieties are easier to dehull, the hull being less rigidly attached to the cotyledons, and give a high yield. On the other hand, the smaller varieties are more difficult to dehull, the seed coats being firmly attached to the cotyledons. They usually require repeated, severe pre-hulling treatments and should be passed through the dehuller a number of times for complete dehulling and splitting. The cost of processing is higher and the yield of cotyledons is reduced due to powdering and breakage (Kurien and Parpia, 1968). Special methods of processing are sometimes used for these difficult-to-mill varieties to impart adequate loosening of hull. Some grains are treated with a small amount of alkali (sodium hydroxide or sodium carbonate) and spread in the sun for 2-4 days and shelled. Though alkali treatment improved the dehulling quality of grains (Kurien and Parpia, 1968). The treatment caused darkening of mung bean cotyledons and of the resulting flour (Wrenshall et al., 1974).

Mung beans are smaller in diameter than soybeans. The hull of the mung bean, unlike that of soybeans, sticks very firmly to the cotyledons. For example, grinding soybean in a domestic stone mill splits the grain and loosens the hull which can then be easily dislodged and separated by winnowing. In contrast, the mung bean under the same conditions is just split, with most of the hull still sticking very tightly to the cotyledons (Wernshall et al., 1974).

Reichert et al. (1984), using a PRL (Prairie Regional Laboratory) mini dehuller, demonstrated marked differences in the dehulling quality of different legume species. Soybean, faba bean, and field pea had particularly good dehulling quality, while mung bean and two cowpea varieties had very low dehulling efficiency (Reichert et al., 1984). The yield, dehulling efficiency, and percent intact seeds of mung beans were generally low. The poor dehulling characteristics probably resulted from tight seed coat adhesion and high susceptibility to seed splitting during dehulling (Ehiwe and Reichert, 1987).

Dehulling characteristics of grain legumes is also influenced by some other factors such as adherence of hull to cotyledons and moisture content. Ramarkrishnaiah and Kurien (1983) showed that when the moisture content for a legume was progressively reduced, the degree of dehulling increased until it reached a maximum. Further reduction in moisture content did not help significantly in increasing the degree of dehulling. This moisture content was referred to as "critical" moisture content for that variety, since the grain showed maximum dehulling efficiency at or below that moisture content (Ramarkrishnaiah and Kurien, 1983).

The fibrous seed-coat of grain legumes is generally tough and smooth. Many grain legumes have a layer of gums which bind the seed coat to the cotyledons, and it varies in quantity among different varieties of legumes. The adherence of the hull to the cotyledons may be firm or loose depending upon thickness of the gum, level of hydration, quality, its chemical nature, etc. (Kurien, 1984). Its amount and properties may determine the duration and severity of treatments required before dehulling. These gums were reported to contain pentosans, hexosans, other polysaccharides and uronic acids (Ramarkrishnaih and Kurien, 1983). However, literature contains very little information on how the gums may influence the dehulling of the grain legumes. It is said that treatments before dehulling may reduce the influence of the gums. The role of the gum and its thickness in binding the hull to the cotyledons has not been fully understood and the various pre-milling treatments employed are largely empirical. Adherence of the hull to the cotyledons is possibly due to the high gum content between the seed coat and cell walls of the cotyledons which acts as a binding substance (Kurien, 1984). However, it is possible that under optimum condition of pre-hulling treatment, maximum loosening of hull from the cotyledons can be obtained (Ramarkrishnaiah and Kurien, 1983).

Water-soaking for long durations helps in loosening the bonding action of gum, possibly by dissolution and leaching. However, there are no suitable wet-processing machines to effectively disengage the hull without breaking the softened cotyledons (Kurien, 1984). Kurien (1984) suggested that soaking and drying may be an effective technique to loosen the hull. When the moistened grains are dried, the shape of cotyledons distorts due to non-uniform shrinkage and touch each other only at the edges. As a result, the hull is loosened and can be removed by the shearing action of dehulling machines. In general, the longer the soaking period (4 to 12 hours), the greater the loosening of hull, and more cave-in of the cotyledons on drying. As a result, milling (dehulling and slitting) is easier. During drying, a certain amount of differential shrinkage of hull and cotyledons takes place. The extent to which these changes take place is probably influenced most by the amount and nature of gums and mucilages present in the grains, and their ability to hold moisture (Kurien and Parpia, 1968). This technique has been effectively employed to dehull pigeon peas in India (Kurien, 1984). The turn-over, however, is restricted because the drying process is dependent on climatic conditions.

CHAPTER III

EXPERIMENT PROCEDURE AND EQUIPMENT

A series of experiments was conducted to determine the effect of various factors on dehulling efficiency. Under appropriate processing conditions, adequate loosening of the hull may be achieved and higher dehulling efficiency obtained.

In this study, the effects of drying temperature, final moisture content and water soaking time on dehulling efficiency of mung beans was evaluated. A factorial experimental design was used in this study to determine optimum levels of the three factors. The levels for each factor were determined by preliminary tests with mung bean dehulling. The treatment combinations were applied to mung bean samples before dehulling to loosen the hull from the cotyledons. The effects of each factor on the dehulling efficiency were obtained by statistical analysis.

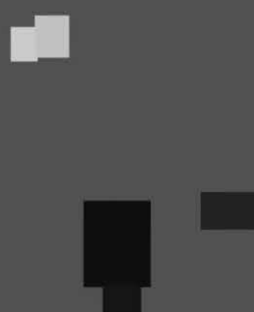
Dryer

A laboratory dryer (Figure 1) was designed and constructed to dry mung bean samples to the required moisture content. The dryer had a airflow rate of 396 - 579 m^3 per minute of heated air per square meter of drying area

(1300 - 1900 cfm per square foot of drying area) depending on static pressure. The dryer consisted of a centrifugal blower attached to an electrical air heater (4kw) from which heated air was blown into a plenum. The size of the plenum was 55 x 55 x 23 cm. A maximum of six 25 x 25 x 11 cm column sections could be added above the plenum. An adjustable orifice was used on the suction side of the fan to control air flow rate. Heated air was circulated through the dryer and passed through the mung bean samples. Air flow rates were high enough to approximate thin layer drying of the beans. The temperature of heated air was measured at the entrance of the drying column by means of thermocouples, and controlled within +/-1°C of test drying temperature.

Dehulling machine

The machine used in this study for dehulling mung bean samples is shown in Figures 2 and 3. It consisted basically of two parallel abrasive cylinder rollers which rotated at different angular velocities. The two rollers had the same diameter of 7 cm (2.73 inches) and were driven by a 0.25 HP motor. They rotated in the same direction as shown in Figure 4 but at different speeds. The operational velocities of the two rollers were 720 rpm for the bottom roller and 900 rpm for the top roller. Both rollers were provided with an abrasive surface material of 80 Grit. The beans were dehulled by the abrasion provided by abrasive rollers mounted on horizontal shafts. Moreover, the



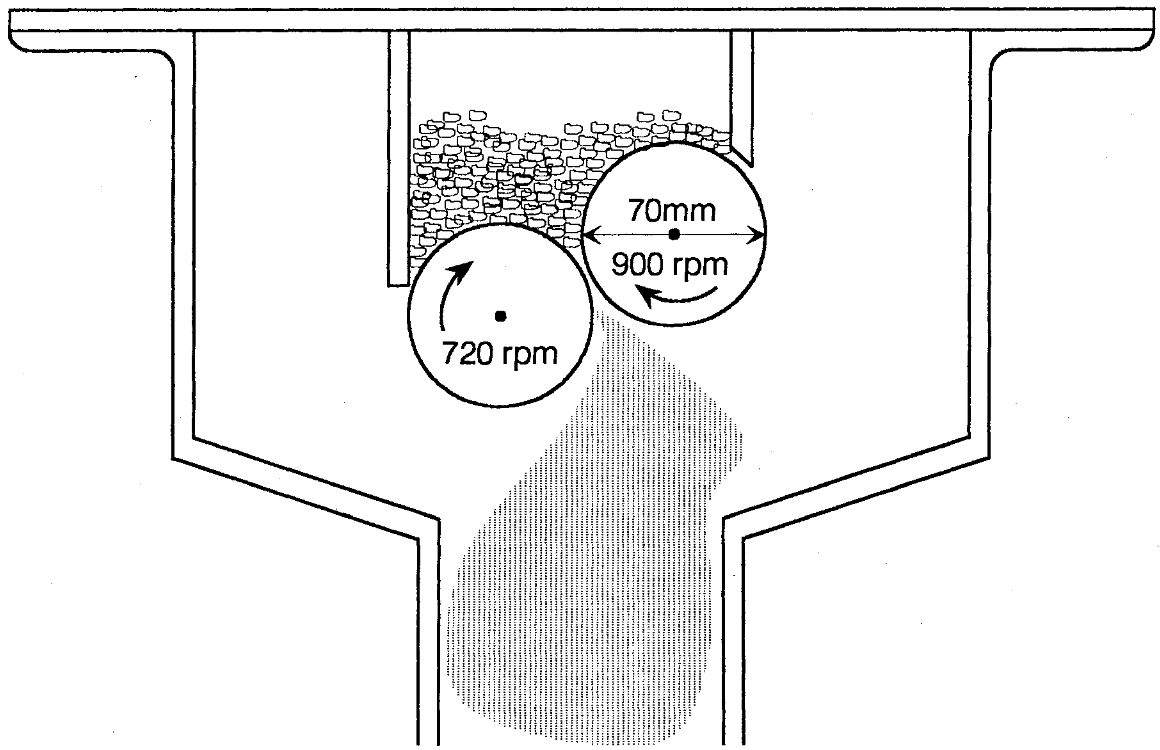


Figure 4. Rotation Directions of the Rollers of the Dehulling Machine

difference in rpm between the two rollers applied a rubbing action to cotyledons in the machine. The clearance between the rollers was 1.27 mm (0.05 inches) which was adjusted so that the rollers would apply both pressure and abrasive action to the cotyledons to remove the hull. At one end of the machine there was a hopper through which the beans were feed into the machine. At the other end of the machine, there was an overflow outlet which could be either closed or open so that retention time of the beans in the machine could be controlled.

Seed Cleaner

The mixture of dehulled kernels, hulls and fines were separated with the electrical driven Seedburo seed cleaner as shown in Figure 5. It combined a three screen vibration mechanism with the drag force of an adjustable air stream for dust, hull and fine material removal. It had four outputs and the screens were 30.5 cm square (12" square) in size. The unit had one top scalping screen for large-size grain or other material removal and two bottom screens for classifying the seeds, as well as removal of some foreign materials. There was no screen for the fourth output. After the beans were dehulled they passed through the seed cleaner to remove hulls and fines. The hull was removed by air classification and air velocity which could be controlled by adjusting the size of the air inlet orifice. The air flow was held constant throughout the entire

experiment.

Sample Divider

A No.34 Seedburo boerner divider as shown in Figure 6 was used to get a small representative fraction of the sample. A sample of the beans was placed in the hopper top and released down the sides of a cone, the point of which was directly under the center of the opening of the hopper. Beans falling down the sides of the cone were cut into thirty eight separate streams alternating into two outputs. One of the two halves was chosen randomly and the above procedure could be repeated until the sample was reduced to the desired size.

Experimental Material

Mung beans used in the study were purchased from a supplier and graded U.S. No.1. They were stored at room temperature before the experiment. Mung bean property data are presented in Table I.

TABLE I

PROPERTIES OF EXPERIMENTAL MATERIALS

Moisture content	11.0 %, wb
Thousand seed weight	51.1 gm
Hull content	9.8 %, by wt
Germ content	1.3 %, by wt

In general, the larger beans are dehulled first due to mechanical advantages, while smaller beans escape abrasion, leaving large amounts of hull remaining on the grains during the dehulling process (Ramarkrishnaiah and Kurien, 1983). To reduce the effect of size variation on dehulling efficiency, a No.6 U.S.A. standard testing sieve with 3.35 mm opening (Tyler equivalent 6 mesh) was used to size and clean the beans. Small beans and small stones, other seeds, insects and other foreign materials passed the sieve and were discarded. The removal of large sized foreign material and damaged beans was accomplished by hand.

After cleaning, the mung beans were divided into 2100 gram samples and stored in air-tight plastic bags for a few days at room temperature. Moisture content was determined for the samples by the oven drying method according to the ASAE Standard S352.1.

Treatment and Dehulling

A soaking treatment before dehulling was applied to the mung bean samples to break the bond between the hull and cotyledons to insure satisfactory dehulling efficiency. Shrinkage of the cotyledons during drying was more than that of hulls and could result in a "bubble" hull which could be easily removed by shearing action of the dehulling machine. Moreover, when beans were soaked for sufficient time and dried, the cotyledons caved in at the surface and touched each other at the periphery leaving the hulls loose (Figure

7). Therefore, it was relatively easy for the dehulling machine to remove the hull as well as split the grains into cotyledons.

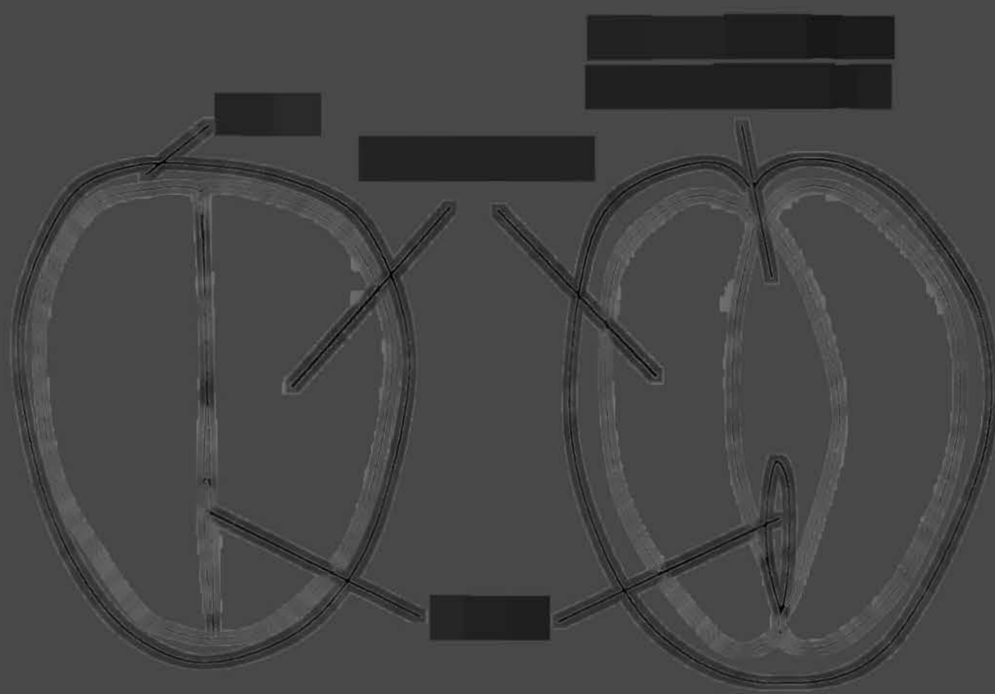
Three factors -- soaking time, drying temperature and final moisture content -- were investigated to determine their effects on dehulling efficiency. The experiment was a 4 x 5 x 4 factorial in a completely random design with three observations per treatment. In this experiment, the no-soaking level for the factor of soaking time was used to determine the effect of water soaking on mung bean dehulling efficiency. The combination of various factor levels gave 80 treatments. The treatment combinations shown in Table II were chosen based on previous experience with mung bean dehulling in preliminary tests.

Each cleaned sample prepared as described above with known moisture content was divided into three subsamples of 650 grams each and soaked in water at room temperature for

TABLE II

FACTORIAL STATISTICAL PLAN FOR SOAKING TREATMENT

Factors	Levels
Drying temperature (°C)	35, 45, 55, 65
Soaking time (hr)	0, 1, 3, 5, 7
Final moisture content (%, wb)	4, 6, 8, 10



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the period of time indicated in Table II. After soaking, samples were removed from water immediately and drained for approximately three minutes. The samples were placed in the dryer as described previously. Heated air at drying temperature as indicated in Table II was circulated in the dryer and passed through the samples. Samples were weighed regularly to determine the moisture content. When the final moisture content reached the indicated values in Table II, the samples were removed from the dryer immediately and stored in air-tight plastic bags for 24 hours to allow moisture equilibrium at room temperature.

After equilibration, 500 grams of mung beans for each sample were dehulled in the machine for removal of the skin. The rest of the beans were used to determine the final moisture content for that sample by the standard oven drying method. The retention time for dehulling each sample was 15 minutes.

After dehulling, all materials were collected from the machine. The seed cleaner was used to separate the hull and fines from the cotyledons by air aspiration. The air flow setting remained constant throughout the entire experiment. Speed of the fan was carefully adjusted to provide the best cleaning result.

After cleaning, the sample was weighed and the boerner sample divider used to reduce the sample size. A small representative fraction of the sample was taken by using the sample divider and inspected to separate incompletely dehulled beans. Broken cotyledons passing through a hand sieve with 2 mm opening were also discarded. Cotyledons with more than 25 percent of the hull still remaining were separated by hand and described as "Partially Dehulled Beans" or "PDB". The remaining beans were considered as "Dehulled Cotyledons". All fractions were weighed and converted to percentage. The weight of dehulled cotyledons for each sample was calculated.

Dehulling Efficiency

1. Hull content (%)

The percent hull content of the beans was determined by soaking approximately 15 grams of beans in distilled water for about 15 hours at room temperature (about 22°C). Seed coats were then removed by hand from each bean and dried in an air oven at 50°C for 24 hours. After drying the hull was weighed and hull content was determined.

2. Cotyledons Yield (CY, %)

After dehulling, the cotyledons with more than 25 percent of hull still remaining (by visual inspection) were separated by hand and described as PDB. The brokens passing through the hand sieve of 2 mm opening were also discarded and described as "broken cotyledons". The remaining beans were considered as "dehulled cotyledons". The weight of dehulled cotyledons was determined for each sample. Cotyledon yield was calculated as a percentage of dehulled cotyledon weight to the sample weight used for dehulling

(500 gram). Hence, cotyledon yield was calculated as following:

$$CY(\%) = 100 * (Wc / Ws) \quad (1)$$

where:

CY -- yield of cotyledons, %

Wc -- weight of dehulled cotyledons, grams

Ws -- sample weight used for dehulling, grams

3. Theoretical yield (TY, %)

Theoretical yield of dehulled beans was dependent on the hull content of the beans. It was determined by deducting the weight of the hull in the whole bean from the sample weight, and calculating that as percentage of sample weight used for dehulling.

$$TY(\%) = 100 * (Ws - Wh) / Ws$$
$$= 100 - Hc \quad (2)$$

where:

TY -- theoretical yield, %

Wh -- weight of hull, grams

Hc -- hull content, %

4. Dehulling Efficiency (DE)

Dehulling efficiency is calculated as the percentage of cotyledon yield to the theoretical yield, higher value indicating less loss of cotyledon either as brokens or fines. Low dehulling efficiency represents considerable kernel losses. It is desirable to remove the hull as completely as possible with minimum breakage of the cotyledons and minimum loss of cotyledon tissue.

$$DE(\%) = 100 * (CY / TY) \tag{3}$$

CHAPTER IV

RESULTS AND DISCUSSION

The weight of one thousand seeds of the grain legume was indicative of the size of the grain. For mung beans used in this study, it was 51.1 grams. The hull content of the mung bean was 9.8 percent and the germ content was 1.3 percent by weight. The initial moisture content was approximately 11 percent, wet basis. The operational characteristics of the dehulling machine, no doubt, has a significant influence on dehulling efficiency, but identical conditions have been used in this study to eliminate this influence.

It is reported that the hull is attached to the cotyledons through a layer of gum, the chemical nature, quantity and level of hydration of which determine its tackiness and influence the dehulling behavior of the grains (Ramakrishnaian and Kurien, 1983). Variations in the degree of dehulling obtained with different pre-hulling treatments are the result of varying extent of loosening of hull from the cotyledons after the treatments reducing the influence of gums. Therefore, it may be inferred that under optimum conditions of pre-hulling treatments maximum loosening of hull from the cotyledons is obtained.

Preliminary tests were run to determine the range of the experiment factor levels, retention time for dehulling, clearance between the rollers of the dehulling machine, sample size and the angular velocities of the rollers. The operation conditions selected in this experiment were based on previous limited tests with the dehuller on mung bean dehulling.

After dehulling, most of the dehulled beans were split. It was observed that the degree of splitting was related to duration of soaking time. The percentage of whole dehulled beans decreased as soaking time increased. The breakage of cotyledons might be expected to be affected by the final moisture content of the beans and the drying temperature. It was noticed that the amount of broken cotyledons was increased as the drying temperature was increased and the final moisture content was decreased. The comparison data of broken cotyledons of dehulled samples dried at 35°C and 45°C are presented in Table III.

Table IV presents an analysis of variance for the data on dehulling efficiency. Tables VI, VII, VIII and IX in Appendix A present the comprehensive data regarding the effects of soaking time, drying temperature and final moisture content on the mung bean dehulling efficiency. Figure 8 through 17 are plots of the data showing effects of each of these factors.

Analysis of the data obtained from the experiments with mung bean dehulling indicated that the final moisture

TABLE III

COMPARISON OF BROKEN COTYLEDONS OF DEHULLED SAMPLES DRIED AT 35°C AND 45°C

Drying temp(°C)	Soaking time(hr)	Moisture content(%)	Broken cotyledon %, by wt
35	3	4	1.39
45	3	4	1.77
35	3	6	1.21
45	3	6	1.70
35	5	4	1.39
45	5	4	2.55
35	5	6	0.89
45	5	6	1.35
35	7	4	1.22
45	7	4	2.19
35	7	6	0.97
45	7	6	1.81

TABLE IV

ANALYSIS OF VARIANCE TABLE FOR DEHULLING EFFICIENCY

Source	df	SS	Mean S	F	PR > F
Treatments	79	28515.59	360.96	158.91	0.0000
Mois.	3	15742.29	5247.43	2310.12	0.0000
Tem.	3	1265.32	421.77	185.68	0.0001
Time	4	10887.96	2721.99	1198.33	0.0000
Mois*Tem	9	51.05	5.67	2.50	0.0107
Mois*Time	12	120.22	10.02	4.41	0.0001
Tem*Time	12	167.69	13.97	6.15	0.0001
Mois*Tem*Time	36	281.06	7.81	3.44	0.0001
Error	160	363.44	2.27		
Total	239	28879.03			

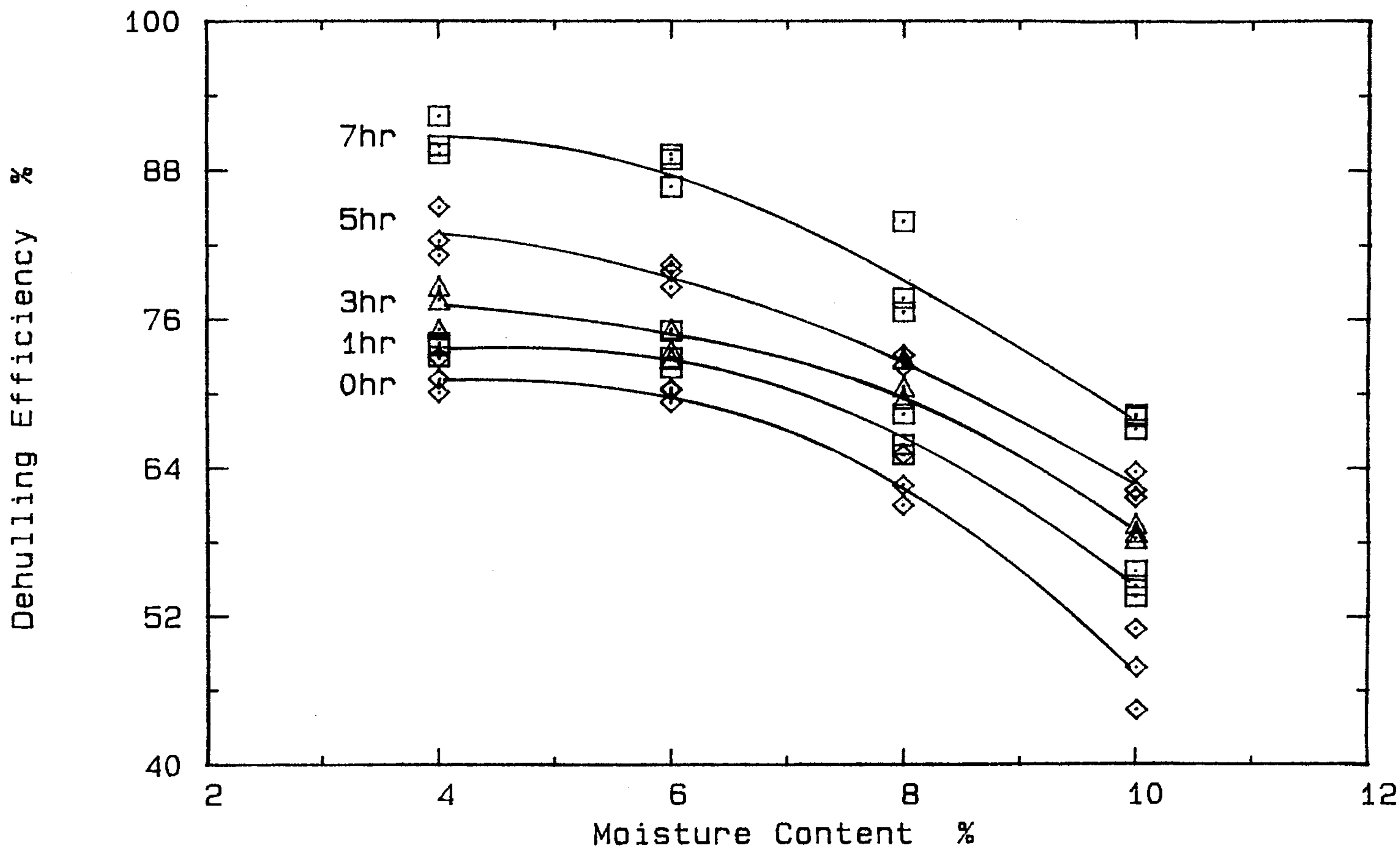

Figure 8. Effects of Soaking Time and Moisture Content at Drying Temperature 35°C on Dehulling Efficiency

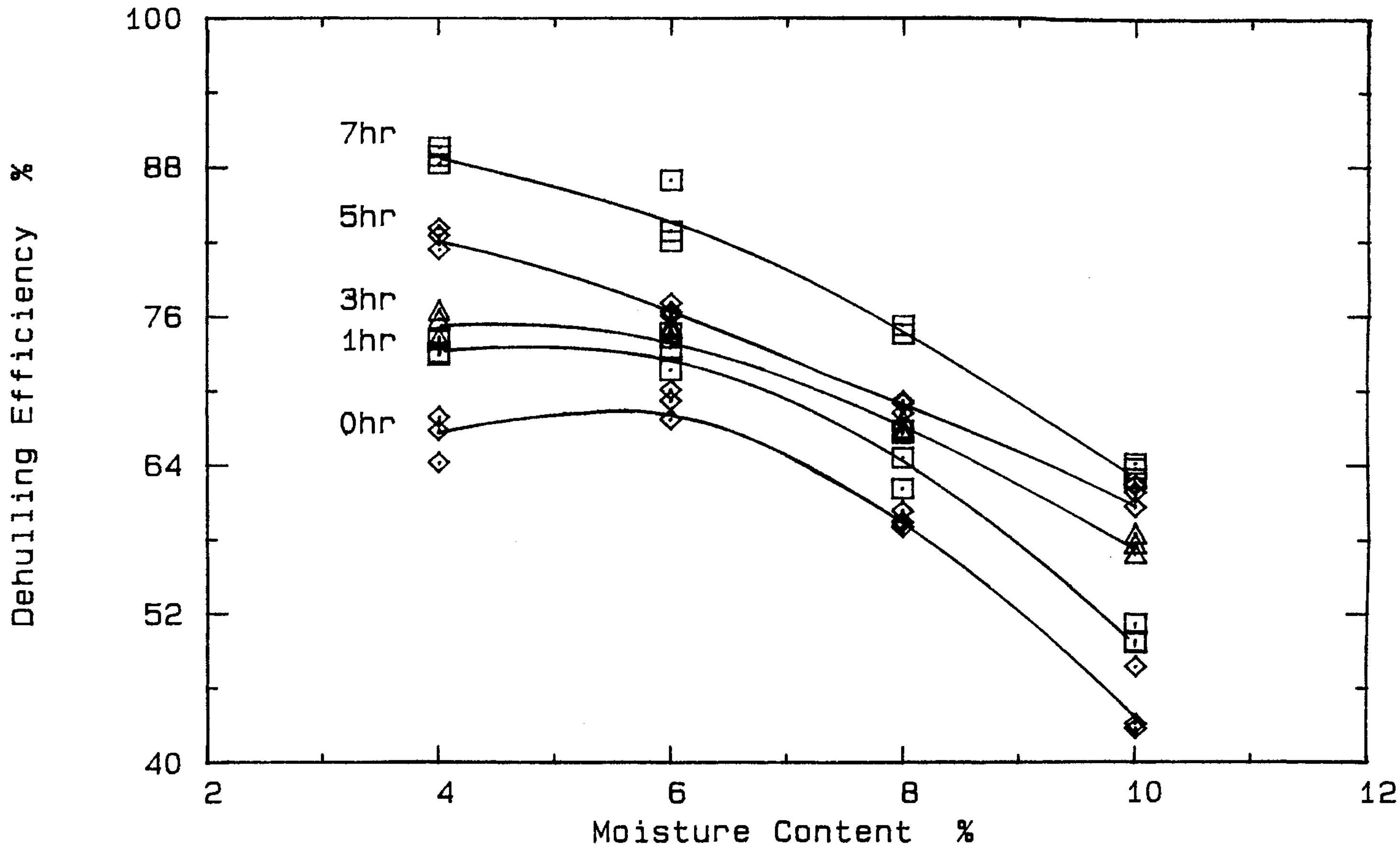

Figure 9. Effects of Soaking Time and Moisture Content at Drying Temperature 45°C on Dehulling Efficiency

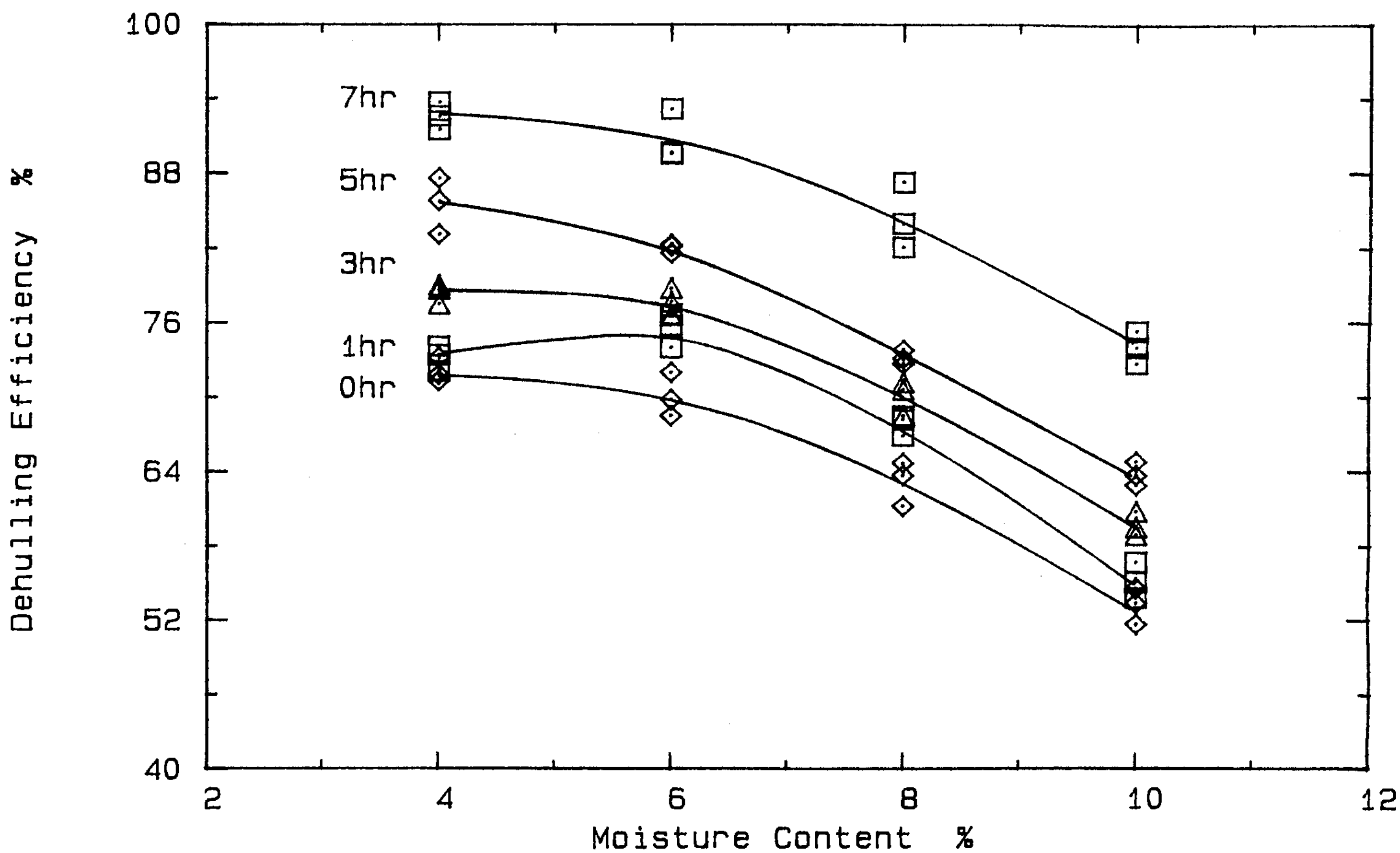

Figure 10. Effects of Soaking Time and Moisture Content at Drying Temperature 55°C on Dehulling Efficiency

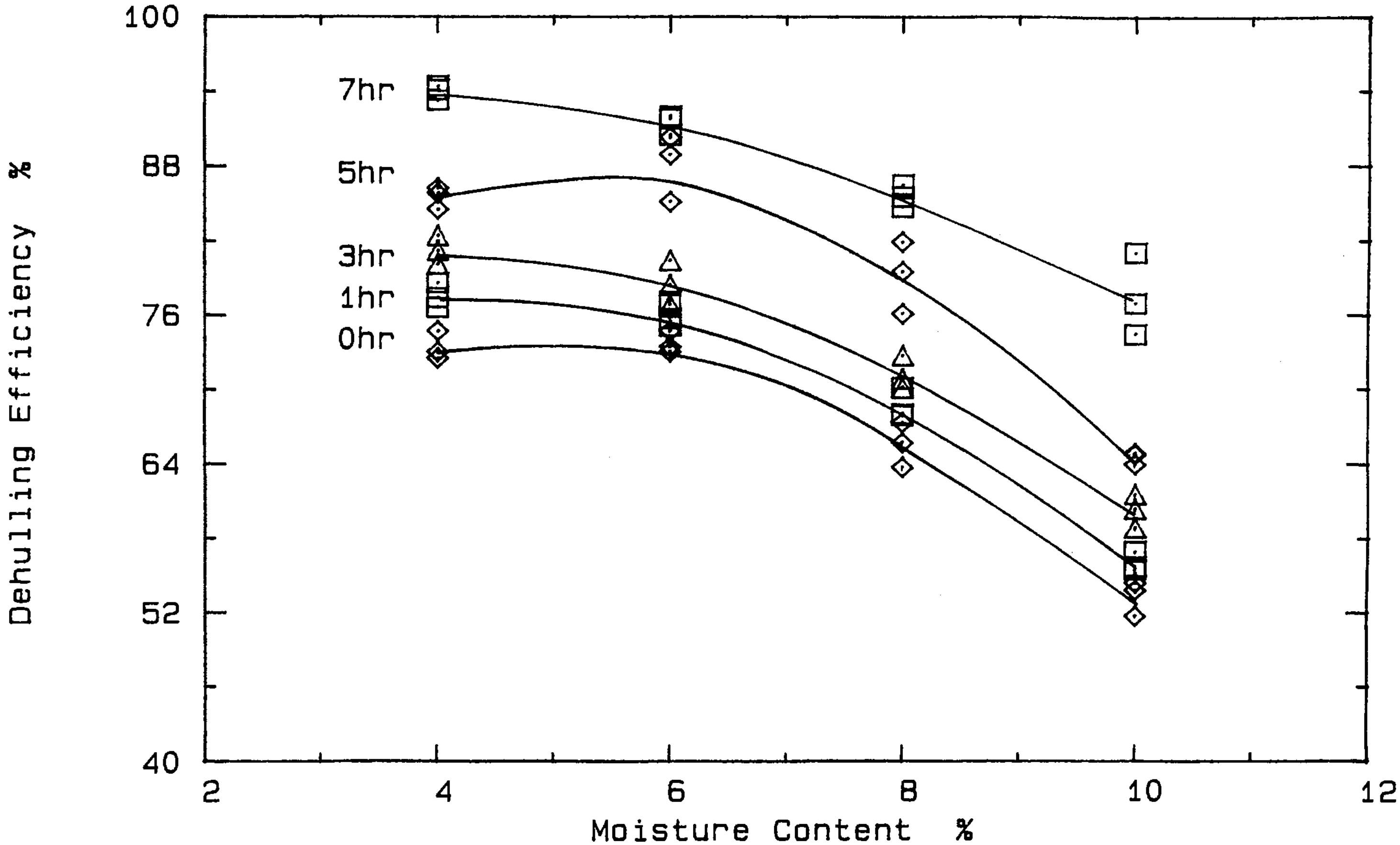

Figure 11. Effects of Soaking Time and Moisture Content at Drying Temperature 65°C on Dehulling Efficiency

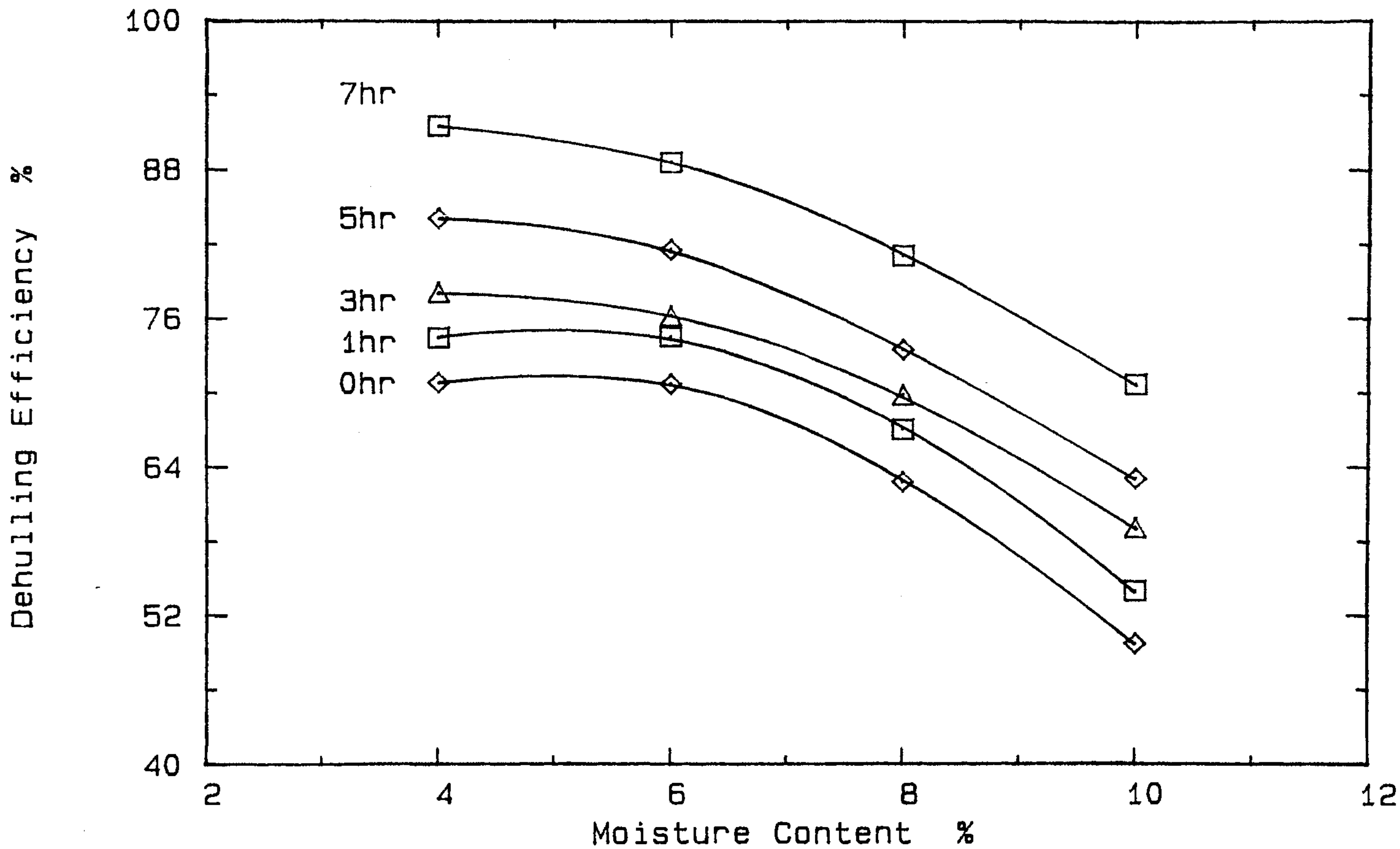

Figure 12. Effects of Soaking Time and Moisture Content on Dehulling Efficiency Averaged Over Drying Temperature

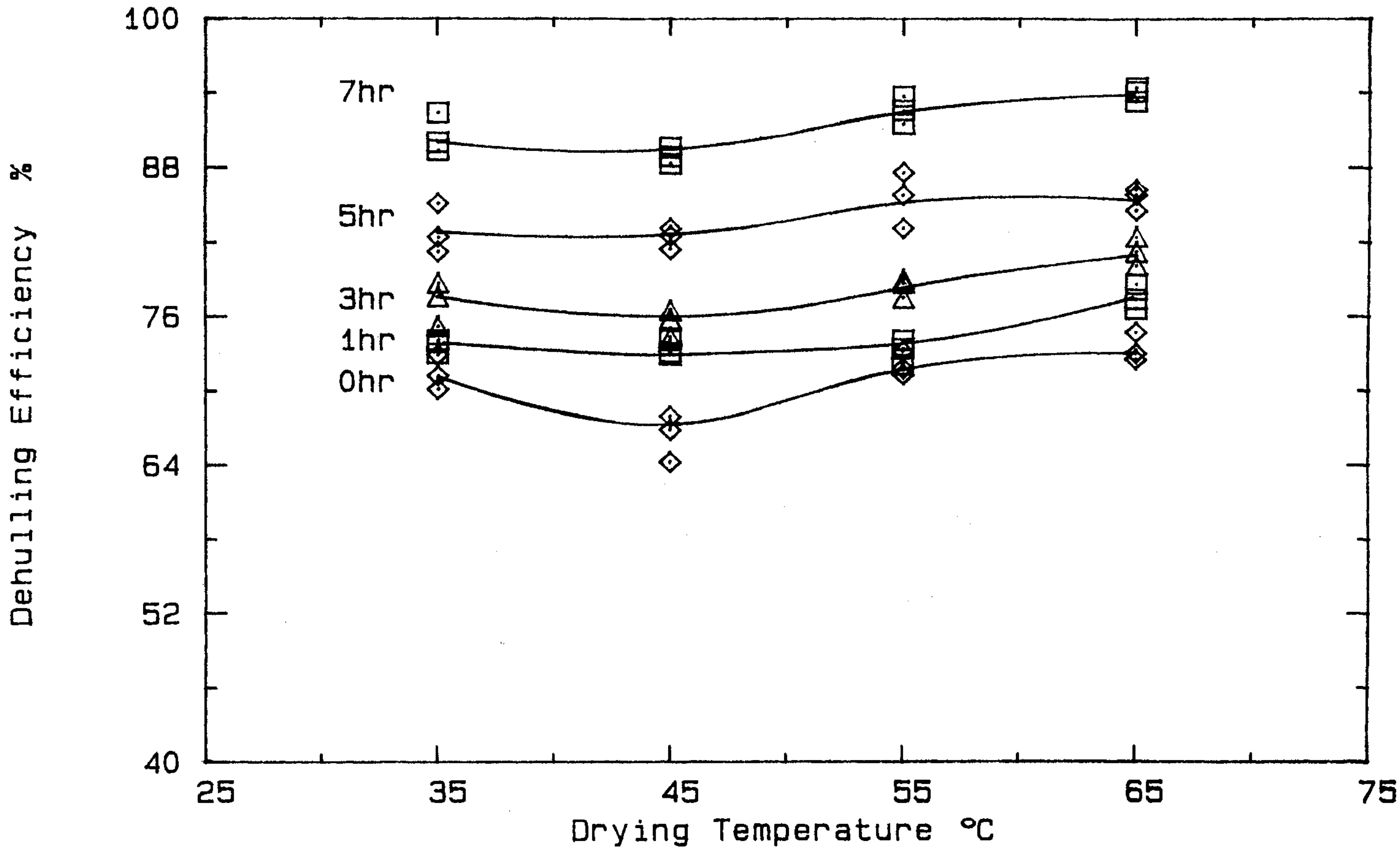

Figure 13. Effects of Soaking Time and Drying Temperature at Moisture Content 4% on Dehulling Efficiency

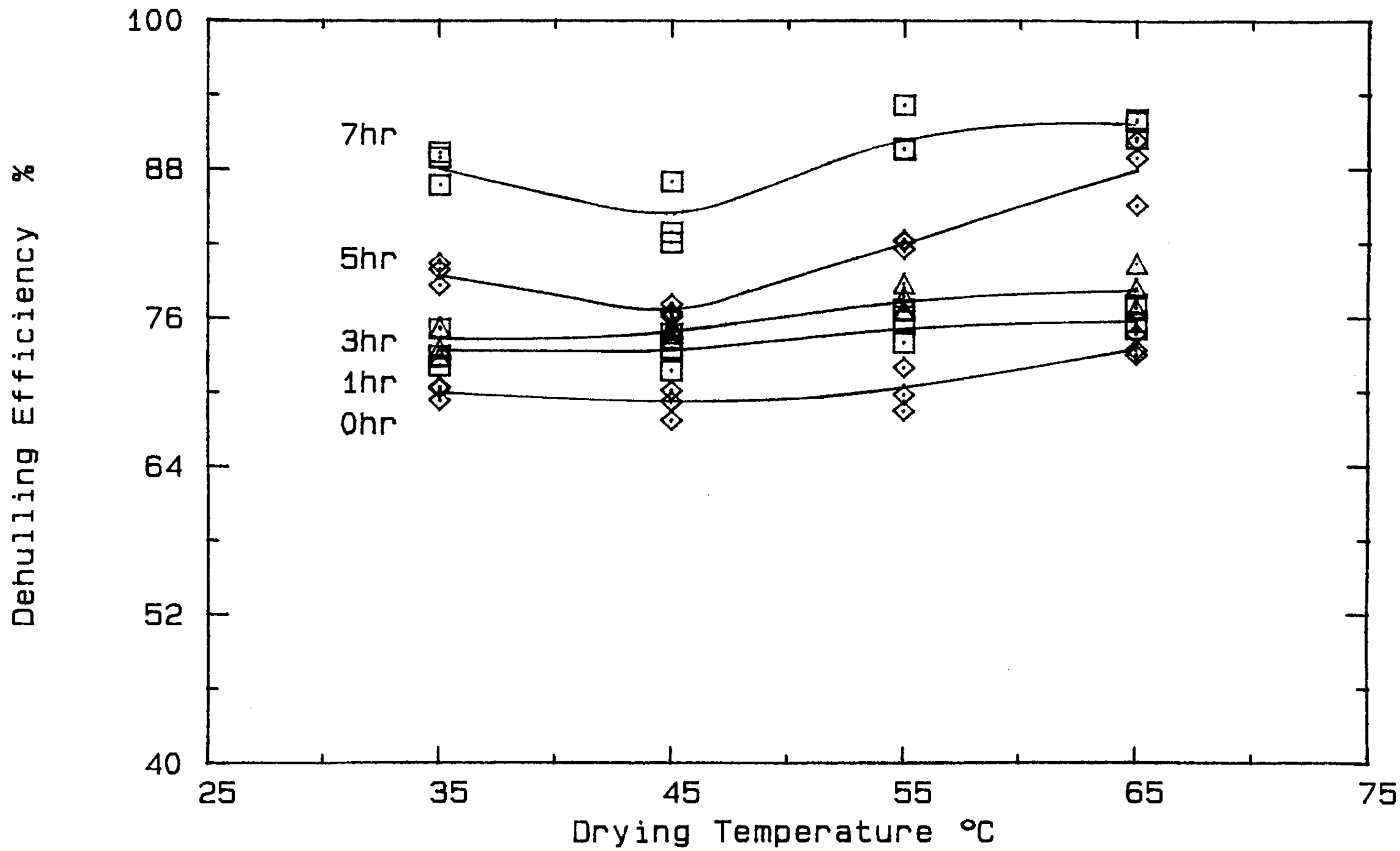

Figure 14. Effects of Soaking Time and Drying Temperature at Moisture Content 6% on Dehulling Efficiency

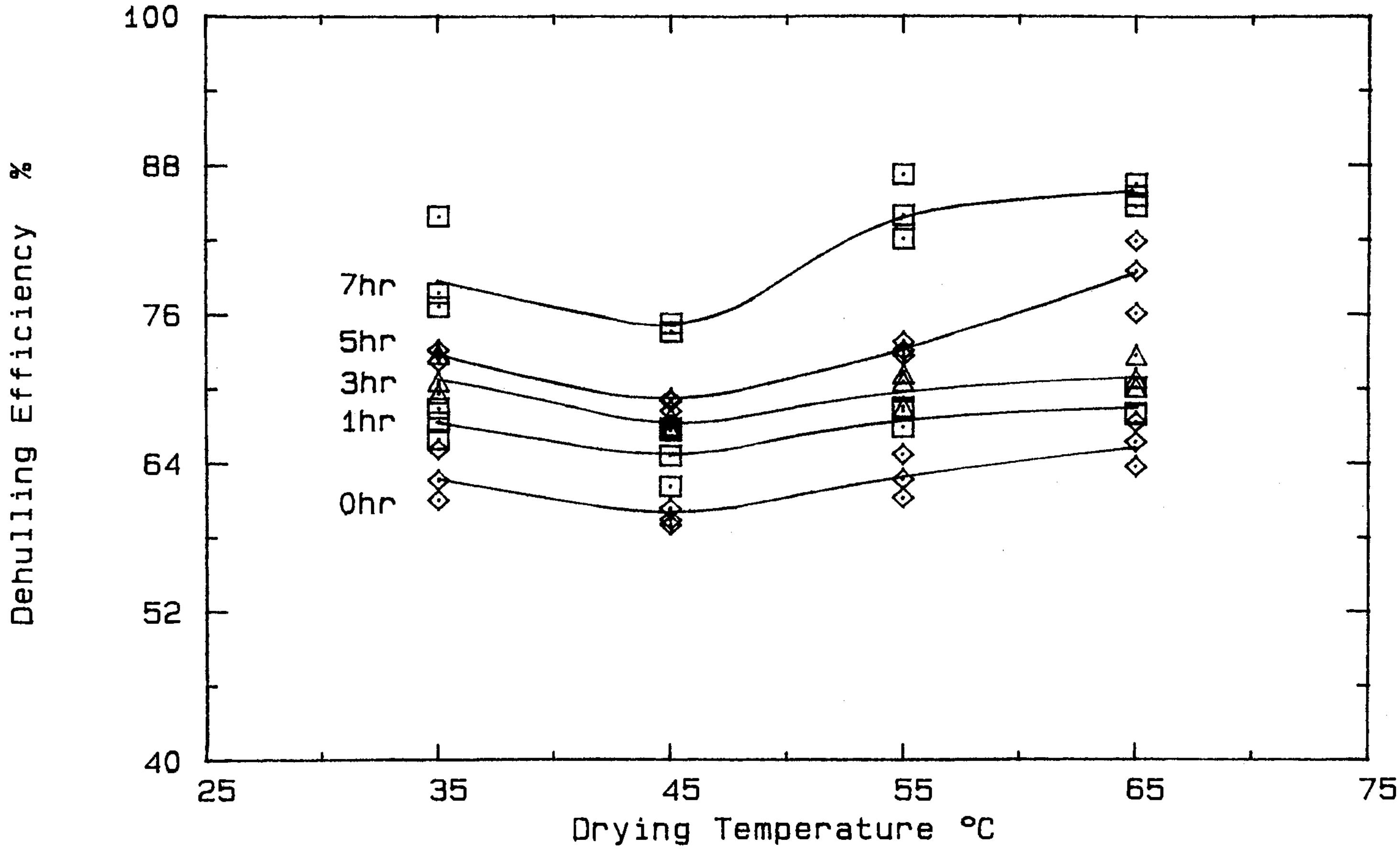

Figure 15. Effects of Soaking Time and Drying Temperature at Moisture Content 8% on Dehulling Efficiency

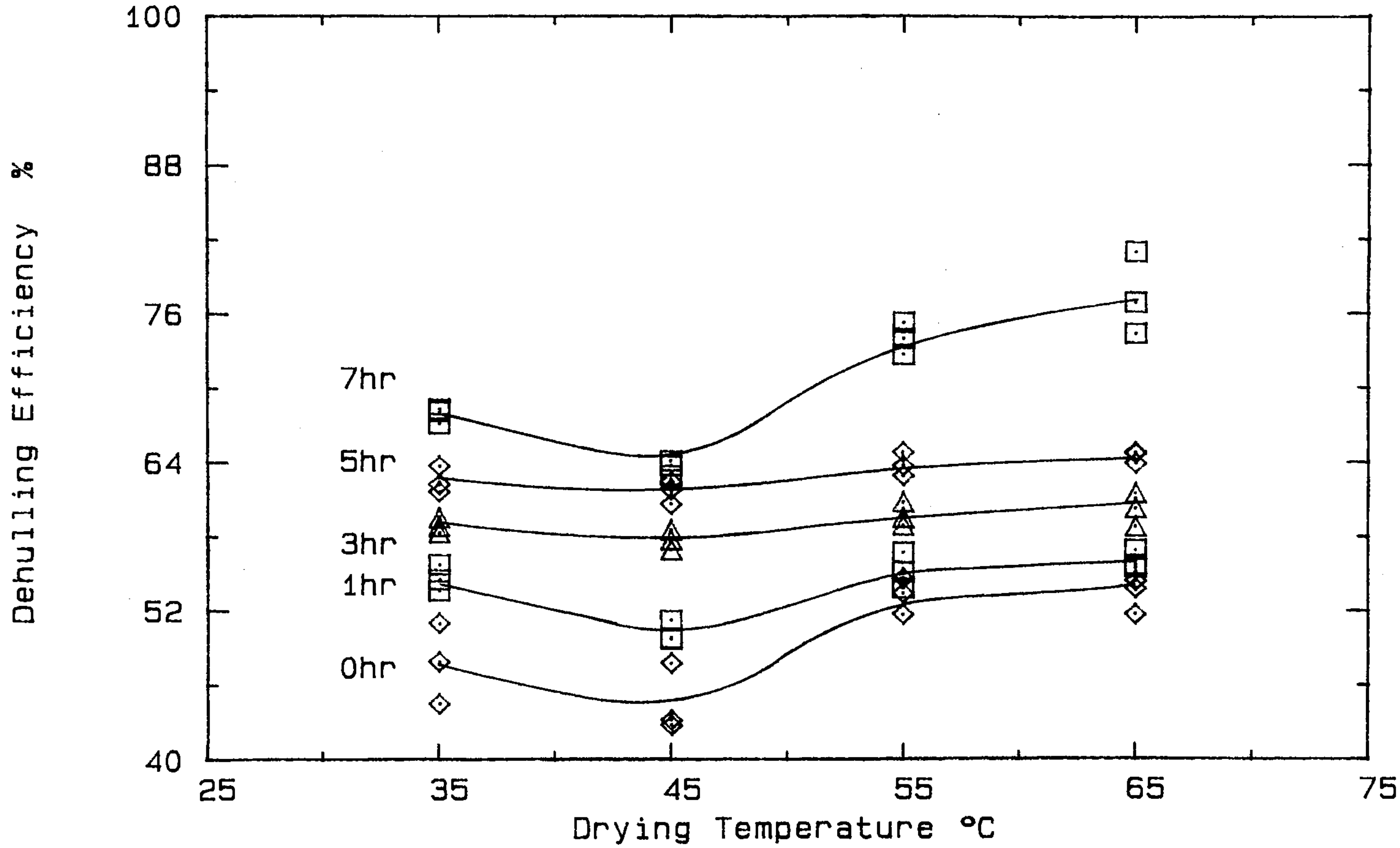

Figure 16. Effects of Soaking Time and Drying Temperature at Moisture Content 10% on Dehulling Efficiency

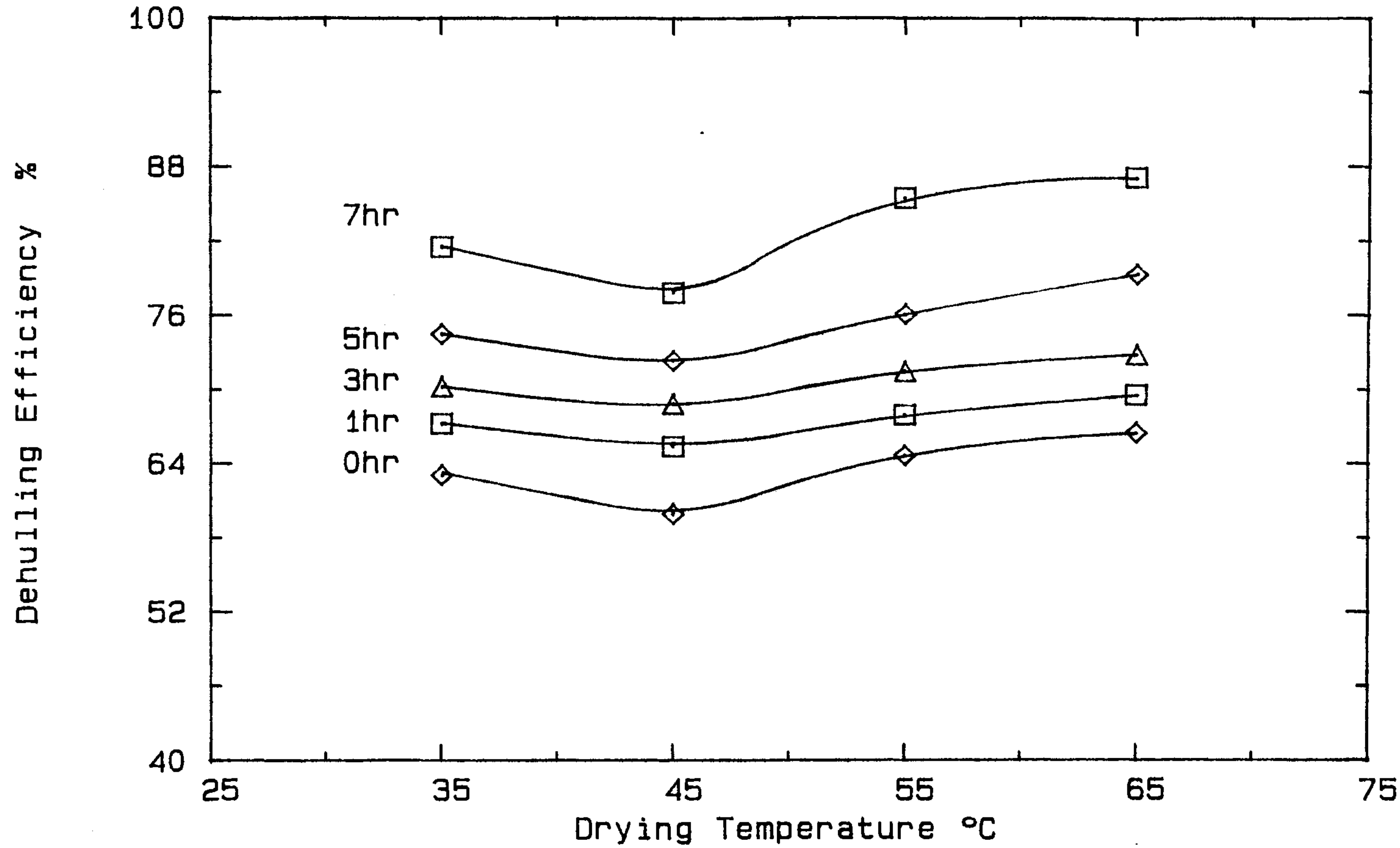

Figure 17. Effects of Soaking Time and Drying Temperature on Dehulling Efficiency Averaged Over Moisture Content

content, drying temperature and soaking time were important factors for predicting or determining the mung bean dehulling efficiency. The analysis of variance showed that each of these factors produced a significant difference in mung bean dehulling efficiency at the 99.5 percent level. As shown in Table IV, the interactions between these factors were also significant at the 95 percent confidence level. For example, the significant final moisture content and soaking time interaction implies that the difference between dehulling efficiencies at different soaking time varied with the level of moisture content, where dehulling efficiencies were measured over all levels of drying temperature. Alternatively, the differences among dehulling efficiencies at different levels of moisture content varied with the level of soaking time, where dehulling efficiencies were again measured over all levels of drying temperature. That is, the differences in dehulling efficiency at different soaking time, when averaged over all levels of drying temperature, were not the same for the four levels of final moisture content. On the other hand, the difference in dehulling efficiency between different moisture contents, when averaged over drying temperature, were not the same for the different levels of soaking time. Similar interpretations could be made for the other interactions.

Effect of Moisture Content

As shown in Figures 8 through 12, when the moisture content was progressively reduced, the dehulling efficiency increased until it reached a maximum. Further reduction in moisture did not result in increased dehulling efficiency due to increased breakage. This moisture level could be called 'critical', as the beans showed maximum dehulling efficiency at or below that moisture level.

Peripheral scouring of the dehulled cotyledons was influenced by the hardness of the beans (to resist scouring), abrasiveness of the scouring machine and the duration of scouring. Addition of moisture softens the beans and makes them more susceptable to scouring; while drying the beans to lower moisture content hardens the beans and increases their resistance to peripheral scouring. However, drying to low moisture content also makes the beans brittle and therefore could result in more breakage of the cotyledons.

From an overall point of view, the samples at 4 percent and 6 percent moisture content, as shown in Figure 8 through 12, were generally superior as regard to dehulling efficiency. This finding was generally correct for all the drying temperatures and also for all soaking times. This study indicated that the 4 to 6 percent moisture content is superior when maximum dehulling efficiency is desired. When the final moisture content was decreased from 10 to 8 percent and from 8 to 6 percent, dehulling efficiency increased significantly at the 95 percent level. The mean dehulling efficiency at various moisture content averaged over drying temperature is plotted in Figure 12. Duncan's New Multiple-Range Test indicated that the difference between 6 percent and 4 percent moisture content in dehulling efficiency was not significant at the 95 percent level among soaking times of 0, 1 and 3 hours when averaged over temperature. The difference in dehulling efficiency between 6 percent and 4 percent moisture content was significant at the 95 percent level at soaking times of 5 hours and 7 hours by using the same test, but it was not significant at the 99 percent level.

Effect of Drying Temperature

The desired moisture level could be reached by drying the beans at low temperatures for prolonged periods or at high temperature for shorter periods. Comparison of the plotted data in Figures 13, 14, 15, and 16 show that from the standpoint of drying temperature, 65°C is the most effective temperature for maximizing mung bean dehulling efficiency. Although the drying temperature of 35°C gave better dehulling efficiency than the drying temperature of 45°C, the drying process was very long.

The drying temperature of 45°C showed a lower dehulling efficiency than other drying temperatures at all moisture contents. The mung bean dehulling efficiency was improved as the drying temperature was increased from 45°C to 65°C. This effect was apparent with all moisture levels used in this study. This indicated that the higher drying temperature had an increased effect on reducing the influence of gums and breaking the bond between the hull and cotyledons. However, the drying temperature of 35°C showed higher dehulling efficiency than that of 45°C. It was observed that the percentage of broken cotyledons passed through the 2 mm sieve at the drying temperature of 45°C was higher than that of 35°C. The data presented in Table III can be used to compare the percentage of broken cotyledons at temperatures of 35°C and 45°C. The drying process at 35°C was much slower than that at 45°C, especially at low final moisture contents (6 and 4 percent). The extended drying time may have some effect on breaking the bond between the hull and cotyledons.

The mean dehulling efficiency at various drying temperatures and soaking times averaged over moisture content is plotted as shown in Figure 17. Duncan's New Multiple-Range Test showed that the increment of dehulling efficiency from 45°C to 55°C at all soaking times averaged over moisture content was significant at the 95 percent level. The increment of dehulling efficiency from 55°C to 65°C averaged over moisture content was significant only at the soaking level of 5 hours at the 95 percent level. The difference (decrement) in dehulling efficiency between the drying temperatures of 35°C and 45°C was significant only at soaking times of 0 and 7 hours at the 95 percent level by using the same test. The drying temperature of 65°C with a low moisture content of 4 percent and/or 6 percent yielded a higher dehulling efficiency than other drying temperatures and moisture contents at each soaking time.

Effect of Soaking Time

Figure 8 through 12 present the experimental data plotted to show the effects of moisture content and soaking time at different drying temperatures on mung bean dehulling efficiency. Figure 13 through 17 present the experiment data plotted to show the effects of drying temperature and soaking time on mung bean dehulling efficiency at four different moisture contents. The data showed that soaking for a certain period of time prior to drying and dehulling was important to achieve a better dehulling efficiency.

It was obvious that the increase in soaking time was invariably associated with increases in mung bean dehulling efficiency. This held for all drying temperatures and moisture contents. At any given drying temperature and moisture content, the shorter soaking times were invariably inferior to the longer soaking times. All the differences in dehulling efficiency for each increment of soaking time were significant at 95 percent confidence level using Duncan's New Multiple-Range Test. The data showed that 65°C drying temperature, together with 7 hours of soaking time was very effective for samples at 4 percent to 6 percent moisture content in this study.

The no-soaking treatments at each temperature level and each moisture level gave lower dehulling efficiencies than the other treatments. The 10 percent moisture samples which were not soaked resulted in the lowest dehulling efficiency of 44.6 percent at the drying temperature of 45°C. The highest dehulling efficiency for the no-soaking treatment was 73.4 percent which was achieved at drying temperature of 65°C and 4 percent final moisture content. In contrast, the dehulling efficiency for samples soaked for 7 hours was 94.1 percent, under the same drying and final moisture conditions. The differences between the no-soaking treatments is of no real importance since all no-soaking samples are not acceptable in dehulling efficiency. This indicates that soaking treatment is necessary to break the bond between the hull and cotyledons to obtain satisfactory dehulling efficiency.

The treatments which produced a high dehulling efficiency for all drying temperatures was 4 percent and/or 6 percent moisture samples dried at 65°C. It was generally apparent that 4 percent and 6 percent moisture content samples had higher dehulling efficiencies at all drying temperatures when a soaking time of 7 hours was used. For other moisture content, soaking time of 7 hours showed better dehulling efficiency than other soaking times. The dehulling efficiency was generally poor when the soaking time was less than 5 hours at moisture content of 8 percent and 10 percent.

Multiple Regression

Table V presents the analysis of variance for the following regression model on mung bean dehulling efficiency and a series of t tests on the significance of the partial regression coefficients for each independent variable:

$$DE = 80.8\ [e^{(-0.0502M)}e^{(0.0364t)}e^{(0.00217T)}] \qquad (4)$$

where:

DE -- dehulling efficiency, %

M -- final moisture content, %, wb

t -- soaking time, hour

T -- drying temperature, °C

Although analysis of variance table for the dehulling efficiency, Table IV, indicated that the interactions among the three factors were significant at 95 percent level, the interactions were relatively small when compared with the main effects of final moisture content, soaking time and drying temperature and had no practical value. Therefore they were deleted from the model.

In the following statistical analysis, the 1 percent probability was used as the level of significance for all tests.

The F value for the regression model was 503.6 which was significant at 99.99 percent level and indicated that there was a strong regression relation between the dependent

TABLE V

ANALYSIS OF VARIANCE AND REGRESSION ANALYSIS
FOR DEHULLING EFFICIENCY

Source	df	SS	Mean S	F ratio	Prob.	R^2
Regression	3	5.2424	1.7475	503.61	0.0	.865
Residual	236	0.8649	0.0035			
Total	239	6.0613				

Variable	Coeff.	T (df=76)	Prob.	Partial r^2
M	-0.0502	-29.495	.00000	.7866
T	0.0022	6.381	.00000	.1472
t	0.0364	24.498	.00000	.7178

variable dehulling efficiency and the independent variables final moisture content, drying temperature and soaking time. R value, the multiple correlation coefficient, was 0.93 (R^2 = 0.865), indicating a good fit of the regression model to the observed points since 86.5 percent of variation around the mean was explained by the independent variable. Figure 18 to 21 present some data by using semi-logarithmic coordinates. The plots using semi-logarithmic coordinates for all the data are presented in Appendix B.

The lower portion of Table V presents a series of t tests on significance of the partial regression coefficients for each independent variable. From the t tests, it was concluded that all the regression coefficients were significant at the 99.99 percent confidence level.

It was observed that the slope for the drying temperature in the above model was much smaller than that for moisture content and for soaking time. This indicated that the effect of temperature on dehulling efficiency was much smaller than that of final moisture content and soaking time. At some moisture and soaking levels, the dehulling efficiency data showed that temperature was not a significant factor statistically, as shown in Figures 22 and 23. However, temperature was a significant factor statistically at most of the moisture and soaking levels as shown in Figure 24 and 25. Figure 22 through 25 are only a few examples. The complete plots are presented in Appendix B at the end of this thesis. Differences in significance of

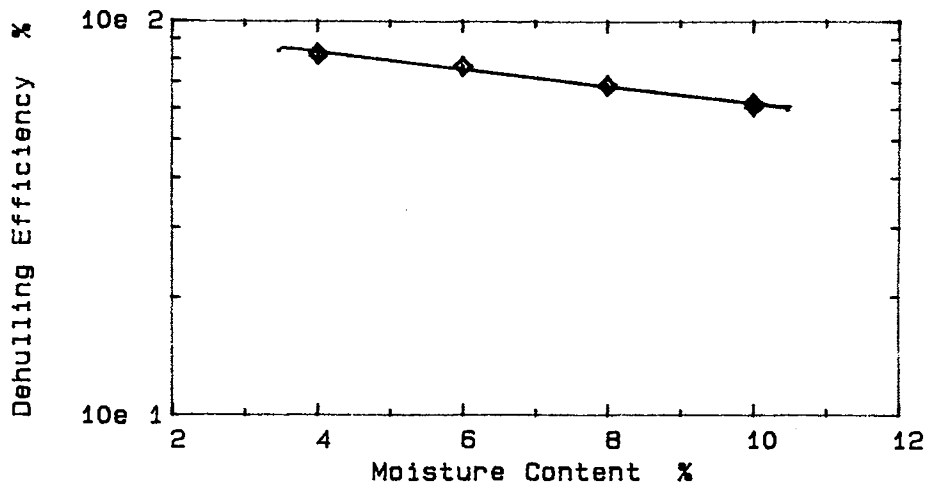

Figure 18. Dehulling Efficiency vs Moisture Content for Soaking Time 5 Hours at Drying Temperature 45°C

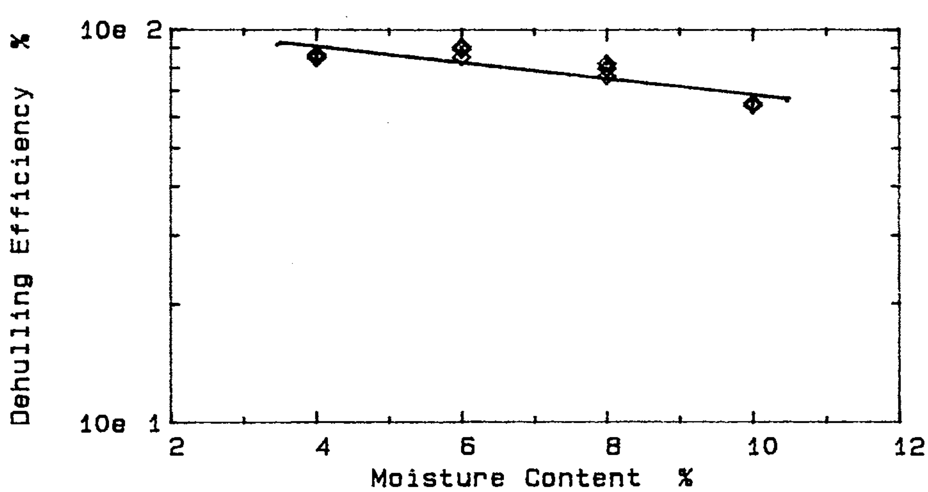

Figure 19. Dehulling Efficiency vs Moisture Content for Soaking Time 5 Hours at Drying Temperature 65°C

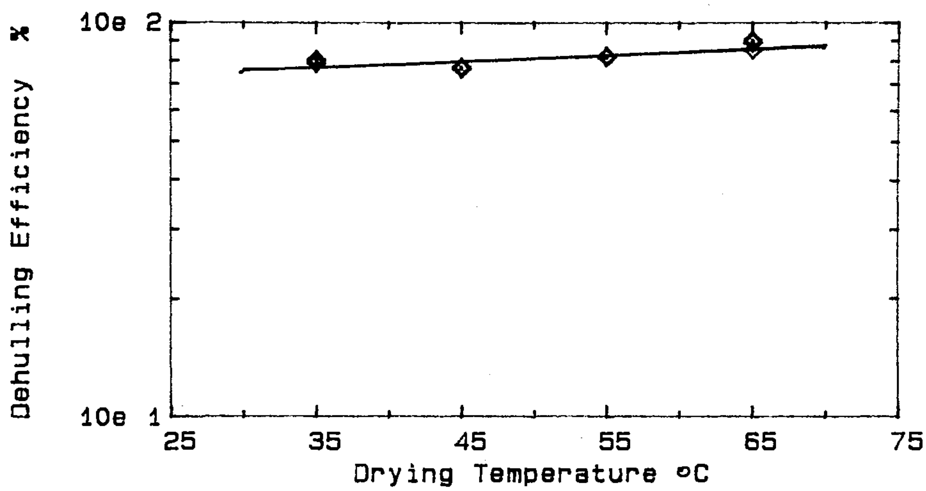

Figure 20. Dehulling Efficiency vs Drying Temperature for Soaking Time 5 Hours at Moisture Content 6%

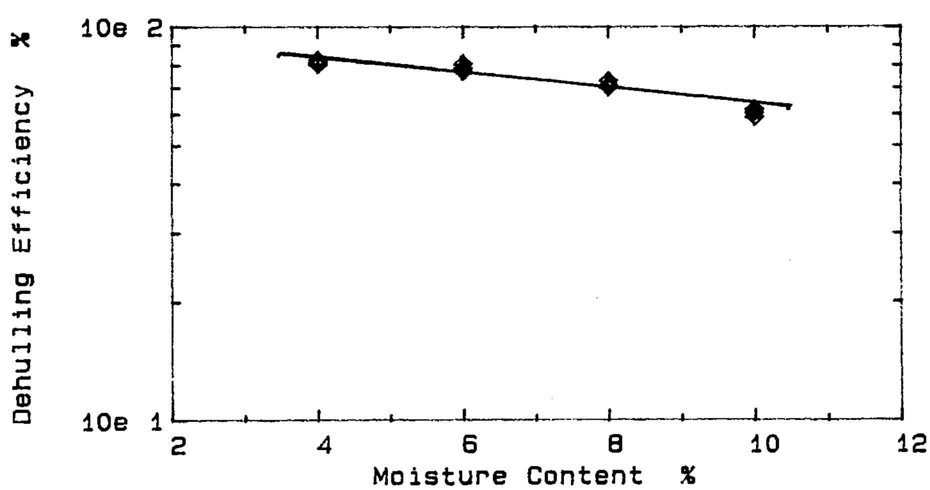

Figure 21. Dehulling Efficiency vs Moisture Content for Soaking Time 3 Hours at Drying Temperature 65°C

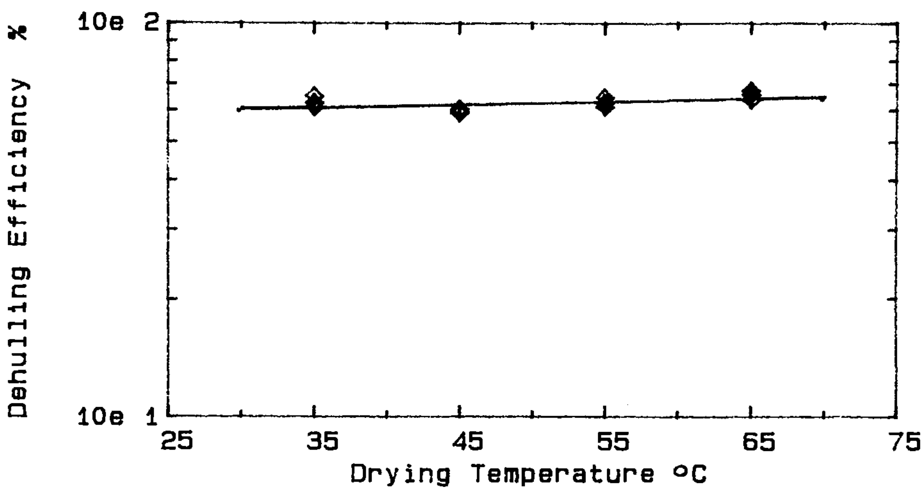

Figure 22. Dehulling Efficiency vs Drying Temperature for No-soaking at Moisture Content 8%

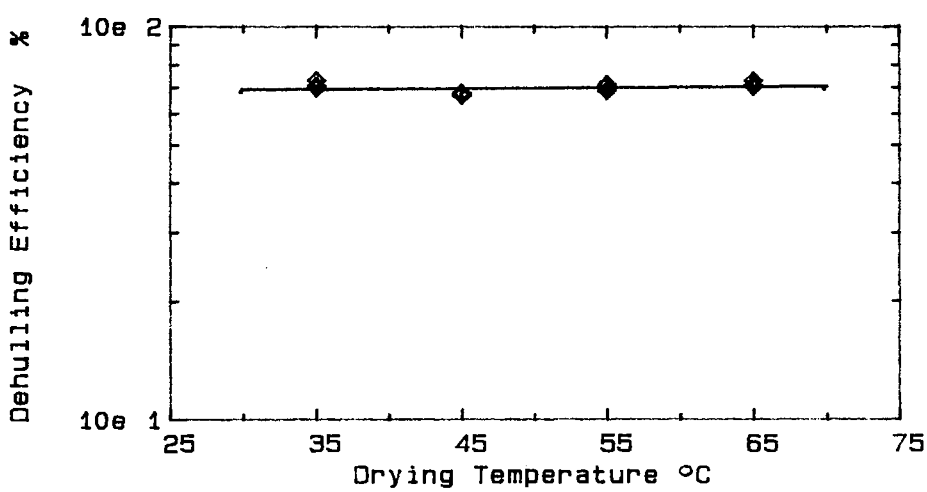

Figure 23. Dehulling Efficiency vs Drying Temperature for Soaking Time 3 Hours at Moisture Content 8%

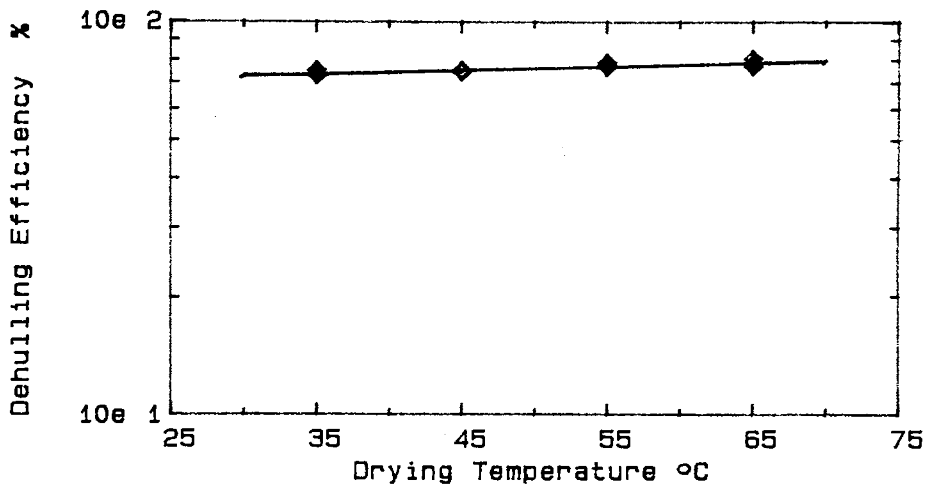

Figure 24. Dehulling Efficiency vs Drying Temperature for Soaking Time 3 Hours at Moisture Content 6%

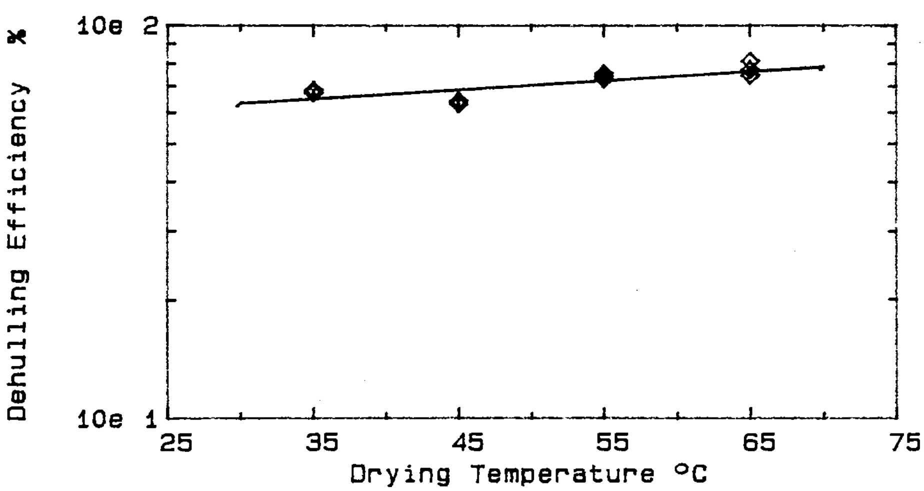

Figure 25. Dehulling Efficiency vs Drying Temperature for Soaking Time 7 Hours at Moisture Content 10%

the temperature coefficients may be due to interactions among the three factors and experiment error. As discussed earlier, although interactions among the three factors were significant at 95 percent level, there was no practical value to consider the effect of them when compared with the main effects of soaking time, drying temperature and moisture content. Tables IV and IX both showed that drying temperature was a significant factor statistically and the predicted value by using the above regression model showed that differences in dehulling efficiency due to the temperature difference can be as high as 6 percent. Therefore, it can be concluded that the differences in coefficients for the temperature was mainly due to sampling error and the effect of drying temperature can not be ignored.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The hull of the mung bean adheres very firmly to the cotyledons. Soaking treatments were used in this study to break the bond between the hull and cotyledons of mung bean to obtain satisfactory dehulling efficiency. The effects of soaking time, drying temperature and final moisture content on mung bean dehulling efficiency were investigated .

Each sample of mung bean was soaked in water at room temperature for the required period of time and then dried at a specific temperature to a desired moisture content. After equilibrium, the sample was dehulled in the dehulling machine. The hull and fines were separated from the cotyledons by air aspiration and dehulling efficiency was determined. Variations in dehulling efficiency obtained with different pre-hulling treatments indicated the extent of loosening the hull from the cotyledons after the treatments. After dehulling, most of the dehulled beans were split into two cotyledons. This study showed that soaking time, drying temperature and final moisture content were important factors for predicting mung bean dehulling efficiency.

The final moisture content had an inverse effect on mung bean dehulling efficiency. When the moisture content was progressively reduced, the dehulling efficiency increased until it reached a maximum. Further reduction in moisture level did not help in increasing dehulling efficiency due to increased breakage. This study showed that the samples at 4 and 6 percent moisture content were generally superior for producing maximum dehulling efficiency.

It was shown that increases in soaking time were invariably associated with increases in mung bean dehulling efficiency. The no-soaking treatment at each temperature and moisture level gave lower dehulling efficiency than the other treatments. Therefore, soaking prior to drying and dehulling was important to achieve a better dehulling efficiency.

Although drying temperature had less effect on mung bean dehulling efficiency than final moisture content and soaking time, it still could not be neglected. This study showed that among the drying temperatures, 65°C was the most effective temperature for maximizing mung bean dehulling efficiency. The drying temperature of 45°C showed a lower dehulling efficiency than other drying temperatures. The mung bean dehulling efficiency was improved generally when the drying temperature was increased. This indicated that higher drying temperature had an increased effect on reducing the influence of gums and breaking the bond between the hull and cotyledons. However the drying temperature of 35°C showed higher dehulling efficiency than that of 45°C due to less breakage and extended drying time.

The following exponential model

$$DE = 80.8 \, [e^{(-0.0502M)} e^{(0.0364t)} e^{(0.00217T)}]$$

was fitted to describe the relationship between the mung bean dehulling efficiency, soaking time, drying temperature and final moisture content.

Conclusions

The following conclusions were derived from analysis of the experimental data collected during this study:

1. The no-soaking treatment clearly showed that soaking was required to break the bond between hulls and cotyledons to achieve higher dehulling efficiency. Soaking mung beans in water for a sufficient time prior to drying and dehulling increased the dehulling efficiency. The soaking time of 7 hours showed best dehulling efficiency among the soaking times.
2. The final moisture content had an important effect on mung bean dehulling efficiency. When moisture content decreased, the dehulling efficiency increased. The final moisture content of 4 to 6 percent, wb, was superior when maximum dehulling

efficiency was desired.

3. Mung bean dehulling efficiency was generally improved when the drying temperature was increased. This implied that the higher drying temperature had a better effect on breaking the bond between the hull and cotyledons. 65°C showed better dehulling efficiency than other drying temperatures.
4. The treatment combination of 7 hour soaking time, 65° dry temperature and 4 to 6 percent moisture content, wb, was effective for loosening hulls from cotyledons and gave dehulling efficiency as high as 92 percent.
5. Splitting during dehulling appeared to be a general characteristic. The breakage of cotyledons after dehulling increased as final moisture content decreased and drying temperature increased.
6. Statistical analysis of the multiple regression model showed that exponential effects of final moisture content, drying temperature and soaking time were significant at the 99.99 percent level.
7. Although interactions among the three factors were significant statistically, they were relatively small and of no practical value when compared with the main effects of soaking time, drying temperature and final moisture content. Therefore, they were not included in the regression model.

Recommendations

The scope of this research was limited to the soaking treatment to obtain satisfactory dehulling efficiency for mung beans. The following recommendations are made for further research work to improve mung bean dehulling efficiency.

1. Heating Treatment

This study showed that when drying temperature increased the dehulling efficiency increased to some extend. This indicates that higher temperature has an effect on breaking the bond between the hull and cotyledons. A heat treatment may be applied to the mung bean samples as pre-hulling treatment to loose the hull from cotyledons to obtain a better dehulling efficiency. When mung beans are heated at a relative high temperature (100 to 150 °C) for a certain period of time and conditioned under controlled conditions to a 'critical moisture content', the hull of the bean should be loosened and become brittle so that they can be removed in the dehulling machine. For the heat treatment, the crucial factors to investigate are heating temperature, duration of heating and moisture content.

2. Treatments with Chemical Solutions

The pre-hulling treatment by using alkaline solutions to impart adequate loosening of hull has been used for the dehulling of some grain legumes. It is much faster than the soaking treatment. But it has not been successfully used for the dehulling of mung beans. The flour made from mung beans dehulled in such method is darker. Further research work on this problem would be valuable to obtain better quality of the dehulled cotyledons.

3. Developing Cultivars with Better Dehulling Character

Different cultivars of mung bean will display varying dehulling characteristics which may be influenced by the varietal characteristics, such as quality and quantity of gums, and the moisture level of the beans. Different varieties of beans have different 'critical moisture level' at which the best dehulling efficiency can be obtained. Further investigations identifying the cultivars with poor seed coat adhesion and acceptable dehulling characteristics are necessary to provide information on how the dehulling quality of each species can be improved in a plant breeding program.

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APPENDIXES

APPENDIX A

EXPERIMENT DATA

TABLE VI

EFFECTS OF MOISTURE CONTENT AND SOAKING TIME AT DRYING TEMPERATURE 35°C ON DEHULLING EFFICIENCY

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		446.1	321.0	72.0	71.2
	0	449.5	316.2	70.3	70.1
		448.9	328.9	73.3	72.9
		450.9	329.3	73.0	73.0
	1	449.3	334.4	74.4	74.1
		452.4	333.3	73.7	73.9
		446.8	354.9	79.4	78.7
4	3	444.7	350.0	78.7	77.6
		444.0	339.2	76.4	75.2
		446.0	371.7	83.3	82.4
	5	444.1	366.2	82.5	81.2
		444.3	384.0	86.4	85.1
		435.9	403.2	92.5	89.4
	7	435.6	405.9	93.2	90.0
		441.9	416.8	94.3	92.4
		451.9	317.6	70.3	70.4
	0	451.7	312.5	69.2	69.3
		455.3	317.2	69.7	70.3
		451.0	338.6	75.0	75.1
	1	448.0	325.3	72.6	72.1
		449.9	329.0	73.1	72.9
		449.2	328.2	73.1	72.8
6	3	448.8	331.5	73.9	73.5
		452.6	339.1	74.9	75.2
		449.7	354.5	78.8	78.6
	5	446.3	362.6	81.2	80.4
		445.0	360.2	80.9	79.9
		440.3	402.9	91.5	89.3
	7	443.5	401.1	90.4	88.9
		440.9	391.0	88.7	86.7

TABLE VI (Continued)

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		452.0	282.5	62.5	62.6
	0	449.4	293.8	65.4	65.1
		451.3	275.1	61.0	61.0
		449.7	297.2	66.1	65.9
	1	448.9	303.5	67.6	67.3
		447.6	308.3	68.9	68.4
		456.0	314.1	68.9	69.6
8	3	445.2	318.3	71.5	70.6
		449.2	328.3	73.1	72.8
		444.5	325.4	73.2	72.2
	5	442.9	329.5	74.4	73.1
		448.4	329.7	73.5	73.1
		435.6	378.6	86.9	83.9
	7	445.9	350.6	78.6	77.7
		443.3	345.5	77.9	76.6
		456.6	230.0	50.4	51.0
	0	454.7	200.7	44.1	44.5
		456.2	216.0	47.3	47.9
		455.8	245.8	53.9	54.5
	1	453.4	241.6	53.3	53.6
		454.5	251.2	55.3	55.7
		451.6	262.9	58.2	58.3
10	3	451.1	265.3	58.8	58.8
		455.8	268.2	58.8	59.5
		452.0	277.7	61.4	61.6
	5	450.7	287.1	63.7	63.7
		447.4	280.5	62.7	62.2
		449.6	307.0	68.3	68.1
	7	444.6	308.2	69.3	68.3
		439.5	302.8	68.9	67.1

TABLE VII

EFFECTS OF MOISTURE CONTENT AND SOAKING TIME AT DRYING TEMPERATURE 45°C ON DEHULLING EFFICIENCY

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		453.9	289.4	63.8	64.2
	0	451.5	306.3	67.8	67.9
		456.6	301.1	65.9	66.8
		452.8	329.5	72.8	73.1
	1	449.2	334.0	74.3	74.1
		448.9	328.9	73.3	72.9
		448.2	335.3	74.8	74.3
4	3	449.0	341.9	76.1	75.8
		448.9	344.9	76.8	76.5
		444.6	367.1	82.6	81.4
	5	446.9	374.9	83.9	83.1
		444.1	372.0	83.8	82.5
		442.1	404.0	91.4	89.6
	7	444.3	398.2	89.6	88.3
		444.7	401.1	90.2	88.9
		451.9	312.1	69.1	69.2
	0	451.7	316.2	70.0	70.1
		450.3	305.5	67.8	67.7
		455.8	323.4	70.9	71.7
	1	452.7	336.9	74.4	74.7
		451.8	331.6	73.4	73.5
		447.4	339.8	75.9	75.3
6	3	452.2	338.1	74.8	75.0
		453.9	335.3	73.9	74.3
		446.7	343.1	76.8	76.1
	5	444.1	344.5	77.6	76.4
		445.2	347.5	78.1	77.1
		447.9	373.9	83.5	82.9
	7	449.2	370.1	82.4	82.1
		440.9	392.3	89.0	87.0

TABLE VII(Continued)

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		455.5	272.0	59.7	60.3
	0	451.7	266.3	59.0	59.0
		453.1	268.1	59.2	59.4
		447.0	301.1	67.4	66.8
	1	449.8	291.2	64.8	64.6
		448.7	280.1	62.4	62.1
		448.9	300.4	66.9	66.6
8	3	452.9	305.3	67.4	67.7
		448.8	302.0	67.3	67.0
		449.2	307.5	68.4	68.2
	5	452.5	312.1	69.0	69.2
		449.7	311.1	69.2	69.0
		444.2	336.5	75.8	74.6
	7	448.5	339.6	75.7	75.3
		448.1	336.5	75.1	74.6
		459.2	195.0	42.5	43.2
	0	457.7	215.6	47.1	47.8
		458.1	192.9	42.1	42.8
		457.7	230.7	50.4	51.2
	1	459.3	224.0	48.8	49.7
		455.8	224.7	49.3	49.8
		455.5	260.3	57.1	57.7
10	3	454.1	263.8	58.1	58.5
		454.8	256.6	56.4	56.9
		453.3	278.7	61.5	61.8
	5	451.4	273.5	60.6	60.6
		447.4	281.4	62.9	62.4
		447.9	283.9	63.4	62.9
	7	452.6	289.1	63.9	64.1
		451.2	287.4	63.7	63.7

TABLE VIII

EFFECTS OF MOISTURE CONTENT AND SOAKING TIME AT DRYING TEMPERATURE 55°C ON DEHULLING EFFICIENCY

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		449.2	330.1	73.5	73.2
	0	449.5	321.5	71.5	71.3
		450.7	323.8	71.8	71.8
		449.1	325.2	72.4	72.1
	1	451.5	334.2	74.0	74.1
		447.9	331.1	73.9	73.4
		446.8	356.3	79.7	79.0
4	3	449.6	349.5	77.7	77.5
		444.8	354.8	79.8	78.7
		443.3	386.9	87.3	85.8
	5	446.9	374.9	83.9	83.1
		444.3	395.1	88.9	87.6
		440.2	417.7	94.9	92.6
	7	443.6	422.6	95.3	93.7
		435.6	412.8	94.8	91.5
		451.3	309.1	68.9	68.5
	0	452.6	324.5	71.7	72.0
		447.1	314.6	70.4	69.8
		446.4	345.9	77.5	76.7
	1	446.8	342.0	76.5	75.8
		443.4	333.7	75.3	74.0
		448.1	355.3	79.3	78.8
6	3	449.7	350.5	77.8	77.7
		450.4	345.5	76.7	76.6
		437.7	371.2	84.8	82.3
	5	441.1	367.9	83.4	81.6
		440.4	370.5	84.1	82.2
		436.8	404.6	92.6	89.7
	7	433.2	420.3	97.0	93.2
		436.4	404.3	92.6	89.6

TABLE VIII (Continued)

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		451.8	276.0	61.1	61.2
	0	455.0	291.7	64.1	64.7
		454.0	287.3	63.3	63.7
		449.7	307.7	68.4	68.2
	1	446.8	301.9	67.6	66.9
		447.6	301.3	67.7	68.5
		445.9	318.5	71.4	70.6
8	3	453.1	321.1	70.8	71.2
		456.4	308.9	67.7	68.5
		443.9	332.9	75.0	73.8
	5	442.9	329.6	74.4	73.1
		452.3	327.9	72.5	72.7
		440.9	393.7	89.3	87.3
	7	449.2	370.1	82.4	82.1
		436.7	378.8	86.7	84.0
		456.6	233.1	51.0	51.7
	0	456.0	240.8	52.8	53.4
		457.4	246.2	53.8	54.6
		455.8	248.5	54.5	55.1
	1	453.2	255.6	56.4	56.7
		454.8	242.6	53.3	53.8
		454.5	265.5	58.4	58.9
10	3	456.6	274.2	60.1	60.8
		455.8	268.2	58.8	59.5
		447.7	292.2	65.3	64.8
	5	450.7	287.1	63.7	63.7
		455.3	283.7	62.3	62.9
		448.0	339.6	75.8	75.3
	7	441.3	328.1	74.3	72.7
		439.9	333.9	75.9	74.0

TABLE IX

EFFECTS OF MOISTURE CONTENT AND SOAKING TIME AT DRYING TEMPERATURE 65oC ON DEHULLING EFFICIENCY

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
		454.4	327.2	72.0	72.5
	0	447.1	329.4	73.7	73.0
		449.5	337.1	75.0	74.7
		445.4	348.9	78.3	77.4
	1	447.2	345.6	77.3	76.6
		447.4	354.4	79.2	78.6
		444.6	366.2	82.4	81.2
4	3	447.2	361.3	80.8	80.1
		446.2	371.6	83.3	82.4
		443.3	381.1	86.0	84.5
	5	436.2	386.8	88.7	85.8
		444.3	388.8	87.5	86.2
		437.2	420.6	96.2	93.3
	7	438.9	425.6	97.0	94.4
		439.0	424.4	96.7	94.1
		449.5	336.9	74.9	74.7
	0	453.6	329.2	72.6	73.0
		448.2	330.9	73.8	73.4
		450.6	341.6	75.8	75.7
	1	449.7	338.7	75.3	75.1
		448.9	347.7	77.5	77.1
		451.1	353.6	78.4	78.4
6	3	445.7	346.4	77.7	76.8
		444.3	362.5	81.6	80.4
		441.8	383.9	86.9	85.1
	5	444.7	407.3	91.6	90.3
		443.5	401.1	90.4	88.9
		440.9	414.7	94.1	92.0
	7	444.0	408.2	91.9	90.5
		442.1	414.2	93.7	91.8

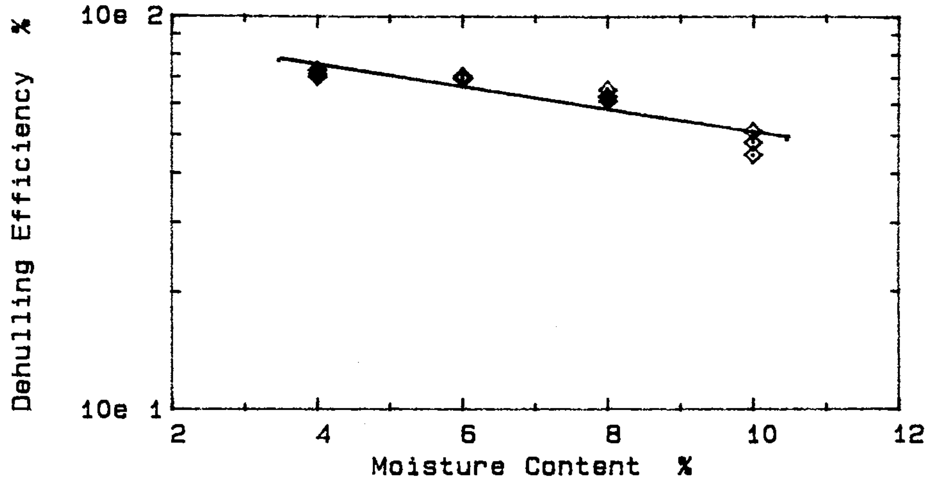
TABLE IX (Continued)

Moisture content (%, wb)	Soaking time (hour)	Sample weight (gm)	Cotyledon weight (gm)	Cotyledon percent by wt.	Dehulling efficiency (percent)
8	0	452.3	296.2	65.5	65.7
		449.4	303.5	67.5	67.3
		454.0	287.3	63.3	63.7
	1	454.9	316.3	69.5	70.1
		451.1	305.2	67.9	67.9
		452.7	306.8	67.8	68.0
	3	452.4	319.3	70.6	70.8
		447.0	327.7	73.3	72.7
		449.9	316.1	70.3	70.1
	5	439.4	343.4	78.2	76.1
		443.6	369.4	83.3	81.9
		435.6	358.6	82.3	79.5
	7	443.6	382.0	86.1	84.7
		434.6	390.3	89.8	86.5
		435.6	385.6	88.5	85.5
10	0	455.5	233.3	51.2	51.7
		454.8	242.6	53.3	53.8
		458.1	245.4	53.6	54.4
	1	451.3	250.2	55.4	55.5
		457.8	251.0	54.8	55.7
		454.3	256.6	56.5	56.9
	3	462.9	272.0	58.7	60.3
		451.1	265.3	58.8	58.8
		453.8	277.3	61.1	61.5
	5	447.7	292.2	65.5	64.8
		447.2	292.0	65.3	64.7
		448.1	288.1	64.4	63.9
	7	444.7	335.5	75.4	74.4
		444.9	346.9	78.0	76.9
		446.0	365.2	81.9	81.0

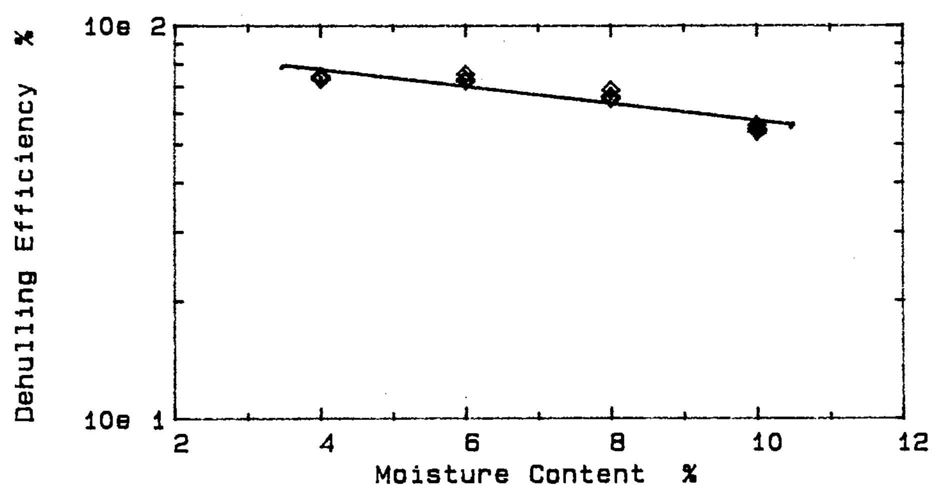
APPENDIX B

PLOTS OD EXPERIMENT DATA USING

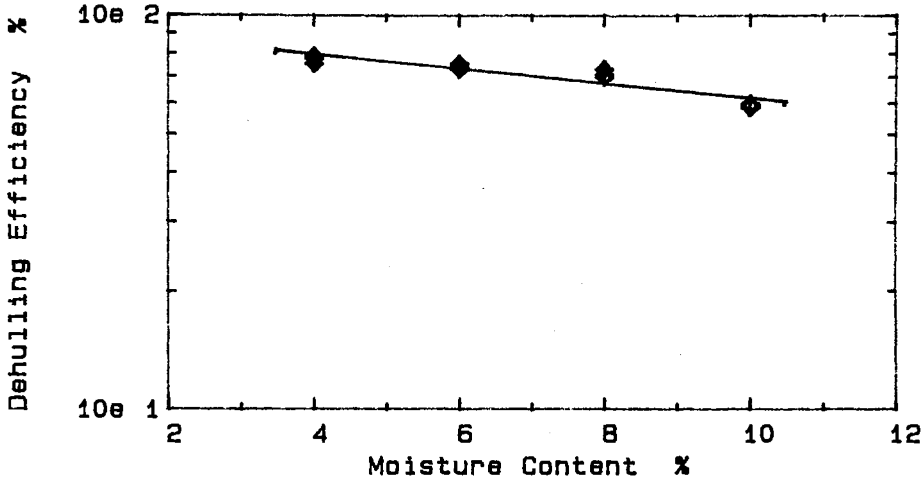
SEMILOGRITHMIC COORDINATES



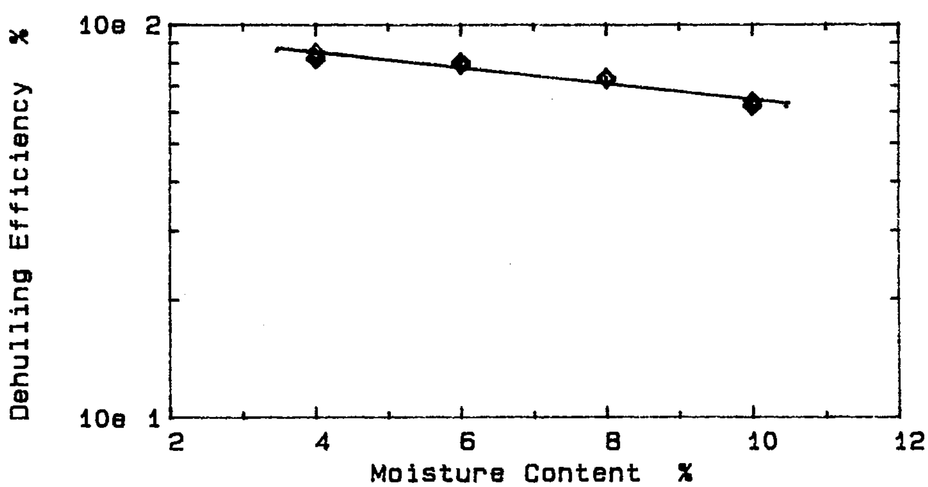
Drying Temperature: 35°C
Soaking Time: No-soaking



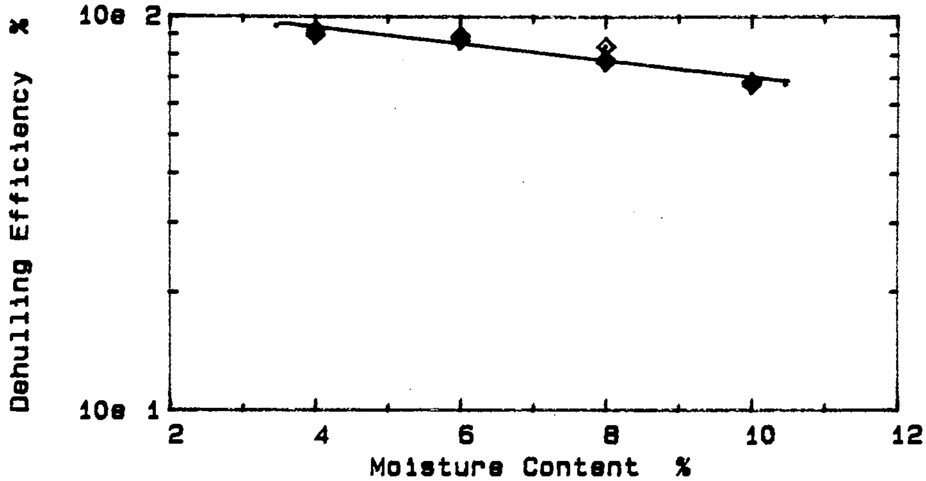
Drying Temperature: 35°C
Soaking Time: 1 Hour



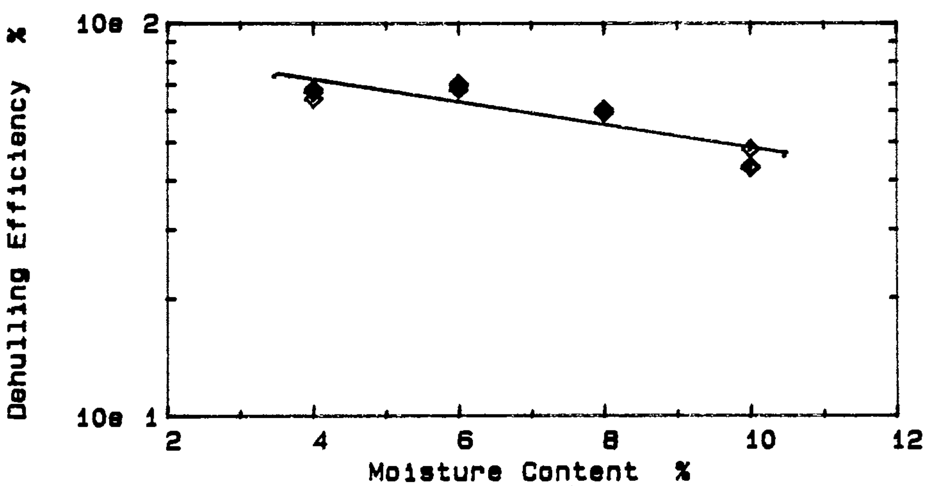
Drying Temperature: 35°C
Soaking Time: 3 Hours



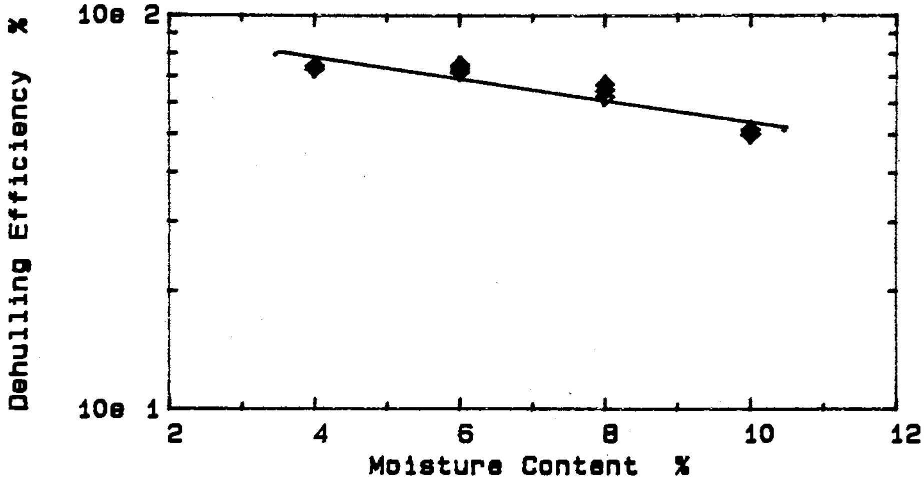
Drying Temperature: 35°C
Soaking Time: 5 Hours



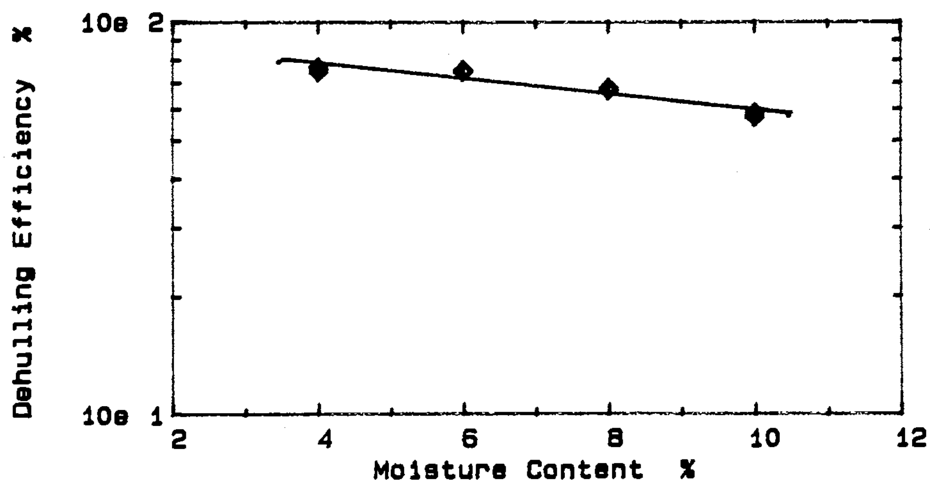
Drying Temperature: 35°C
Soaking Time: 7 Hours



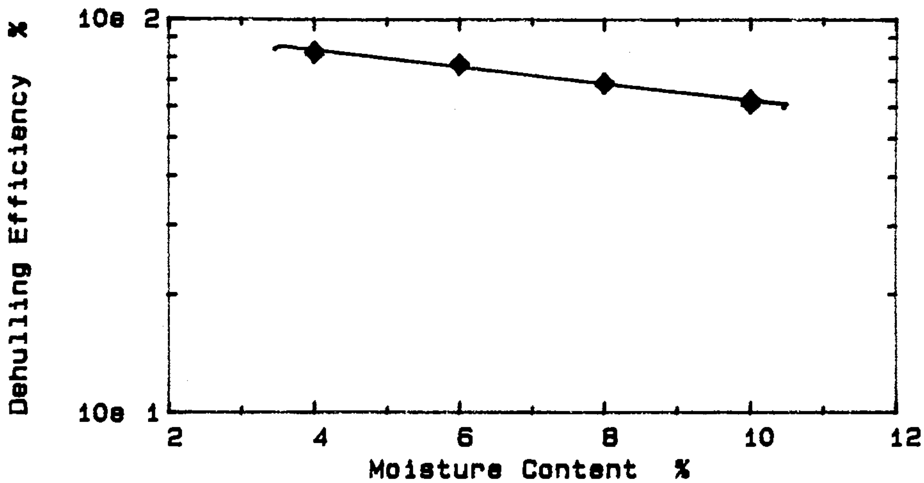
Drying Temperature: 45°C
Soaking Time: No-soaking



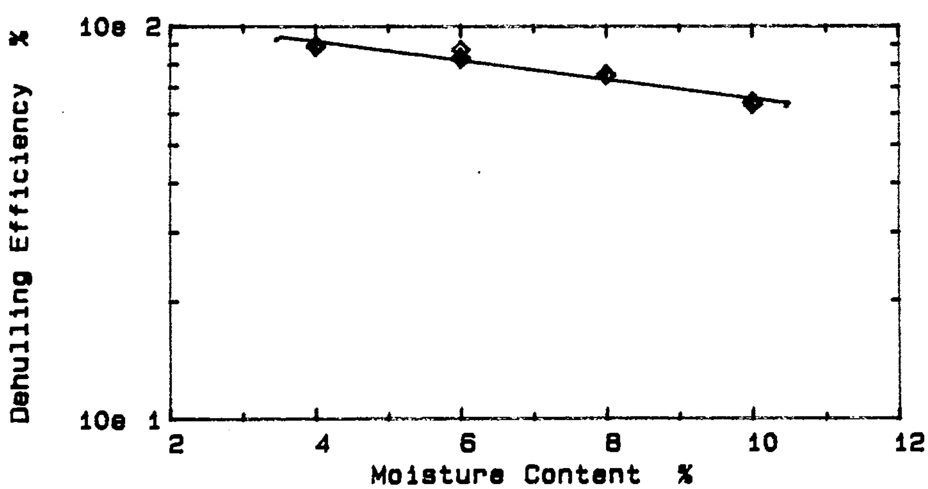
Drying Temperature: 45°C
Soaking Time: 1 Hour



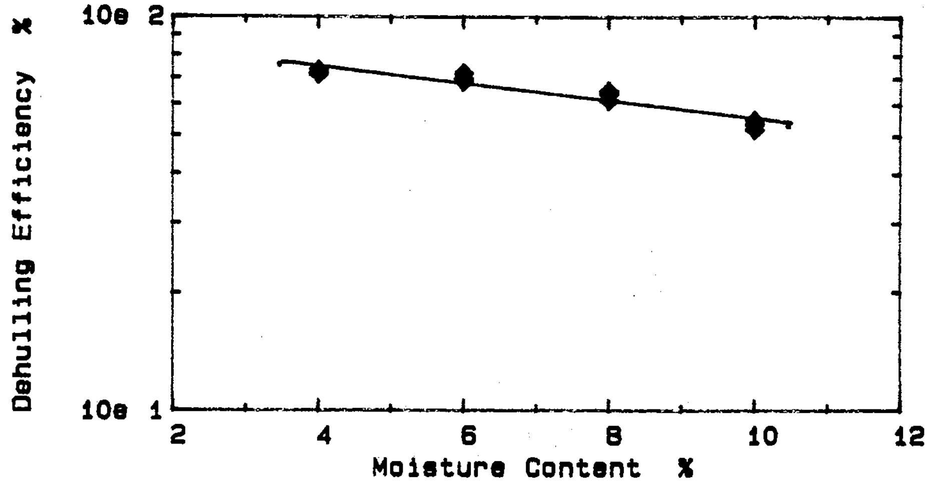
Drying Temperature: 45°C
Soaking Time: 3 Hours



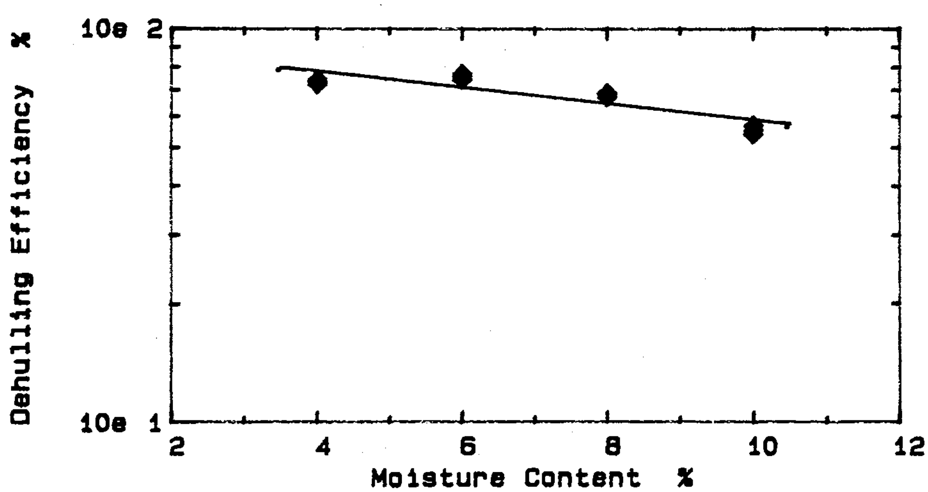
Drying Temperature: 45°C
Soaking Time: 5 Hours



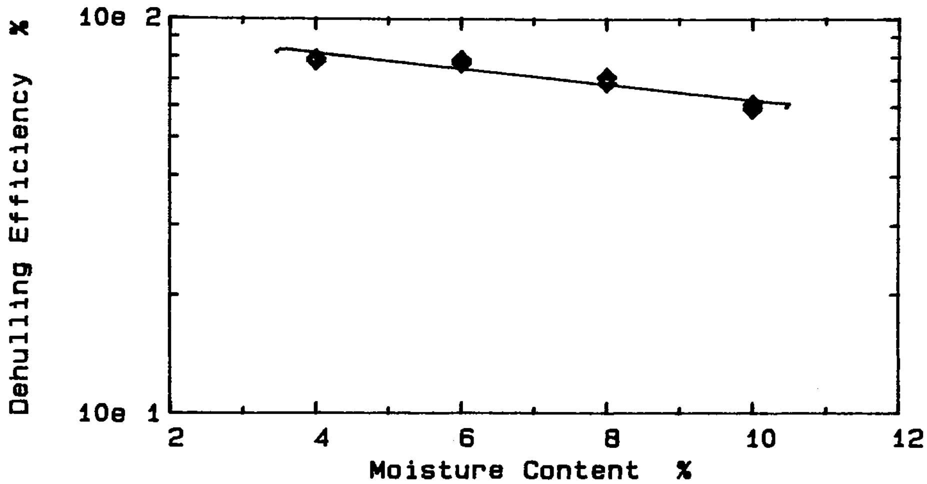
Drying Temperature: 45°C
Soaking Time: 7 Hours



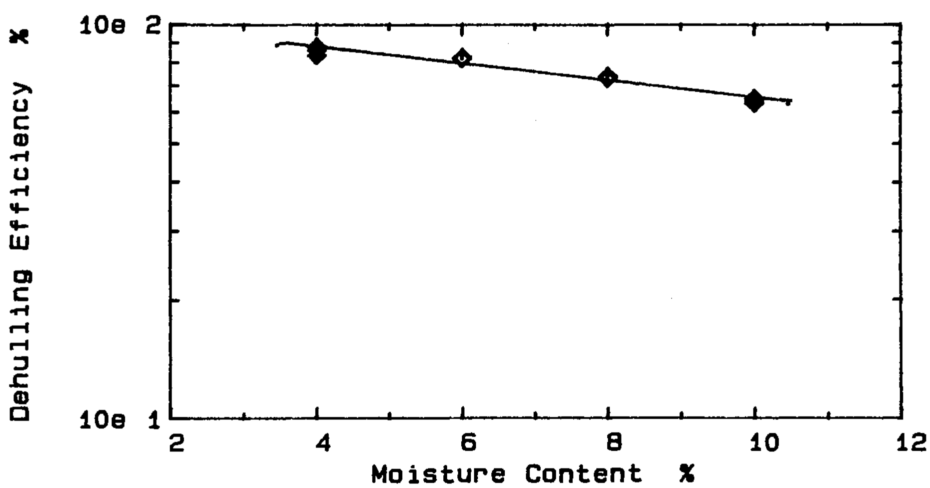
Drying Temperature: 55°C
Soaking Time: No-soaking



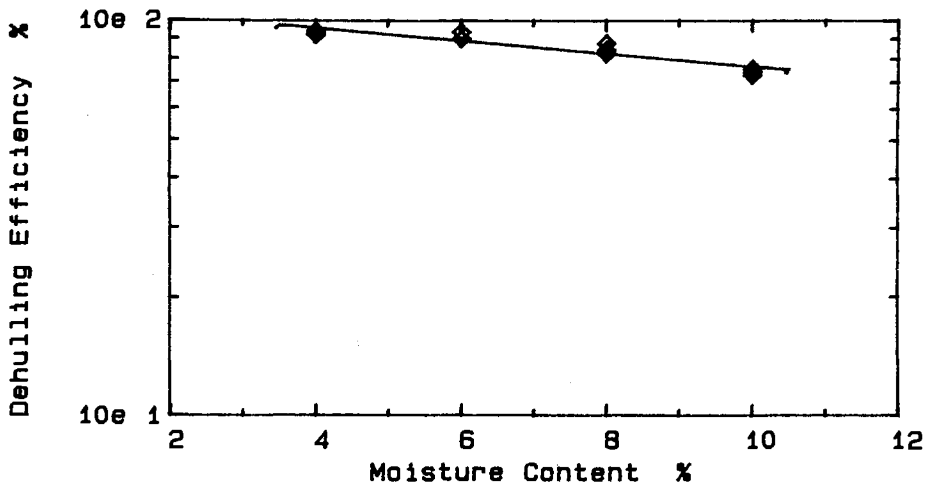
Drying Temperature: 55°C
Soaking Time: 1 Hour



Drying Temperature: 55°C
Soaking Time: 3 Hours

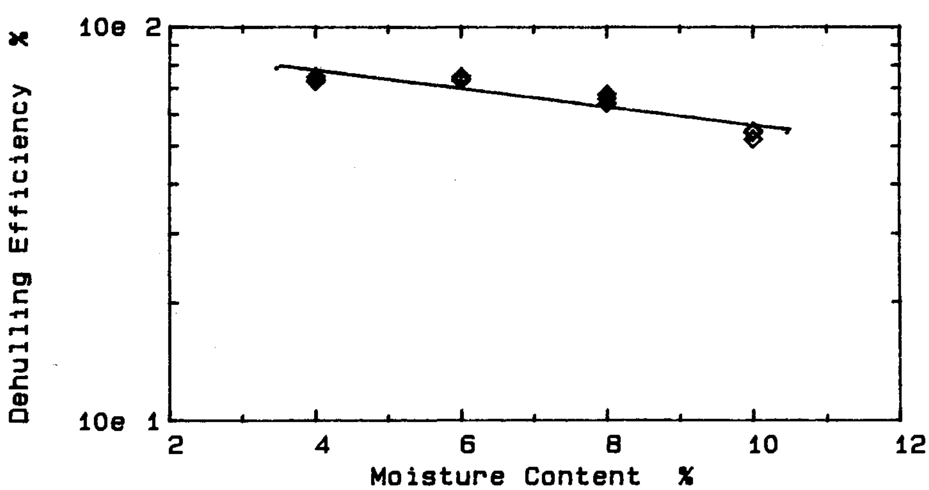


Drying Temperature: 55°C
Soaking Time: 5 Hours



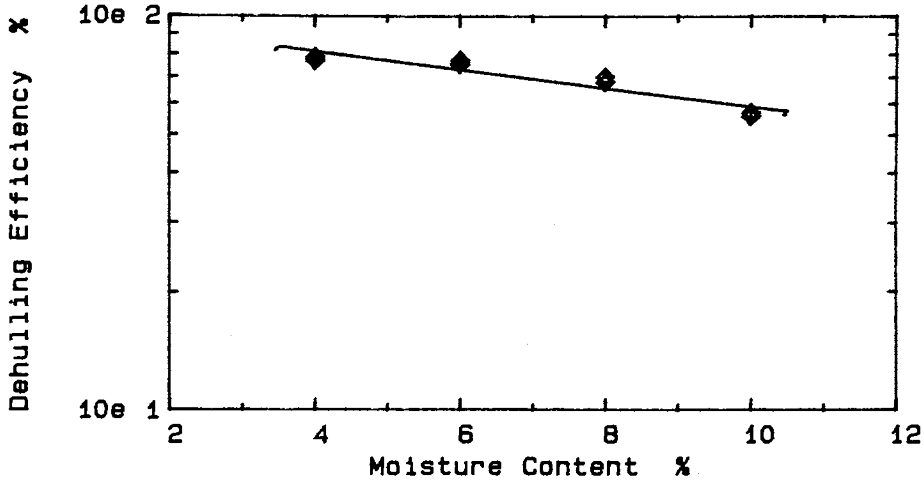
Drying Temperature: 55°C

Soaking Time: 7 Hours

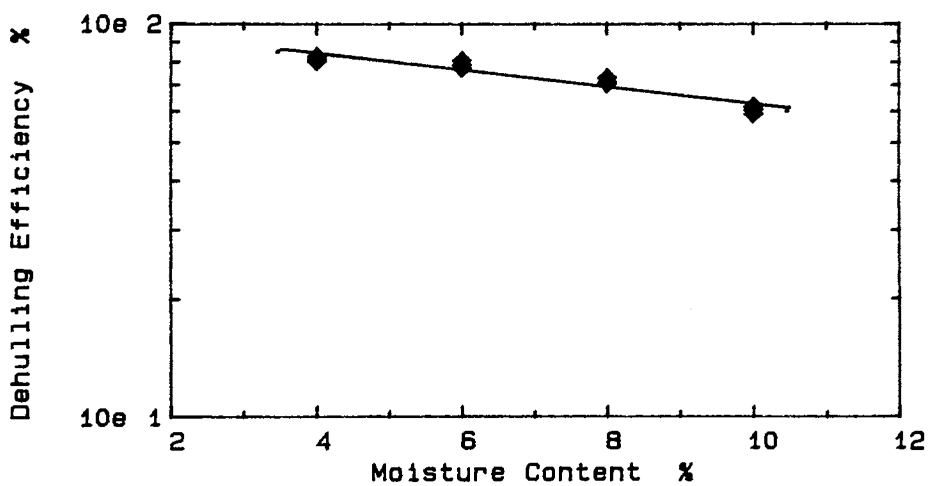


Drying Temperature: 65°C

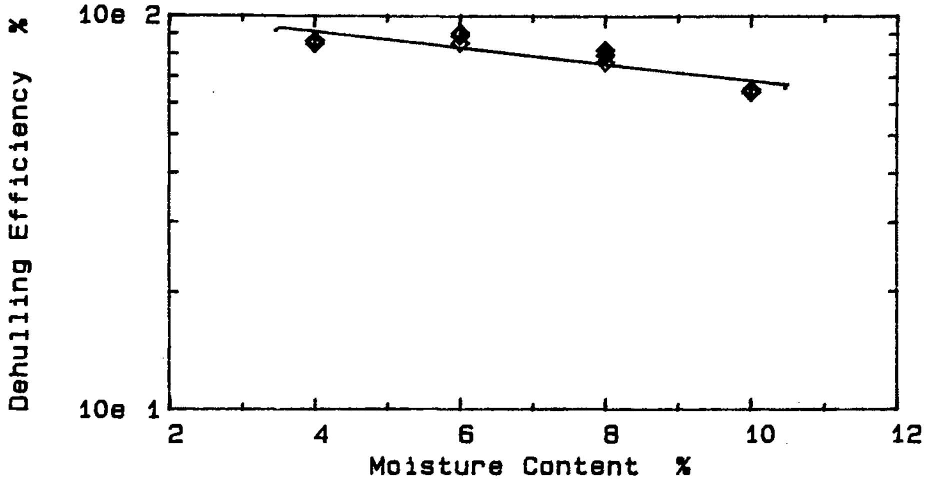
Soaking Time: No-soaking



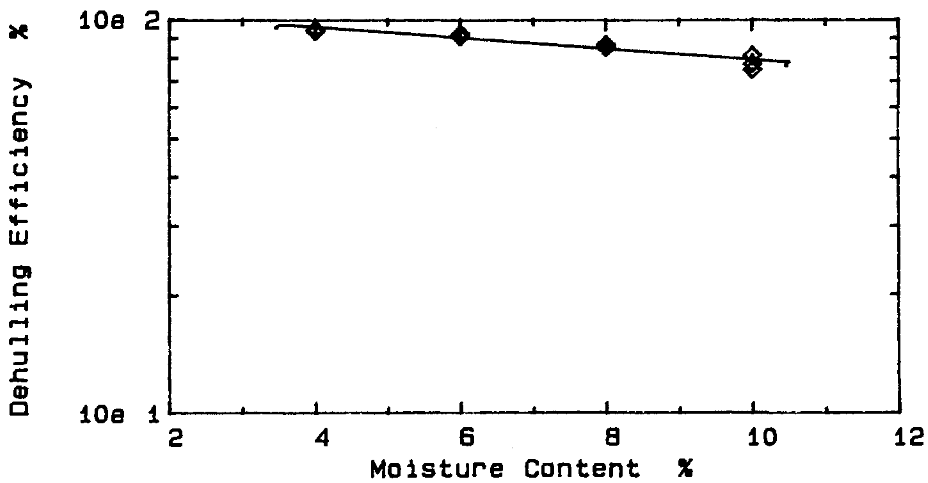
Drying Temperature: 65°C
Soaking Time: 1 Hour



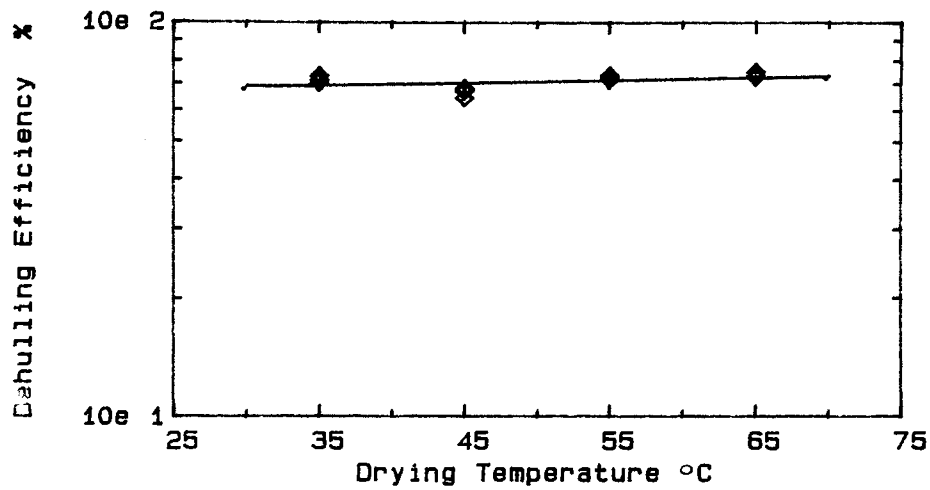
Drying Temperature: 65°C
Soaking Time: 3 Hours



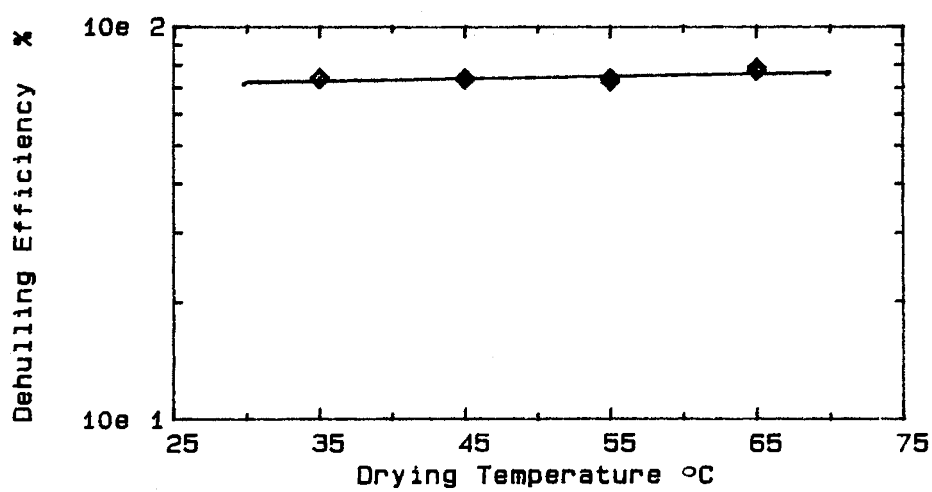
Drying Temperature: 65°C
Soaking Time: 5 Hours



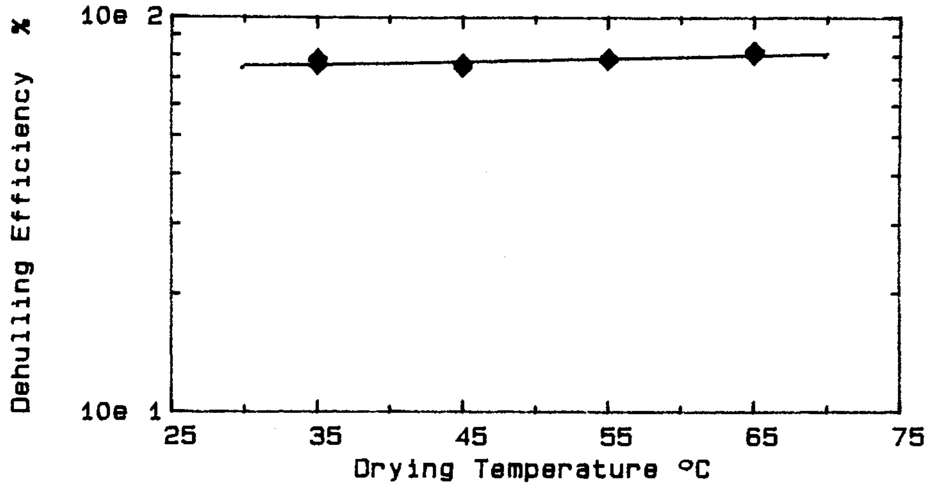
Drying Temperature: 65°C
Soaking Time: 7 Hours



Moisture Content: 4%
Soaking Time: No-soaking

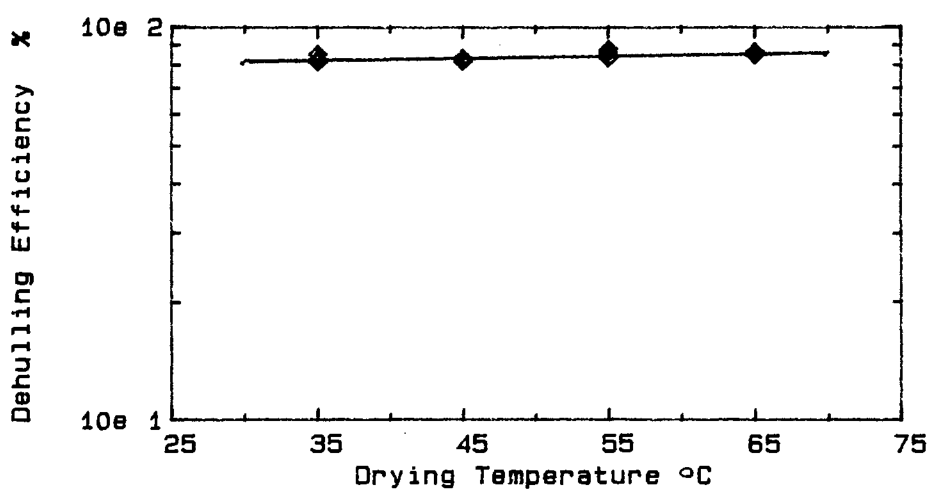


Moisture Content: 4%
Soaking Time: 1 Hour



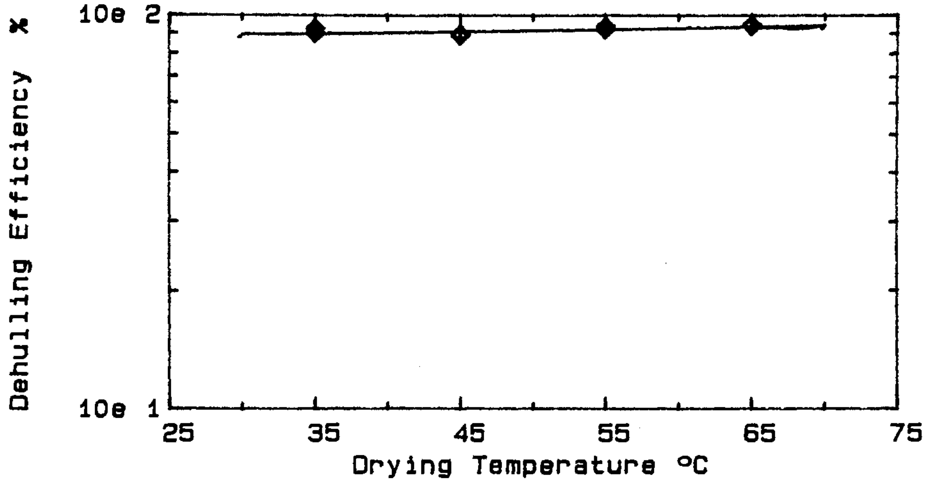
Moisture Content: 4%

Soaking Time: 3 Hours



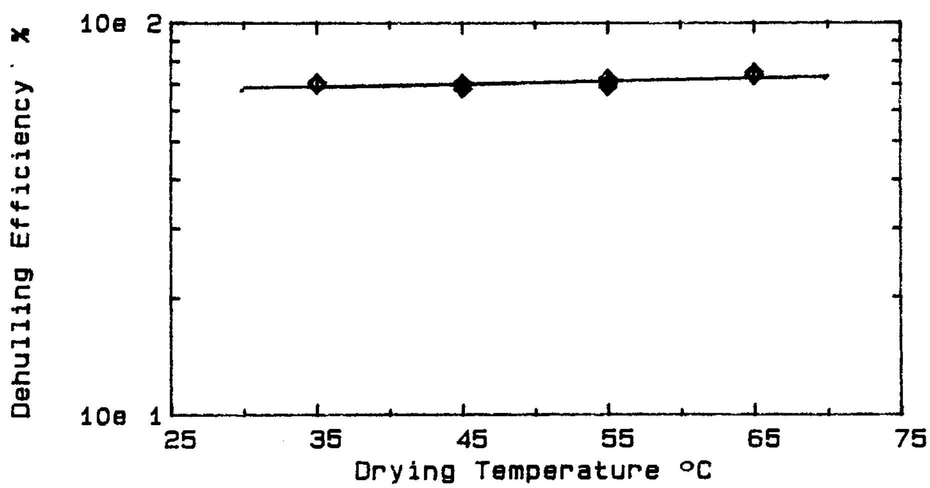
Moisture Content: 4%

Soaking Time: 5 Hours



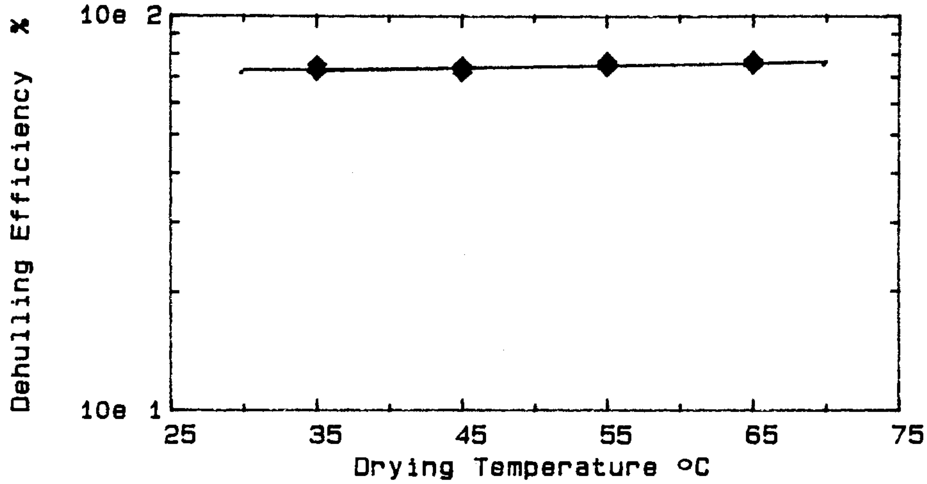
Moisture Content: 4%

Soaking Time: 7 Hours



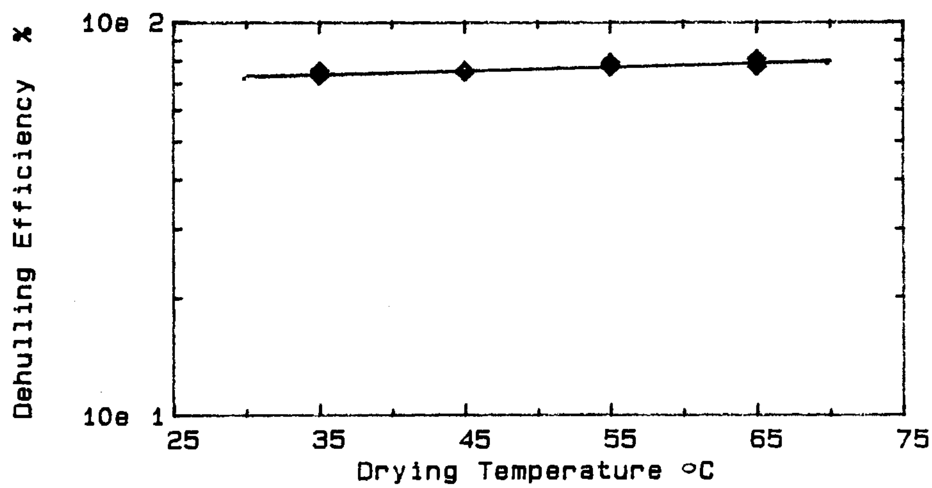
Moisture Content: 6%

Soaking Time: No-soaking



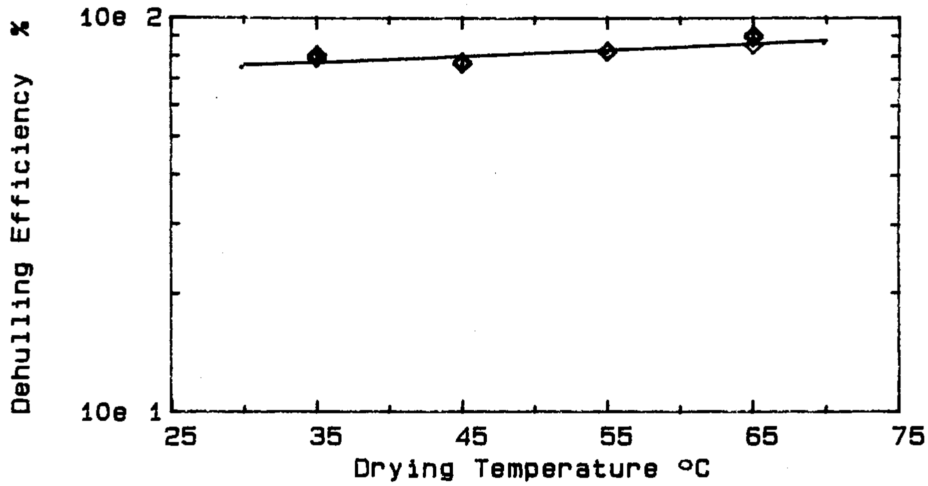
Moisture Content: 6%

Soaking Time: 1 Hour



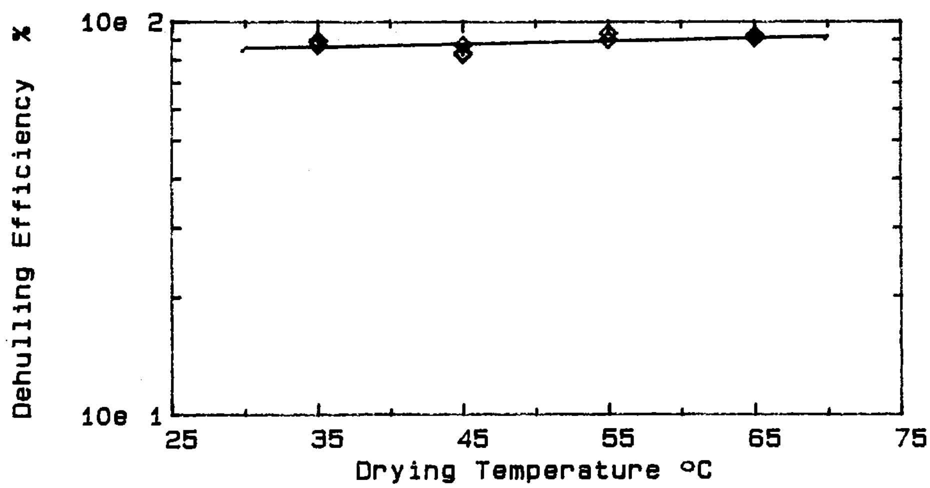
Moisture Content: 6%

Soaking Time: 3 Hours



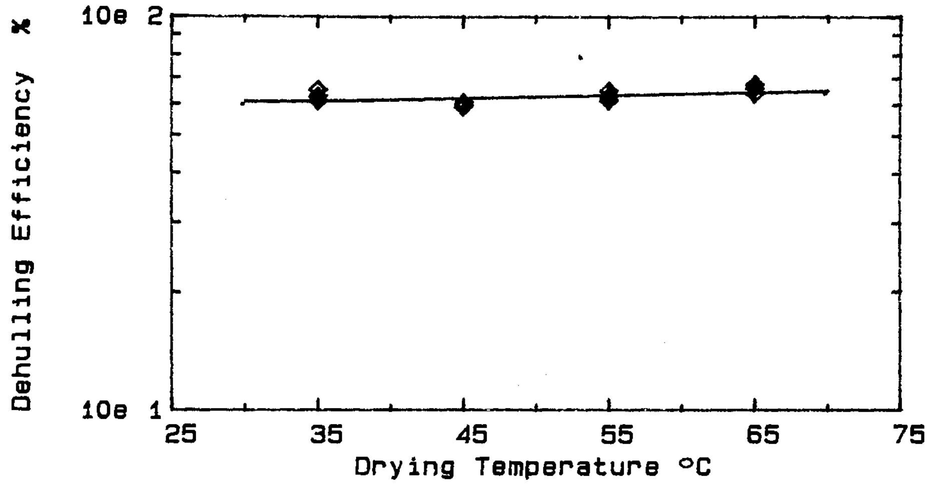
Moisture Content: 6%

Soaking Time: 5 Hours

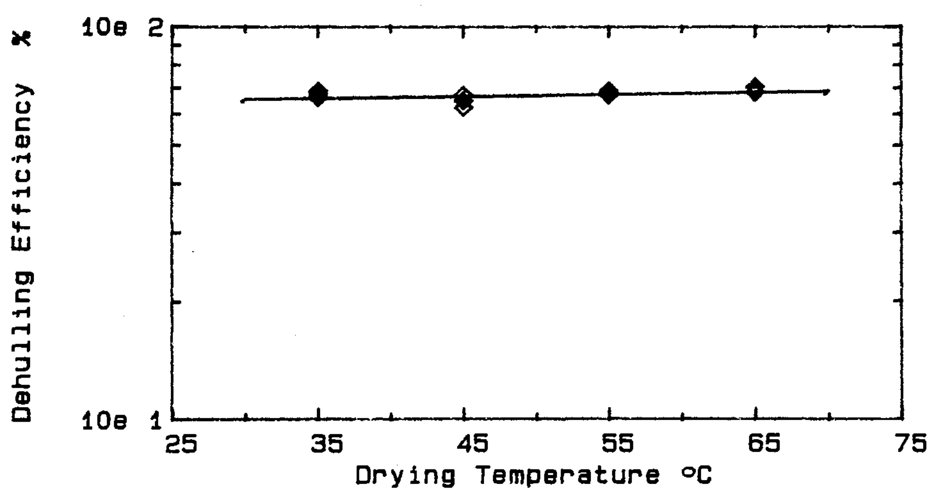


Moisture Content: 6%

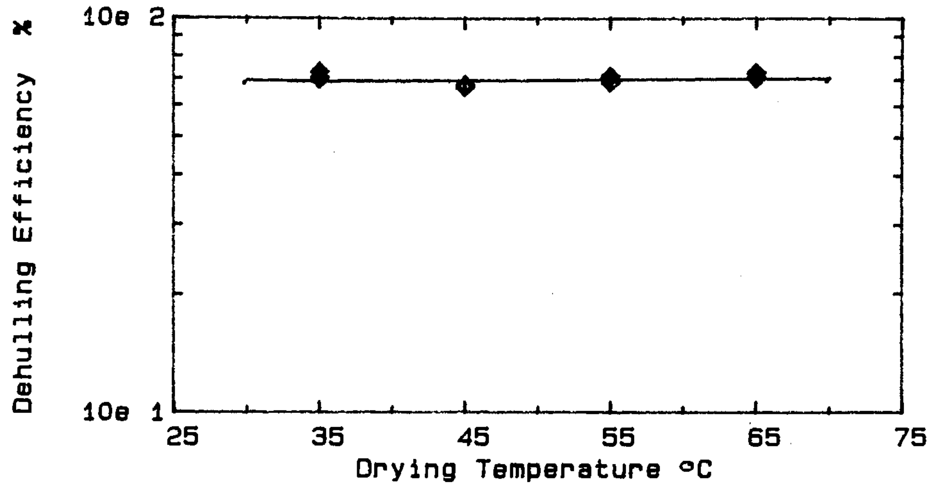
Soaking Time: 7 Hours



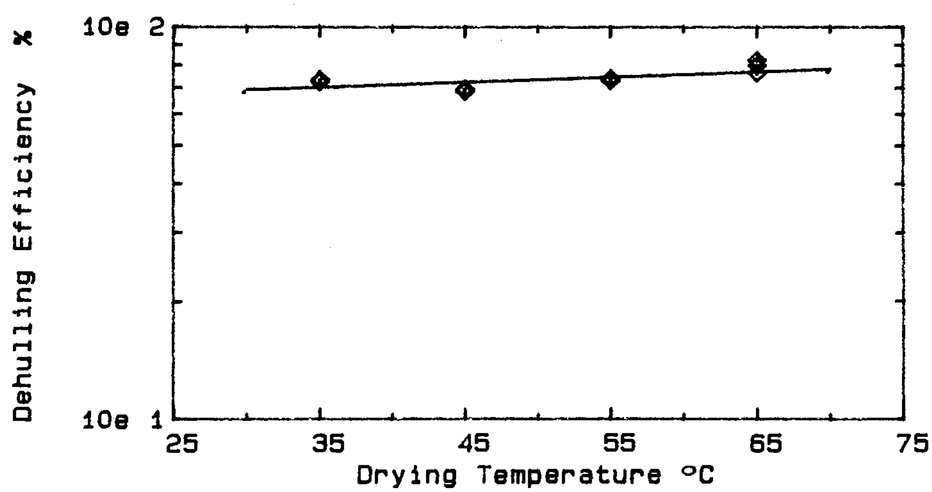
Moisture Content: 8%
Soaking Time: No-soaking



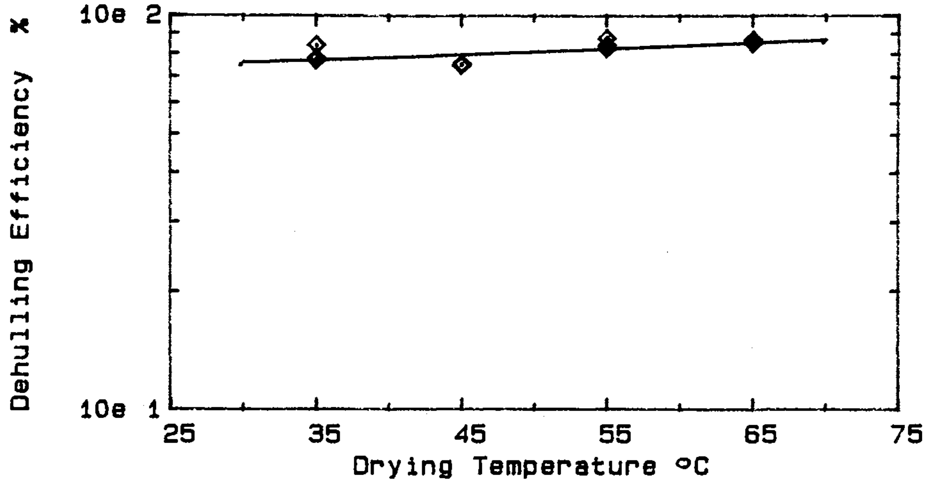
Moisture Content: 8%
Soaking Time: 1 Hour



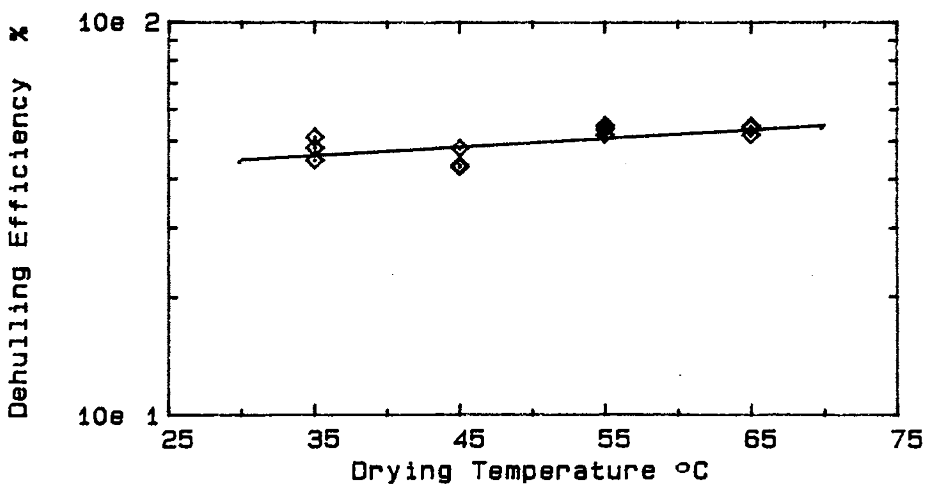
Moisture Content: 8%
Soaking Time: 3 Hours



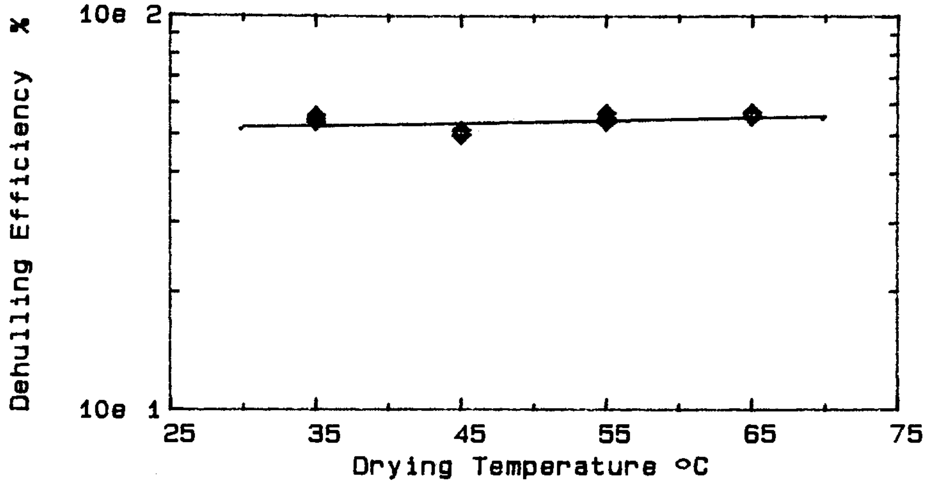
Moisture Content: 8%
Soaking Time: 5 Hours



Moisture Content: 8%
Soaking Time: 7 Hours

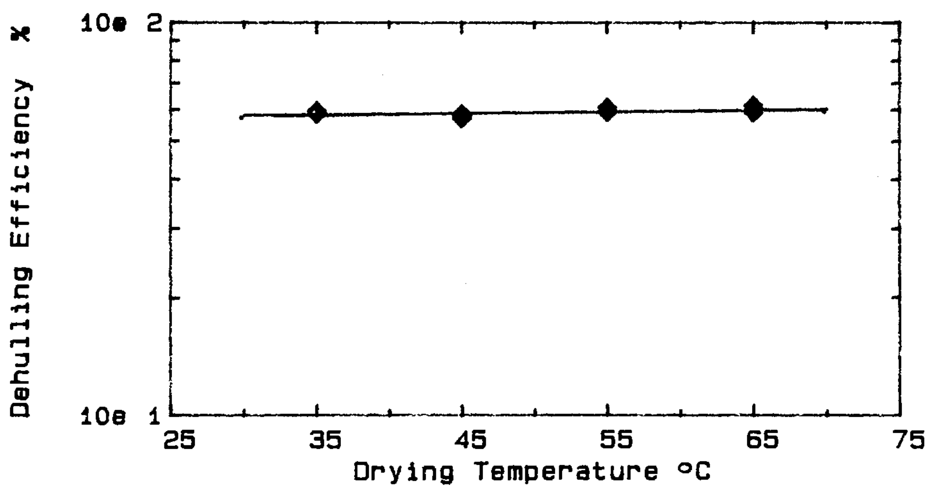


Moisture Content: 10%
Soaking Time: No-soaking



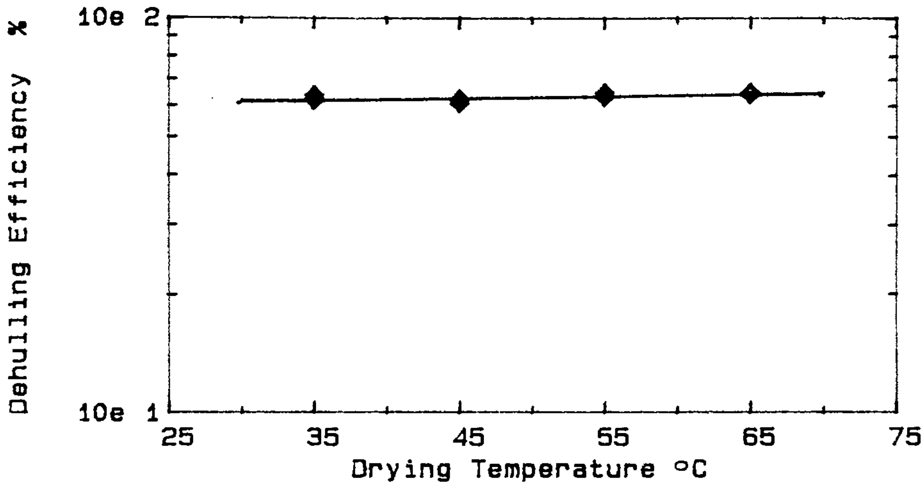
Moisture Content: 10%

Soaking Time: 1 Hour



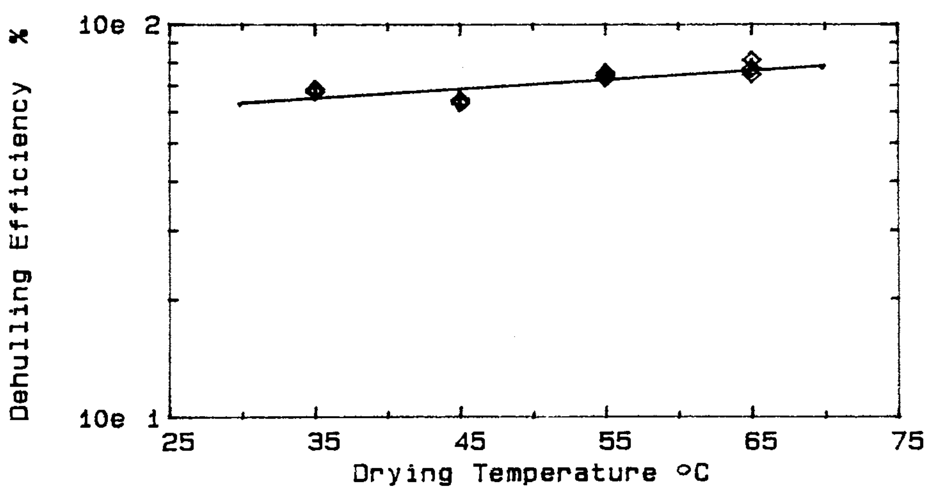
Moisture Content: 10%

Soaking Time: 3 Hours



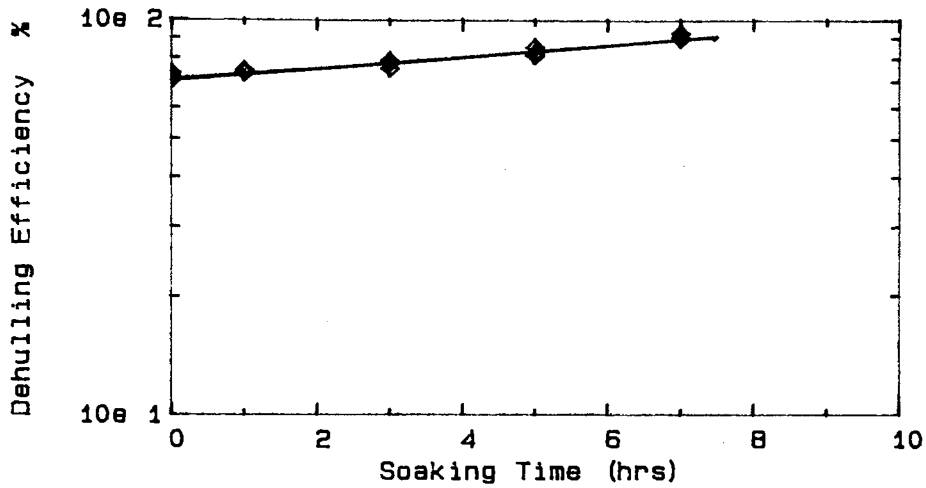
Moisture Content: 10%

Soaking Time: 5 Hours

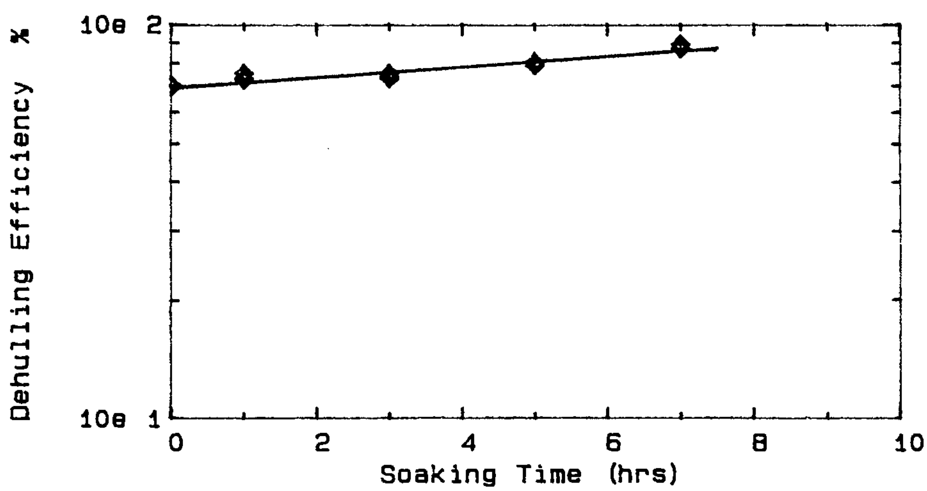


Moisture Content: 10%

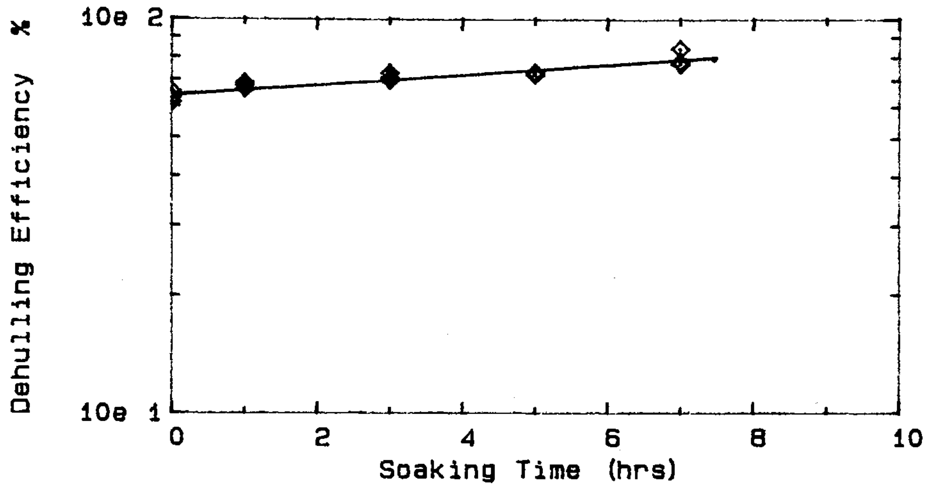
Soaking Time: 7 Hours



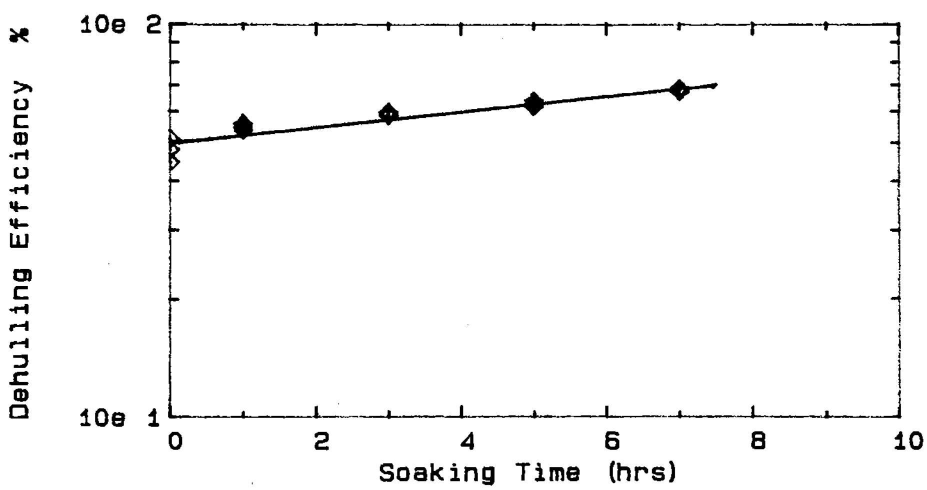
Drying Temperature: 35°C
Moisture Content: 4%



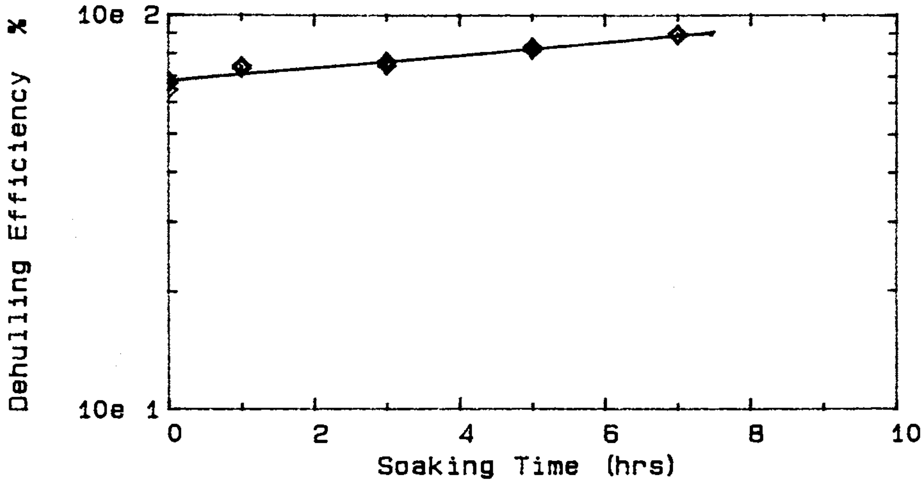
Drying Temperature: 35°C
Moisture Content: 6%



Drying Temperature: 35°C
Moisture Content: 8%

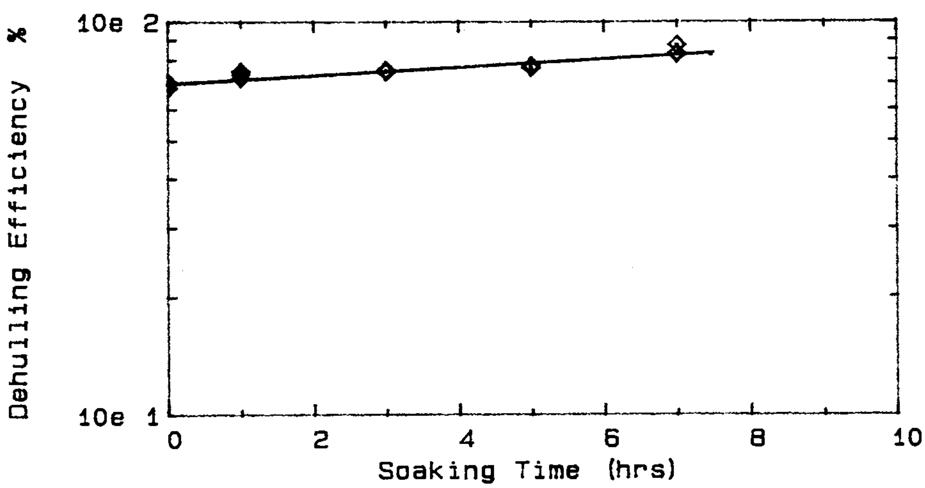


Drying Temperature: 35°C
Moisture Content: 10%



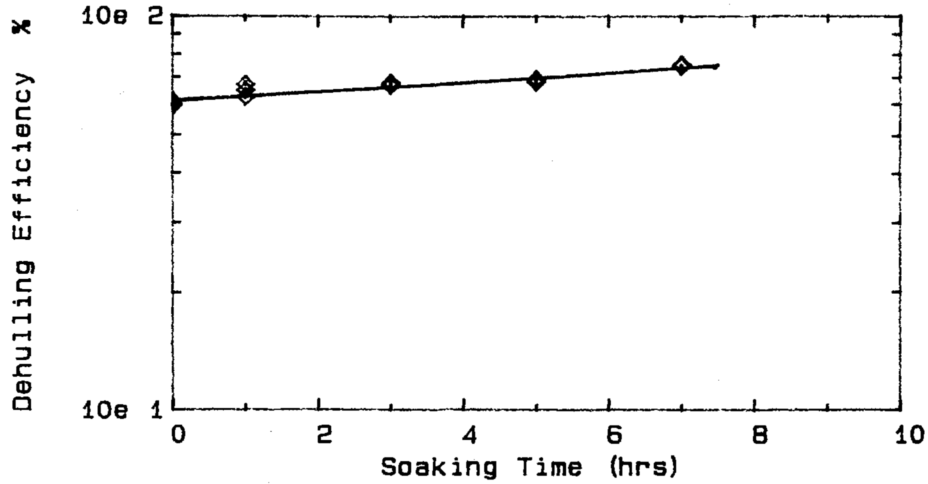
Drying Temperature: 45°C

Moisture Content: 4%



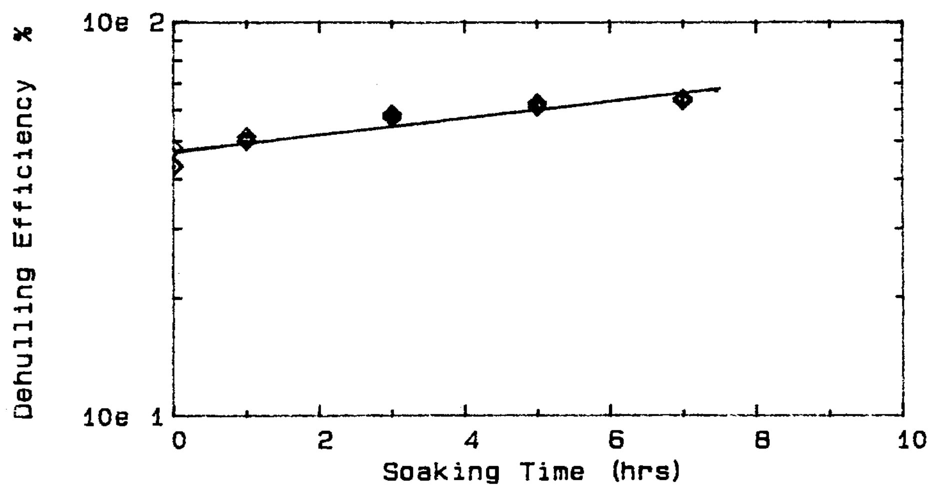
Drying Temperature: 45°C

Moisture Content: 6%



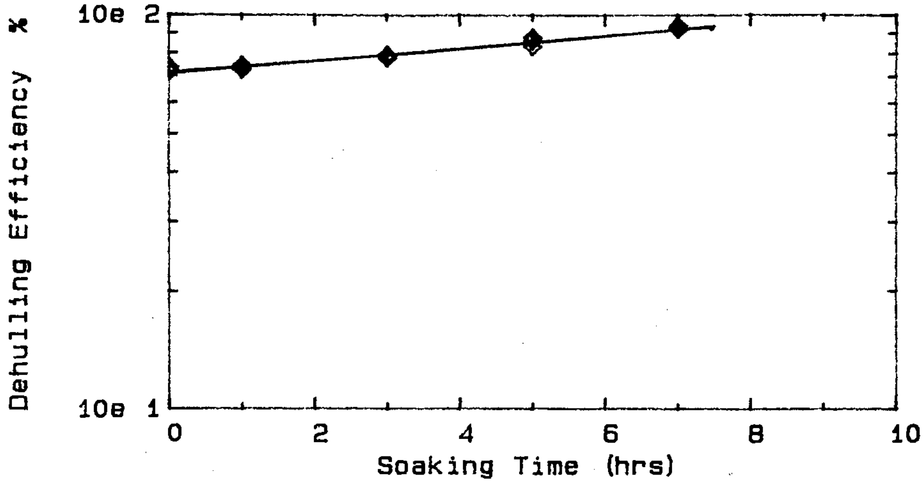
Drying Temperature: 45°C

Moisture Content: 8%



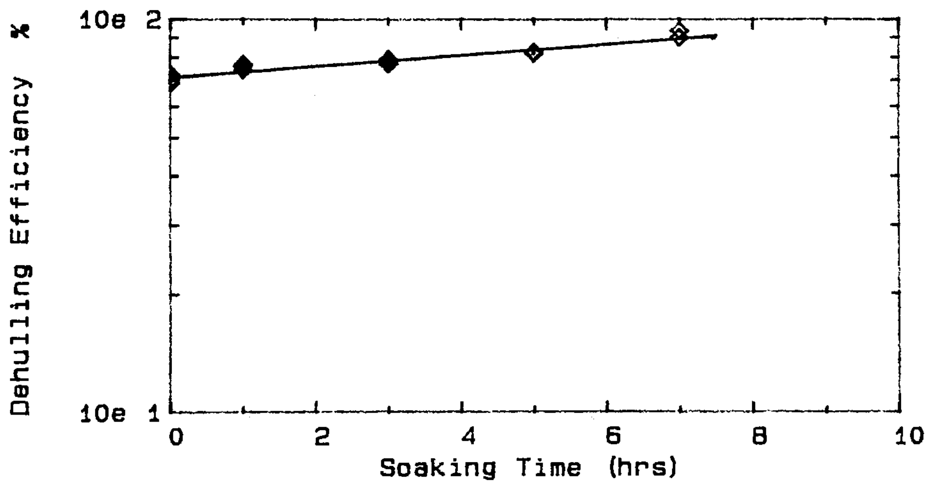
Drying Temperature: 45°C

Moisture Content: 10%



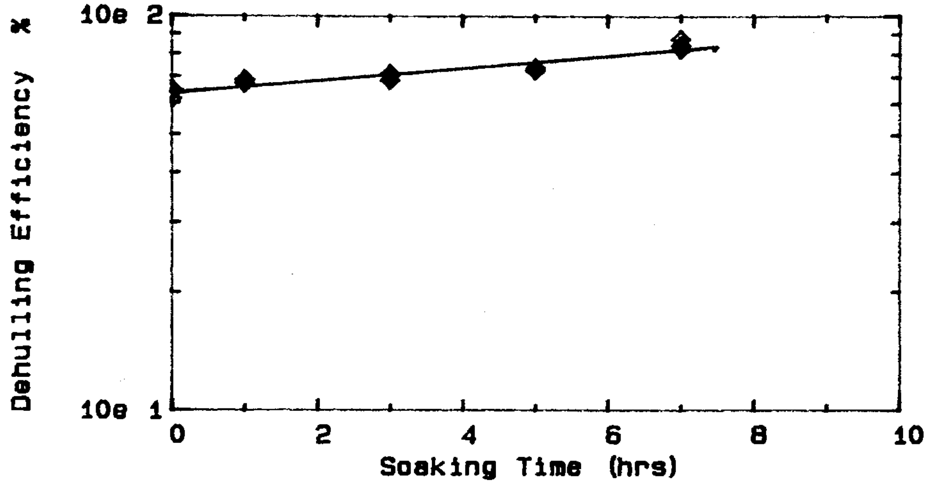
Drying Temperature: 55°C

Moisture Content: 4%

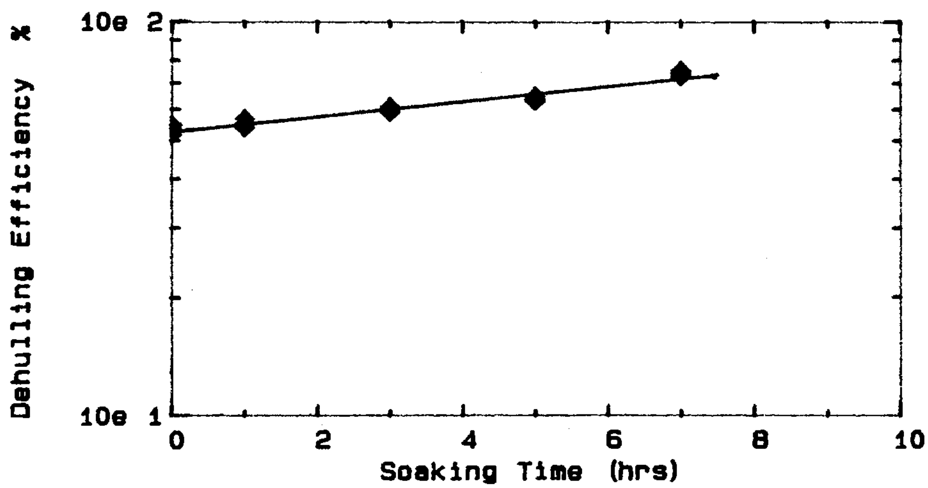


Drying Temperature: 55°C

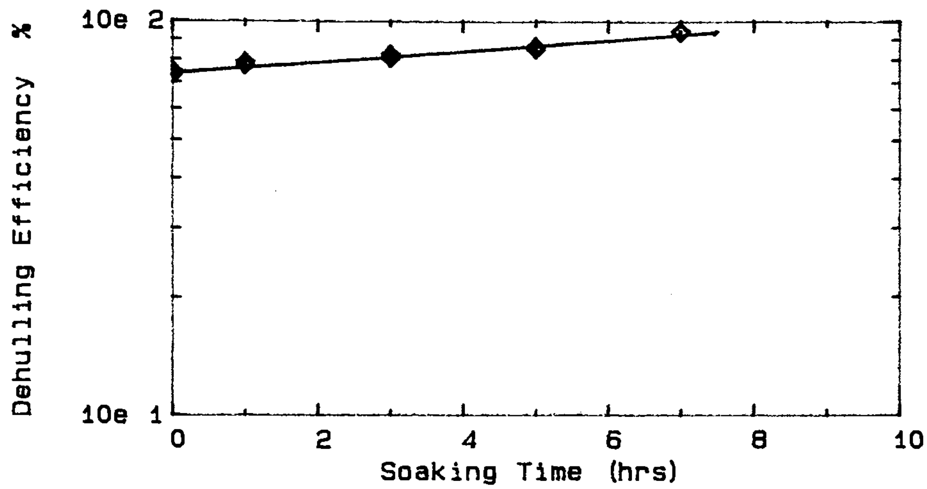
Moisture Content: 6%



Drying Temperature: 55°C
Moisture Content: 8%

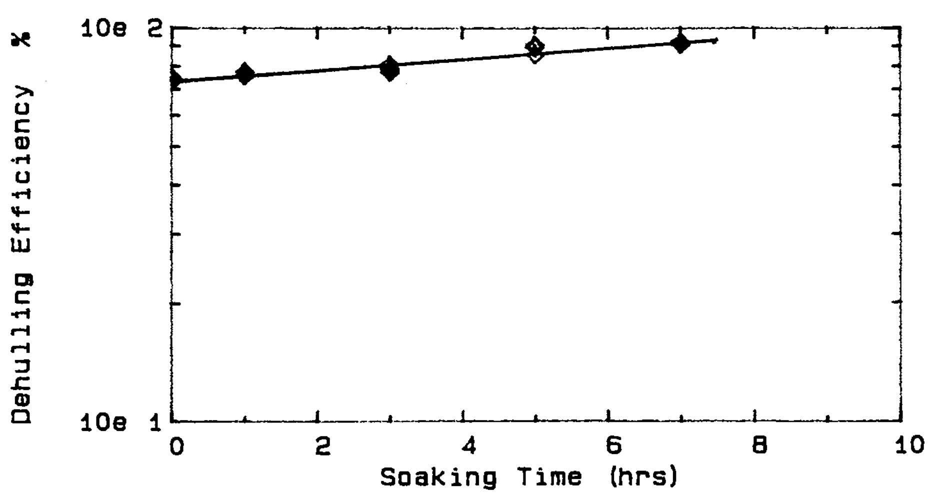


Drying Temperature: 55°C
Moisture Content: 10%



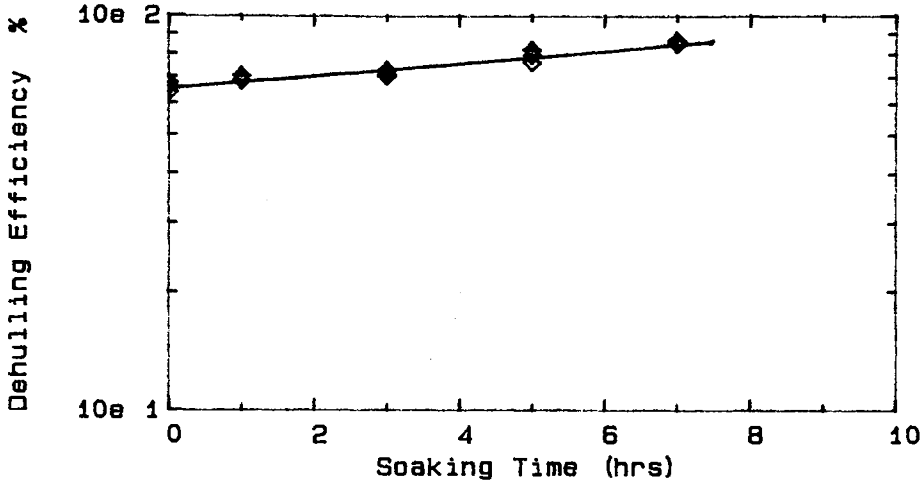
Drying Temperature: 65°C

Moisture Content: 4%

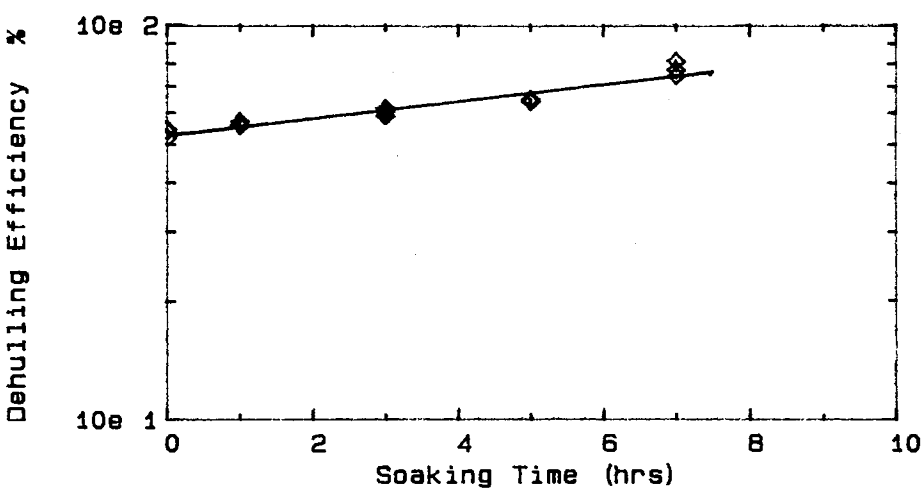


Drying Temperature: 65°C

Moisture Content: 6%



Drying Temperature: 65°C
Moisture Content: 8%



Drying Temperature: 65°C
Moisture Content: 10%

VITA

Yanling Cheng

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF PRE-HULLING TREATMENTS ON MUNG BEAN DEHULLING EFFICIENCY

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Zhengzhou City, Henan Province, the People's Republic of China, March 14, 1960, the daughter of Fazheng Cheng and Chailan Wang. Married to Wei Zhao on July 5, 1984. Mother of son Bob Zhao.

Education: Graduated from the High School of the First Desiel Engine Factory of Zhengzhou City, Henan, China, in July, 1977; Received Bachelor of Science Degree in Agriculture from Henan Agricultural University, Henan, China in 1982. Completed requirements for Master of Science Degree at Oklahoma State University in July, 1989.

Professional Experience: Teaching Assistant, Department of Agricultural Engineering, Henan Agricultural University, January, 1982 to August, 1987; Graduate Research Assistant, Department of Agricultural Engineering, Oklahoma State University, Augest, 1987 to present.

Organizations: The Society of Agricultural Engineering of Henan Province, the Society of Mechenical Drawing of Henan Province, People's Republic of China.