STUDIES ON THE DEVELOPMENT OF A SMALL RICE THRESHING AND WINNOWING MACHINE.

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INTRODUCTION.

The Place of Mechanisation in Rice Cultivation.

It is obvious that mechanisation is highly desirable in all forms of agriculture, (Barger, Carleton, McKibben, Bainer, (1952)) and particularly so in swamp rice culture in order to reduce the high man-hour requirement and fatigue, and to facilitate increased production by 'timeliness' of operations, better cultivation, etc. This is especially important where rice is grown on a part time basis, i.e., the peasant works for most of the time on an estate or plantation and cultivates his rice plots in his own time, as is widely practised in Malaya.

Where mechanisation is concerned, however, great difficulties are encountered, both agronomic and economic. The agronomic problems are mostly peculiar to the crop, i.e., for swamp rice, traction, sinkage of vehicles, etc., but these have largely been overcome for relatively large machines, that is tractors of 30 HP or more. Unfortunately, these problems have not yet been overcome completely for the smaller machines, that is, the sort of machine that would prove most useful to the peasant farmer. The economics of the situation prevent the farmer from having large machines of his own, so at first glance, the problem seems insuperable.

In this situation, therefore, alternative systems must be sought. Firstly, there is the place of the contractor who can provide services for cultivation and spraying, etc., using machinery suitable for the local conditions. This also has the advantage that the peasant farmer is not involved in any capital expenditure. Unfortunately, this is not a complete answer, for although the contractor could fulfil cultivation and spraying requirements, he could not help with harvesting as every farmer would want the machinery at the same time. There is also the danger that cultivations would be poorly done, especially in the absence of the farmer.

Another way is to "collectivise" the peasant farmers, and so make possible the use of heavy machinery for cultivation and harvest. Although it is possible to do this in theory, in practice it would be well-nigh impossible to achieve.

Co-operation is another possible answer but this suffers exactly the same drawbacks as the contractor system, insofar as the harvest is concerned.

It seems, therefore, that each of these methods can be ruled out as an answer on some point or other, and so we are again faced with the possibility of developing small machines specially for peasant use. As already mentioned, problems of traction and sinkage were at first very serious, but with the newer types of small two-wheeled tractors being developed it now seems that this problem may be overcome. If this is so, then a range of machinery can be manufactured to be used as attachments to such a power unit, for land preparation, planting, after-cultivation, water control (i.e. pumping), spraying, harvesting and threshing. The mechanisation of each of these sections in this way is faced with tremendous agronomic problems but there seems no reason to believe that they could not be overcome.

Within this framework, therefore, one section which requires investigation is threshing. Hand threshing involves a great deal of time and manual effort e.g., 69.3 man hours per acre for threshing and winnowing in Trinidad (Steer and Benson (1953)).

Most of the research work done to date on the general problem of threshing has been carried out in Malaya, both on commercially produced machines and prototypes. One standard machine that was tried initially was the Tullos hand powered threshing machine (Allen and Haynes 1953). Although producing a satisfactory threshed sample, the machine was unfortunately not received favourably by the peasant farmers, due to the hard work required to turn the handle. An engine was subsequently fitted, but no further reports on later trials have been published.

Ashby (1949) produced a simple mechanism designed expressly for threshing peasant rice. This machine (a simple peg drum similar to the type designed by Taylor 1956) was given trials (Allen and Haynes 1953) but again was not successful, due to the lack of any increase in output over hand threshing, with the added costs of running the power unit.

Several simple rice threshing machines have been produced in Japan for either hand, foot, treadle, or small engine power, but no information can be obtained on them, except for some eye-witness reports. From these reports it seems that the hand or foot powered models are disliked because of the energy input required, and the engine powered models are too expensive to operate due to the "wastage" of the small motor for the greater part of the year.

Work was also started in Trinidad on the problem of threshing, as part of a complete programme of research into rice production in the West Indies, involving cultivation problems, herbicides, varietal trials, and harvesting.

Early work was carried out using the Howard 'Gem' Rotary Hoe as a power unit, (Taylor 1956, Scott 1957) on the basis that this type of machine would fulfil the requirements of a general power unit for small scale mechanisation of rice. A partially satisfactory drum was devised, which although producing acceptable threshed padi, did not reduce the man hours per acre sufficiently to be economic, mainly due to the high overheads of the power unit. It was felt that in order to further reduce the man hours required without increasing the high overhead charges of the 'Gem', the threshing machine should winnow as well, and so in order to develop this principle the drum was mounted in a wooden frame, leaving sufficient space below it for a winnowing unit. The machine so constructed was merely intended as a form of test structure, and the preliminary trials carried out by Scott on this machine proved satisfactory, although it was felt that the simple fan devised was not sufficiently powerful to deal with the throughput of the drum.

The following chapters of this report describe the next stages in the development of this machine.

As already stated, the main object of the project series is to devise a small mechanical threshing unit, based on a machine of a type similar to the Howard 'Gem' Rotary Hoe. To be of value, the machine must effectively thresh a sample of a quality at least equal to traditional hand methods, and must furthermore winnow the threshed rice to a standard equal to normal hand winnowing. It must also show a significant saving in man hours per acre of threshed rice and must be designed as simply as possible with the minimum of moving parts, and maximum utilisation of cheap materials.

The objects of the work reported in this paper are:-

1) To test the drum made by Taylor and Scott, and determine the best speed of operation, and

2) to devise a suitable sieving and winnowing action to be used in conjunction with the drum.

The two problems are inter-related, as a clean sample from the drum simplifies the winnowing problem, but they are most simply handled separately, at least in the first instance, and so work on 1) and 2) above is reported in Parts I and II respectively. The work was done as a joint investigation, and a second report has been produced by Jabati (1959).

PART I

THE THRESHING UNIT.

MODIFICATIONS.

The machine as found consisted of the drum mounted in its wooden frame, and one or two parts of the original fan as used by Scott.

The most satisfactory power unit available was a 3-phase 220 volt, 1.4HP electric motor which was removed from a derelict air-conditioning unit. In a test machine, the advantages of this form of drive compared with an engine are threefold:-

a) The drive speed is relatively constant, regardless of load;

b) the motor can be stopped and started easily, hence a clutch mechanism could be dispensed with;

c) the motor is compact, which permits direct mounting on a foundation frame which would also carry the threshing machine.

The disadvantage of the electric motor drive was as follows:-

All rice used in the trials would have to be cut and transported to Old Farm, in order to keep the machine near to a source of power. This would entail possible losses through vibration in transport and extra handling, and extra work to everybody concerned.

It was considered that the advantages far outweighed this disadvantage, and the electric motor was selected.

From the trials carried out previously by Scott, the speed range that seemed to give best results was from about 100 RPM up to 400 RPM. From this it was decided to use three speeds of approximately 150, 300 and 450 RPM in the trial. As the motor speed was 1710 RPM considerable reduction is required even for the highest test speed. The use of a V-pulley and belt system was initially considered, but rejected because expensive pulleys would have to be used, and control of belt tension also offered problems. Chain drives were eliminated on the grounds of cost and complexity, and the possibility of some form of enclosed gear drive was investigated, the main idea being a form of automobile gearbox.

The advantages of such a form of transmission are:-

a) the unit is compact and self supporting, i.e. no alignment of bearings, etc. is necessary;

b) the change speed requirement is automatically catered for.

A Ford 10 gearbox was available and considered suitable. The gear ratios provided were3.071: 1, 1.765:1 and 1.00 : 1, or approximately 3 : 1, 1.75 : 1 and 1 : 1 giving drum speeds of 475, 270 and 158 RPM if a final reduction of 3.6 : 1 was used, obtained by driving from a 2.5" diameter pulley on to a 9" diameter pulley. These speeds were considered sufficiently near to the initially chosen 450, 300 and 150RPM to warrant the use of the gearbox.

A foundation or sub-frame was constructed of 2½" x 1½" pine to carry the threshing machine, drive unit, and fan unit for the winnowing section. Provision was made on the drive unit section to allow the unit to slide laterally in order to faciliate belt tension adjustment of the final drive to the drum.

The motor and gearbox were then mounted on their base plate, and the coupling constructed and fitted (Drawing 2). Wood was used for the central section of this coupling as it was felt that if at any time the starting torque of the motor should be too severe for the gearbox, the wood would split before any damage to the gearbox could occur. A coupling of heavy hydraulic hose was considered, but hose of appropriate strength was not available.

Attention was then given to the problem of fitting pulleys to the output shaft of the gearbox. This shaft was very short (5/8" only protruding) and was in a recess formed by the end plate of the gearbox (Drawing 2). Fortunately, however, the shaft had axially a tapped hole 5/16" BSF to a depth of about 1", and the end of the shaft was splined. A sleeve was then obtained (internally splined to suit the shaft) from another Ford transmission shaft, and was cut to leave 1" protruding from the end of the gearbox shaft after being driven on.

A special M.S. shaft was then made such that a 1" length of one end was a tight fit into the splined sleeve, and the remaining 3" length was turned down to 5/8" diameter to carry the pulleys. A hole was drilled axially right through this shaft so that a long 5/16" BSF bolt could be screwed into the gearbox shaft to hold the two components together. In order to prevent the turned shaft from revolving inside the sleeve, grub screws were fitted to the sleeve. The complete assembly is shown on Drawing 2.

It was calculated from engineering tables (Oberg and Jones, 1948) that one Class A V-belt (½") would just be sufficient to carry the full power of the motor (1.4 HP) at the lowest belt linear speed envisaged (178 ft. per minute over a 2.5" diameter pulley). In order to avoid any breakages and hold-ups during the test runs, it was decided to use twin ½" V-belts rather than one

5/8" belt, as the larger belt would entail the use of larger diameter pulleys, i.e., belt flexibility would be reduced.

Shortly after assembly, the machine was given a short test run in each of the three speeds. In the low and medium speed everything proved quite satisfactory, but at the high speed, the whole machine was subject to extreme vibration due to the lack of balance in the drum. Rough balance was obtained by adding a small weight to the light side, and vibration did not re-occur.

The machine was then set up in a shed adjoining the workshop, from which a power supply cable was run out from the 3-phase, 220 volt generator. The motor was connected straight through a simple three pole switch, this being considered quite sufficient as the motor-generator equipment supplying the power was fully protected by overload relays.

A sheet metal tray was fitted below the drum, and a sheet of galvanised iron fitted at the back of the machine to catch all material that passed through the drum. The hood over the drum, previously left open at one side was temporarily closed in to further reduce any possible losses of grain. (See photographs).

After a short test run, the machine was considered ready for trials.

THE FIRST TRIAL

DESIGN

The design of the experiment was somewhat pre-determined by the equipment used, i.e., sieves available, basic machine characteristics, etc. For example, for a complete analysis of optimum drum speed, effective tooth length, shape and spacing should also be varied. As time and resources were strictly limited these factors have had to be ignored and what was thought to be the more important basic variables of drum speed, time, and variety of rice used only.

The machine was tested by threshing bundles of rice of known weight for varying periods of time, these periods being governed by stop watch. The longest period of threshing was selected by determining the time required to completely remove the grain from a known weight of rice by beating in the traditional manner. Shorter periods of threshing represented $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ of this basic time.

As already explained, drum speeds were governed by the design of the test unit, and were theoretically 475, 270 and 158 RPM.

Results were assessed on the basis of quality and rate of work. The latter presents no problems, but quality can only be arbitrarily defined, and in this case was assessed on the basis of passage of the threshed material through a sieve. This gave an estimate of the grain that would be retained as unthreshed heads, etc., in the machine in its final form. In addition, the grain left on the threshed straw was measured, as a further criterion of quality. Finally, the material that passed through the sieve was assessed for purity. Thus, the test consisted of threshing twelve bundles of rice, one for each drum speed/time combination.

The moisture content of the samples was also taken, and the actual speed of the drum read by means of a tachometer during the tests. The size of the bundle of rice used for each determination was governed by the maximum that the operator could comfortably hold in both hands, and this was decided at the time of the tests, together with the maximum time value to be used (from the results of the hand threshing trial).

Thus the hand threshing trial was arranged to find:-

a) rate of work of one man;

b) proportion of time spent threshing, and time spent doing other things, i.e. picking up bundles, removing straw, resting, etc. and

c) provide a sample of threshed rice for comparison with the machine threshed samples.

This rice was threshed on the traditional Trinidad slatted table, and both hand and machine tests were of course replicated.

Thus it was considered that a fairly complete picture of the pattern of quality of threshing could be obtained from the data, and this data could be analysed statistically by the arrangement of the treatments, i.e., speed, time, (and their interaction) and the provision of replication.

METHOD

The first trial took place at Old Farm on 10th December, 1958, the variety of rice used being Joya.

Arrangements were made to have a small area of rice from the experimental plots of New Farm cut and transported immediately to Old Farm on the morning of the trial. The rice was not cut, however, until all thedew had evaporated, and care was taken in the loading of the rice on to the trailer to ensure minimum losses of loose grains. On arrival at Old Farm, the rice was used directly from the trailer, again to minimise handling losses.

The hand threshing trial was executed first in order to obtain the information needed for the machine trial.

The slatted table (which had been made specially for this experiment, differing in no way from those used in practice, except that it was slightly smaller, and not so robust) was set up on a tarpaulin spread on the floor, the tarpaulin being carried up round the sides of the table in the form of a screen in order to catch flying grain. Approximately, 50 lbs of unthreshed rice was then weighed out, and placed conveniently near the table, the operator being instructed to thresh out this rice as near as possible to a rate that he could maintain all day long. It was realised, of course,that even after this instruction, the rate of threshing of the sample would be appreciably faster than a daily rate, but it was felt that the machine, if it were to be of value, must at least equal this fast rate, and so no correction was applied.

The time taken for actual beating, and the time occupied byother activities were recorded separately by two watches, and the number of bundles (handfuls) made out of the total quantity recorded also. The weight of threshed rice obtained was noted and the moisture content read. A sample was taken for analysis later.

From this data, the size of bundle to be held in the machine trials, and the maximum time any one bundle could be held on the machine to equal hand threshing rates were determined, and twelve bundles of unthreshed rice of this size (approximately 3 lbs) were made up, taking material from the trailer at random to do this. The machine was then run at low speed (158 RPM), and a quantity of rice threshed to "fill up" odd corners and niches of the machine and to remove rust etc. from the teeth. The bulk of this material was then cleared out and discarded.

The first weighed bundle was then held on the machine for the maximum time allowed (15 seconds T_1) after which the straw was placed in a bag and labelled for removal of any remaining grain later.

The material on the tray was sieved over a ¼" square wire mesh and the sievings and sieved material bagged separately for analysis.

A second bundle was then threshed on the machine for three-quarters of the maximum time (11 seconds T_2) and each component bagged for analysis as above. The threshing was then repeated for periods of seven seconds (T_3) and 4 seconds (T_4) after which the whole procedure was repeated at drum speeds of 270 RPM and 475 RPM.

The whole experiment was then repeated to provide a replicate.

Tachometer readings showed the actual drum speeds to be 138, 250, and 380 RPM at low, medium and high speeds respectively.

For analysis, the straw in the bags was rubbed (in the bag) to remove all grain, the grain then being sieved out from the straw and collected. Similarly the sievings were rubbed out to remove the grain from the unthreshed heads, etc.

The analytical procedure consisted of weighing the collected material, then winnowing from a fixed height over a metal container, the material falling through the draught from a fan set at a fixed distance away. Thus, 'grain' was deemed to be all material falling into the container, and 'non-grain' all material blown away. (Heavy material such as long straw etc., was removed by hand before winnowing) Although this is not an ideal method in theory of separating grain from non-grain, in practice it worked remarkably well, and at least was constant for all samples winnowed.

The winnowed grain was then reweighed and the weights tabulated. In the case of the material passing through the sieve, the sample was 'scored' before winnowing on the basis of quantity of rachis present, no set standard being employed, but merely being a subjective judgement by the author and his colleague. Number 1 denoted a lot of rachis present, number 4 denoted practically none.

RESULTS

From the data collected, a table of results was constructed showing, for each speed/time combination:-

i) The total "losses" of grain (i.e., grain left on straw and grain retained on the sieve) expressed as a percentage of total grain input to the machine, (total grain being the sum of grain left on straw, grain retained on sieve, and grain passing through the sieve).

ii) The grain retained on the sieve as a percentage of the total grain input.

iii) The non-grain in the sieved sample as a percentage of the grain in this sample, i.e. impurities present.

iv) The grain remaining on the threshed straw as a percentage of the total grain input.

These tables, together with the results of the hand threshing (control) tests, will be found in the Appendix.

DISCUSSION.

Statistical analysis of the results showed that no significant differences existed between the replicates of any treatment, consequently values given in the following summarised tables are averages of the two replicates.

i) It can be seen from Table 1 that the total 'losses' of grain, that is including the grain retained on the sieve, are consistently high at about 14%. Statistical analysis shows that there is no significant difference between drum speeds, but a difference does exist between T_4 and T_1, T_4 and T_2, and T_4 and T_3 at the 5% level.

TABLE I

	Threshing Period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Med.	High
	15 secs	11 secs	7 secs	4 secs	138 RPM	250 RPM	380 RPM
Total grain Losses as % of Total grain	12.6	13.3	12.5	17.6	15.4	14.2	12.5

ii) On examination of Table 2, it will be found that the amount of grain retained on the sieve is also consistently high at about 9 - 10% i.e. whole unthreshed heads and broken lengths of rachis. Statistically, there are no significant differences within any of the treatments in this section. Thus, the vast majority of total grain losses referred to in i) above can be attributed to broken lengths of rachis on the sieve.

TABLE 2

	Threshing period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Med	High
	secs 15	secs 11	secs 7	secs 4	138 RPM	250 RPM	380 RPM
Grain retained on sieve as % of Total grain	10.2	9.9	9.4	9.2	9.3	9.9	9.8

iii) From the purity point of view, high speed produced more impurities in the sieved sample than either medium or low speeds (Table 3), but the difference is only statistically significant between the highest and lowest speed. Differences due to times were not significant.

TABLE 3

	Threshing period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Med	High
	secs 15	secs 11	secs 7	secs 4	138 RPM	250 RPM	380 RPM
Impurities as % of sieved grain	5.9	4.9	4.8	4.4	3.9	4.5	6.7

iv) As expected, the longer the rice was left on the drum, the less grain remained on the straw, and although minor anomalies were recorded (Table 4), in general it can be seen that high and medium speeds have sustained less losses than low speed, and times of T_1 T_2 or T_3 are best.

TABLE 4

	Threshing period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Medium	High
	secs 15	secs 11	secs 7	secs 4	138 RPM	250 RPM	380 RPM
Grain left on straw as percentage of total grain	2.3	3.4	3.1	8.2	5.8	4.3	2.7

The moisture content of all samples taken was above 24%, i.e., beyond the scope of the meter used, although to the touch the rice appeared relatively dry. This high moisture content was not thought to have affected the results in any way.

From these results, it can be seen that overall there appears to be no significant difference between any of the treatments except at the extremes of speeds and times; medium speed and times of 7 to 11 seconds (T_2, T_3) appear to be slightly better overall as regards quality of threshing. An outstanding feature brought out by these results was the high proportion of grain retained on the sieve in the form of broken rachis. This led to the conclusion that the combing action of the drum pegs was too harsh, and before carrying out the second trial, an attempt was made to make the action less severe by grinding the pegs to a narrow taper.

THE SECOND TRIAL

DESIGN AND METHOD

The design, and method of conducting the second trial were basically similar to that used in the first, with the following important differences:-

i) The maximum time of threshing by machine was fixed at 15 seconds.

ii) The pegs of the drum were pointed as already described.

iii) The variety of rice used was Dima.

This variety differs widely from the Joya used in the first trial. It is a short stiff-strawed type specially bred for direct seeding and combine harvesting and reputed to be non-shattering. It is of particular interest, therefore, as a variety of potential value in rice systems where the use of machinery is proposed. The sample used was directly sown whereas the Joya used in the first trial was transplanted. This may have some bearing upon the performance of the machine, as the ratio of grain to straw may be less in the directly sown sample.

The observations made, and the method of assessing quality of threshing were the same as in the first trial.

The second trial took place on 7th January, 1959, at Old Farm.

DISCUSSION OF THE SECOND TRIAL.

As in the first trial, no significant differences were found statistically between the replicates, and so values given will again be averages of the two replicates.

i) From Table 5, it can be seen that total grain losses varied more widely than in the first trial, and showed a marked response to both drum speed and time variation. Statistical analysis proves that there is a significant difference between low and medium, and low and high speeds, but not between medium and high. Analysis also shows significant differences between T_4 and T_1, T_4 and T_2, and T_4 and T_3, but no difference between T_1 and T_2 or T_1 and T_3. From this it appears that medium speed (250 RPM) produces the best result, together with times of T_1, T_2, or T_3.

TABLE 5.

	Threshing period				Drum speed		
	T_1 secs 15	T_2 secs 11	T_3 secs 7	T_4 secs 4	Low 138 RPM	Med 250 RPM	High 380 RPM
Total grain losses as % of Total grain	4.7	8.3	8.6	14.4	16.3	4.9	5.8

ii) On examination of Table 6, it will be found that the amount of grain retained on the sieve is much lower than in the first trial. Indeed, the results were quite spectacular, in some cases no unthreshed heads were found at all, and at most 1 - 2% of grain was lost. (No significant differences could be found at all). Unfortunately, however, it cannot be ascertained whether this improvement is due to the sharpening of the drum teeth or to the variety of rice used, but it seems probable that both factors are operative.

TABLE 6

	Threshing period				Drum speed		
	T_1 15 secs	T_2 11 secs	T_3 7 secs	T_4 4 secs	Low 138 RPM	Med 250 RPM	High 380 RPM
Grain retained on sieve as % of total grain.	1.0	0.3	1.8	1.0	0.7	1.0	1.4

iii) The impurities of the sieved sample varied widely with treatment (Table 7). Statistical analysis shows a significant difference between each of the speed groups and also differences between T_1 and T_3, and $T_2$and T_4 at the 5% level, and differences between T_1 and T_4 at the 1% level. Thus is appears here that low speed gave the best results, in combination with a time of T_3or T_4 .This does not coincide with the results obtained in the other sections, i.e., grain losses and it must be emphasized here that the loss factor is considered most important. Therefore, as any subsequent winnowing action can quite easily deal with the relatively high impurity level produced by the medium drum speed, the results in this section are not too important. They do show however , that the winnowing unit subsequently devised will have to deal with a greater volume of material than was at first thought .

TABLE 7

	Threshing Period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Med	High
	15 secs	11 secs	7secs	4 secs	138RPM	250RPM	380RPM
Impurities as percentage of sieved grain	8.7	7.8	5.7	6.0	4.1	6.6	10.5

iv) As in the first trial, the longer the rice was held on the drum, the less grain remained on the straw, and again high and medium speeds have given substantially smaller losses than low speed (Table 8) Thus medium speed and times of T_1, T_2 or T_3 appear to give best results. The losses in this section account for quite a high proportion of the total losses shown in Table 5, as the amount of grain retained on the sieve was relatively small. Consequently, for this variety of rice, it seems particularly important not to under-thresh by removing the rice too quickly from the drum.

TABLE 8

	Threshing period				Drum speed		
	T_1	T_2	T_3	T_4	Low	Med	High
	15secs	11secs	7secs	4secs	138RPM	250RPM	380RPM
Grain left on straw as % of total grain	3.7	8.0	6.8	13.4	15.6	3.9	4.2

From the results of the second trial, it can be seen that the overall pattern is much the same as the first trial, in that extremes of speed and time produce slightly worse results than, say, medium speed and times of 7 to 11 seconds. Moisture content was again high (above 24%) although the rice felt relatively dry.

As already explained, the ~~maximum~~ MINIMUM rate of threshing was chosen such that it approximately equalled hand threshing, using a bundle of 3 lbs as the amount that the operator could comfortably hold. In practice, however, the rate of threshing would be markedly affected by the actual amount the operator could hold, perhaps up to 6 lbs per bundle.

PART II

THE WINNOWING UNIT

OBJECT OF WORK

From the results obtained by Scott (1954)[7] it was obvious that if any significant saving in costs were to be achieved by the use of the threshing machine, then it would have to winnow the threshed rice as well. He did suggest, and build a form of winnowing unit which although proving that such a function could be performed in the same machine, was not particularly successful, due mainly to insufficient blast from the fan.

The object of the work described below was to develop an improved winnowing section.

A satisfactory unit must be capable of winnowing the whole throughput of the drum to a standard at least equal to that of ordinary hand winnowing. The mechanism should contain as few moving parts as possible, be simple and easy to clean with no danger to the operator, and should not be prone to blockage or loss of efficiency through temporary overloading.

In practice, of course, it was extremely difficult to achieve any of these aims, without sacrificing simplicity, and this latter feature was considered most essential, in order to keep within the general terms of reference of the work and to render the machine "peasant-proof".

With this end in view, therefore, all the empirical methods tried involved the use of stationary sieves rather than any form of reciprocating grain shoes, with a strong blast of air from a blower unit to remove light material, chaff and dust. The sieve mesh used was not varied, but a standard 3/8" square wire mesh was used throughout.

MODIFICATIONS AND TESTING.

Very little modification was necessary to the machine to enable this part of the work to be carried through. A blower unit with a small driving motor mounted together on a sub-frame was already available from a scrap air conditioning unit and this was placed on the foundation frame of the whole machine, such that the blast of air was directed under the drum, the exact angle of blast being variable by tilting the fan frame. The temporary galvanised iron sheeting, and collecting tray fitted for the drum trials were removed, and in order to confine the air blast to a more or less straight path, a short length of ducting was constructed to fit over the outlet of the fan casing, extending over the fan motor (See photographs and Drawing 1).

DESIGN AND METHOD.

Limitations to time and rice available for threshing prevented formal testing of the machine.

After one or two attempts using the sieves in a horizontal position, it was obvious that this method was not suitable as the fan blast just blew a mixture of straw and grain out of the machine, with no separation, even when the blast was reduced to such a point that the sieves blocked up.

The main sieve was then placed in the machine at an angle of about 40° with the air blast directed against the under side. On threshing a small sample it was found that although the sieve effectively separated grain and straw, etc, inside the machine, the grain was blown along under the sieve, and the straw over the sieve until they were mixed again outside the machine. However, it was felt that this would be a good basis for separation, provided the problem of mixing outside the machine could be solved.

Two methods were tried in order to overcome this. One consisted of fixing a second extension sieve outside the machine (as in Drawing 3) in order to catch straw, rachis, etc., and allow the grain to be blown out into a box at the base of the sieve, the chaff being blown out over the edge of the box. The second consisted of placing the extension sieve so that it continued in the same plane as the main sieve down to the ground. On trial, however, it was found that some grain was blown back up through this sieve into the straw etc, and so the idea was laid aside in favour of the first method, although it is felt by the author that this method is worthy of further consideration.

The sieve arrangement as outlined above was then given a rough trial, by threshing a quantity of rice through the drum and winnowing unit, the drum being run at the optimum speed and times determined in the drum trials, i.e., 250 RPM and threshing periods of 7-11 seconds. The grain produced was weighed, as was the material on the sieve and chaff blown out, and an analysis identical to that used in the drum trials was then made of each fraction, and the results tabled. The timetaken to thresh each sample was noted in order to get some estimate of the rate of work of the complete unit. Finally, the rate of air flow was measured with an anemometer, the mean value of nine readings being taken at the end of the blower outlet duct.

It should be carefully noted that although two operators were used in these tests, one threshing, the other clearing the extension sieve, it was found that the second operator was completely unnecessary, as the one man threshing could quite easily cope with clearing the sieves,which was required about once every 10-12 minutes the job taking about 1 - 1½ minutes. Consequently, the rate of work per man hour as assessed from the following results, is rather low, and can be raised by at least half as much again, if the second man is dispensed with. This point will be discussed more fully in the conclusions.

RESULTS AND DISCUSSION OF WINNOWING TESTS.

It must be pointed out that the Joya rice used in these tests was stored in the heap for thirty-six days at an initial moisture content of over 24%, consequently the condition was very poor, the straw particularly starting to rot badly. The figures obtained for sieve losses, therefore, i.e. unthreshed heads, are very high. Normally, of course, rice would not be threshed in this condition and so the results should not be examined too critically; the rice was used simply to see how the machine would cope with such very bad conditions. It must be reported that, in general, the machine handled the rice very well, but the sieves blocked very quickly, and it was estimated that if any quantity of this rice had been put through, stops would have had to be made every 2 - 3 minutes to clear the sieves. The final purity of the threshed rice was, however, over 90%(Table 9) but 16% of the total rice was in the form of broken heads on the sieves which had to be ribbed out separately and would have considerably reduced the rate of work if any quantity had been threshed.

The hand threshing controls of PartI drum trials were used as a comparison for rate of work, but this rice was then in good condition, and the time was for threshing only.

TABLE 9

Joya (condition very bad)	Rate of work lbs/man hr.	Grain retained on sieve %	Grain lost in chaff %	Purity of sample %
Machine threshed and winnowed	116	16.4	0.3	92.7
Hand threshed control. (From Part I drum trials)	155	(Threshing only. Rice in good condition).		
Hand threshing of 36 day old rice.	80	(Threshing only, rice in bad condition) Estimated result, from an unrecorded trial.		

For Dima, however, which was only stored a few days, the results were very promising (Table 10). Only 0.5% of the grain was lost in the chaff, and even this grain was light and of doubtful value. 2.0% of the total grain was retained on the sieves, this grain not being lost, as it was collected to be rubbed out by hand.

TABLE 10.

Dima (Condition good)	Rate of work lbs/man hr.	Grain retained on sieve %	Grain lost in chaff %	Purity of sample %
Machine threshed and winnowed.	58.5	1.9	0.5	97.3
Hand threshed control (From Part I drum trials)	101	(Threshing only)		

No attempt was made to vary the force of the air blast during these tests, the full output of the blower was used the whole time.

In all, the winnowing unit was considered to produce a sample at least equal to that produced by hand threshing and winnowing with the Dima variety, the Joya being in such poor condition that any judgement on this issue would not be conclusive.

The full results of these tests will be found in the Appendix.

CONCLUSIONS.

The ability of the machine to thresh and winnow rice to a standard at least equal to traditional hand work was proved by the full trials on the drum, and the brief trials on the winnowing section. Needless to say, it is not claimed that the particular winnowing technique used is the best possible, much more exhaustive work is necessary to prove or disprove this, but the method does give satisfactory results, and has the great virtue that only one moving part is involved, the fan rotor.

The optimum drum speed seems to be about 250 RPM on a 12" diameter drum, (or peripheral speed of 785 ft/min) and the optimum length of time that the straw should be held on the machine to ensure maximum rate of threshing with minimum losses 7 - 11 seconds. This conclusion was verified by statistical analysis of the results of the main trials.

No work was done on varieties other than Joya and Dima, consequently it cannot be said that this speed/time relationship holds for all rice.

The rate of work of the machine was entirely satisfactory with Dima rice; with reference to the winnowing trial results, the rate of work was 58.5 lbs per man hour of winnowed rice, when operating with two men, one virtually idle and unnecessary. An unrecorded short test showed that only 1 - 1½ minutes in ten was lost if the threshing operator was also made to clear the sieves, thus if the output per man hour is increased by a conservative 50%, the rate of work of the machine should be about 87 lbs per man hour. On examination of the hand threshing (control) test results, it can be seen that the output is only 100 lbs per man hour of unwinnowed rice. If it is assumed that a further ½ man hour is necessary to winnow this rice, (Steer and Benson, 1953), the overall output is about 66 lbs per man hour. Thus the saving in labour seems significant, but of course this could only be proved or disproved in an actual field trial under peasant working conditions.

Another method of working that was tried but not recorded, was two men both threshing on the machine, one picking up his bundle whilst the other was actually threshing and vice versa, thus 'filling in' the periods when the machine ran empty. The routine worked quite well, the machine being run loaded for a much greater proportion of the total time. With this method one operator had to clear the sieves about every five minutes, whilst the other continued threshing. It is suggested that in any future work on the machine this system should be adopted as standard practice.

Thus, from this work and that preceeding it by Scott and Taylor, it is concluded that sufficient data has been accumulated to build a small threshing mechanism consisting basically of a toothed drum revolving in bearings on a simple frame, with a form of winnowing unit mounted below the drum, but that the data obtained on the winnowing principle described is far from complete.

SUGGESTIONS FOR FUTURE WORK.

It is suggested that a modified machine be built as in Drawing 3, which can then be given a long field trial under peasant conditions, and alongside traditional hand threshing methods in order to accurately determine the rate of work, and the increase over hand threshing. It would be difficult to estimate any costings, as depreciation, etc., would be very hard to guess, but some attempt to evaluate the economics of the machine should be made. It is suggested that two operators should be used both threshing, as outlined earlier, one or the other clearing the sieves as necessary, placing the sievings in a bag for rubbing out.

The extension sieve should be fitted with two simple handles, in order that the clearing operation can be carried out more quickly; simply by lifting out the sieve and dumping the contents on a tray.

SUMMARY.

A brief outline of the problems of mechanising peasant rice cultivation is given; especially those apertaining to threshing and winnowing.

From trials with a peg drum mounted in a temporary test rig it is shown that the best operation is obtained at a peripheral speed of approximately 780 ft/minute, but it is recognised that further improvement might be achieved by modifications of peg length and shape.

From further limited tests, it is shown that promising results can be obtained by winnowing with an air blast of 2,280 feet/minute used in conjunction with a pair of stationary 3/8" sieves inclined to each other in the form of a wide V, included angle of approximately 100°.

Although further improvements might yet be made it is concluded that sufficient progress has been made to construct a combined threshing and winnowing machine for field testing.

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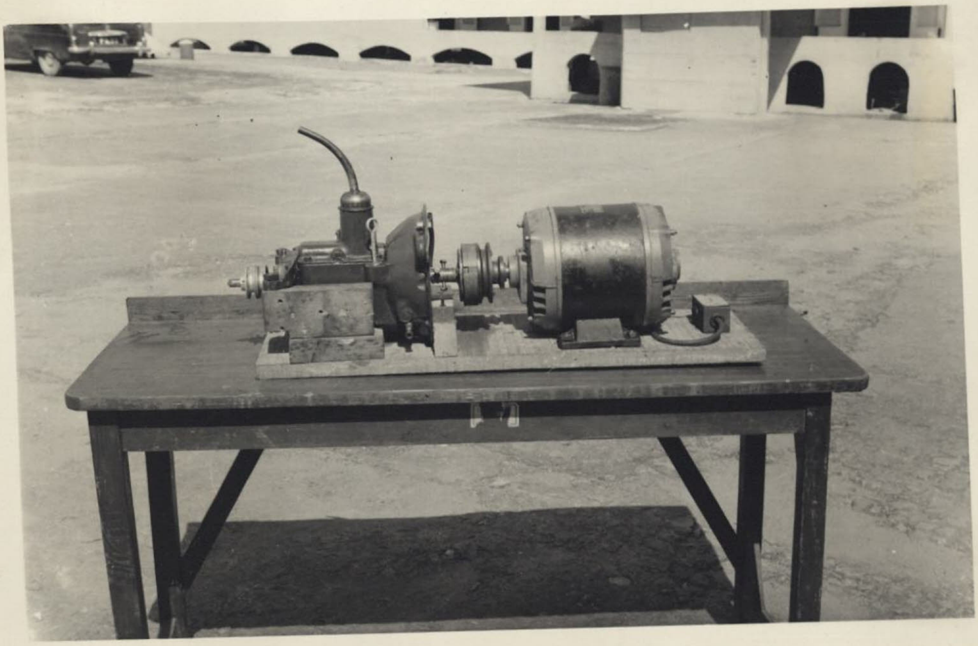
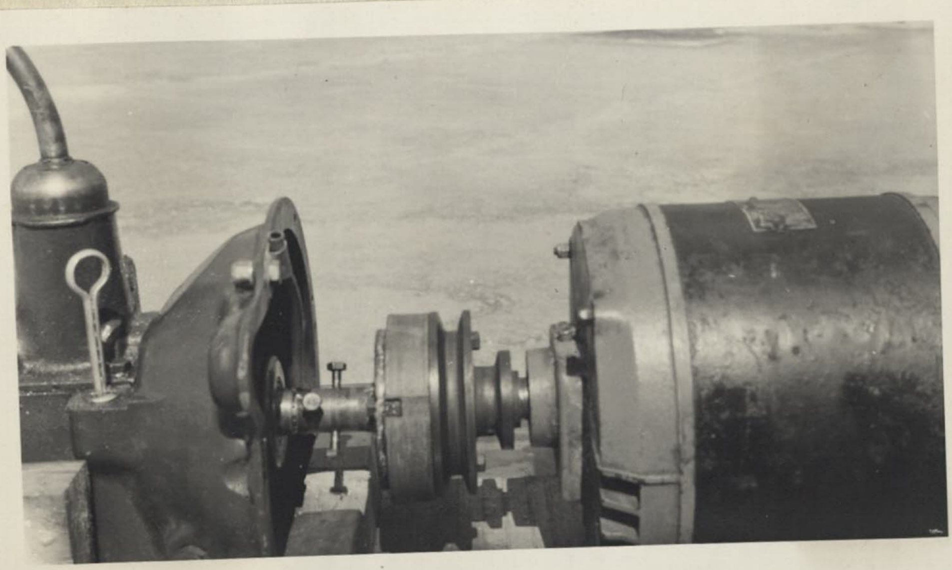
PHOTOGRAPHS

PHOTOGRAPH 1



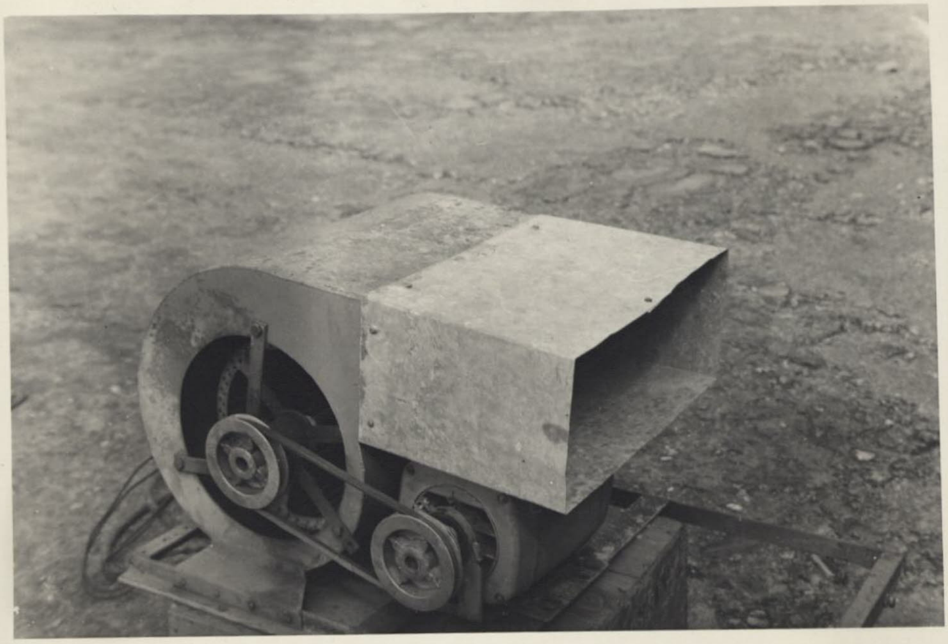
THE DRIVE UNIT ON ITS BASEPLATE.

PHOTOGRAPH 2.



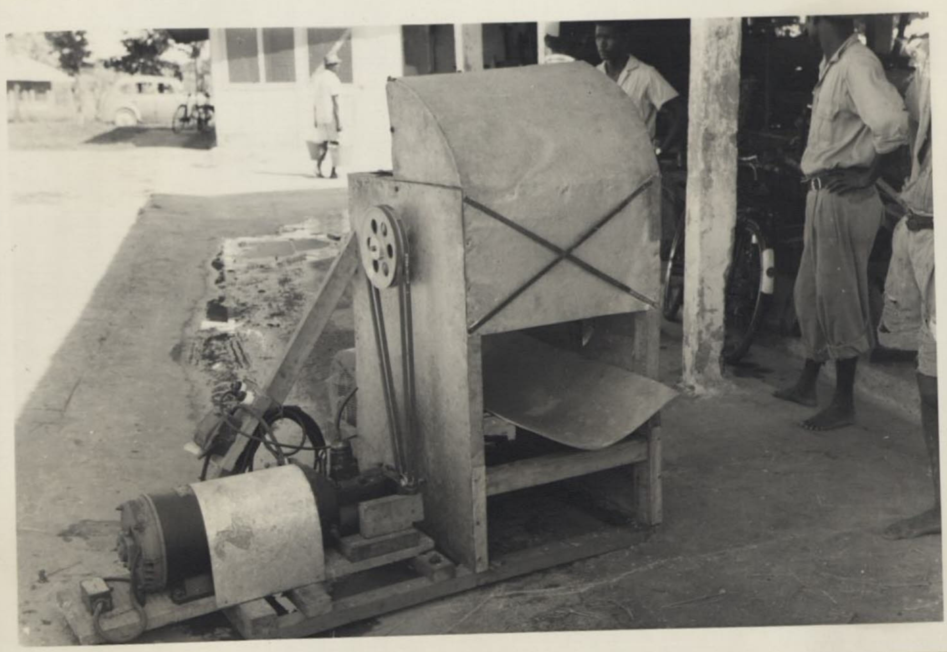
THE COUPLING.

PHOTOGRAPH 3



THE BLOWER UNIT

PHOTOGRAPH 4



THE MACHINE AS USED IN THE TRIALS.

PHOTOGRAPH 5

THE MACHINE AS USED IN THE TRIALS.

RESULTS OF 1st TRIAL (10/12/58)
VARIETY:- JOYA

HAND THRESHING (CONTROL)

REPLICATE 1

Time Threshing Mins.	Time picking up, etc Mins.	Total Time Mins	Wt. used lbs.	Rice produced lbs	% material passing through sieve
4	3	7	52	18.5	Approx 100%

THUS:-

Approx: 5 secs per lb of unthreshed rice required (threshing time only)

Therefore, for 3 lb bundle T_1 = 15 secs (for hand threshing, average bundle held weighed 4.3 lb)

Temperature:- 30°C
Moisture content: 24%

REPLICATE 2

Time Threshing Mins	Time picking up, etc Mins	Total Time Mins.	Wt. used lbs.	Rice produced lbs.	% material passing through sieve
3.75	3.1	6.85	52	17.5	Approx 100%

THUS:-

Approx. 4.3 secs/per lb of unthreshed rice required (threshing time only)

Therefore, for 3 lb bundle T_1 = 12.9 secs (in machine test, T_1 = 15 secs used)(For hand threshing, average bundle held weighed (4.0 lbs))

Temperature :- 30°C
Moisture content: 24%.

RESULTS OF 1st TRIAL (10/12/58)
VARIETY:- JOYA

TOTAL GRAIN LOSSES AS PERCENTAGE OF TOTAL GRAIN

	TIME	SECS	REPLICATE I			REPLICATE 2.			Av.
			Total grain lost ozs	Total grain .ozs	%	Total grain lost .ozs	Total grain .ozs	%	%
Low speed 138 RPM	T_1	15	1.5	14.5	10.4	1.25	11.25	11.1	10.8
	T_2	11	1.75	11.5	15.2	2.0	12.0	16.6	15.9
	T_3	7	1.25	14.25	8.7	1.75	11.25	15.6	12.2
	T_4	4	2.0	9.5	21.0	3.25	13.5	24.0	22.5
Medium speed 250 RPM	T_1	15	1.75	10.75	16.4	1.75	13.75	12.8	14.6
	T_2	11	1.75	11.25	15.6	1.5	14.0	10.7	13.2
	T_3	7	1.75	13.75	12.7	1.75	13.25	13.2	12.9
	T_4	4	2.75	14.25	19.2	1.75	13.5	12.9	16.0
High speed 380 RPM	T_1	15	1.25	9.75	12.8	1.75	14.75	11.9	12.3
	T_2	11	1.25	12.0	10.4	1.5	13.5	11.1	10.8
	T_3	7	0.75	7.25	10.3	2.0	13.75	14.6	12.4
	T_4	4	1.5	12.25	12.3	2.0	12.0	16.6	14.4

GRAIN RETAINED ON SIEVE AS PERCENTAGE OF TOTAL GRAIN

	TIME	SECS	REPLICATE I			REPLICATE 2			Av.
			Grain on sieve ozs	Total grain ozs	%	Grain on sieve ozs	Total grain ozs	%	%
Low speed 138 RPM	T_1	15	1.25	14.5	8.6	1.0	11.25	8.9	8.8
	T_2	11	1.25	11.5	10.9	1.0	12.0	8.3	9.6
	T_3	7	0.75	14.25	5.3	1.25	11.25	11.1	8.2
	T_4	4	0.75	9.5	7.9	1.75	13.5	13.0	10.5
Medium speed 250 RPM	T_1	15	1.25	10.75	11.7	1.25	13.75	9.1	10.4
	T_2	11	1.5	11.25	13.3	1.25	14.0	8.9	11.1
	T_3	7	1.25	13.75	9.1	1.0	13.25	7.6	8.4
	T_4	4	1.75	14.25	12.3	1.0	13.5	7.4	9.8
High speed 380 RPM	T_1	15	1.25	9.75	12.8	1.5	14.75	10.2	11.5
	T_2	11	1.25	12.0	10.4	1.0	13.5	7.4	8.9
	T_3	7	0.75	7.25	10.3	1.75	13.75	12.7	11.5
	T_4	4	1.0	12.25	8.2	0.75	12.0	6.3	7.3

RESULTS OF 1st TRIAL (10/12/58)
VARIETY:- JOYA

	TIME		LOSSES ON STRAW AS PERCENTAGE OF TOTAL GRAIN			NON-GRAIN AS PERCENTAGE OF GRAIN			SCORE	
		SECS	Rep 1 %	Rep 2 %	Av. %	Rep 1 %	Rep 2 %	Av %	Rep 1	Rep 2
Low speed 138RPM	T_1	15	1.7	2.2	1.9	3.8	7.5	5.6	3	2
	T_2	11	4.3	8.3	6.3	2.6	5.0	3.8	1	3
	T_3	7	3.5	4.4	3.9	1.9	2.6	2.2	3	3
	T_4	4	12.8	9.3	11.0	3.3	4.9	4.1	3	3
Medium speed 250RPM	T_1	15	4.6	3.6	4.1	5.6	6.2	5.9	2	3
	T_2	11	2.2	1.8	2.0	2.6	4.0	3.3	2	3
	T_3	7	3.6	5.6	4.6	4.2	4.4	4.3	2	3
	T_4	4	7.0	5.5	6.3	6.5	2.1	4.3	3	3
High speed 380 RPM	T_1	15	-	1.7	0.8	8.8	3.8	6.3	3	2
	T_2	11	-	3.7	1.8	9.3	6.2	7.7	2	3
	T_3	7	-	1.8	0.9	11.6	4.3	7.9	2	3
	T_4	4	4.1	10.4	7.3	4.7	5.0	4.8	3	3
HAND			-	-	-	3.5	3.4	3.4	4	3

Scores:-

1. Large amount of Rachis present
2. Some rachis present
3. Very little rachis present
4. No rachis present

RESULTS OF 2nd TRIAL (7/1/59)
VARIETY:- DIMA

HAND THRESHING (CONTROL)

REPLICATE I

Time Threshing Mins.	Time picking up, etc Mins.	Total Time Mins.	Wt. used lbs.	Rice produced lbs.	% material passing through sieve.
4.4	3.1	7.5	42	11.5	Approx 100%

THUS:-

approx.: 6.3 secs per lb of unthreshed rice required (threshing time only)

Therefore, for 3 lb bundle, T_1 - 18.9 secs
(In machine test, T_1 - 15 secs used)

(For hand threshing, average bundle held weighed 3.5 lbs)

Temperature:- 30.5°C
Moisture content:- 24%

REPLICATE 2

Time Threshing Mins.	Time picking up, etc Mins.	Total Time Mins.	Wt. used lbs.	Rice produced lbs.	% material passing through sieve.
4.5	3.1	7.6	47	14	Approx 100%.

THUS:-

Approx. 5.7 secs per lb of unthreshed rice required (threshing time only)

Therefore, for 3 lb bundle, T_1 - 17.1 secs
(In machine test T_1 - 15 secs used)

(For hand threshing, average bundle held weighed 3.5 lbs)

Temperature:- 30.5°C
Moisture content:- 24%

RESULTS OF 2nd TRIAL (7/1/59)
VARIETY:-DIMA.

			TOTAL GRAIN LOSSES AS PERCENTAGE OF TOTAL GRAIN							GRAIN RETAINED ON SIEVE AS PERCENTAGE OF TOTAL GRAIN						
		TIME	REPLICATE I			REPLICATE 2			Av	REPLICATE I			REPLICATE 2			Av
		SECS	Total grain lost ozs	Total grain ozs	%	Total grain lost ozs	Total grain ozs	%	%	Grain on sieve ozs	Total grain ozs	%	Grain on sieve ozs	Total grain ozs	%	%
Low speed 138 RPM	T_1	15	1.0	12.25	8.2	0.75	13.25	5.7	6.9	0.25	12.25	2.0	-	13.25	-	1.0
	T_2	11	3.0	13.5	22.3	1.0	12.25	8.2	15.2	-	13.5	-	-	12.25	-	-
	T_3	7	2.25	12.0	18.8	1.75	12.5	14.0	16.4	-	12.0	-	0.25	12.5	2.0	1.0
	T_4	4	2.25	8.5	26.5	3.75	14.0	27.0	26.7	-	8.5	-	0.25	14.0	1.8	0.9
Medium speed 250 RPM	T_1	15	0.25	6.0	4.2	0.25	10.5	2.3	3.2	-	6.0	-	-	10.5	-	-
	T_2	11	0.5	11.5	4.4	0.5	13.75	3.6	4.0	-	11.5	-	0.25	17.75	1.8	0.9
	T_3	7	0.75	14.25	5.3	0.5	11.0	4.5	4.9	0.25	14.25	1.8	0.25	11.0	2.3	2.0
	T_4	4	0.5	10.25	4.9	1.25	12.25	10.2	7.5	-	10.25	-	0.25	12.25	2.0	1.0
High speed 380 RPM	T_1	15	0.5	13.5	3.7	0.5	12.25	4.1	3.9	0.25	13.5	1.9	0.25	12.25	2.0	1.9
	T_2	11	0.5	12.75	3.9	0.75	10.0	7.5	5.7	-	12.75	-	-	10.0	-	-
	T_3	7	0.5	12.5	4.0	0.5	9.75	5.1	4.5	0.25	12.5	2.0	0.25	9.75	2.6	2.3
	T_4	4	0.75	8.75	8.6	1.0	10.5	9.5	9.0	-	8.75	-	0.25	10.5	2.4	1.2

RESULTS OF 2nd TRIAL
(7/1/59)
VARIETY:- DIMA

		TIME	LOSSES ON STRAW AS % OF TOTAL GRAIN			NON-GRAIN AS % OF GRAIN			SCORE	
		SECS	Rep.1 %	Rep.2. %	Av %	Rep.1. %	Rep.2 %	Av. %	Rep.1	Rep.2
Low speed 138 RPM	T_1	15	6.2	5.7	5.9	6.7	6.0	6.3	4	3
	T_2	11	22.3	8.2	15.2	4.8	4.5	4.6	4	3
	T_3	7	18.8	12.0	15.4	2.6	2.3	2.4	4	4
	T_4	4	26.5	25.2	25.8	4.0	2.5	3.2	4	4
Medium speed 250 RPM	T_1	15	4.2	2.3	3.3	8.7	4.9	6.8	4	4
	T_2	11	4.4	1.8	3.1	9.1	7.6	8.3	3	4
	T_3	7	3.5	2.2	2.8	5.6	4.8	5.1	4	4
	T_4	4	4.9	8.2	6.6	5.1	6.8	6.0	3	3
High Speed 380 RPM	T_1	15	1.8	2.1	1.9	11.5	14.8	13.1	3	3
	T_2	11	3.9	7.5	5.7	10.2	10.8	10.5	3	4
	T_3	7	2.0	2.5	2.3	8.4	10.8	9.6	4	3
	T_4	4	8. 6	7.1	7.8	9.5	7.9	8.7	3	3
Hand			-	-	-	2.8	5.7	4.2	4	4

Score:-

1 Large amount of rachis present.

2 Some rachis present.

3 Very little rachis present.

4 No Rachis present.

RESULTS OF WINNOWING TRIALS (9/1/59)

VARIETY:- DIMA (3 days after cutting)

(condition good)

		Rate of work												
		Time	Wt of Rice	Wt of Rice per hr	Wt of Rice Man/hr	Grain off sieve	Total grain	Grain retained on sieve	Grain in chaff	Total grain	Grain lost in chaff	Grain	Non-grain	Purity of sample
		Mins	lbs	lbs	lbs	ozs	ozs	%	ozs	ozs	%	ozs	ozs	%
Machine threshed and winnowed.	Rep.1	11.0	23.5	128	64	9.8	385	2.5	1.5	385	0.4	6.5	.25	96.2
	Rep.2	15.0	26.5	106	53	6.5	450	1.4	2.5	450	0.5	16	.25	98.5
	Av.			117	58.5			1.9			0.5			97.3
Hand threshed controls (from Part I drum trials)	Rep.1	7.5	11.5	92	92									
	Rep.2	7.6	14.0	111	111									
	Av.			101	101	(Threshing only)								

Air flow:-(Average of nine readings) 2279 ft/min At blower outlet

RESULTS OF WINNOWING TRIALS (9/1/59)
VARIETY:- JOYA. (36 days after cutting)
(Condition very bad)

		Rate of Work TIME (mins)	Wt of Rice (lbs)	Wt of Rice per hr. (lbs)	Wt. rice per man/hr (lbs)	Grain off sieve (ozs)	Total grain (ozs)	Grain retained on sieve (%)	Grain in chaff (ozs)	Total grain (ozs)	Grain lost in chaff (%)	Grain (ozs)	Non-grain (ozs)	Purity of sample (%)
Machine threshed and winnowed	Rep.1	4.5	11.0	147	73	32.0	209.0	15.3	0.8	209.0	0.3	6.3	0.8	89.0
	Rep.2	2.3	12.0	320	160	40.8	233.0	17.5	0.5	233.0	0.2	7.5	0.3	96.5
	Average			233	116			16.4			0.3			92.7
Hand threshed controls (From Part I drum trials).	Rep.1	7	18.5	158	158									
	Rep.2	6.9	17.5	152	152									
	Average			155	155	(Threshing only, rice in good condition)								
Hand threshing, using 36 day old rice.		165	218	80	80	(Threshing only, rice in bad condition) (Time only estimated)								

Air Flow:- (Average of nine readings) 22 79 ft/min at blower outlet.

STATISTICAL ANALYSIS

Transformation of Percentages to Degrees

Transformed data

JOYA

		Total grain lost %		Grain on sieve %		Non-grain as % of grain	
		Rep. 1	Rep. 2	Rep. 1.	Rep.2	Rep. 1	Rep.2
Low	T_1	19.0	19.5	16.8	17.1	11.2	15.7
	T_2	23.0	24.0	19.3	16.6	9.3	12.8
	T_3	16.9	23.2	13.2	19.5	7.9	9.3
	T_4	27.3	29.3	16.2	21.1	10.4	12.6
Med	T_1	23.9	20.9	20.0	17.2	13.6	14.3
	T_2	23.2	19.1	21.3	17.1	9.3	11.5
	T_3	20.9	21.3	17.2	15.8	11.8	12.0
	T_4	26.0	20.9	20.6	15.6	14.6	8.3
High	T_1	20.9	20.2	20.9	18.6	17.0	11.2
	T_2	19.0	19.5	18.8	15.6	17.5	14.3
	T_3	19.0	22.4	18.8	20.8	19.6	11.9
	T_4	20.6	24.0	16.4	14.4	12.4	12.8

DIMA

Low	T_1	16.4	13.7	8.1	-	14.9	14.0
	T_2	28.2	16.4	-	-	12.6	12.1
	T_3	25.6	21.4	-	8.1	9.3	8.7
	T_4	31.0	31.3	-	7.7	11.5	9.0
Med	T_1	11.8	8.7	-	-	16.9	12.6
	T_2	12.0	10.8	-	7.7	17.3	15.8
	T_3	13.2	12.1	7.7	8.7	13.6	12.6
	T_4	12.6	18.3	-	8.1	13.0	15.0
High	T_1	11.0	11.6	7.9	8.1	19.4	22.0
	T_2	11.3	15.7	-	-	18.3	18.9
	T_3	11.5	13.0	8.1	9.3	16.6	18.9
	T_4	16.8	17.7	-	8.9	17.7	16.1

FIRST TRIAL. (JOYA)　　　　% TOTAL GRAIN LOST

TOTALS:-

Grand Total:-　　524.0

Replicates:-　　Rep. 1:- 259.7　　Rep. 2 :- 264.3

Speeds (S):-　　Low:- 182.2　　Med:- 176.2　　High:- 165.6

Times (T):-　　T_1:- 124.4　　T_2:-127.8　　T_3:-123.7　　T_4:-148.1

S x T :-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
38.5	47.0	40.1	56.6	44.8	42.3	42.2	46.9	41.1	38.5	41.4	44.6

Correction Factor

$$\frac{(524.0)^2}{24} = 11440.67$$

Sum of squares of:-

Total　　11637.48 - 11440.67 = 195.93

Replicates　　$\frac{137298.58}{12} - 11440.67 = 0.88$

Speeds　　$\frac{91666.64}{8} - 11440.67 = 17.66$

Times　　$\frac{69043.50}{6} - 11440.67 = 66.58$

S x T　　$\left(\frac{23154.18}{2} - 11440.67 \right) - 84.24 = 52.18$

Error　　195.93 - 137.30 = 58.63

	D/F	Sum of squares	S^2	f	5%	1%
Reps	1	0.88	0.88	0.1651	4.84	9.65
S	2	17.66	8.83	1.657	3.98	7.20
T	3	66.58	22.19	4.163	3.59*	6.22
S x T	6	52.18	8.7	1.632	3.09	5.07
Error	11	58.63	5.33			

For times　　5%

Least sig. difference:- $2.201 \sqrt{5.33 \times 6 \times 2}$

$= 17.60$

1%

$3.106 \sqrt{5.33 \times 6 \times 2}$

$= 24.84$

FIRST TRIAL (JOYA) % TOTAL GRAIN LOST

(continued)

	T_1	T_2	T_3	T_4
T_1		3.4	0.7	23.7*
T_2			4.1	20.3*
T_3				24.4*

Therefore, significant differences exist between T_4 T_1

T_4 T_2

T_4 T_3

at 5% level.

FIRST TRIAL (JOYA) % GRAIN ON SIEVE

TOTALS:-

Grand Total:- 428.9

Replicates:- **Rep:1:-** 219.5 **Rep:2:-** 209.4

Speeds (S):- **Low:-** 139.8 **Med:-** 144.8 **High:-** 144.3

Times (T):- T_1:- 110.6 T_2:- 108.7 T_3:- 105.3 T_4:-104.3

S x T:-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
33.9	35.9	32.7	37.3	37.2	38.4	33.0	36.2	39.5	34.4	39.6	30.8

CORRECTION FACTOR:- $\left(\frac{428.9}{24}\right)^2$ = 7664.80

SUM OF SQUARES OF:-

Total 7781.95 - 7664.80 = 117.15

Replicates $\frac{92,028.61}{12}$ - 7664.80 = 4.30

Speeds $\frac{61,333.57}{8}$ - 7664.80 = 1.90

Times $\frac{46,014.63}{6}$ - 7664.80 = 4.31

S x T $\left(\frac{15,416.85}{2} - 7664.80\right)$ - 6.21 = 37.42

Error 117.5 - (4.30 + 1.90 + 4.31 + 37.42) = 69.22

	D/F	Sum of squares	S^2	F
Reps	1	4.30	4.30	.680
Speeds	2	1.90	0.95	.151
Times	3	4.31	1.437	.228
S x T	6	37.42	6.237	.985
Error	11	69.22	6.293	

All non-significant.

FIRST TRIAL (JOYA) NON-GRAIN AS % OF GRAIN

TOTALS:-

Grand Total:- 301.3

Replicates:- Rep. 1:- 154.6 Rep 2:- 146.7

Speeds (S):- Low:- 89.2 Med:- 95.4 High:- 116.7

Times (T):- T_1 83.0 T_2 74.7 T_3 72.5 T_4 71.1

S x T :-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
26.9	22.1	17.2	23.0	27.9	20.8	23.8	22.9	28.2	31.8	31.5	25.2

CORRECTION FACTOR:- $\frac{(301.3)^2}{24}$ = 3782.57

SUM OF SQUARES OF:-

Total 3980.11 - 3782.57 = 197.54

Replicates $\frac{45,422.05}{12}$ - 3782.57 = 2.60

Speeds $\frac{30,676.69}{8}$ -3782.57 = 52.02

Times $\frac{22,780.55}{6}$ -3782.57 = 14.19

S x T $\left(\frac{7772.53}{2} - 3782.57\right)$ - 66.21 = 37.49

Error 197.54 - (2.60 + 52.02 + 14.19 + 37.49) = 91.33

	D/F	Sum of squares.	S^2	f	5%	1%
Reps	1	2.60	2.60	1.140	4.84	9.65
S	2	52.02	25.97	11.39	3.98*	7.20*
T	3	14.19	4.73	2.08	3.59	6.22
S x T	6	37.49	6.25	0.753	3.09	5.07
Error	11	91.33	8.30			

FIRST TRIAL (JOYA) NON-GRAIN AS % OF GRAIN

(continued)

FOR SPEEDS

Least Sig. difference @ 5% $2.201 \sqrt{8.30 \times 8 \times 2} = 25.38$

@ 1% $3.106 \sqrt{8.30 \times 8 \times 2} = 35.81$

	L	M	H
L		6.2	27.5 *
M			21.3
H			

Therefore, a significant difference exists between H and L at 5% level.

SECOND TRIAL (DIMA) % TOTAL GRAIN LOST

TOTALS:-

Grand Total:- 392.1

Replicates:- Rep. 1 201.4 Rep. 2 190.7

Speeds (S):- Low 184.0 Med 99.5 High 108.6

Times (T):- T_1 73.2 T_2 94.4 T_3 96.8 T_4 127.7

S x T :-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
30.1	44.6	47.0	62.3	20.5	22.8	25.3	30.9	22.6	27.0	24.5	34.5

CORRECTION FACTOR :- $\frac{(392.1)^2}{24}$ = 6405.93

SUM OF SQUARES OF:-

Total: 7391.25 - 6405.93 = 985.32

Replicates: $\frac{76,928.45}{12}$ - 6405.93 = 4.77

Speeds: $\frac{55,550.21}{8}$ - 6405.93 = 537.85

Times: $\frac{39,947.13}{6}$ - 6405.93 = 251.93

S x T: $\left(\frac{14,550.71}{2} - 6405.93\right)$ - 789.78 = 79.65

Error: 985.32 - (4.77 + 537.85+ 251.93 + 79.65)= 111.12

	D/F	Sum of squares	S^2	f	5%	1%
Reps	1	4.77	4.77	.4723	4.84	9.65
S	2	537.85	268.93	26.63	3.98*	7.20*
T	3	251.93	83.98	8.315	3.59*	6.22*
S x T	6	79.65	13.28	1.315	3.09	5.07
Error	11	111.12	10.10			

SECOND TRIAL (DIMA) % TOTAL GRAIN LOST

(Continued)

FOR SPEEDS

Least sig. diff. @ 5% $2.201\sqrt{10.10 \times 8 \times 2}$

= 27.97

@ 1%

$3.106\sqrt{10.10 \times 8 \times 2}$

= 39.48

	L	M	H
L		84.5 *	75.4*
M			9.1
H			

Therefore sig. diffs exist between

M and L

H and L

at 1% level

FOR TIMES

Least sig. diff.

@ 5% $2.201\sqrt{10.10 \times 6 \times 2}$

= 24.23

@ 1% $3.106\sqrt{10.10 \times 6 \times 2}$

= 34.19

	T_1	T_2	T_3	T_4
T_1		21.2	23.6	54.5 *
T_2			2.4	33.3 *
T_3				30.9 *
T_4				

Therefore sig. diffs. exist between T_4 T_2 T_4 T_3 at 5% level, and between T_4 T_1 at 1% level.

SECOND TRIAL (DIMA) — % GRAIN ON SIEVE

TOTALS:-

Grand Total:- 98.4

Replicates:- Rep 1 31.8 Rep 2 66.6

Speeds (S):- Low 23.9 Med 32.2 High 42.3

Times (T):- T_1 24.1 T_2 7.7 T_3 41.9 T_4 24.7

S x T:-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
8.1	0.0	8.1	7.7	0.0	7.7	16.4	8.1	16.0	0.0	17.4	8.9

CORRECTION FACTOR:- $\frac{9682.56}{24} = 403.44$

SUM OF SQUARES OF:-

Total: $809.72 - 403.44 = 406.28$

Replicates: $\frac{5446.80}{12} - 403.44 = 50.46$

Speeds: $\frac{3397.34}{8} - 403.44 = 21.23$

Times: $\frac{3005.80}{6} - 403.44 = 97.53$

S x T: $\left\{ \frac{1222.34}{2} - 403.44 \right\} - 118.76 = 88.97$

ERROR: $406.28 - (50.46 + 21.23 + 97.53 + 88.97) = 148.09$

	D/F	Sum of squares	S^2	f
Reps	1	50.46	50.46	3.749
S	2	21.23	10.62	0.789
T	3	97.53	32.51	2.415
S x T	6	88.97	14.83	1.102
Error	11	148.09	13.46	

All non-significant

SECOND TRIAL (DIMA) NON-GRAIN AS % OF GRAIN

TOTALS:-

Grand total:- 356.8

Replicates:- Rep. 1 181.1 Rep. 2 175.7

Speeds (S):- Low 92.1 Med 116.8 High 147.9

Times (T):- T_1 99.8 T_2 95.0 T_3 97.7 T_4 82.3

S x T :-

Low				Med				High			
T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
28.9	24.7	18.0	20.5	29.5	33.1	26.2	28.0	41.4	37.2	35.5	33.8

CORRECTION FACTOR:-

$$\frac{127,306.24}{24} = 5304.43$$

SUMS OF SQUARES OF:-

Total	$5587.36 - 5304.43$	= 282.93
Replicates	$\frac{63,667.70}{12} - 5304.43$	= 1.21
Speeds	$\frac{43,999.06}{8} - 5304.43$	= 195.45
Times	$\frac{32,110.42}{6} - 5304.43$	= 47.31
S x T	$\frac{11,126.34}{2} - 5304.43$	= 15.98
ERROR	$282.93 - (1.21 + 195.45 + 47.31 + 15.98)$	= 22.98

	D/F	Sum of squares	S^2	f	5%	1%
Reps	1	1.21	1.21	0.579	4.84	9.65
S	2	195.45	97.73	46.76	3.98*	7.20*
T	3	47.31	15.77	7.55	3.59*	6.22*
S x T	6	15.98	2.66	1.27	3.09	5.07
Error	11	22.98	2.09			

SECOND TRIAL (DIMA)   NON-GRAIN AS % OF GRAIN

(continued)

FOR SPEEDS

Least sig. diff @ 5% 2.201 $\sqrt{2.09 \times 8 \times 2}$ = 12.73

@ 1% 3.106 $\sqrt{2.09 \times 8 \times 2}$ = 17.96

	L	M	H
L		24.7*	55.8 *
M			31.1 *
H			

Therefore sig. diffs. exist between H and L, H and M, and L and M at 1% level.

FOR TIMES

Least sig. diff. @ 5% 2.201 $\sqrt{2.09 \times 6 \times 2}$ = 11.02

@ 1% 3.106 $\sqrt{2.09 \times 6 \times 2}$ = 15.55

	T_1	T_2	T_3	T_4
T_1		4.8	20.1*	17.5*
T_2			2.7	12.7*
T_3				2.6
T_4				

Therefore, sig. diffs. exist between T_3 and T_1, T_4 and T_1 at 1% level, and between T_3 and T_1, T_4 and T_1 and T_4 and T_2 at 5% level.