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Determination of Biological Maturity and Effect of Harvesting and Drying Conditions on Milling Quality of Paddy

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With recent advances in paddy production and processing technology in India, the practice of early harvesting of paddy coupled with mechanical drying has been introduced. This study was undertaken to determine the biological maturity and variation of moisture content in the grain from 15 days to 45 days after flowering and to evaluate the difference between the milling quality of sun dried and mechanically dried paddy. The results from the study have indicated that for the Jaya variety of paddy during the "*Aman*" (winter) season in West Bengal, the maximum grain yield was obtained by harvesting between 28 to 36 days after flowering, and moisture content of the grain during the period varied from 24 to 22%. No significant difference between the total yield of sun dried and mechanically dried samples was observed within the experimental range. However, the head yield of the samples harvested at relatively higher moisture content and dried mechanically was higher than the sun dried samples. Maximum head yield and total yield of rice was obtained from the samples harvested during the optimum harvest period. This study, therefore, suggests that Jaya paddy should be harvested within 28 to 36 days after flowering in order to obtain maximum grain yield per hectare as well as a grain of superior milling quality and the paddy should preferably be dried by mechanical means for higher head rice yield.

1. Introduction

Maturity of paddy grain is adjudged by the Indian farmer with the appearance of a golden yellow colour of the grains on the panicle of the plant. Therefore, conventionally, paddy is harvested at 17–18% moisture content by the farmers. Ease of threshing and preservation of straw have been the primary concern of the farmers in evolving this practice of harvesting of paddy. Recent investigations[1] have shown that there are considerable shedding losses, losses to birds and insects, and deterioration of milling quality of the paddy harvested by conventional practices. The practice of harvesting the crop immediately after maturity is being advocated by agricultural scientists all over the world. In addition to reducing the losses during harvest, an early harvest of crop from the field saves valuable time for the farmer for field preparation and sowing operations for the next crop, thus increasing the effective utilization of land for crop growth. This is a very important factor in view of the multicropping practice of growing three paddy crops per year.

What is the period of maturity of paddy? How should the crop harvested at high moisture content be dried? What is the effect of harvesting conditions and methods of drying on the quality of paddy? These are a few of the major questions which are often asked regarding the practice of early harvesting. An agro-economic study, to investigate the economic feasibility of harvesting practices and quality of paddy and rice produced, was undertaken at the experimental farm of the Indian Institute of Technology, Kharagpur, for the Jaya variety of paddy during the period August to November, 1973. The specific objectives of this investigation were:

(a) to study the variation of moisture content in paddy grains in relation to the time of harvest, and thus determine a prediction equation for moisture content of paddy grains with respect to date of harvest, i.e. number of days after flowering;

(b) to determine the optimum harvest period for maximum grain yield per unit area;

(c) to evaluate the effect of harvesting time on milling quality of paddy;

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(d) to compare sun drying and mechanical drying methods in relation to milling quality, i.e. total yield and head yield of the paddy.

Milling quality of paddy is the measure of its performance during a standard milling operation. The milling quality is represented by total yield and head yield. The total yield is the amount of polished rice (whole rice+brokens) obtained from a given paddy sample and is expressed in percent weight of the paddy. The head yield is the quantity of whole kernals of milled rice ($\geq \frac{3}{4}$ length of the whole kernal) expressed in percent weight of the paddy.

$$\text{Total yield} = \frac{\text{weight of polished rice (whole rice+brokens)}}{\text{weight of the paddy sample}} \times 100.$$

$$\text{Head yield} = \frac{\text{weight of whole rice}}{\text{weight of the paddy sample}} \times 100.$$

The measurement of milling quality of paddy is important in the rice milling industry and research, because it reflects the varietal character, harvesting conditions and effect of all pre-processing treatments such as drying, parboiling, conditioning etc. given to paddy before milling. In this investigation the milling quality was used for comparing the effectiveness of two drying methods and to determine the effect of harvesting conditions on the quality of paddy.

2. Materials and methods

The Jaya variety of paddy was planted and grown under normal agronomic practices as shown in Appendix A, in a levelled field of 43 m × 43 m size. A record of growth stages of the crop was kept and at the time of flowering the experimental plot was divided into 49 sub-plots of 5 m × 5 m with a 1 m border around each plot as shown in *Fig. 1*. These plots were demarked by harvesting 1 m strips in between the plots at the time of flowering. This layout provided for 16 harvesting treatments with three replications for each treatment, which were randomly denoted in the experimental plots (*Fig. 1*). Paddy was harvested manually from 3 sub-plots on every alternate day starting from 15 days after flowering for a period of 1 month. Harvested paddy from each sub-plot was bundled separately with an identification tag and carried to the threshing yard on the farm, where it was threshed. Grains obtained from each sub-plot were collected separately, weighed and their moisture content was measured by a Universal electronic moisture meter. Each grain sample was then divided into two equal parts. One part of the sample was dried on a cement drying yard in the sun, to 14% m.c. The other half of the sample was dried by hot air in an experimental dryer. The experimental dryer as shown in *Fig. 2* was built of plywood, and had 25 ports to accommodate 4·5 l capacity cylindrical containers with perforated bottoms to hold paddy samples for drying. Air was blown by an electric air blower through an electric heater box (for heating the air) into the dryer. The quantity of air flow into the dryer was controlled by a butterfly-valve at the inlet end of the blower and the temperature of the hot air was controlled by powerstats connected in the circuit of electric heaters in the heater box. Hot air at 45° C was blown through the paddy sample in the containers, and paddy in each container was intermittently mixed thoroughly by hand to get uniform drying of the sample to a moisture content of 14%.

Each dried sample was packed in a moisture proof polyethylene bag with an identification tag, indicating the treatment number, replication number and the method of drying. These samples were then milled in a standard rice grading laboratory consisting of a laboratory McGill sheller, a McGill miller No. 3, a laboratory aspirator, a rice sizing device, a Mettler electronic balance, and a Osaw Universal moisture meter to determine the total yield and head yield of rice.

In order to determine moisture variation during the period of maturity, a small sub-plot of 5 m × 5 m size was marked for this purpose in the experimental layout as shown in *Fig. 1*. Moisture samples from this sub-plot were taken 5 times every day from 8 a.m. to 4 p.m. at intervals

of 2 h starting from 15 days after flowering for a period of one month. The moisture content was measured by the Universal moisture meter. Special care was taken to remove the surface moisture from the grain samples in case of rain or dew formation on the surface. An average of five observations was taken to determine the moisture content of the rice grains on the plant.

Field yield is the amount of paddy produced per hectare measured at a uniform moisture content. Therefore, from the weight of wet paddy harvested at higher moisture content, wet yield of grains per hectare is given by:

$$Y_1 = \frac{W_p}{A} \times 10{,}000 \text{ kg/ha} \qquad \ldots (1)$$

where Y_1 = wet yield paddy, kg/ha;

W_p = weight of paddy harvested from a sub-plot, kg;

A = area of the sub-plot, m^2.

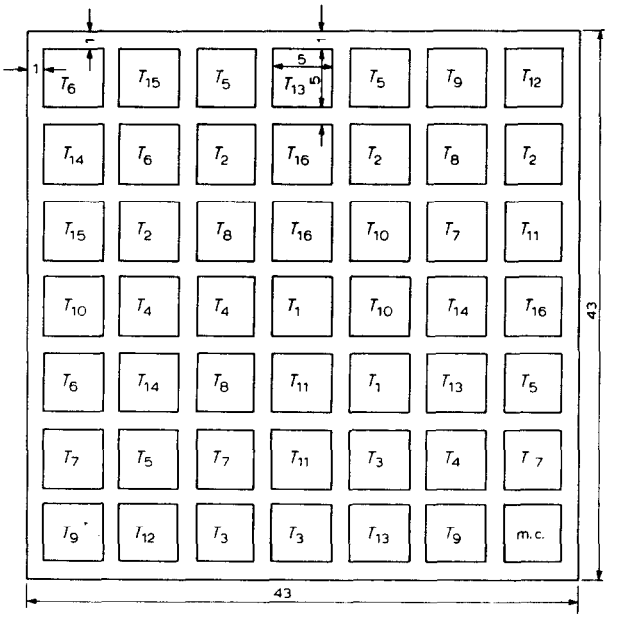

Fig. 1. Plot layout for harvesting and drying studies. All dimensions in metres

The field yield is then calculated from the wet yield by calculating the equivalent weight of the grains at 14% m.c. as follows:

$$Y_2 = \frac{100 - M_1}{100 - M_2} Y_1 \qquad \ldots (2)$$

where Y_1 = wet yield of paddy harvested at moisture content M_1, kg/ha;

Y_2 = field yield of paddy at 14% m.c. (M_2) kg/ha;

M_1 = harvest moisture content on % w.b.;

M_2 = moisture content at which Y_2 is calculated = 14%.

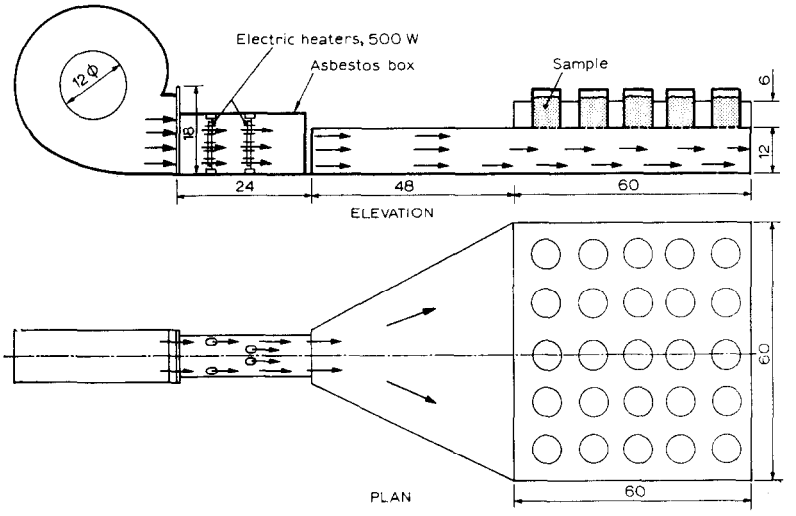

Fig. 2. Experimental model dryer (not to scale). All dimensions in inches

3. Results and discussion

3.1. *Variation of moisture content of paddy grain on the plant stalk during the period of maturity*

Continuous observations of the moisture content of paddy grains during the period of maturity of the crop (i.e. from 16 days to 46 days after flowering) revealed a definite correlation of moisture loss with the days after flowering. The moisture content of Jaya paddy during the "*Aman*" (winter) season reduced linearly with the days after flowering for the period under investigation. Linear regression[2] of the data gave the following prediction equation for moisture content of the paddy with a correlation coefficient of 0·92:

$$M = 32{\cdot}48 - 0{\cdot}32\,N \qquad \ldots (3)$$

where M = moisture content of paddy grain, % w.b. and

N = number of days after flowering.

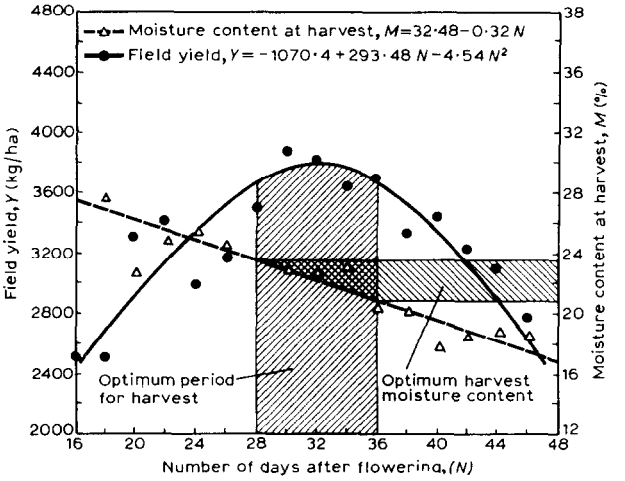

Fig. 3. Effect of date of harvest on moisture content at harvest and field yield

TABLE I

Summary of results of harvesting and drying studies on Jaya variety of paddy. Date of flowering: 10 October 1972

Treatment no. (1)	*Date of harvesting* (2)	*No. of days after flowering* (3)	*Harvest moisture content* (% *w.b.*) (4)	*Wet yield* (*kg/ha*) (5)	*Field yield at 14% m.c.* (*kg/ha*) (6)	*Moisture content of dried paddy* (%)		*Total yield* (%)		*Head yield* (%)	
						Mech. dried (7)	*Sun dried* (8)	*Mech. dried* (9)	*Sun dried* (10)	*Mech. dried* (11)	*Sun dried* (12)
T_1	26 Oct. 1972	16	28·43	3044	2508	14·41	14·76	53·7	57·2	31·2	31·2
T_2	28 Oct. 1972	18	27·70	2997	2518	13·90	13·67	63·9	56·9	42·5	34·2
T_3	30 Oct. 1972	20	22·60	3682	3304	12·50	12·80	72·0	70·5	50·7	53·8
T_4	1 Nov. 1972	22	24·80	3868	3423	13·80	14·60	70·7	71·5	49·8	48·3
T_5	3 Nov. 1972	24	25·50	3519	3057	15·30	14·10	73·0	72·7	50·7	51·4
T_6	5 Nov. 1972	26	24·65	3641	3190	14·10	14·30	72·5	72·0	53·0	51·0
T_7	7 Nov. 1972	28	24·15	3627	3500	13·25	13·90	74·1	74·0	58·0	59·5
T_8	9 Nov. 1972	30	22·90	4327	3883	13·80	13·70	74·7	75·7	58·6	60·7
T_9	11 Nov. 1972	32	22·80	4250	3823	14·40	13·60	71·3	74·8	56·4	54·3
T_{10}	13 Nov. 1972	34	23·00	4055	3646	13·20	13·60	76·0	75·0	60·1	56·4
T_{11}	15 Nov. 1972	36	20·40	4050	3708	13·50	14·10	75·0	74·6	50·3	52·3
T_{12}	17 Nov. 1972	38	20·14	3591	3333	13·90	13·50	73·5	74·6	50·3	52·3
T_{13}	19 Nov. 1972	40	17·38	3659	3517	12·00	13·00	76·8	74·8	47·7	44·4
T_{14}	21 Nov. 1972	42	18·50	3425	3241	15·40	13·55	73·5	75·0	44·8	47·3
T_{15}	23 Nov. 1972	44	18·73	3280	3103	14·70	15·00	73·5	74·0	45·3	46·9
T_{16}	25 Nov. 1972	46	18·70	2940	2776	14·30	14·20	73·6	73·8	48·3	49·4

This equation is valid for the range $16 \leqslant N \leqslant 46$ days. The rate of moisture loss from the grain during the period of maturity can be calculated by differentiating Eqn (3) with respect to days after flowering (N) as follows:

$$\frac{dM}{dN} = -0{\cdot}32 \ \%/\text{ day}. \qquad \ldots (4)$$

3.2. *Variation of the field yield of paddy with time of harvest and moisture content*

The field yield of paddy harvested at different days starting from 16 days after flowering is shown in Table I, for a period of 30 days. Increase in the field yield of paddy from the 16th day to the 28th day after flowering is due to increase in the solid matter of the grains indicating the continuation of the process of grain formation in the plant. Shrunken and chalky grains are normally in abundance when harvested during this period. The grains attain biological maturity during a period of 28 to 36 days after flowering which is shown by the maximum field yield during this period when the grain yield observations are plotted against the time of harvest as shown in *Fig. 3*. A prediction equation to determine the field yield of paddy with respect to days after flowering was obtained by fitting to the observed data the equation of a parabola by least squares (2), as given below:

$$Y = -1070{\cdot}4 + 293{\cdot}48\,N - 4{\cdot}54\,N^2 \qquad \ldots (5)$$

where Y = field yield of paddy, kg/ha; and

N = number of days after flowering.

Eqn (5) is valid only for the range $16 \leqslant N \leqslant 46$ days, and it was used for calculating the estimated field yield and the calculated values as given in Table II, along with the observed values of field yield and harvest moisture content at different dates of harvest. In order to determine the theoretical day of biological maturity of the crop, Eqn (5) can be differentiated with respect to N as follows:

$$\frac{dY}{dN} = 0 = 293{\cdot}48 - 4{\cdot}54 \times 2\,N$$

$$\text{or} \quad N = \frac{293{\cdot}48}{9{\cdot}08} = 32{\cdot}35 \text{ days after flowering.} \qquad \ldots (6)$$

This shows that biological maturity occurs 32 days after flowering in the Jaya variety of paddy and that the theoretical maximum yield of paddy can be calculated by substituting this value of N in Eqn (5), as follows:

$$Y_{max} = -1070{\cdot}4 + 293{\cdot}48 \times 32 - 4{\cdot}54 \times 32^2$$

$$= 3676 \text{ kg/ha}. \qquad \ldots (7)$$

As shown in Table II, in the first half of the experiment lower field yields were obtained due to harvesting of immature paddy and hence the loss of field yield has been indicated as a growth loss. However, after biological maturity has been attained by the crop (which occurs at the 32nd day after flowering), harvesting of paddy after the 36th day from flowering date, results in losses caused by shedding of paddy grains from the plants. This loss increases with decrease in moisture content of grain on the plant stalks and has been estimated to be 21·6% on the 46th day after flowering. Percentage losses due to immaturity or shedding have been obtained with respect to the estimated maximum yield of paddy at the optimum harvest period.

According to this investigation, the optimum harvest period for obtaining maximum field yield of paddy as shown in *Fig. 2* and by Eqn (5) is from 28 to 36 days after flowering.

TABLE II

Calculation of field losses and growth losses at different harvest dates

Treatment no.	*No. of days after flowering*	*Harvest moisture content (w.b.)*		*Field yield (kg/ha)*		*Growth loss* $(Y_{max}-Y)$ *kg/ha*	*Field loss* $(Y_{max}-Y)$ *kg/ha*	*Loss of paddy with respect to max. yield* $\left(\frac{Y_{max}-Y}{Y_{max}}\right)\times 100$	*Remarks*
		Observed	*Calculated*	*Observed*	*Calculated*				
T_1	16	28·43	27·34	2508	2464	1212		32·97	
T_2	18	27·70	26·70	2518	2743	933		25·38	
T_3	20	22·60	26·06	3304	2985	691		18·80	
T_4	22	24·80	25·41	3423	3191	485		13·19	
T_5	24	25·50	24·77	3057	3361	315		8·57	
T_6	26	24·65	24·13	3190	3494	182		4·95	
T_7	28	24·15	23·49	3500	3591	85		2·31	
T_8	30	22·90	22·84	3883	3652	24		0·65	Optimum harvest period. Calculated maximum field yield = 3676 kg/ha
T_9	32	22·80	22·20	3823	3676	0	0	0·00	
T_{10}	34	23·00	21·56	3646	3665		11	0·30	
T_{11}	36	20·40	20·92	3708	3617		59	1·61	
T_{12}	38	20·14	20·28	3333	3532		144	3·92	
T_{13}	40	17·38	19·63	3517	3412		264	7·18	
T_{14}	42	18·50	18·99	3241	3255		421	11·45	
T_{15}	44	18·73	18·35	3103	3062		614	16·70	
T_{16}	46	18·70	17·71	2776	2832		844	22·96	

3.3. *Variation of milling quality of paddy with the time of harvest and harvest moisture content of paddy*

Milling quality of paddy is normally expressed by the total rice yield and the head yield both expressed as percent weight of the paddy. Total yield and head yield of sun dried and mechanically dried samples of paddy are tabulated in Table I, and have been plotted in *Fig. 4*.

For the harvest period from 16 days to 20 days after flowering, total yield of paddy increased from 54% to 73%. Immature paddy, harvested in the early part of the experiment, resulted in very poor rice yield. For the harvest period beyond 28 days after flowering, the total yield of paddy samples remained constant at 73%, within the limits of this investigation.

The head yield of paddy samples harvested at different days after flowering showed a parabolic variation with the maximum value of head yield falling in the range of optimum harvest period. Immature grains harvested in the early part of the experiment gave a large quantity of broken grains in milling. The poor head yield was due to chalky and white belly rice, which is more fragile than healthy sound grain. On the other hand paddy harvested beyond 36 days after flowering developed cracks or checks in the kernels due to non-uniform drying of paddy on the plant stalk and thus resulted in poor head yield. The head yield of immature paddy was found to be as low as 30% and increased to 58% for paddy samples harvested within the optimum harvest period (28 to 36 days after flowering). The head yield of the samples beyond the optimum harvest period again fell down to as low as 42%, due to development of cracks and checks in the paddy kernal during the drying of grain on the plant stalk.

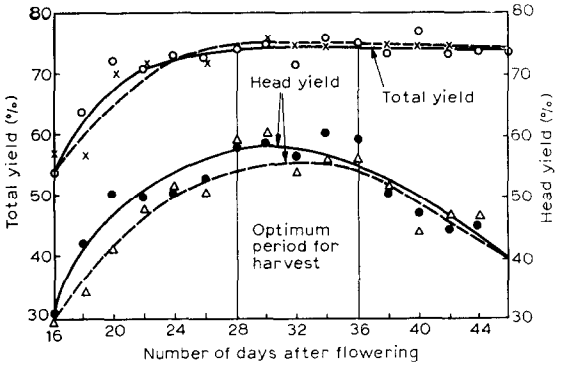

Fig. 4. Effect of date of harvest on total yield and head yield of paddy. ——, *Mechanical drying;* – – –, *sun drying*

3.4. *Effect of methods of drying on milling quality of paddy*

As shown in *Fig. 4*, no significant difference was observed in the total yield of the sun dried and mechanically dried samples of paddy. However, the head yield of paddy harvested at higher moisture content (i.e. from 16 to 36 days after flowering) and dried mechanically, was approximately 3–5% higher than the head yield of the samples harvested at the same time but dried under the sun. Lower head yields of the sun dried samples is due to non-uniform drying of grain in the sun resulting in the development of sun checks or cracks in the paddy kernal during the drying operation. On the other hand mechanical drying of paddy resulted in slow and uniform removal of moisture from the grain mass without causing any damage to the paddy kernal during the drying operation and the dried sample gave a higher head yield on milling. Therefore, this study indicates that paddy should be harvested at higher moisture content within 28 to 36 days after flowering and preferably should be dried by mechanical drier to obtain higher total rice yield and whole rice yield from paddy.

4. Conclusions

The following specific conclusions can be drawn from the results of the harvesting and drying studies on the Jaya variety of paddy.

(1) The crop attains its biological maturity 32 days after flowering and in order to obtain maximum field yield of paddy per hectare, the crop should be harvested within 28 to 36 days after flowering. This is known as the optimum harvest period.

(2) Moisture content of the grains on the plant stalk decreases linearly in a period of 16 to 46 days after flowering with the average rate of moisture loss being 0·32%/day.

(3) Paddy samples harvested during the optimum-harvest period were observed to give maximum total rice yield and head rice yield in addition to maximum field yield during this period.

(4) The head yield of paddy samples harvested at relatively high moisture content (i.e. in the first half of the experimental period) and dried mechanically was estimated as 3–5% higher than the head yield of paddy harvested during the same period but dried under the sun.

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Appendix A

The cultural schedule of Jaya rice grown during the "Aman" season in 1972 for the study

Date	*Operation*
27 June 1972	Nursery sowing
22 July 1972	Land preparation for transplanting: (a) one ploughing by mould-board plough followed by lengthwise and crosswise puddling in standing water by bullock drawn puddler; (b) fertilizer application: 40 kg/ha of nitrogen, 80 kg/ha of phosphate and 60 kg/ha of potash
26 July 1972	Transplanting (spacing 20 cm × 13 cm)
15 August 1972	Urea application at active tillering stage at 40 kg/ha of nitrogen
17 August 1972	Dimecron application (0·05% conc.)
25 August 1972	First weeding
6 September 1972	Dimecron application (0·05% conc.)
15 September 1972	Second weeding
17 September 1972	Urea application as top dressing at 40 kg/ha of nitrogen
26 September 1972	Dimecron application (0·05% conc.)
10 October 1972	Flowering date (50% flowering intensity)
15 November 1972	Date of harvesting