A STUDY OF MECHANIZED THRESHING AND TWO THERMAL PROPERTIES OF QUINUA

by

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ABSTRACT

Quinua is a pseudocereal grown in the Andes mountains of South America. In Peru it is grown primarily by subsistence farmers for consumption within the home. In 1989 an International Development Research Centre (IDRC) project was started to investigate, among other things, mechanized threshing of quinua and thermal properties of quinua.

A stationary thresher developed by the International Rice Research Institute (IRRI) was built and tested at the University of Manitoba. It was found that a cylinder with a combination of teeth and rubber flaps adequately threshed quinua. The highest efficiency obtained was 89.6 percent of the total seed being threshed.

The specific heat of quinua was studied using the method of mixtures. It was found that specific heat increased with increasing moisture content. The specific heat at 26 percent moisture content (wet basis) (mcwb) and an intial temperature of 2.5 C was 2.48 kJ/(kg·K). Thermal conductivity, k, also increased with increasing moisture content. At 8 percent mcwb k equalled 0.127 W/(m·K). At 13 percent mcwb k was 0.135 W/(m·K). Thermal conductivity was studied using a transient line heat source method.

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PART I INTRODUCTION

1 BACKGROUND TO THE PROJECT

The International Development Research Centre (IDRC) has been sponsoring projects in Peru for the past 12 years. Out of this experience research areas have been identified for several Andean crops including tarwi (lupin), bitter potatoes and quinua. In order to address some problems with these crops the project ANDEAN FOODS (Manitoba/Peru) (3-P-1048) was begun in April, 1989.

This thesis project addresses two of the research areas: the problem of threshing quinua and the thermal properties of quinua. Major losses are incurred before and during the threshing of the grain due to poor handling and lack of appropriate technology. Furthermore, quinua is harder to thresh than wheat or barley and this problem limits the amount of quinua a farmer, who is dependent on manual threshing, can grow. Thermal properties of grains are important for designing drying and storing facilities and for predicting temperature changes in the grain due to internal and external influences.

2 DESCRIPTION OF QUINUA

2.1 Botanical Characterization

Quinua (Chenopodium quinoa)[1] is an annual herb of the goosefoot family (Figure 1). It is related to the grain amaranth and lambsquarter or "pigweed" of North America. The plants grow to heights of between 0.5 m and 2 m tall with roots reaching depths almost equal to the height of the plant (Cusack, 1984).

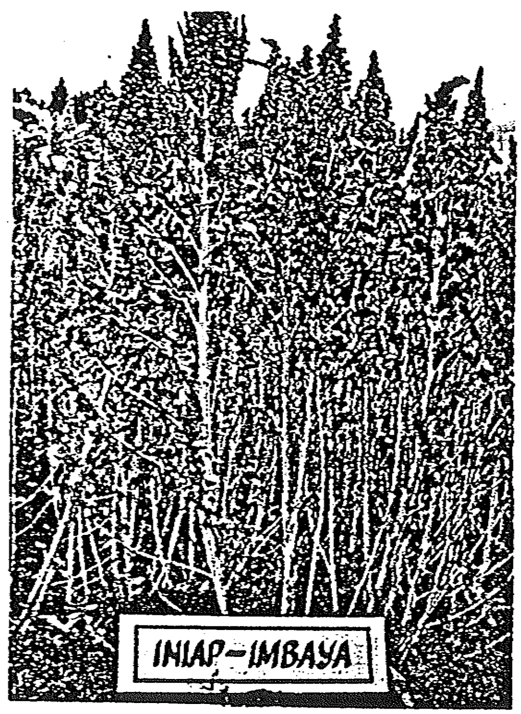


Figure 1 Example of a quinua plant.

[1]The scientific spelling of 'quinua' is 'quinoa' but in this thesis the generic Spanish spelling, using a 'u', will be used.

There is one main stalk with secondary branches growing from it. One of the principal ways of classifying different varieties of quinua is the way in which the branches grow. In some varieties the branches are only a few centimetres in length while in other varieties the secondary branches can reach as high as the primary panicle of the plant and grow secondary panicles. The way in which the plant will branch sometimes depends on the amount of space available to it (Tapia, 1979).

The leaves of the plant have a characteristic number of points - from 3 to 20 - depending on the variety. The lower leaves can measure up to 15 cm long and 12 cm wide, and the upper leaves up to 10 cm long and 2 cm wide (Tapia, 1979).

The basic colours of the plants are red, purple, and green during the growing phase, and generally yellow at maturity. The plant can be uniform in colour or mixed colour with a striped stalk (Tapia, 1979).

The panicles of the plant consist of compact groups of flowers. There are two different types of panicles - "glomerulada" and "amaratiforme" (Figure 2). The "glomerulada" panicle has a glomerular stem, 0.5 to 3 cm long, growing from secondary stems. Clusters of 20 or more flowers grow along the glomerular stem on "receptacles". On the "amaratiforme" panicle the flower clusters grow directly from the secondary branches, resulting in a more compact panicle. The size of panicles varies from 15 cm to 70 cm (Tapia, 1979).

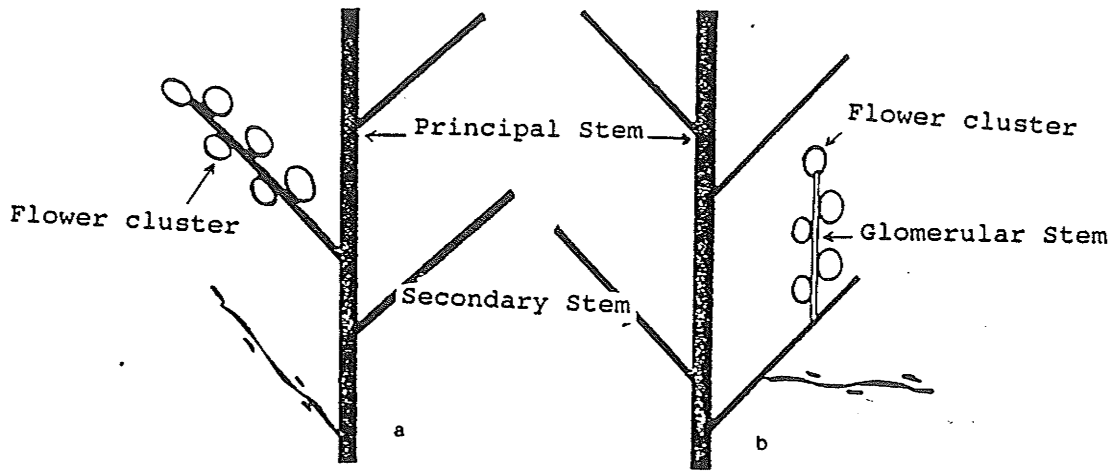


Figure 2 Two forms of panicles. A) Amarantiforme, B) Glomerulada.

At maturity the seed is covered by the perigonium (Figure 3) which can easily be removed by rubbing when it is dry. The perigonium is star shaped with 5 points. The seeds can have diameters as large as 2.6 mm. Seeds less than 1.8 mm in diameter are classified as small.

The outer surface of the seed, the pericarp, can be white, yellow, orange, grey, black, or pink. Underneath the pericarp is the episperm made up of the radicle and cotyledons that form a ring around the perisperm. The perisperm is starchy and normally white (Tapia, 1979).

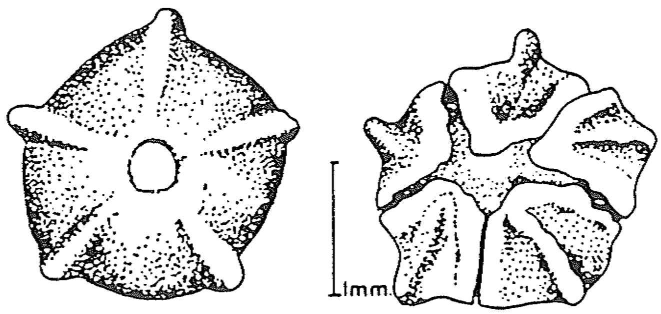


Figure 3 Quinua seed covered by the perigonium. (Taken from Tapia, 1979)

The pericarp contains saponins, a bitter tasting substance, which is one of the drawbacks of using quinua as a food product. The saponins need to be removed before eating the quinua. Saponins are not unique to quinua. They occur in a wide variety of plants including spinach, beet root, sugar beet, asparagus, alfalfa, and soybeans. Saponins are characterized by their bitter taste, foaming in aqueous solutions, and hemolyzing red blood cells (Birk 1969).

Quinua has the advantage of being able to grow under harsh growing conditions where corn and wheat do not grow well. It can grow under conditions of high altitude, relatively poor soil, low rainfall, and cold temperatures (Cusack, 1984). It is generally grown in temperate-cold climates at elevations of 3,000-4,000 metres above sea level (m.a.s.l) although there are valley varieties which grow at 2,000 m.a.s.l. The growing period is between 5 and 8 months depending on the variety, climate, and altitude (Sanchez, Valdez, 1986).

2.2 Nutritional Characteristics

Due to its unusual composition and exceptional balance between oil, protein, and fat, quinua has been called both a pseudocereal and a pseudo-oilseed. Quinua is high in proteins but particularly significant is the protein quality. There is a high percentage of essential amino acids. It is exceptionally high in lysine, an essential amino acid, which is very scarce in most products of the vegetable kingdom. Quinua's lysine level is comparable in quantity to major sources in animal products. Table 1 provides nutritional comparisons between quinua and several other grains (Cusack, 1984).

In addition to the seeds, the leaves and stems have good nutritional value. The leaves are suitable for human consumption from 60-80 days after germination to a short time before flowering occurs. Table 2 shows a nutritional comparison of fresh quinua foliage and other vegetables. One hectare of quinua provides around four metric tonnes of material (leaves, stems, etc.)and is a good source of animal feed.

Table 1 Nutritional comparison of quinua seed to other foods (%)

	Protein	Water	Fat	Carbo-hydrates	Fibre	Ash
Quinua	16.2	11.4	6.9	63.9	3.5	3.3
Wheat	14.0	13.0	2.2	69.1	2.3	1.7
Oats	13.0	12.5	5.4	66.1	10.6	3.0
Buckwheat	11.7	11.0	2.4	72.9	9.9	2.0
Rice	9.4	11.0	1.0	77.9	0.4	0.7
Corn	3.5	72.7	1.0	22.1	0.7	2.0

(Taken from Cusack, 1984)

Table 2 Comparison of protein and lipid content of quinua foliage and other foliage

	Protein (%)	Lipids (%)
Quinua	3.3	2.1
Artichoke	3.0	0.2
Onion	1.4	0.2
Watercress	1.7	0.5
Spinach	2.2	0.3

(Taken from Tapia, 1979)

2.3 Utilization

The biggest drawback in the use of quinua as a food product is the need to remove the saponin. The saponin can be removed through a wet process, a dry process, or a combination of the two. The wet process involves repeatedly washing the quinua until no more foaming occurs. The problem with this process is the cost of drying the grain and the large amounts of foam generated and water used. The dry process uses abrasive stones to rub the surface of the quinua thereby removing the saponins. The problem with this process is that protein may also be removed and the seeds can be damaged (Tapia, 1979).

Quinua can be used in soups, mixed grain dishes, biscuits, drinks, and as a flour additive. It is prepared by first cleaning and then boiling one part quinua in two parts water for 20 minutes. The cooked texture is similar to barley or wild rice.

Quinua has potential uses in several areas. Firstly, it has potential as a weaning food for infants especially in developing countries where the people are often nutritionally deficient. Unusual qualities of the tiny and cohesive quinua starch granules may have important industrial uses. Finally, the removed saponin may have pharmaceutical, industrial, and cosmetic uses (Cusack, 1894).

3 QUINUA IN PERU

3.1 History

Quinua has been utilized as a food source in the Andes since 3000 B.C. and possibly longer. It has been identified with the expansion of the Inca empire which was at its most dominant just prior to the arrival of the Spaniards in 1532. The Spanish conquest brought a decline in the production of quinua and other Andean crops. Corn and potatoes were cultivated, improved, and exported but not quinua. From the time of independence from Spain in the 1820's until the 1940's, Andean crops held their own alongside the European farming system of barley, cattle, sheep, and other crops and animals.

At the beginning of the 1940's the economic importance of Andean crops declined due to external factors. Improved transportation and excess wheat in North America lead to massive wheat importation into Andean countries. The largely white upper and middle class urban populations shifted to imported cereals and processed food in preference to the unprestigious "Indian food" of the Andes.

In the 1950's and 60's, production of Andean crops and quinua was further undermined by foreign aid efforts to modernize the traditional agricultural society of Third World countries. The Andean market was flooded with cheap, surplus U.S. government subsidized white flour, undercutting the production of quinua and local wheat.

Andean farmers were put under pressure to sow high-yielding supercrops instead of traditional crops. This was supposed to give them increased yields and bring them into the national cash-crop economies. The use of supercrops caused several problems. There was a loss of security because new crops were more vulnerable to climatic variations and disease. Small farmers lost land because they lacked the capital to cultivate, fertilize, and manage new crops. There was a loss of the traditional way of life. Finally, there was a loss of local genetic resource material. The total area of quinua planted dropped from 47,000 ha in 1951 to 15,000 ha in 1975. Since then there has been a slow recovery to the level of 20,788 ha in 1982 (Cusack, 1984).

3.2 Production

Today quinua is commonly grown at high altitudes throughout the Andes of South America especially in the altiplano and mountain valleys of Bolivia and Southern Peru. It is estimated that if Peru were to revive valley varieties and stimulate altiplano production it could profitably cultivate 150,000 to 200,000 ha or about 7 times more than current production. This is assuming improvements in yield, processing technology, and urban acceptance (Cusack, 1984).

The southern altiplano province of Puno cultivates 75 percent of the total national land surface used in quinua production (Cusack, 1984). The soil there is low in organic material but rich in potassium. The average temperature for the months during the growing season is 9.5 °C and the annual precipitation is 550 mm (Reinoso, 1982).

Yields are traditionally low, 400 to 800 kg/ha, but are improving on some farms and experimental stations with yields of up to 2000 kg/ha. Individual test fields have had yields as high as 5000 kg/ha (Cusack, 1984).

Much of the farming is done on small plots of land, up to 5 ha or less, with land holdings often scattered around the community.

3.3 Cultivation and Processing

Quinua is planted in October with a seeding rate of 10 to 12 kg/ha. It is grown in a rotation with potatoes, barley, oats and beans, generally following potatoes. Potatoes leave the soil with suitable nutrients and in a condition which requires little additional tillage. It is seeded alone or sometimes intercropped with corn. About 45 days after seeding the crop is weeded and thinned. Harvesting is done in April or May. Quinua is harvested by cutting the stalk about 10 cm above the soil surface or by pulling it out of the soil. The harvested quinua is transported to a suitable place where it is stacked, sometimes with corn, and allowed to dry for about 15 days (Zvietcovich, Molina and Huerta, 1985).

The threshing is carried out on a blanket, animal skin, or hard surface by beating the plant with a stick, having animals walk over it, or rubbing the panicle by hand against a rock. When there is a suitable wind, the grain is cleaned by winnowing (Zvietcovich, Molina and Huerta, 1985).

The quinua is stored in jugs or bags in the house of the farmer. It is either used for seed, consumed in the home, or sold. Prior to cooking, the saponins must be removed from the pericarp of the quinua. In the home setting this is done by repeatedly washing the quinua in water until there is no foaming, a characteristic indicating the presence of saponin (Zvietcovich, Molina and Huerta, 1985).

In terms of mechanization, production in Peru is carried out across the whole spectrum, from totally manual methods to advanced mechanization. Table 3 gives an indication of the work and investment required to cultivate one hectare of land with quinua under four different levels of mechanization. The levels are defined as follows:

Manual A: Oxen are used for preparing the soil but the rest of the labour is done by hand. Manure is used as fertilizer. This system is characteristic of the region around Lake Titicaca.

Manual B: There is no special preparation of the soil. The seeds are placed in spaced holes. All the work is by hand. There is no application of fertilizer and threshing is done by hitting or by driving over the heads with a truck. This system is typical of the southeast part of Bolivia where they grow the variety Real.

Semi-mechanized: Machines are used for preparing the soil but the rest of the labour is manual. Fertilizers and clean seed are used.

Mechanized: Machines are used for soil preparation, seeding, harvesting, and threshing. The rest of the labour is done manually. Fertilizers, herbicides, and pesticides are used.

Table 3 Comparison of levels of mechanization in quinua production (per hectare basis)

	Manual A	Manual B	Semi-mech	Mech.
Preparing soil	4 pr + 5 days	3.5 days	6 h	5 h
Fertilization				
Transport/apply	2.5 days		2.5 days	0.5 days
Material	Manure		Chemical	Chemical
Seeding				
Material	10 kg	20 kg	10 kg	10 kg
Application	2.5 days	10 days	3.5 days	0.5 days +2 h
Other practices				
Weeding/thinning	3 days	8 days	6 days	
Fertilizer			1 day	1 day
Pesticide/herbicides				
Material			3 L	3 L
Application			3 days	3 days
Harvest				
Cutting/stacking	15 days	7 day	15 days	15 days
Threshing	10 days	10 days	10 days	5 h
Drying/bagging	5 days	5 days	6 days	2 days
Summary Machine/Animal	4 pr		6 h	12 h
Summary Human	43 days	43.5 days	48 days	22 days

pr = pair of oxen working for one day
h = machine working for one hour

(Taken from Tapia, 1979)

PART II THRESHER RESEARCH

4 REVIEW OF WORK DONE ON THRESHERS

The experience of mechanized quinua threshing in Peru has been limited mainly to research stations. The machines have been obtained through various development projects to assist in the stations' work but there is not much documentation on the threshing machines' performance. Generally it has been found that rasp cylinder bars work better than teeth and provide a cleaner output.

One of the more successful projects is a Swiss sponsored project in Cuzco. Project personnel have designed a multicrop thresher with rasp bars but several difficulties have been encountered. The first problem is that adjusting the cylinder/concave spacing is difficult because of the difference in size between the seeds and the stalk. This problem is somewhat solved by cutting the heads off and feeding only the heads through the thresher.

There is also the problem that the quinua passes through the thresher too quickly to be completely threshed. This problem is alleviated by using "hold-on" threshing instead of allowing the material to pass through the machine.

Table 4 summarizes some of the experimental results on threshers and manual methods tested in Peru and Ecuador.

The International Rice Research Institute (IRRI) in the Philippines has designed a stationary, axial-flow type thresher. It was originally designed for rice but has been adapted to other crops.

One crop that it was adapted to was sorghum. It was found that threshing sorghum with teeth resulted in high (6.5 percent) separation losses and that 10 percent of the grain detached in clusters. These clusters were difficult to rethresh without the use of a different machine such as a rice mill. Rubber flaps mounted on the cylinder reduced unthreshed losses to less than 1 percent while a combination of pegs and flaps reduced losses to less than 2 percent. Smaller concave openings reduced the problem of clusters remaining unthreshed.

Table 4 Summary of threshing methods tested for quinua threshing

Method	Capacity kg/h	Losses %	Clean Grain %	Ref.
John Deere (90 hp)	151	9.4	88.8	9*
Pullman (12 hp)	37	4.6	96.3	9*
Kincaid (5 hp)	22	3.8	91.8	9*
Prototype (9 hp)	37	5.2	95.8	9*
Prototype, adjusted (9 hp)	37	3.4	94.8	9*
Traditional, rubbing	2	3.2	82.7	9*
Alvan Blanch (16 hp)	123		67	6
Traditional, rubbing	19		67	6
Manual Thresher	7	38.2		15+
Traditional, beating	43	7.5	49.3	15+
Manual Thresher	7			12
Traditional, rubbing	2			12
Thresher	28			16
Traditional, beating	15			16
Triton Tourner	600			14

* Losses defined as grain which is recovered when the material is threshed again.
+ Losses defined as grain which is not removed from the panicle by threshing.

5 RESEARCH OBJECTIVES

Based on information gathered in Peru the decision was made to test the IRRI TH6 thresher to determine if it could be adapted to quinua and whether use of the machine was feasible in Peru.

It was felt that because quinua seeds grow in clusters the sorghum adaption should be used. The rubber flaps would allow more flexibility in letting thick stalks pass through. The axial nature of the thresher would allow the material to be threshed for a longer period of time.

The purpose of the tests was to find the effect that cylinder r/min, type of flaps, and moisture content of quinua had on the efficiency and cleanness of the threshing operation. Threshing capacity was also investigated.

6 METHOD

6.1 Material and Apparatus

The quinua used for the tests was supplied by the Agricultural Research Station (Agriculture Canada) in Morden, Manitoba. The quinua was harvested in two stages - half was collected on October 10, 1990 and the other half on October 18, 1990. The average moisture content at harvest of both groups of quinua was 29.8 percent wet basis (wb). The plants were harvested by manually breaking at the bases or by cutting the stalks with shears. The whole plants were then transported to the University of Manitoba and piled and allowed to dry.

Three different varieties of quinua were harvested but they were all very similar in terms of stalk size, height, and seed development. Two sample plants were measured to obtain data of the physical characteristics of the plants. The heights were 147 cm and 150 cm. One plant had six main branches and the other seven main branches. The diameters of the stalks at the bases were 2.2 cm and 2.1 cm. The diameters of the branches where they left the main stalk ranged between 0.5 cm and 1.4 cm.

The thresher that was tested was the IRRI TH6. This is a thresher designed in the Philippines and originally used for rice. It was built at the University of Manitoba from November 1989 to January 1990 (Figure 4 and Figure 5).

The IRRI TH6 stationary thresher is an axial flow machine. The dimensions are 128 cm x 79 cm x 52 cm (LxHxD) with the feed tray in the upright position. The cylinder with the sorghum modification consists of eight alternating rows of teeth and rubber flaps. The portion of the cylinder in front of the feed opening contains teeth on all eight rows. Opposite the feed entrance, at the rear of the cylinder, are stationary teeth on a concave which rip the stalks as they make their first rotations through the thresher.

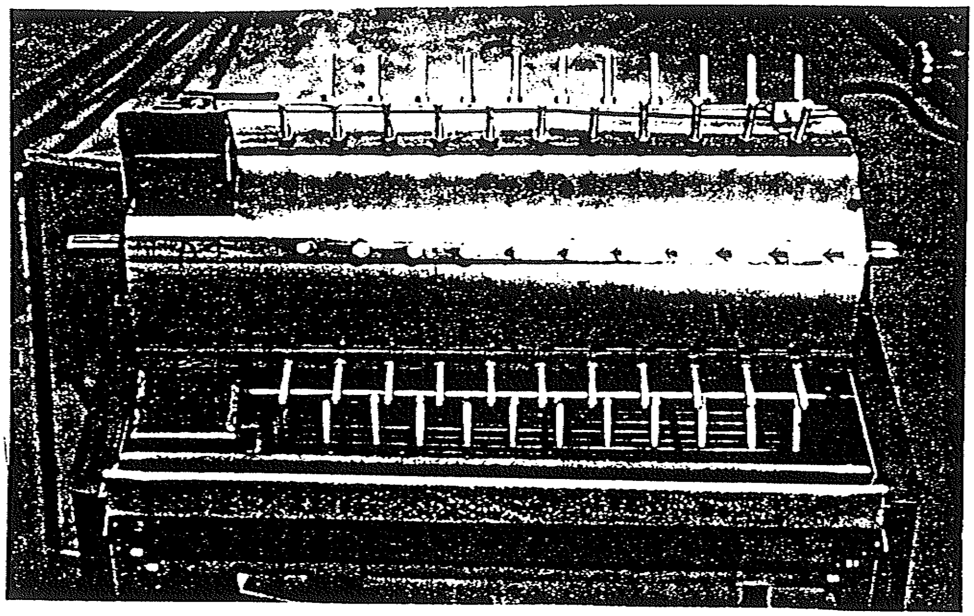


Figure 4 IRRI TH6 thresher - cylinder

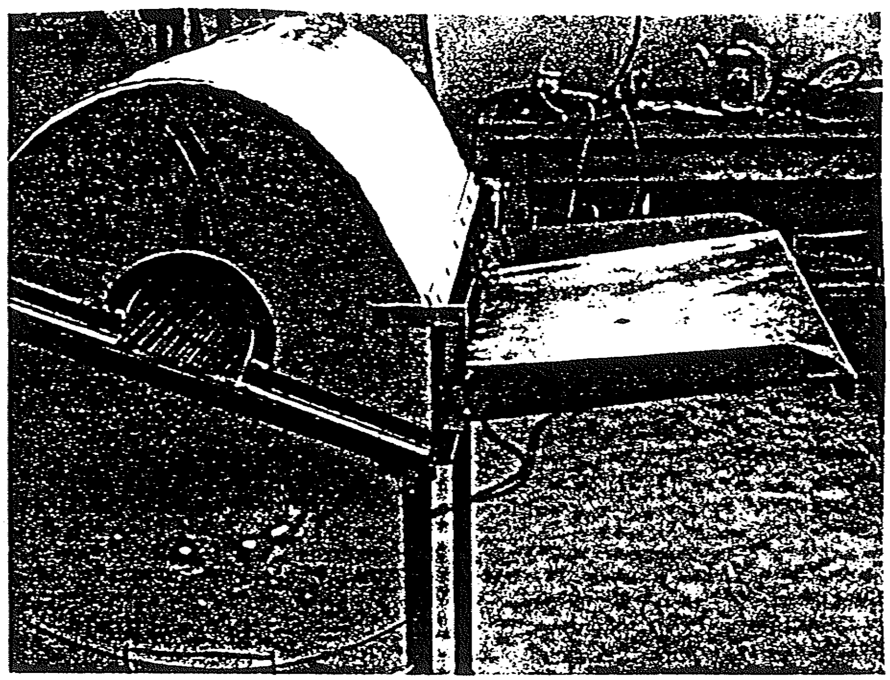


Figure 5 IRRI TH6 thresher - with cover and feed tray

The concave is two rows of 0.47 cm diameter rods. One row is removable to allow crops with different seed sizes to be threshed.

Normally a gas engine would be used in the field but for these tests a 1.5 hp electric motor was used.

6.2 Preliminary Tests

Preliminary tests were carried out in order to identify any obvious problems with the thresher, to compare the Canadian grown quinua with Peruvian seed in terms of size, and to develop a cleaning method for the samples.

6.2.1 Modifications to the Thresher

The major problem identified during preliminary tests was that quinua fell outside the collection bin. The major leak occurred on the right hand side of the intake due to threshed quinua being ejected there instead of travelling further along the cylinder. This problem was solved by attaching a side guard on the right hand side and a guard along the top of the intake to prevent material from being thrown back.

Another leak occurred between the feed tray and the front of the thresher. This caused loose grain to fall to the floor before entering the thresher. This was solved by placing a plastic sheet over the gap. Another cause of losses was seeds being blown out by the fan and the wind created by the rotating cylinder. These losses were eliminated by removing the fan and hanging plastic sheets around the back and right hand side of the thresher.

The preliminary tests showed that the thick stalk of the quinua plant was a problem. Two teeth were bent when a particularly large stalk was fed into the thresher. For this reason only the top half of the plant was fed through during subsequent tests.

Another adjustment made was to place perforated sheet metal (0.28 cm holes) on top of the concave rods. This was to prevent larger pieces of material and unthreshed clusters from falling through the concave.

6.2.2 Comparison of Canadian Grown and Peruvian Grown seeds

The quinua which was harvested from Morden was not at full maturity. This caused some concern over the behaviour of the test seed compared with that of the material in Peru. Seeds brought back from southern Peru were used as a standard to compare with Manitoban seeds. A comparison of size was done between the seeds by passing them through a series of screens. The Peruvian seeds were of the variety Rosada. The results are shown in Table 5. The Peruvian seeds were slightly more uniform in size. The North

American seeds had a higher percentage of smaller seeds than those from Peru.

Table 5 Comparison of Canadian and Peruvian quinua seed sizes

Screen #	Canadian Seed (%)	Peruvian Seed (%)
10	1.3	0.8
14	79.7	94.3
16	13.1	3.6
20	4.1	1.0
pan	dust 1.2	dust 0.2

6.2.3 Cleaning Method for Samples

Preliminary tests were done to determine a method of easily cleaning samples. The method chosen was to winnow the sample in front of an airflow created by a small household fan and to collect the seed which fell in front of a fixed line. This provided a fairly clean sample. The seeds which fell in front of the line were the largest ones and were quite free of dust and light chaff. Tests with the Peruvian seeds showed that 4.8 percent of the samples were lost, that is the seeds fell beyond the fixed point. The purity of the threshed samples from the tests was between 65 and 96 percent of the seeds by weight.

Cleaning Procedure:

1. The mixture to be cleaned was first screened with wire mesh (hole size 2.6 mm x 2.6 mm).
2. The screened mix was passed in front of the air stream of a household fan. The mix fell a distance of 59 cm at a distance of 42 cm from the fan.
3. The seeds that fell in front of a pan 52 cm from the fan were collected, weighed and recorded as the "seeds in bin". The chaff and material other than grain which fell in the pan and past it were weighed and recorded as "other chaff", and the chaff left on the screen was weighed and recorded as "chaff on screen".

6.3 Procedure for Threshing Tests

Three variables were considered in the tests: angular velocity (r/min) of the cylinder, type of flaps, and moisture content of the quinua seeds. The angular velocity of the cylinder was 360 or 670 r/min. The flaps were of different thickness, 0.15 cm (referred to in the rest of the paper as soft flaps) and 0.36 cm (hard flaps). They were clamped in place with 1.2 cm of the flap extending beyond the clamp. The moisture content was dry (8.4 percent) or wet (between 9.9 and 14.8 percent). Two tests were performed for each variable for a total of 16 tests.

The procedure for each individual test was as follows:

1. Quinua plants were broken up until a sample of approximately 1 kg of material was collected.
2. The sample was threshed.
3. Seed in the bin was collected and cleaned and weighed according to the cleaning procedure outlined above.
4. Seed thrown out was collected, cleaned, and weighed.
5. Moisture content of seed was determined.
6. The total seed mass was the seed in the bin plus the seed thrown out.
7. Total mass in bin was seed in bin plus chaff in bin.

The thresher was tested for efficiency and cleanness of output. These terms were determined as follows:

$$Efficiency = \frac{seed\ in\ bin\ (g)}{total\ seed\ (g)} * 100 \qquad (1)$$

$$cleanness = \frac{seed\ in\ bin\ (g)}{total\ mass\ in\ bin\ (g)} \qquad (2)$$

Tests were also made to determine the threshing capacity of the thresher. Two tests were carried out - one with just the heads fed in and one with loose material that had fallen off the plant during handling. The tests were carried out by two people - one person kept the feed tray full, and one person fed the material in.

7 TEST RESULTS

7.1 Efficiency

The test results for efficiency are graphically shown in Figure 6. Efficiency varied between 68 percent and 89 percent.

7.2 Cleanness

The test results of cleanness are shown in Figure 7. Higher values are more desirable as this means there is less chaff mixed in with the seed. Cleanness varied between 0.3 and 0.88.

7.3 Threshing Capacity

The threshing capacity when the heads were thrown in was 9.9 kg of clean grain per hour. The capacity when loose material was thrown in was 33.3 kg/h of clean grain.

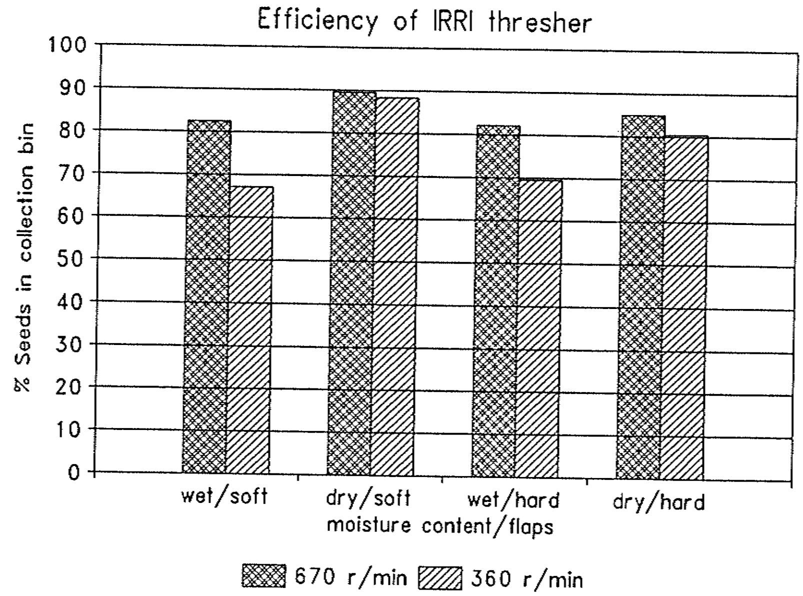


Figure 6 Efficiency of IRRI thresher for quinua threshing

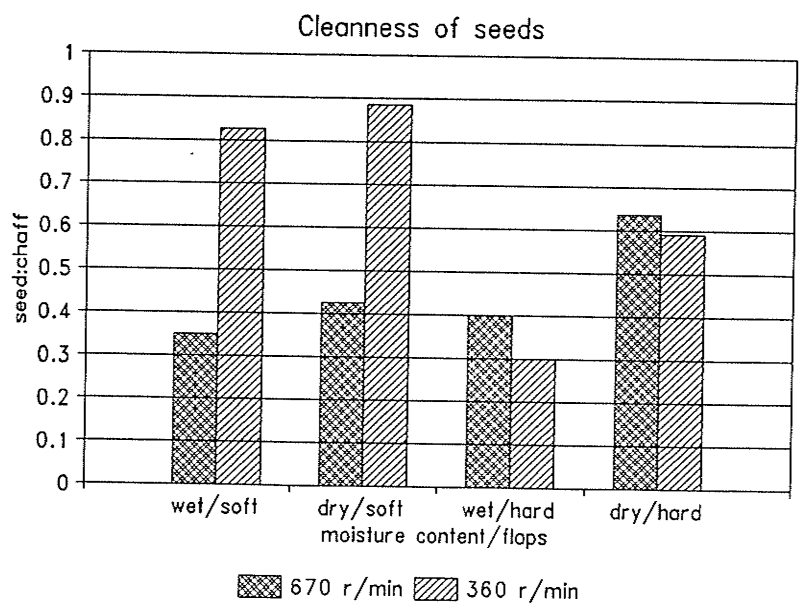


Figure 7 Cleanness of threshed seed with IRRI TH6 thresher

8 DISCUSSION

There were several shortcomings to the tests. Due to the small amount of test material available only two replications were done of each test. Also, the "wet" moisture content varied between 9.9 and 14.8 percent. Finally the cleaning method included some material other than grain in the mass which was supposed to be pure grain only.

A statistical analysis was done to a level of significance of 0.05. This showed that none of the tests differed significantly from each other. There were however definite patterns as can be seen in the graphs. These can be summarized as follows.

8.1 Effect of r/min

Threshing at 670 r/min was more effective than 360 r/min. The output was cleaner using 670 r/min with hard flaps, but less clean when using soft flaps. The lower speed was more pleasant to work with as there was less noise, virbation, and dust.

8.2 Effect of Flaps

The type of flap did not appear to influence the efficiency greatly. The type of flap did effect the cleanness. Soft flaps gave a considerably cleaner product than hard flaps at 360 r/min. The best cleanness result with soft flaps was 0.88 at 360 r/min and the best cleanness result with hard flaps was 0.63 at 670 r/min.

8.3 Effect of Moisture Content

The higher moisture content samples threshed less efficiently and were not as clean. It was necessary to thresh the two wettest samples twice as many seeds were not knocked off the plant the first time.

8.4 Threshing Capacity

As could be expected from the two capacity tests, when there is less material other than grain to thresh, the capacity is higher. The second test however did not represent the type of material that would normally be fed in as it was all the loose material that had fallen off during handling. The majority of the time the material to be threshed will be the complete heads of the plant together with some short stalks. This method would require a minimum of two people - one to separate the head from the stalk and another to feed it into the thresher. One disadvantage in having to break off the head is that this requires more handling and each time handling occurs there are more losses, especially with drier material. These losses could be decreased by handling the quinua on a blanket near the thresher so that loose material could be collected and threshed.

8.5 General Observations

The most noticeable observation about the IRRI thresher as it performed on quinua was the large amount of seed being thrown out the straw discharge area. This could be expected due to the size of the seeds and their very small mass. The seeds that were thrown out the straw discharge were in the form of threshed seeds. In only two of the tests with high moisture content were there noticeable amounts of unthreshed material which need to be rethreshed. In many cases the perigonium was intact but the seed had been knocked out.

One option that could be used to recover the loose seed would be to eliminate the straw discharge area and have all material fall into the bin to be sorted later. This would create more bulk in the bin but cleaning would not be made that much more difficult as the large pieces could easily be screened out. Another option would be to have the thresher on a hard floor or on a tarpaulin so that loose material could be swept up later. This would still require a cleaning step.

The IRRI thresher has a lower threshing capacity than the threshers summarized earlier. The lowest capacity among the mechanical threshers was 22.54 kg/h for the Kincaid 5 hp thresher as opposed to 9 kg/h for the TH6. The percentage of pure grain collected was 91.83 percent as opposed to 88 percent at its best for the TH6. The TH6 does have the advantage of being a relatively simple design to build and maintain.

The results for the TH6 may have been better if the quinua had been more represenatative of the quinua in Peru and Ecuador. The quinua from Morden did not have very many seeds and so the tests required more material other than grain to be fed in per kilogram of seed than would be necessary with South American grown plants.

8.6 Comparison with Hand Threshing

In order to get a rough idea of the problems of manual threshing a sample of quinua (8.4 percent m.c.) was threshed by hitting it with a stick. The quinua was placed on a concrete floor with all the heads facing in one direction.

A block of wood was used to beat the quinua. About half way through the threshing process the larger stalks and branches were removed from the pile to make the seeds more accessible. It was observed that many seeds were off the plant but that the perigonium was still surrounding the seed.

At the conclusion of threshing there was still a noticeable amount of seeds with the perigonium attached. The threshing action should probably have been a bit more aggressive with some rubbing action. Seed loss was 2.2 percent. These losses were as a result of the larger pieces of material being removed from the pile before the threshing was complete. The seed:chaff ratio was 0.43. The manual threshing capacity was 1.1 kg/hr. This was low compared to values reported in literature. This was most likely due to the lack of practice in manual threshing.

9 CONCLUSIONS

1. The IRRI TH6 thresher modified to include rubber flaps and a perforated concave is capable of threshing quinua.
2. Many threshed seeds were ejected from the straw discharge but they were recoverable.
3. None of the variables had a statistically significant effect on the efficiency or cleanness

of the threshed grain but observation indicated that 670 r/min is more efficient than 360 r/min, and soft flaps provide cleaner output.

10 RECOMMENDATIONS

1. An additional modification that could be made to the TH6 is to make an open cylinder, that is the sheet metal covering on the cylinder frame could be eliminated. This has been done in later models of IRRI threshers.
2. A chute could be added to guide the material falling through the concave into a bag at the end of the thresher instead of having the material just fall straight into the bin. This would make it easier to collect and move the material for cleaning.
3. The IRRI TH6 should be tested under Peruvian conditions with the recommended modifications made.

PART III THERMAL PROPERTIES RESEARCH

11 RESEARCH OBJECTIVES

The specific heat and thermal conductivity of quinua were determined and the effect of moisture content and temperature on the these properties were also investigated.

12 SPECIFIC HEAT

12.1 Introduction

Specific heat is the amount heat required to raise the temperature of one gram of a substance one degree Celsius. Mathematically it is expressed as

$$\Delta Q = w\int_{t_1}^{t_2} c\,dt \qquad (3)$$

Where
ΔQ = change in heat content, J
w = mass of sample, g
t_1 = initial temperature, K
t_2 = final temperature, K
c = specific heat of sample, kJ/(kg·K)

(ASTM Standard C 1045 - 90, 1990)

If we assume c is constant then

$$c = \frac{\Delta Q}{w\,(t_2 - t_1)} \qquad (4)$$

A common method used to measure specific heat is the "method of mixtures". This method requires that a sample at a specific temperature be introduced into a calorimeter vessel (thermos) containing a calorimeter fluid at a different temperature from the sample. The fluid and sample are mixed until the change in temperature with time is linear. Specific heat can then be calculated as follows.

$$c_s = \frac{(m_w + E)\, c_w\, (T_c - T_m)}{m_s\, (T_m - T_s)} \quad (5)$$

Where
c_s = average specific heat of sample between T_s and T_m, kJ/(kg·K)
m_s = mass of sample, g
m_w = mass of water, g
T_c = initial temperature of water, °C
T_s = initial temperature of sample, °C
T_m = equilibrium temperature of mix, °C
E = water equivalent of calorimeter, g

12.2 Preliminary Tests

Preliminary tests were performed to see if the method of mixtures could be used with the equipment and material. It was discovered that the magnetic stirrer would stall when quinua was added to the water. Different water to quinua ratios were tried to see if that would solve the problem but it was impossible to get the stirrer working consistently. It was decided to try to eliminate the stirrer. During various tests the thermos flask was manually shaken after the tests were considered ended to see if any change in temperature occurred. Shaking did not alter the temperature pattern and so it was concluded that the stirrer could safely be eliminated.

12.3 Material and Apparatus

The quinua used for the experiment came from Peru and was the variety Rosada de Junin.

The calorimeter was a glass insulated thermos. A small hole was drilled through the lid and a thermocouple was inserted. A drinking straw was used to keep the thermocouple in a fixed place for each test. A freezer was used to cool the samples and the initial sample temperatures were also measured with a thermocouple. The two thermocouples were connected to a Taurus data aquisition board and a Tandy computer system to measure and record all the data. Distilled water was used as the calorimeter fluid.

12.4 Procedure

The procedure had three main steps - calibration with a standard, checking procedure with a standard, and finally the actual tests with quinua.

12.4.1 Calibration

Calibration was done to determine the water equivalent of the thermos. The standard used for calibration was aluminum pellets. The reported specific heat for aluminum is 0.90 kJ/(kg·K) at 25 °C. Using this value for c_p the water equivalent E could be calculated.

$$E = \frac{c_s m_s (T_m - T_s)}{c_w (T_c - T_m)} - m_w \qquad (6)$$

Twelve tests were run and the average E was calculated to be 12.65 g with a standard deviation of 4.62 g.

For each calibration test 20 g of aluminum was put in a small glass container and cooled to approximately -12 °C. Forty grams of water were put in the thermos and left at room temperature, approximately 17 °C. The temperatures of the sample and water were recorded for a minute and then the sample was quickly poured into the water and the lid screwed on tightly (an elapsed time of about 5-7 seconds). The glass container had a layer of fibreglass insulation around it to minimize heat loss during the sample transfer. The temperature of the sample and the water was allowed to equilibrate until the rate of temperature change was approaching zero. This length of time was around 13 minutes.

The water temperature was recorded at intervals of one second. The temperature of the mix (T_m) was calculated by taking the average of the last 10 readings.

12.4.2 Checking Procedure

Granular copper was tested to determine the accuracy of the calibration and procedure. The published value for c_p of copper is 0.385 kJ/(kg·K) at 25 °C. Three replications gave a result of 0.37 kJ/(kg·K) and a standard deviation of 0.04 kJ/(kg·K) at an initial temperature of -14 °C.

12.4.3 Quinua Tests

The procedure for the quinua tests was much the same as for the calibration tests. Four samples of 20 g of quinua were prepared in glass containers. The quinua seeds of higher moisture content were prepared by adding the appropriate amount of water, mixing, and allowing to sit in a refrigerator for at least 24 hours. It was necessary to keep the seed in the refridgerator (set at approximately 5 C) to prevent germination.

Three different moisture contents and initial temperatures were used and three replications of each combination were done resulting in 27 tests (3 m.c. x 3 temp. x 3 replications).

12.5 Results and Discussion

A sample of the data collect for one test is shown in Figure 8. The results of the tests are shown in Figure 9. Each set of replications was averaged to give one c_p value for each combination.

A complete listing of averages and standard deviations appears in Appendix C. Statistical analysis did not give consistent significant differences between the tests at different moisture content or initial temperatures. However the general trend is that higher moisture content results in higher c_p. This is consistent with the reported behaviour of other grains. Moysey, Shaw, and Lampman (1977) reported that rapeseed at 19.64 percent m.c. and 1.7 °C initial temperature had a c_p of 1.807 kJ/(kg K). At 5.45 percent m.c. and 1.7 °C the c_p value was 1.397 kJ/(kg K).

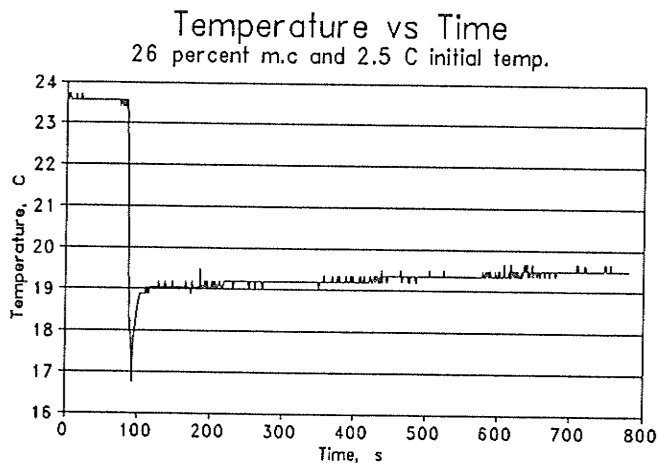


Figure 8 Sample data for specific heat test: 26 percent m.c. and 2.5 C initial temperature.

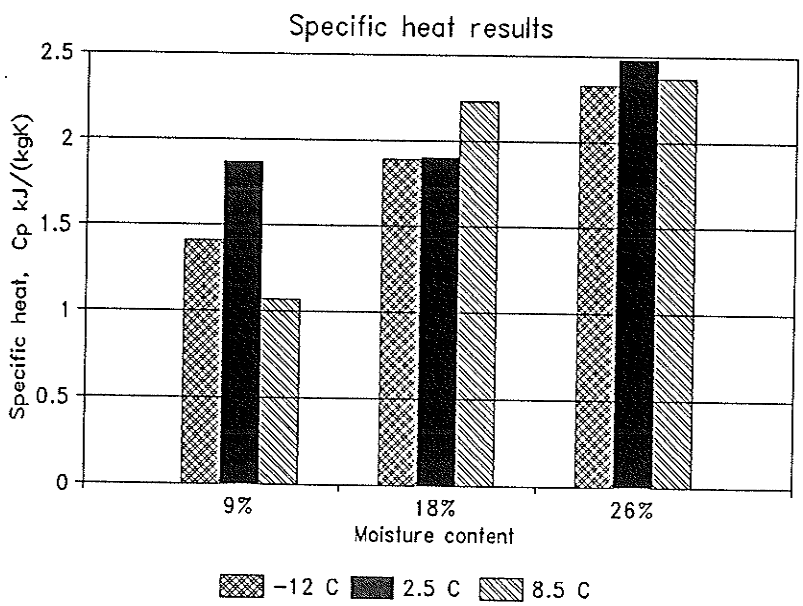


Figure 9 Specific heat test results with varying moisture content and initial temperature.

13 THERMAL CONDUCTIVITY

13.1 Introduction

The thermal conductivity for a material is defined as

$$k = \frac{q}{\Delta T/L} \tag{7}$$

where k = thermal conductivity, W/(m·K)
ΔT = temperature gradient across material, K
L = thickness of material, m
q = rate of heat flux, W

(ASTM Standard C 1045 - 90, 1990)

There are two general methods by which to measure thermal conductivity: steady state and transient. The disadvantages of steady state methods are that a long time is required to obtain a steady state, and moisture migration along the temperature gradient can occur during the long test period (Chandra and Muir, 1971).

The method chosen for determining the thermal conductivity of quinua was the transient method using a simple line heat source as outlined by Alagusundaram, Jayas and Muir (1990). This method uses a line heat source heated at a constant rate placed in a sample of uniform initial temperature. The sample is generally put in a cylindrical container in which case the solution of the transient heat conduction equation in the radial direction with a cylindrical coordinate system is:

$$\theta_2 - \theta_1 = \frac{Q}{4\pi k}\ln\left(\frac{t_2}{t_1}\right) \quad (8)$$

where θ_1 = temperature at time t_1, K
θ_2 = temperature at time t_2, K
Q = line heat-source strength, W/m
k = thermal conductivity of the sample, W/(m·K)

This equation assumes an ideal line heat source of infinite length in an infinite medium with heat flow in the axial direction only.

13.2 Material and Apparatus

The quinua used for the experiment came from Peru and was the varieties Rosada de Junin and Amarillo Marangani.

The cylinder used to hold the sample was made from aluminum and was 300 mm long and 150 mm in diameter. The line heat source was a 250 mm long 31 gauge chromel wire, stretched between copper leads along the axis of the cylinder. The resistance of the chromel wire was 0.274 Ω/cm. A DC power supply gave a current of 317 mA. A 28-gauge thermocouple, placed along side the line heat source at the centre of its length, measured temperature rise of the heat source. A

Taurus-102 data acquisition system and a PC/XT were used to measure and record temperature rise and current and voltage across the line heat source.

13.3 Procedure

One variable, moisture content, was considered in determining thermal conductivity. Two different moisture contents were used and three replications were done.

The initial temperature of the samples was around 20°C. Each test was run for a duration of 10 minutes. The short test time and the length of the heat source ensured that insignificant axial heat flow occurred.

The container was manually filled through a hole in the top. The average bulk density of all the tests was 794 kg/m^3 with a standard deviation of 16.5 kg/m^3.

13.3.1 Calculations

Calculating k required an adjustment to Equation (8). To compensate for the finite diameter of the line heat source, which replaces a small amount of grain, a time correction, t_o is subtracted from the recorded times. The equation to find k is

$$k = \frac{Q}{4\pi(\theta_2-\theta_1)}\ln\left(\frac{t_2-t_o}{t_1-t_o}\right) \qquad (9)$$

There are several different methods for calculating t_o. The method chosen for this paper was reported by Hooper and Lepper (1950). As can be seen in Figure 10, the temperature rise of the line heat source was a linear function of ln(time). Linear regression was done on this line for all tests and new temperature values were calculated based on the resulting equations. Using the calculated temperatures, a plot of $dt/d\theta$ vs time was made. The time at which $dt/d\theta=0$ represented t_o. In these tests t_o was found to be 7.8 s.

There are several reported ways to calculate k. Alagusundaram, Jayas, and Muir (1990) found that the slope method as reported by Sharma and Thompson (1973) and Chang (1986) gave the most consistent results for barley, lentils, and peas. This method was chosen to find k for quinua. Linear regression was done on the temperature rise after four minutes vs $\ln((t_2-t_0)/(t_1-t_0))$. The value of t_2 was chosen to be 10 minutes. The slope, S, found through linear regression can be used to calculate k as follows:

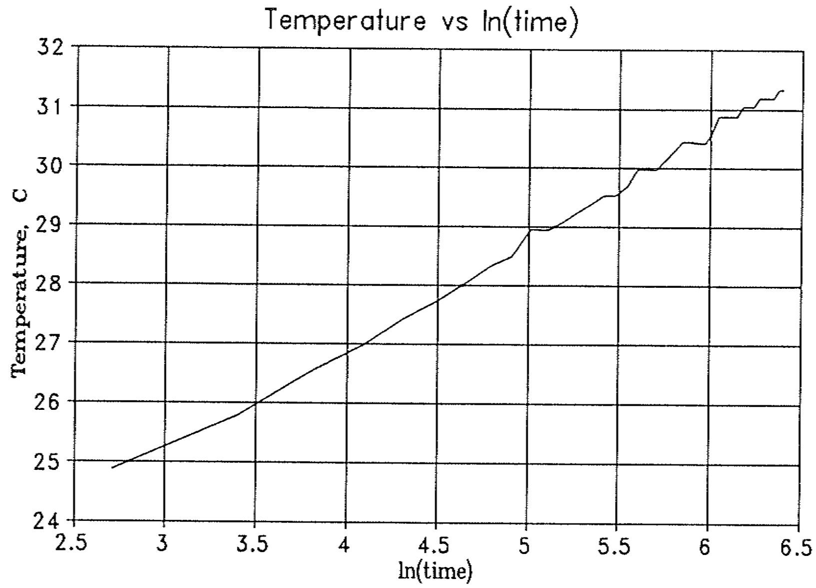


Figure 10 Temperature vs ln(time) for quinua

$$S = \frac{Q}{4\pi k} \tag{10}$$

13.4 Results and Discussion

The test results showed that moisture content had a significant effect on the thermal conductivity of quinua. The average k value at 8 percent mcwb was 0.127 W/(m·K) with a standard deviation of 0.003 W/(m·K). At 13 percent mcwb the average k was 0.135 W/(m·K) with 0.006 W/(m·K) standard deviation. The higher moisture content samples were of the variety Amarillo Marangani and the drier samples were Rosada de Junin.

The quinua values are higher than those of rapeseed as reported by Moysey, Shaw, and Lampman (1977). They reported that rapeseed at 15.5 percent mcwb and 19.4 °C initial temperature had a k of 0.1129 W/(m K) while at 5.45 percent mcwb and 19.4°C the k value of rapeseed was 0.1034 kJ/(kgK).

REFERENCES

1. Alagusundaram, K., D.S. Jayas, and W.E. Muir. 1990. Thermal Conductivity of barley, lentils and peas. ASAE meeting presentation.

2. ASTM Standard C 1045 - 90. 1990. Standard Practice for Calculating Thermal Transmission Properties from Steady-State Heat Flux Measurements. 538.

3. Birk, Yehudith. 1969. Saponins: Toxic Constituents of Plant Food Stuffs ed. Irvin E. Liener. Academic Press. 169-175.

4. Chandra, S. and W.E. Muir. 1971. Thermal Conductivity of Spring Wheat at Low Temperatures. Transactions of the ASAE. 644-645.

5. Cusack, David F. 1984. Quinua:Grain of the Incas. The Ecologist, Vol 14 (1). 21-31.

6. Gonzales Gallegos, Domingo. 1988. Estudio Comparativo de trilla y Limpieza de granos Tesis, Universidad Nacional San Antonio Abad del Cusco, Cusco, Peru.

7. Maletta, Héctor and Katia Makhlouf. 1982. Peru las provincias en cifras 1976-1981 Volumen III. Estructura Agaraia. Sefie Estadisticas No. 2. Ediciones Amidep. Universidad del Pacifico.

8. McMennamy, John A. and Jose S. Policarpio. 1977. Development of a Portable Axial Flow Thresher: Grain and Forage Harvesting: The Proceedings of the International Grain and Forage Harvesting Conference. American Society of Agricultural Engineers. Sept 25-29. 170-173.

9. Montoya M., Gonzalo, and Carlos C. Nieto. 1990. Diseño, construccion y evaluacion de un prototipo de trilladora de quinua: Seminario Taller sobre Investigacion en posporduccion de quinua en Ecuador June 4-5. Quito, Ecuador.

10. Moysey, E.B., J.T. Shaw, and W.P. Lampman. 1977. The effect of Temperature and Moisture on the Thermal Properties of Rapeseed. Transactions of ASAE. 461-464.

11. Reinoso R., Jorge. 1982. Variables de la oferta y la demande de quinua en Puno. Tercer Congreso Internacional de Cultivos Andinos, La Paz, Bolivia 8-12 Febrero. 181-182.

12. Salazar, Marco David and Jose Karl Charles Villacres Cabrera. 1990. Estudio de Postcosecha Tradicional de Quinua en Colta y Pujili y construccion de un equip de trillado y limpieza. Tesis. Titulo de Ingeniero en Alimentos. Tecnica de Ambato. Ambato, Ecuador.

13. Sanchez, Isabel Rodriquez and Jose Maria Ortega Valdez. 1986. Cultivo de Tarwi, Quinua, y Kiwicha: Informe del Proyecto FIPS 5. Corporación Departmental de Desarrollo del Cusco, Cusco, Peru.

14. Tapia, Mario et al. 1979. La Quinua y la Kañiwa: Cultivos Andios Instituto Interamericano de Ciencias Agricolas (IICA).

15. Zvietcovich, Guillermo Masciotti, Oscar Goméz Goméz, and Hernán Cortés, editores. 1987. Evaluacion de la trilla de quinua: Informe Tecnico Anual 1986. Instituto Interamericano de Cooperación para la Agricultura (IICA) Peru.

16. Zvietcovich, Guillermo Masciotti, Oscar Goméz Goméz, and Hernán Cortés editores. 1987. Evaluacion de trilladora de quinua: Informe Tecnico Anual 1986. Instituto Interamericano de Cooperación para la Agricultura (IICA) Peru.

17. Zvietcovich, Guillermo Masciotti, Wilfred Salas Molina, and Mercedes Vega Huerta. 1985. Inventario Tecnológico de los Sistemas Poscosecha en la Sierra del Péru Instituto de Cooperación para la Agricultura. Publicación Misceánea No. 629.

APPENDIX A: Statistical Analysis

The statistical significance of the difference between mean values in all tests was determined using a t-test for small samples. The general equation is

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

where x_1, x_2 = test average of each test

n_1, n_2 = number of samples in each test

s_1, s_2 = standard deviation of each test

t = significance

The value of t which determines whether two tests are significantly different is dependent on the degrees of freedom and the level of significance desired. The degrees of freedom is equal to n_1+n_2-2. The level of significance for all tests was 0.05. This meant that for the thermal properties tests t had to be between 2.776 and -2.776 for the averages to be considered statistically the same. For the thresher tests the significant values were $\pm$ 4.303.

APPENDIX B: Thresher Test Data

The following are the data for each of the thresher tests. The Scale Reading is the weight of the material plus the can in which it was weighed. The Mass is Scale Reading minus the weight of the Can. Original Mass refers to the mass of the sample that was fed through the thresher. The Chaff-Sieve mass is the material that does not pass through the sieve and the Chaff-Other is the material that does pass through. The symbol **** indicates that the data were not collected properly and so calculations did not provide valid results.

Test #: 1a DATA

			Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	hard			
M.C. (w.b.) %:	8.4	Seed in bin	370.8	209.9
Wt of can (g):	160.9	Chaff		
Original Mass (g):	995.0	Sieve	186.0	25.1
		Other	470.5	309.6
		Seed thrown out	****	-160.9

EVALUATION

seed in bin	428.4%	****
seed thrown out	-328.4%	****
seed in bin/chaff	0.6	
seed/org.mass	0.0	

Test #: 1b DATA

			Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	hard			
M.C. (w.b.) %:	8.4	Seed in bin	348.4	187.5
Wt of can (g):	160.9	Chaff		
Original Mass (g):	842.0	Sieve	173.2	12.3
		Other	440.0	279.1
		Seed thrown out	194.0	33.1

EVALUATION

seed in bin	85.0%
seed thrown out	15.0%
seed in bin/chaff	0.6
seed/org.mass	0.3

Test #: 1c DATA

			Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	hard			
M.C. (w.b.) %:	8.4	Seed in bin	325.8	164.9
Wt of can (g):	160.9	Chaff		
Original Mass (g):	****	Sieve	****	-160.9
		Other	468.7	307.8
		Seed thrown out	190.4	29.5

EVALUATION

seed in bin	84.8%	
seed thrown out	15.2%	
seed in bin/chaff	1.1	****
seed/org.mass	ERR	****

Test #: 2a DATA

Speed (rpm): 360.0
Flaps: hard
M.C. (w.b.) %: 8.4
Wt of can (g): 163.5
Original Mass (g): 1031.0

	Scale Reading	Mass(g)
Seed in bin	325.8	162.3
Chaff		
Sieve	175.5	12.0
Other	452.1	288.6
Seed thrown out	195.6	32.1

EVALUATION

seed in bin 83.5%
seed thrown out 16.5%
seed in bin/chaff 0.5
seed/org.mass 0.2

More chaff thrown out than 670 rpm a perig. in tact but many of the seeds knocked out.

Test #: 2b DATA

Speed (rpm): 360.0
Flaps: hard
M.C. (w.b.) %: 8.4
Wt of can (g): 163.5
Original Mass (g): 1006.0

	Scale Reading	Mass(g)
Seed in bin	327.8	164.3
Chaff		
Sieve	181.3	17.8
Other	400.7	237.2
Seed thrown out	211.9	48.4

EVALUATION

seed in bin 77.2%
seed thrown out 22.8%
seed in bin/chaff 0.6
seed/org.mass 0.2

Test #: 3a DATA

Speed (rpm): 360.0
Flaps: soft
M.C. (w.b.) %: 14.0
Wt of can (g): 160.9
Original Mass (g): 1071.0

	Scale Reading	Mass(g)
Seed in bin	266.5	105.6
Chaff		
Sieve	170.1	9.2
Other	248.1	87.2
Seed thrown out	238.4	77.5

EVALUATION

seed in bin 57.7%
seed thrown out 42.3%
seed in bin/chaff 1.1
seed/org.mass 0.2

Rethreshed the seeds thrown out the day after when they were drier. Wet stuff gets tossed to the opening more than dry material.

Test #:	3b	DATA		
			Scale Reading	Mass(g)
Speed (rpm):	360.0			
Flaps:	soft			
M.C. (w.b.) %:	12.9	Seed in bin	282.1	121.2
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1001.0	Sieve	186.0	25.1
		Other	356.0	195.1
		Seed thrown out	198.8	37.9

EVALUATION

seed in bin	76.2%
seed thrown out	23.8%
seed in bin/chaff	0.6
seed/org.mass	0.2

Test #:	4a	DATA		
			Scale Reading	Mass(g)
Speed (rpm):	360.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	477.2	316.3
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1143.0	Sieve	173.1	12.2
		Other	455.5	294.6
		Seed thrown out	203.4	42.5

EVALUATION

seed in bin	88.2%
seed thrown out	11.8%
seed in bin/chaff	1.0
seed/org.mass	0.3

Test #:	4b	DATA		
			Scale Reading	Mass(g)
Speed (rpm):	360.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	371.5	210.6
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1147.0	Sieve	179.6	18.7
		Other	428.4	267.5
		Seed thrown out	188.2	27.3

EVALUATION

seed in bin	88.5%
seed thrown out	11.5%
seed in bin/chaff	0.7
seed/org.mass	0.2

Test #:	5a	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	332.5	171.6
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1023.0	Sieve	166.8	5.9
		Other	527.0	366.1
		Seed thrown out	189.0	28.1

EVALUATION

seed in bin	85.9%
seed thrown out	14.1%
seed in bin/chaff	0.5
seed/org.mass	0.2

Test #:	5b	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	351.6	190.7
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1145.0	Sieve	170.9	10.0
		Other	642.2	481.3
		Seed thrown out	184.0	23.1

EVALUATION

seed in bin	89.2%
seed thrown out	10.8%
seed in bin/chaff	0.4
seed/org.mass	0.2

Test #:	5c	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	386.0	225.1
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1019.0	Sieve	174.0	13.1
		Other	651.1	490.2
		Seed thrown out	174.0	13.1

EVALUATION

seed in bin	94.5%
seed thrown out	5.5%
seed in bin/chaff	0.4
seed/org.mass	0.2

Test #:	5d	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	8.4	Seed in bin	321.0	160.1
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1063.0	Sieve	192.0	31.1
		Other	507.1	346.2
		Seed thrown out	181.0	20.1

EVALUATION

seed in bin	88.8%
seed thrown out	11.2%
seed in bin/chaff	0.4
seed/org.mass	0.2

Test #:	6a	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	14.8	Seed in bin	200.0	39.1
Wt of can (g):	160.9	Chaff		
Original Mass (g):	950.0	Sieve	169.2	8.3
		Other	331.6	170.7
		Seed thrown out	170.9	10.0

EVALUATION

seed in bin	79.6%
seed thrown out	20.4%
seed in bin/chaff	0.2
seed/org.mass	0.1

Test #:	6b	DATA	Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	soft			
M.C. (w.b.) %:	14.8	Seed in bin	267.7	106.8
Wt of can (g):	160.9	Chaff		
Original Mass (g):	825.0	Sieve	175.9	15.0
		Other	350.4	189.5
		Seed thrown out	179.6	18.7

EVALUATION

seed in bin	85.1%
seed thrown out	14.9%
seed in bin/chaff	0.5
seed/org.mass	0.2

Test #: 7a DATA

			Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	hard			
M.C. (w.b.) %:	11.0	Seed in bin	217.0	56.1
Wt of can (g):	160.9	Chaff		
Original Mass (g):	756.0	Sieve	178.9	18.0
		Other	315.2	154.3
		Seed thrown out	179.8	18.9

EVALUATION

seed in bin	74.8%
seed thrown out	25.2%
seed in bin/chaff	0.3
seed/org.mass	0.1

Test #: 7b DATA

			Scale Reading	Mass(g)
Speed (rpm):	670.0			
Flaps:	hard			
M.C. (w.b.) %:	10.9	Seed in bin	360.4	199.5
Wt of can (g):	160.9	Chaff		
Original Mass (g):	1170.0	Sieve	182.3	21.4
		Other	554.0	393.1
		Seed thrown out	184.6	23.7

EVALUATION

seed in bin	89.4%
seed thrown out	10.6%
seed in bin/chaff	0.5
seed/org.mass	0.2

Test #: 8a DATA

			Scale Reading	Mass(g)
Speed (rpm):	360.0			
Flaps:	hard			
M.C. (w.b.) %:	wet	Seed in bin	211.6	50.7
Wt of can (g):	160.9	Chaff		
Original Mass (g):		Sieve	178.0	17.1
		Other	291.5	130.6
		Seed thrown out	178.9	18.0

EVALUATION

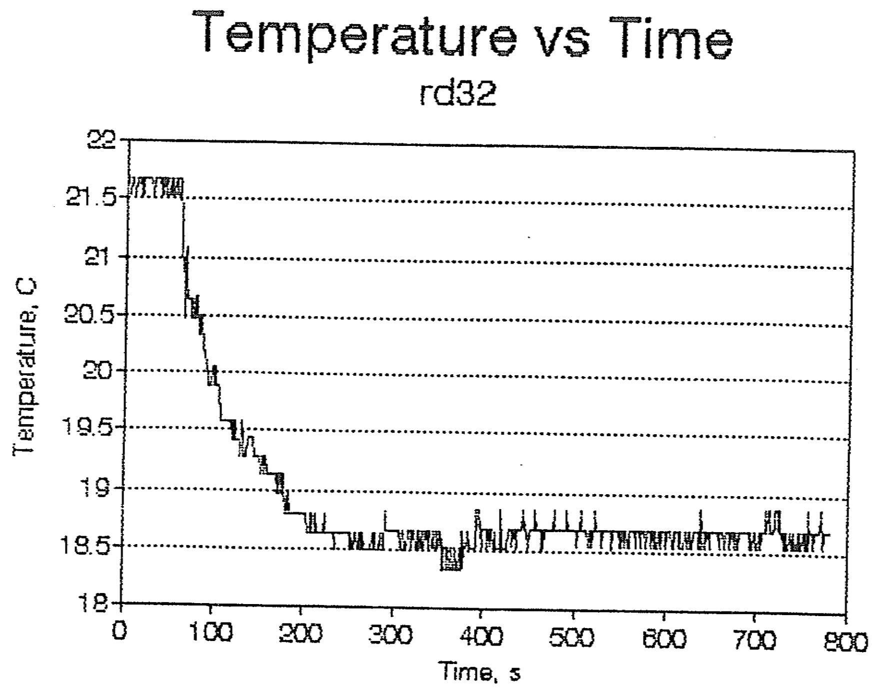
seed in bin	73.8%
seed thrown out	26.2%
seed in bin/chaff	0.3
seed/org.mass	ERR

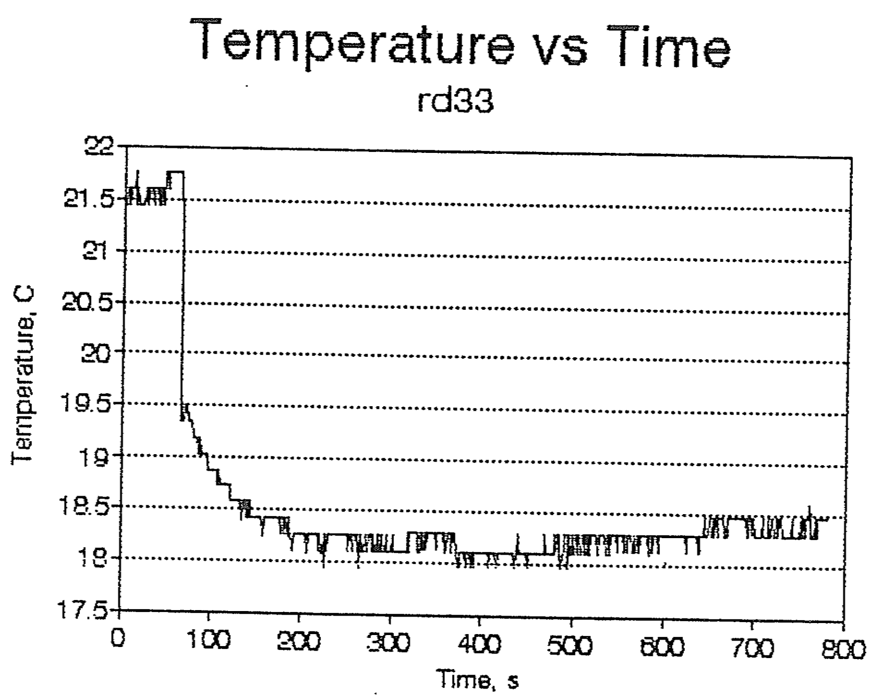
Test #: 8b DATA

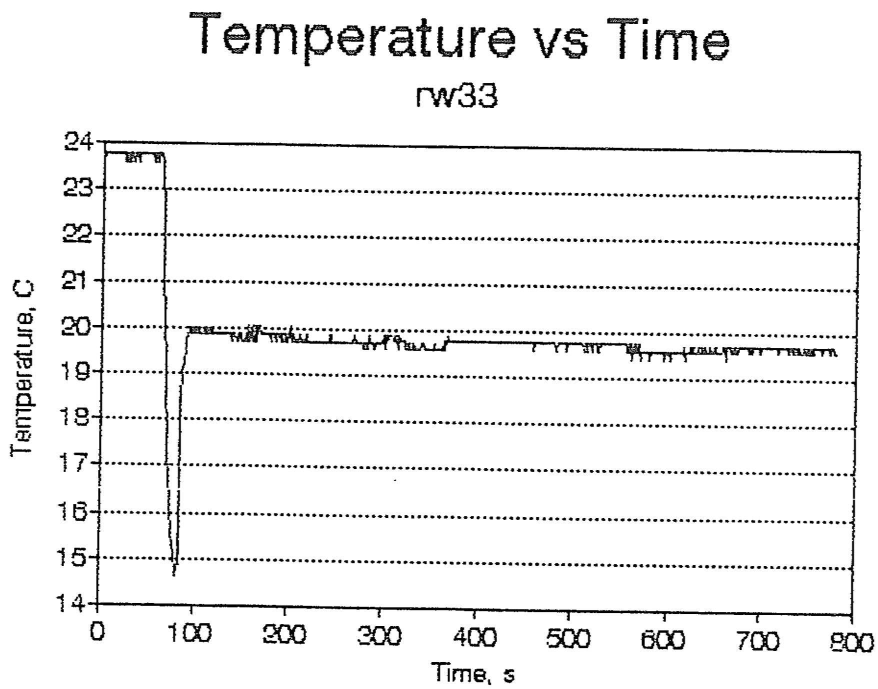
			Scale Reading	Mass(g)
Speed (rpm):	360.0			
Flaps:	hard			
M.C. (w.b.) %:	wet	Seed in bin	187.2	26.3
Wt of can (g):	160.9	Chaff		
Original Mass (g):		Sieve	****	-160.9
		Other	306.7	145.8
		Seed thrown out	175.0	14.1

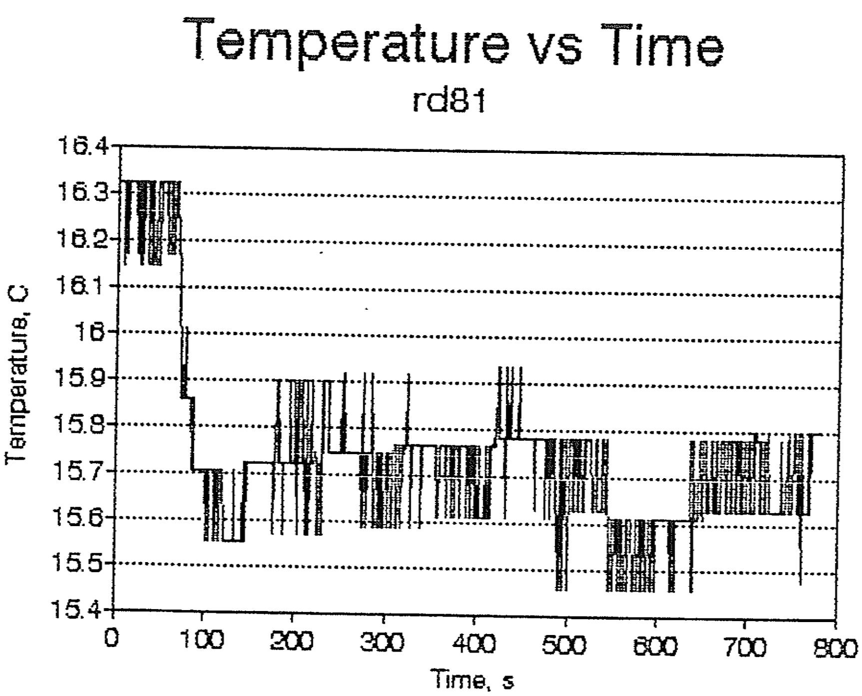
EVALUATION

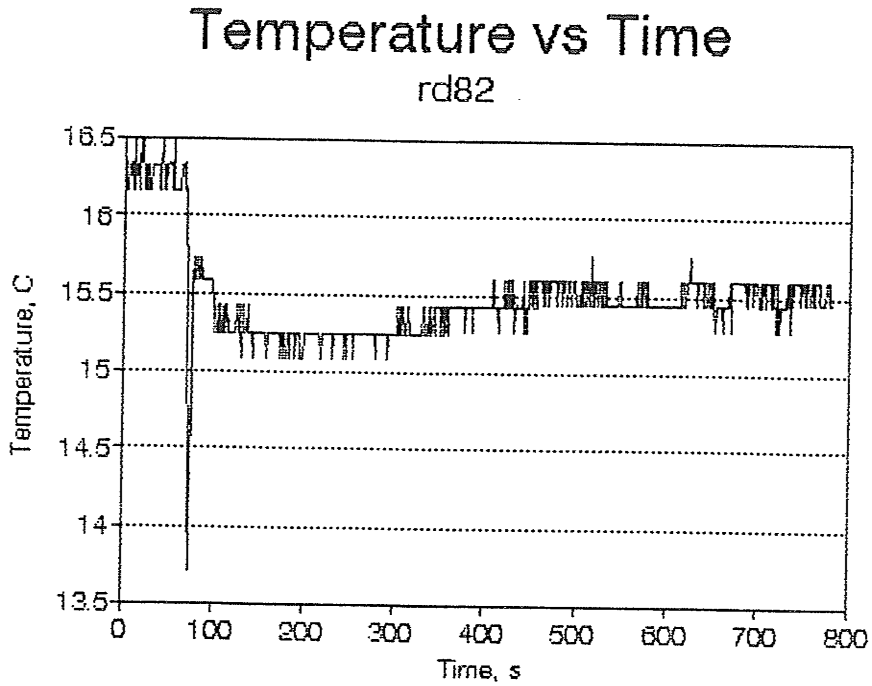
seed in bin	65.1%	
seed thrown out	34.9%	******
seed in bin/chaff	-1.7	
seed/org.mass	ERR	

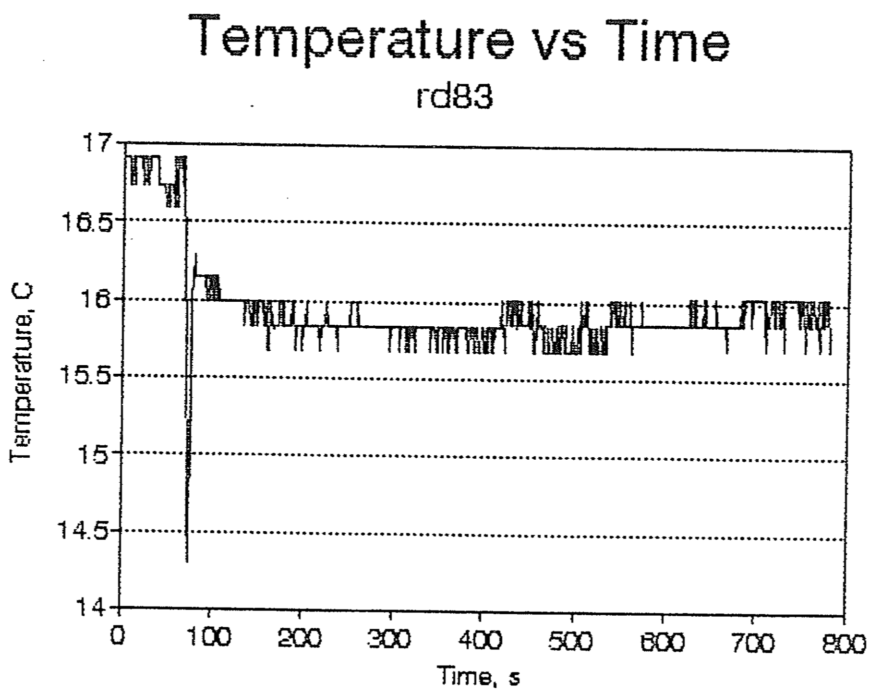

Temperature vs Time
rd32
Temperature, C
22
21.5
21
20.5
20
19.5
19
18.5
18
0
100
200
300
400
500
600
700
800
Time, s

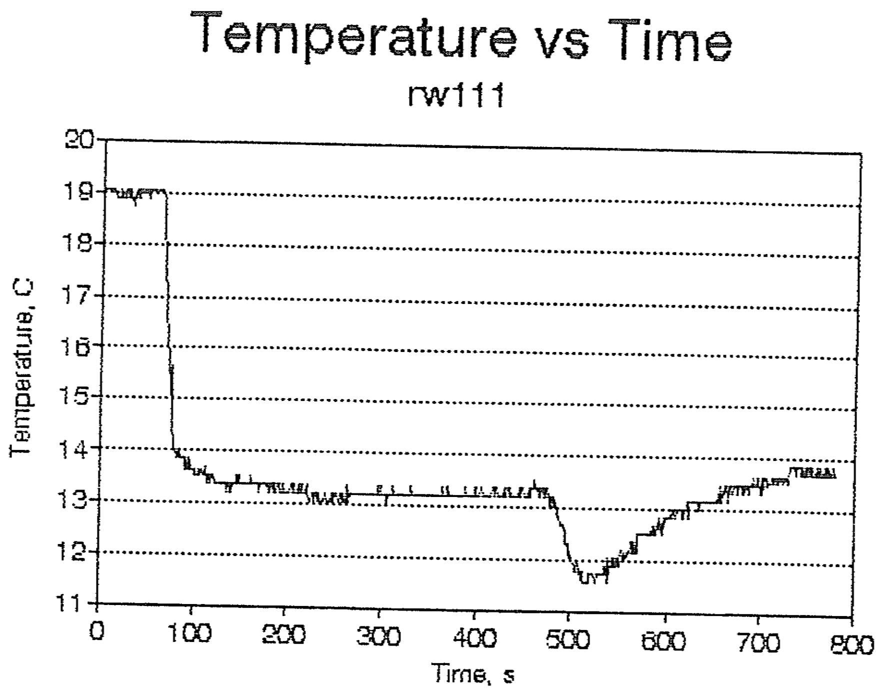

Temperature vs Time
rd33
Temperature, C
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
0
100
200
300
400
500
600
700
800
Time, s

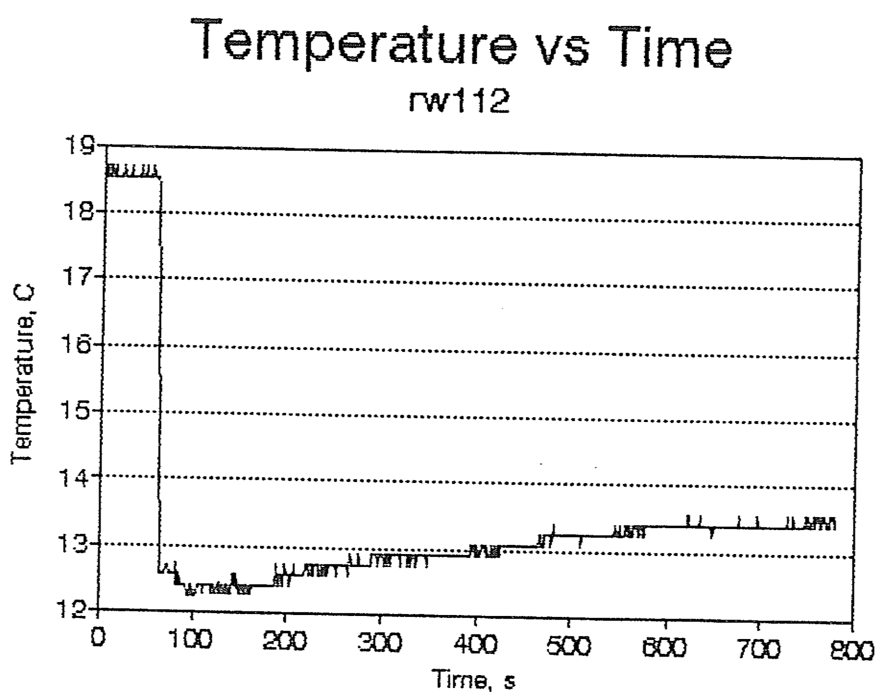

Temperature vs Time
rw33
Temperature, C
24
23
22
21
20
19
18
17
16
15
14
0
100
200
300
400
500
600
700
800
Time, s

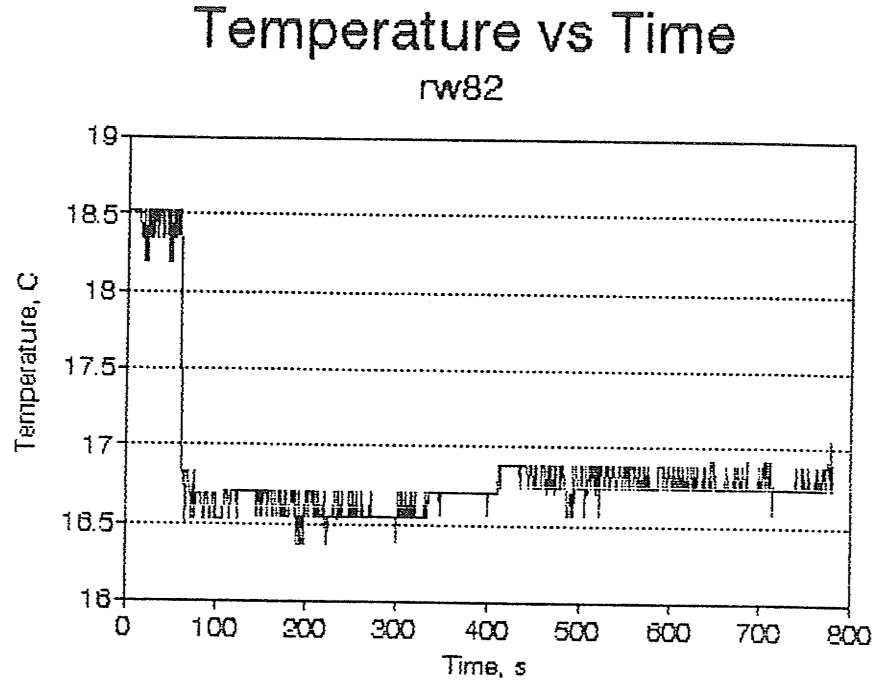

Temperature vs Time
rd81
Temperature, C
16.4
16.3
16.2
16.1
16
15.9
15.8
15.7
15.6
15.5
15.4
0
100
200
300
400
500
600
700
800
Time, s


Temperature vs Time
rd82
Temperature, C
Time, s
16.5
16
15.5
15
14.5
14
13.5
0
100
200
300
400
500
600
700
800

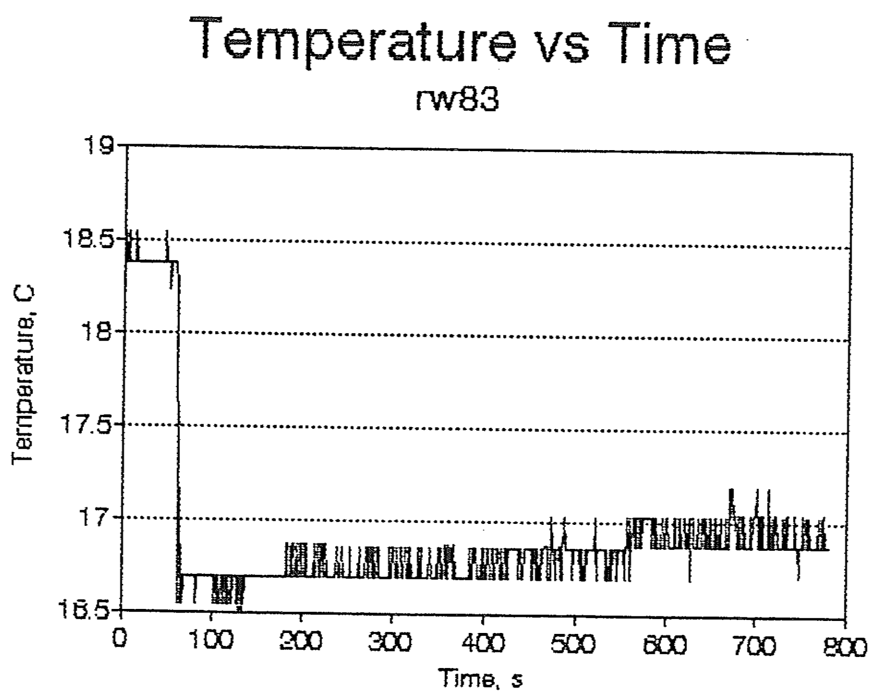

Temperature vs Time
rd83
Temperature, C
Time, s
17
16.5
16
15.5
15
14.5
14
0
100
200
300
400
500
600
700
800


Temperature vs Time
rw111
Temperature, C
20
19
18
17
16
15
14
13
12
11
0
100
200
300
400
500
600
700
800
Time, s

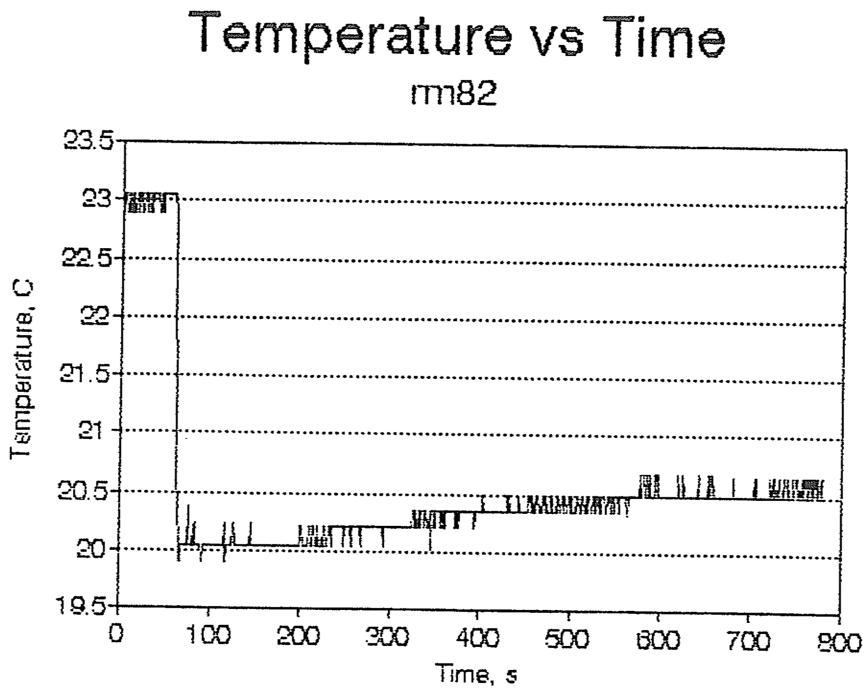

Temperature vs Time
rw112
Temperature, C
19
18
17
16
15
14
13
12
0
100
200
300
400
500
600
700
800
Time, s

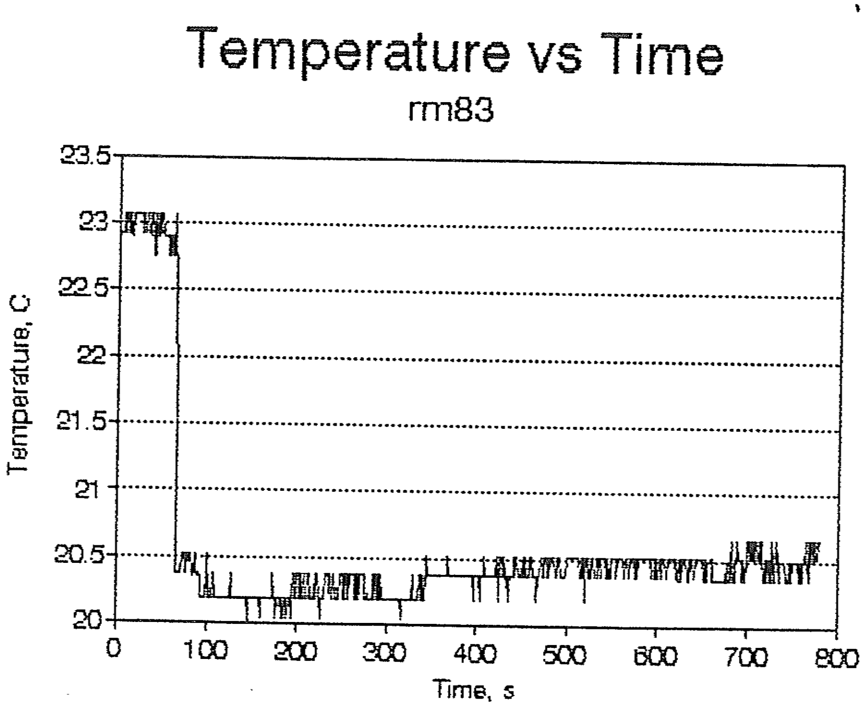


Temperature vs Time
rw82
19
18.5
18
17.5
17
16.5
16
Temperature, C
0
100
200
300
400
500
600
700
800
Time, s



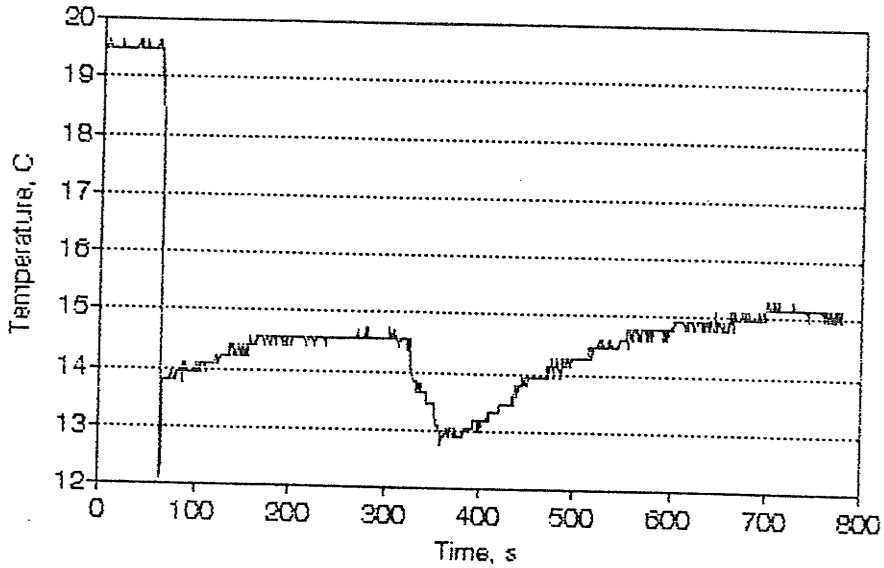
Temperature vs Time
rw83
19
18.5
18
17.5
17
16.5
Temperature, C
0
100
200
300
400
500
600
700
800
Time, s


Temperature vs Time
rm82
Temperature, C
23.5
23
22.5
22
21.5
21
20.5
20
19.5
0
100
200
300
400
500
600
700
800
Time, s


Temperature vs Time
rm83
Temperature, C
23.5
23
22.5
22
21.5
21
20.5
20
0
100
200
300
400
500
600
700
800
Time, s

Temperature vs Time

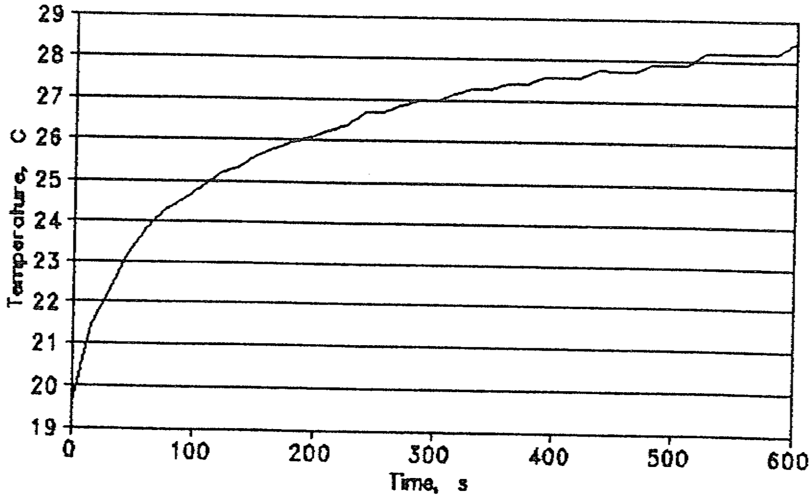
rm113



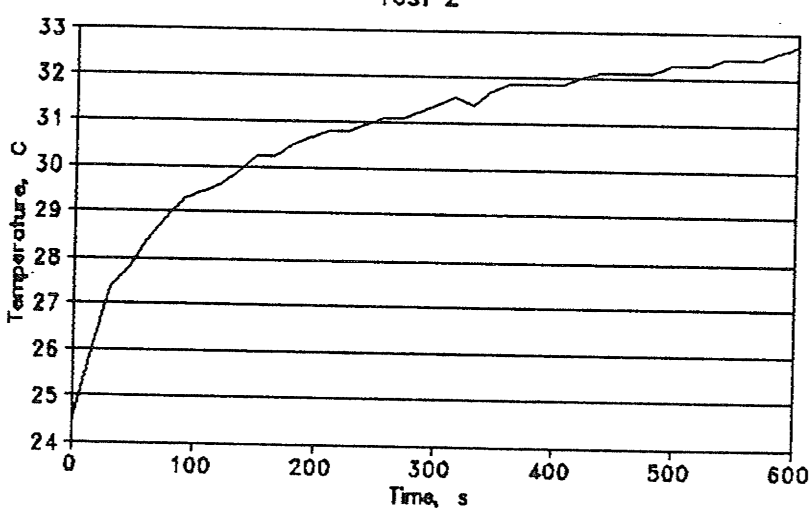
APPENDIX D: Thermal Conductivity Test Data

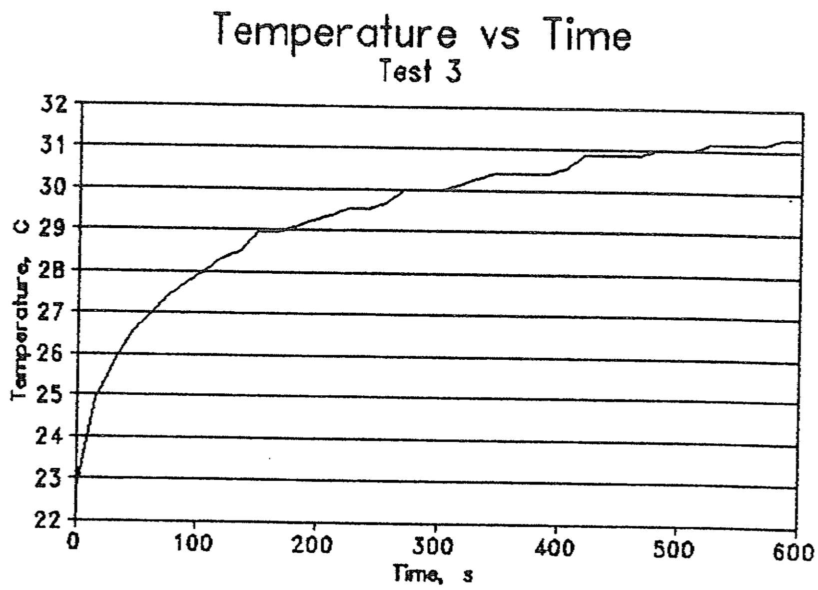
The following graphs display the data collected for the 6 thermal conductivity tests. Tests 1, 2 and 3 are the 8 percent mcwb tests and tests 4, 5 and 6 are the 13 percent tests.

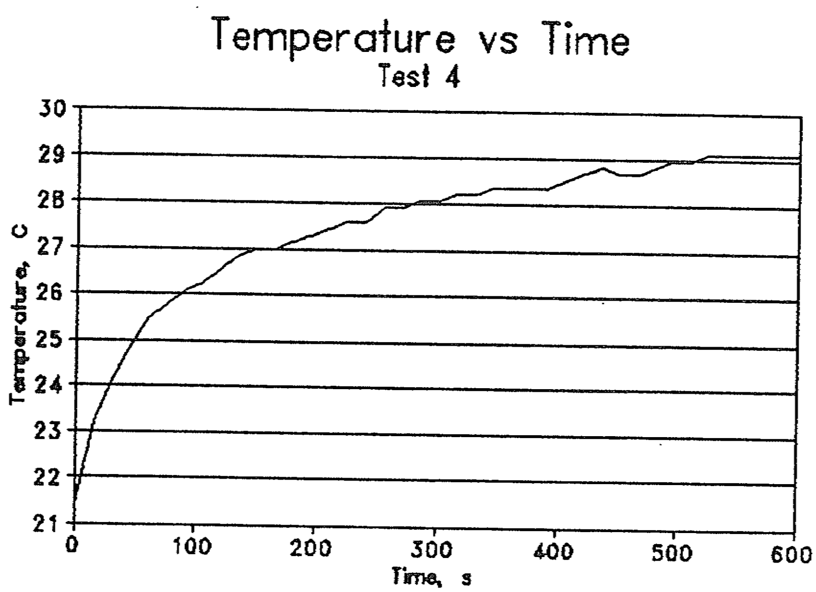
Temperature vs Time
Test 1

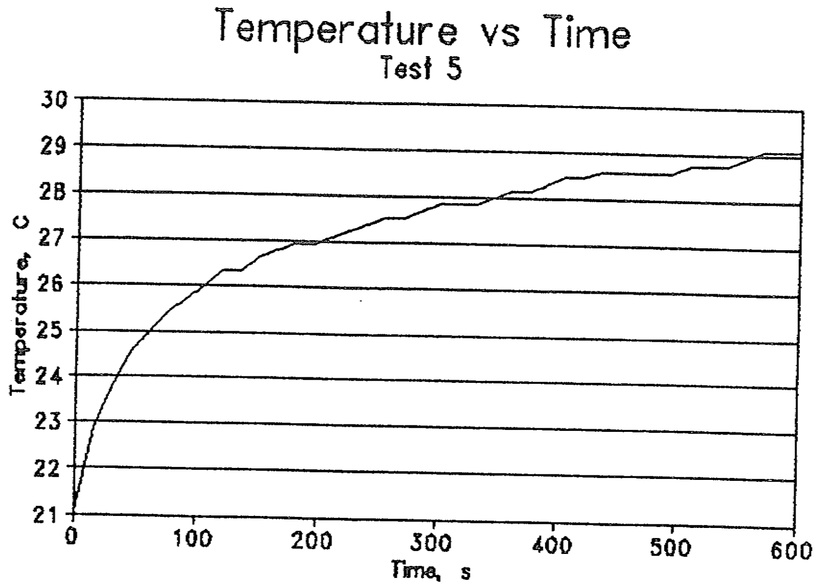


Temperature vs Time
Test 2

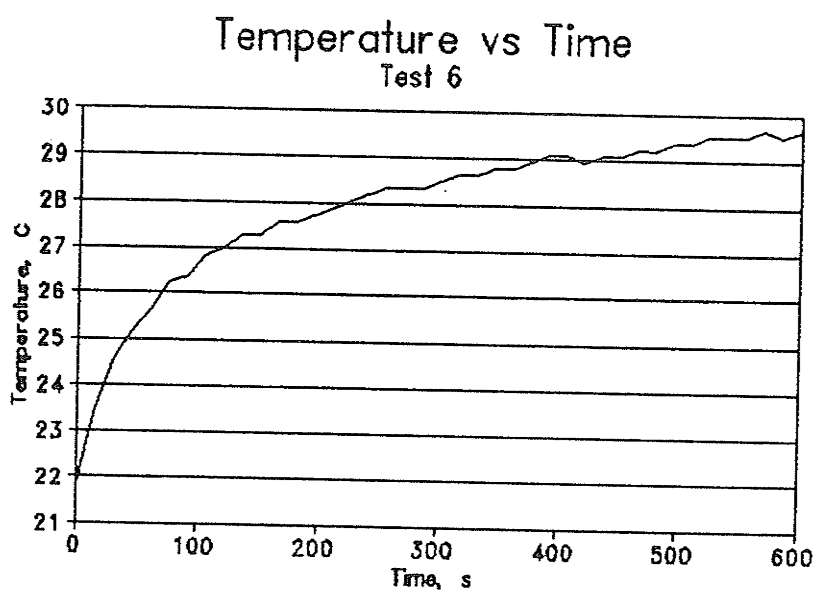



Temperature vs Time
Test 3
32
31
30
29
28
27
26
25
24
23
22
Temperature, C
0
100
200
300
400
500
600
Time, s

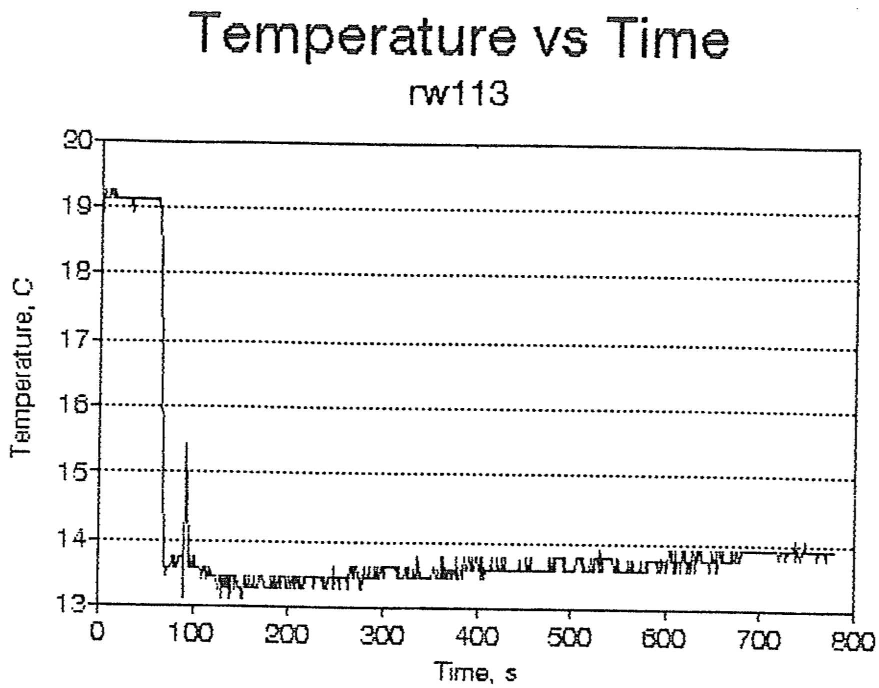

Temperature vs Time
Test 4
30
29
28
27
26
25
24
23
22
21
Temperature, C
0
100
200
300
400
500
600
Time, s

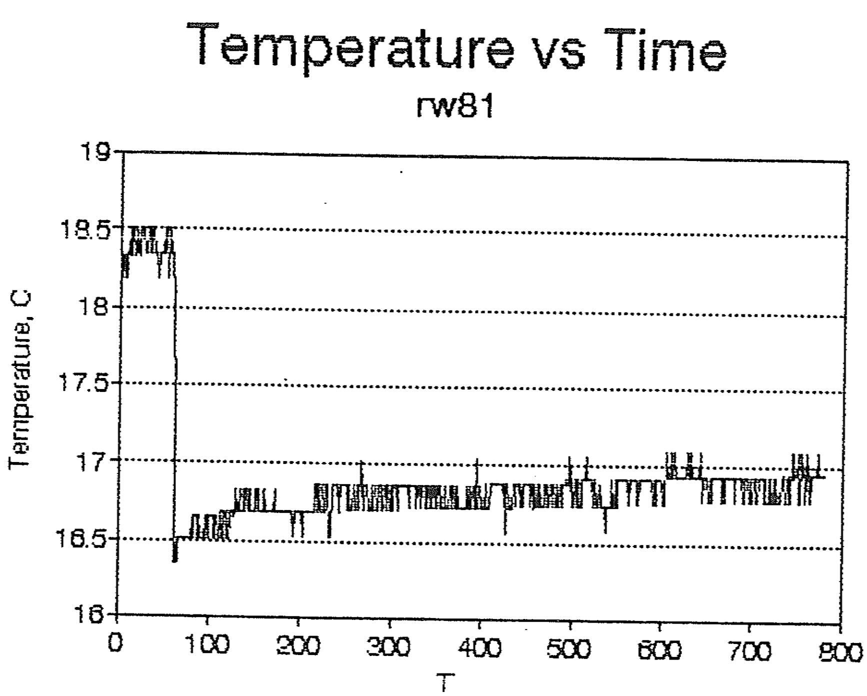


Temperature vs Time
Test 5
30
29
28
27
26
25
24
23
22
21
Temperature, C
0
100
200
300
400
500
600
Time, s



Temperature vs Time
Test 6
30
29
28
27
26
25
24
23
22
21
Temperature, C
0
100
200
300
400
500
600
Time, s


Temperature vs Time
rw113
Temperature, C
Time, s
20
19
18
17
16
15
14
13
0
100
200
300
400
500
600
700
800


Temperature vs Time
rw81
Temperature, C
T
19
18.5
18
17.5
17
16.5
16
0
100
200
300
400
500
600
700
800