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PHYSICAL LOSSES AND QUALITY DETERIORATION IN RICE POSTPRODUCTION SYSTEMS

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PHYSICAL LOSSES AND QUALITY DETERIORATION IN RICE POSTPRODUCTION SYSTEMS[1]

ABSTRACT

This paper is based on a series of field trials in Central Luzon and Bicol regions from 1975 to 1977. One of the objectives of these field trials was to assess the factors influencing the physical and qualitative losses in rice postproduction systems. It compares the performance of IRRI-designed threshers and dryers with the traditional systems prevailing in the study area. Results show that the mechanized systems incurred lesser physical losses and produced better quality milled rice than did the traditional methods. Inferior quality characteristics such as cracked, fermented, damaged, and chalky kernels, and impurities were significantly associated with lower quantity, quality, and market grade of milled rice. Timeliness in performing postproduction tasks, as well as type of machine or equipment used, also influenced head rice percentage and grade of milled rice.

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PHYSICAL LOSSES AND QUALITY DETERIORATION IN RICE POSTPRODUCTION SYSTEMS

The concept of average loss levels is almost meaningless because postproduction losses are location- and season-specific. Because *loss* is multifaceted, it has no generally accepted definition. Loss may involve weight, quality, nutritive value, market value, etc. Each of these losses may vary in importance by country, culture, time and place, and method and conditions of loss evaluation. This paper assesses the factors influencing the quantitative and qualitative losses in paddy and milled rice. Four postproduction systems were studied in pilot trials in Central Luzon and Bicol (Fig. 1). Each system was classified into specific tasks according to procedures, tools, and machines used. The trial results form the data base for this study.

RESEARCH METHODS

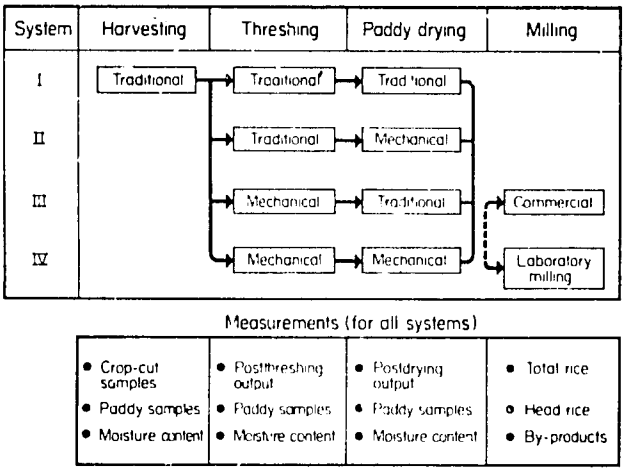
Loss assessment methodology

The field trials were conducted by the Department of Agricultural Engineering of the International Rice Research Institute (IRRI) in Central Luzon and Bicol regions from 1975 to 1977. Four villages of Nueva Ecija (Soledad, Sta. Rosa; Malapit, San Isidro; Polilio, Cabanatuan City; and Sta. Cruz, Zaragosa), 20 farmer-cooperators, and 190 plots were included in the Central Luzon field trials. Bicol trials included 3 villages (Libon, Albay; San Jose and Buhi, Camarines Sur), 17 farmer cooperators, and 151 plots (Table 1).

Quantitative losses

Physical losses were measured in each postproduction operation from harvesting through drying (see Fig. 1). All yield and weight measurements were corrected for moisture content and purity. In harvesting, the losses assessed included:

a. Shattering loss – the premature shedding or separation of sound and mature grains from the panicle, caused by wind, birds, rats, varietal characteristics, maturity, handling operations, etc.
b. Lodging loss – sound and mature grains that remain intact when the plants lodge or fall on the ground because of varietal characteristics or environmental conditions.
c. Standing crop loss – sound, mature grains left intact on the standing plants during harvesting because of oversight, carelessness, or haste. This is very common for border plants where tall grass or weeds grow adjacent to them.



1. Farm-level postproduction systems.

Harvesting loss was assessed using a 2-m^2 sampling frame. Replicated crop-cut and harvest samples were taken immediately after harvest to measure grain quality. All grains on the ground or left intact on standing as well as lodged plants within the area of the frame were manually gathered and weighed.

To measure stacking losses, plastic or canvas sheets were used as underlays for harvested paddy before threshing. Stacking losses were counted as grains remaining on the sheets after bundles were taken to the threshing site.

For threshing, loss components included:

a. Loose straw and chaff loss – sound and mature grains mixed with the straw or chaff and/or other impurities during threshing or cleaning. With mechanical threshers, this is called blower loss.
b. Scatter loss – sound and mature grains scattered on the ground during threshing or cleaning.
c. Unseparated grain loss – sound and mature grains remaining on or in the straw after threshing. In mechanical threshing this is usually called separation loss.

Canvas or plastic sheets were spread on the threshing floor to retain all grain lost or scattered during threshing. When people gleaned or rethreshed the straw, the grain recovered by these gleaners (*mambabarog*) was considered part of the threshing loss. With mechanical threshers, the threshed straw was manually rethreshed or recycled in the machine to determine separation loss.

Table 1. Characteristics of villages included in postproduction trials, Central Luzon and Bicol region, Philippines, 1975-77.

Location	Season	Cooperators (no.)	Plots (no.)	Av area (m^2/plot)	Variety
Central Luzon (Nueva Ecija)					
Soledad, Sta. Rosa	Wet	5	80	771.4	IR20 IR26 IR529 IR1561
Malapit, San Isidro	Wet	6	46	1423.2	IR26 IR30 IR579 IR1529 IR1561
Polilio, Cabanatuan	Dry	4	42	1242.3	IR26 IR30 C4-63G
Sta. Cruz, Zaragosa	Dry	5	22	1350.27	IR747 IR30 IR20
Bicol Region					
Libon, Albay	Wet	3	25	1209.197	C-4
	Dry	5	32	1739.392	C4 IR26 Peta
San Jose, Camarines Sur	Dry	5	55	1037.914	C4 IR20 IR26 IR30
Buhi, Camarines Sur	Dry	4	39	1017.041	C4 IR26

Grain lost during cleaning or winnowing was measured only in the traditional system using either the winnowing basket (*bilao*) or wooden winnower (*hungkoy*). Loss included grain mixed with the chaff or straw during cleaning and not normally recovered by farmers. Canvas or plastic sheets facilitated recovery of scattered grains.

Drying loss refers to spilling, improper or careless handling; pilfering; consumption by birds, rodents, or chickens; and wind losses from either natural causes or from vehicles passing paddy drying on or beside a road.

To derive handling loss, weights obtained before and after drying were first adjusted to a constant percentage of purity. The remainder consists of the paddy weight and the moisture in the grain. The moisture content, measured as wet weight, was taken before and after drying and converted to dry weight using the Brooker et al (2) conversion scale.

Qualitative losses

To evaluate the impact of postproduction technologies on the quality of paddy and milled rice, 750 g paddy samples were taken at each stage: (a) before and after harvest, (b) after threshing, (c) after cleaning, and (d) before and after drying. The samples were dried to 14% in a sample dryer. Dried samples were then placed in plastic bags, labeled, sealed, and delivered to the National Food Authority (NFA) laboratories for analysis.

To assess quality, samples collected during the field trials were evaluated using criteria prescribed by the Philippine Grades and Standards for paddy and milled rice. These include: moisture content; presence of foreign material and other varieties; cracked, damaged, fermented, chalky, and immature kernels; red kernels; head rice; brokens; and brewer's rice (Appendix 1). In the current procurement and pricing scheme for paddy, however, the NFA considers only two criteria, moisture content and impurities.

Limitations

Timeliness must be considered in assessing losses because delays greatly affect the results. A calendar for planning and monitoring farm operations was kept for each farmer-cooperator. Optimal harvest dates (farmer-estimated) were recorded so all preliminary steps for operations such as crop-cutting were accomplished in advance. Because harvest dates can be earlier or later than the optimal time due to uncontrolled factors, field assessors had to check regularly with farmers for any changes in the calendar during the waiting period. Despite this, the team was sometimes not notified of harvest date changes, resulting in incomplete data.

In assessing harvesting loss, recovery of fallen grains was hampered by flooded or muddy fields during the wet season and by cracked soils during the dry season. Harvest loss data were, therefore, limited and probably underestimate the real loss. Timing problems were also encountered in farmer use of mechanical threshers. Farmers liked the axial-flow thresher so much that occasionally the schedule was not observed. Farmers who were supposed to have priority use of the machines had to wait 2-4 d because the threshers were being used by others. Lack of funds to

operate and maintain equipment further complicated timing. At times, fuel and oil were purchased only when needed, prompting the field staff to make cash advances for timely execution of the field trials.

Monitoring drying was complicated because some farmers needed cash immediately and so they sold their paddy immediately after threshing without waiting for the full completion of data collection. Some farmers were willing to dry only a portion of their crop. Others were reluctant to use batch dryers.

FIELD TRIAL RESULTS

Physical loss

The traditional system incurred losses two to three times greater than the mechanical thresher (Table 2). This loss would be greater if one includes the further cleaning required with traditional threshers, to remove impurities mixed with the grain (thus the cleaning loss of 1.1% needs to be added to the threshing loss using threshing frame and flail or stick). The axial-flow machine threshes and cleans simultaneously, delivering clean threshed and commercially acceptable grain right after harvest. Between the two drying systems, sun drying produced greater losses, amounting to 1.2%, compared to only 0.1-0.4% loss with batch drying.

The analysis measured threshing loss as the difference between the harvest yield and the threshing yield, expressed in kilograms per hectare. Harvest yield was based on the potential yield obtained from replicated crop-cut samples. Threshing yield is the total amount of paddy recovered after threshing and cleaning, including gleanings.

Timely harvesting reduced threshing loss significantly, increasing yield 226 kg/ha compared to delayed harvest (Table 3). Further delays during field handling (including in-field drying, bundling, piling, and/or stacking) meant an additional loss of about 110 kg/ha. Between the two threshing systems, the axial-flow thresher significantly reduced threshing loss about 230 kg/ha. This grain saving is even greater if one considers the 209 kg/ha loss difference during cleaning in favor of the mechanized system.

Quality deterioration

Uncontrolled variables made it difficult to validly assess grain quality between systems. Rain between harvest and threshing often damaged stacked or bundled grain. Lack of timeliness in using mechanical threshers likewise affected the results. Subsequent drying could do little to correct these effects.

The quality deterioration analysis showed that timely harvest produced significantly higher percentage of head rice, 83% compared to only 73% with delayed harvest (Table 4). No significant difference was observed between timely and delayed handling.

Among threshing techniques, the threshing frame (*hampasan*) and the axial-flow thresher produced 82 and 78% head rice respectively, significantly higher than the flail and/or stick. The threshing frame performed slightly better than the axial-flow thresher. This is partly attributed to the practice of threshing high moisture paddy with mechanical threshers, reducing the percentage of head rice. With traditional systems, only lower moisture paddy can be threshed and cleaned effectively.

Timely drying with the batch dryer yielded 83% head rice, significantly higher than delayed batch drying (77%) and sun drying (77% for timely and 76% for delayed) (Table 4).

Table 4 shows the influence of timeliness in handling, and threshing and drying method on the percentage of cracked, fermented, and damaged kernels in paddy and milled rice. Samples from plots using timely handling had significantly lower percentages of cracked and fermented kernels than those from delayed handling.

Of the threshing methods, the mechanical thresher (as well as the flail and/or stick) yielded significantly less foreign matter and impurities than the threshing frame, although most farmers thresh high moisture paddy using the axial-flow thresher. This practice, however, contributes

Table 2. Average physical losses among alternative systems, Central Luzon and Bicol Region, Philippines, 1975-77.

Postproduction systems	Av loss (%)	
	Central Luzon	Bicol Region
Axial-flow thresher	1.1	0.5
Threshing frame	2.4	1.6
Flail and/or stick	--	1.2
Winnowing basket (*bilao*)	1.1	–
Wooden winnower (*hungkov*)	–	1.1
Batch dryer	0.1	0.4
Sun dryer	1.2	1.2

Table 3. Means for threshing loss (THLOSS) by alternative groupings in postproduction operations, Philippines, 1975-77.

Item	THLOSS[a] (kg/ha)	Difference[b]
Harvesting		
Timely harvest	623 a	
Delayed harvest	849 b	226*
Handling (bundle, haul, stack)		
Timely handling	711 a	
Delayed handling	821 a	110
Threshing		
Axial-flow thresher	626 a	
Threshing frame/flail or stick	856 b	230*
Cleaning		
Axial-flow thresher	640 a	
Winnowing basket/wooden winnower	849 b	209*
Comparative THLOSS by region		
Central Luzon	695 a	
Bicol Region	764 a	69

[a]Threshing loss (THLOSS) is the difference between potential harvest yield per hectare and the yield obtained after the paddy is threshed and cleaned. Treatment means with the same letter are not significantly different from each other at .05 level of significance.
[b]* = difference highly significant.

Table 4. Average percentage of head rice and other quality characteristics by alternative postproduction operations, Philippines, 1975-77.[a]

Item	Head rice	Cracked kernels	Fermented kernels	Damaged kernels
Harvesting				
Timely	83 a	–	–	–
Delayed	73 b	–	–	–
Handling				
Timely	85 a	6 a	0 a	1 a
Delayed	78 a	9 b	2 b	1 a
Threshing				
Threshing frame	82 a	3 a	1 a	1 a
Axial-flow thresher	78 a	5 a	2 b	2 a
Flail/stick	70 b	7 b	2 b	1 a
Drying				
Timely batch drying	83 a	3 a	2 a	1 a
Delayed batch drying	77 b	6 a	3 a	2 a
Timely sun drying	77 b	6 a	2 a	1 a
Delayed sun drying	76 b	10 a	3 a	1 a

[a]Using Duncan Multiple Range Test (DMRT) at 5% level of significance. Treatment means with the same letter are not significantly different from each other.

to a higher percentage of fermented kernels in the axial-flow thresher compared to the traditional threshing frame. Threshing with the threshing frame gave less cracked kernels than the axial-flow thresher although the difference was not statistically significant.

Alternative drying techniques did not produce significant differences in the amount of cracked and fermented kernels, partly because of the limited size of subcategory samples. Among the four drying systems, however, timely batch drying gave the best performance in relative percentage values, followed by timely sun drying. Except for cracked kernels, delayed batch drying produced higher percentage values for inferior-quality characteristics in both paddy and milled rice than delayed sun drying. This can be attributed to the farmer's practice of using mechanical dryers only when sun drying is not possible and only batch drying can save the grain.

LOSS RELATIONSHIPS

Loss relationships were estimated with linear models using results of the village field trials in Central Luzon and Bicol Region. Data from the 2 regions were combined to increase the sample size to 295 observations (145 from Central Luzon and 150 from the Bicol Region).

The variables considered in the models were those expected to significantly influence physical and quality losses: a) postproduction input variables, b) inferior quality characteristics of paddy and milled rice, c) varietal characteristics ,and d) interactions between pairs of independent variables. Threshing and drying were the two postproduction tasks considered in assessing physical and quality losses. Only these two were used, because preliminary results from Central Luzon indicated the influence of paddy and milled rice characteristics on physical losses and rice recovery was more evident in threshing and drying. Physical loss responses and quality deterioration responses were analyzed separately:

1. *Physical loss models.* The physical loss models considered two independent variables – threshing loss (THLOSS) and total milling recovery (MILLREC). (See Appendix 3 for a complete list of variable abbreviations. They are used to enable concise presentation of results in the tables.)

Threshing loss, in kilograms per hectare, is the difference between the potential harvest yield from replicated crop-cutting and the actual amount of paddy recovered after threshing and cleaning including gleaning.

$$\text{THLOSS} = \frac{\text{harvest yield} - \text{threshing yield}}{\text{plot size}} \times 10{,}000.$$

Total milling recovery is expressed in percent as a measure of milling yield rather than of milled rice.

$$\text{MILLREC} = \frac{\text{wt of milled rice}}{\text{wt of paddy sample used in hulling} - \text{wt of unhulled rice}} \times 100$$

2. *Quality deterioration functions.* The two dependent variables in the quality deterioration models were percentage of head rice recovery (HDRICE), and numerical grade for milled rice (GRADE) as defined in the Philippines Standard Grade Requirements for milled rice (Appendix 2). Head rice recovery (HDRICE) was selected because the correlation between percentage of head rice and brokens is almost −1.0 (because the percentage of brewer's rice was very small for all samples) which means one measure acts as proxy for the other. The higher the percentage of head rice, and conversely, the lower the percentage of brokens and brewer's rice, the higher the quality and the greater the value of milled rice.

The grade of milled rice (GRADE) refers to the overall quality of the grain expressed in total percentage points of head rice, brokens, brewers' rice or *binlid*, damaged and chalky kernels, presence of other varieties, red kernels, and percentage of foreign matter, ie,

GRADE = head rice + brokens + binlid + damaged kernels + chalky kernels + other varieties + red rice + foreign materials.

Using the Philippine Standard Specifications of Grades for Milled Rice, three grade classifications were used in this analysis:

- when total percentage points are less than or equal to 110, the millled rice is classified as Grade 1;
- when total percentage points are greater than 110 but less than or equal to 125, the milled rice is classified as Grade 2;
- when the total percentage points are greater than 125, the milled rice is classified as Grade 3.

Since the amount of head rice, brokens, and brewer's rice sums to 100%, the residual above 100 reflects the total percentage points of the inferior-quality characteristics of milled rice. Therefore, a total percentage points of 110 or less means best quality rice and 125 or greater, the poorest.

The General Linear Models used in the physical and quality deterioration loss functions are described in Appendix 3.

RESULTS

Physical loss functions

The R^2 value obtained from the THLOSS model was low indicating that other relevant variables were not included (Table 5). The F-test for the entire model, however, showed significant results. Among the four groups of variables expected to influence physical loss, varietal characteristics did not show significant relationship. Of the combined physical and quality deterioration factors considered to affect variability in the amount of THLOSS, four were significant – plot size, man-hours harvesting, percentage of brokens, and interaction between elapsed time from harvesting to threshing and threshing to drying (ETHVTH).

Except for man-hours harvesting (MDHVHA), all other significant variables exhibited the expected sign (Table 5). Man-hours harvesting may either be positively or negatively correlated with THLOSS depending on whether the increase or decrease in labor input reflects changing efficiency in the performance of the task or factors other than the harvester's skill. These factors include: a) the presence or absence of immature or unfilled grains mixed with mature panicles which require more time and care in harvesting, b) tungro-infested plots which require careful selection of healthy grains, c) weedy fields, d) bad weather resulting in muddy or flooded fields, e) harvesters' availability during peak months and, f) harvesters' age, sex, and skill.

In the total milling recovery (MILLREC) model, impurity and other varieties were significantly negatively associated with variability in total milling recovery in threshing (Table 6). Other significant variables include man-hours threshing (MDTHHA), elapsed time from threshing to drying (ETTH), timeliness in harvesting, and interaction terms such as method of threshing by moisture content (THRHMC) and by cracked kernels (THRHCRAK), method of cleaning by impurities (CLENIMPU), and moisture by cracked kernels (MCRACK).

Except for timeliness in harvesting, all other significant variables exhibited signs consistent with expectations. The sign for timeliness in harvesting can either be positive or

Table 5. Summarized result of the functional relation between threshing loss (THLOSS) and the combined explanatory variables, Philippines, 1975-77.

Explanatory variables	b-value[a]
Intercept	299.160
Thresh (threshing method)	273.788
Clean (cleaning method)	-156.614
Plot size	0.167**
Region (Central Luzon or Bicol)	24.421
MDHVHA (man-hours harvesting/ha)	- 39.317*
ETHV (hours elapsed from harvesting to threshing)	- 0.034
ETTH (hours elapsed from threshing to drying)	- 0.030
ETHVTH (ETHV x ETTH)	3.376E-05**
Brokens	28.816**
Impurity	36.963
THRHBROK (thresh x brokens)	- 7.172
THRHIMPU (thresh x impurity)	- 23.938
R^2	0.235**
F-value	5.90
PR > F	0.0001

[a]** = highly significant at .01 level, * = significant at ≤.10 level.

Table 6. Summarized result of the functional relation between total milling recovery (MILLREC) and the combined explanatory variables in threshing and drying operation, Philippines, 1975-77.

Explanatory variables	Total milling recovery[a] (b-values)	
	Threshing	Drying
Intercept	65.927	67.879
Moisture	0.170	0.109
ChalkyK (chalky kernels)	0.038	- 0.128*
Impurity	- 0.839**	- 0.630**
CrackK (cracked kernels)	- 0.216	- 0.610**
FermentK (fermented kernels)	0.164	0.294*
DamageK (damaged kernels)	- 0.064	- 0.164
Othervar (other varieties)	- 0.204**	- 0.066
Harvest (timeliness of harvest)	0.492*	0.157
Thresh (threshing method)	1.828	1.895
MDTHHA (man-hours threshing/ha)	0.280*	0.110
ETTH (hours elapsed from threshing to drying)	0.0004*	0.00013
MDTHHA x ETTH	- 6.303E-05	- 2.249E-05
ETTH x FermentK	- 6.168E-05	1.899E-05
Clean x Impurity	0.138*	0.178**
Thresh x CrackK	- 0.103*	0.113*
Thresh x Brokens	- 0.009	- 0.022*
Moisture x CrackK	0.019*	0.014*
Thresh x Moisture	- 0.1009*	- 0.114*
R^2	0.423**	0.390**
F-value	9.19	7.69
PR > F	0.0001	0.0001

[a]** = highly significant at .01 level, * significant at ≤.10 level.

negative depending on the field conditions while the harvested stalk paddy is being bundled, piled, and/or stacked waiting for threshing. These conditions may either enhance or prevent grain cracking depending on the rapid moisture adsorption or desorption within and outside the grain kernels (5).

In the drying operation, impurities, and cracked, fermented, and chalky kernels were significantly associated with reduction in total milled rice (Table 6). Except for fermented kernels, other inferior-qulaity characteristics exhibited negative signs as expected. Interaction terms such as method of threshing by percentage of cracked kernels (THRHCRAK), broken kernels (THRHBROK), and moisture content (THRHMC), method of cleaning by percentage of impurities (CLENIMPU), and moisture content by cracked kernels (MCRACK) were also significant. Of these variables, two – THRHCRAK and MCRACK – did not exhibit the right expected signs.

Quality deterioration functions

Variables exhibiting a significant association with variability in percentage of head rice (HDRICE) in the threshing operation included cracked and chalky kernels and the interaction between man-hours harvesting and the elapsed time from harvesting to threshing (MDETHV). Cracked kernels exhibited a negative association with percentage of head rice whereas chalky kernels which were expected to show a negative relation, exhibited a positive b-value (Table 7).

In the HDRICE model for drying, more variables were considered because drying is the final step in postproduction before milling. (Farm-level storage was excluded from this study because of the short period of the field trials and the limited amount of paddy stored for home consumption.) Cracked and fermented kernels were significantly negatively associated with variability in percentage of head rice during drying. Among the remaining explanatory variables, timeliness in harvesting and handling, and total elapsed time from harvest to drying (ETDR), as well as region, were significant. Interaction terms such as method and timeliness of drying by fermented kernels (DRYFERK), damaged kernels (DRYDAM), and cracked kernels (DRYCRAK) were also significant (Table 7). All explanatory variables, except timeliness in harvesting, exhibited the right signs. The sign of this variable indicates omission of factors that might have contributed to early or delayed harvest other than crop maturity.

Compared to HDRICE for threshing, the R^2 value was relatively higher for drying, indicating that the impact of alternative postproduction technologies on percentage of head rice is especially pronounced at the drying stages. The F-test for the entire model shows a highly significant R^2 value.

In the GRADE model for threshing, moisture content, fermented kernels, timeliness in handling, region, elapsed time from harvesting to threshing (ETHV), and crop maturity exhibited significant association with variability

Table 7. Summarized result of the functional relation between head rice recovery and combined explanatory variables in threshing and drying operations, Philippines, 1975.

Explanatory variables	Head rice recovery[a] (b-values)	
	Threshing	Drying
Intercept	62.154	70.279
CrackK (cracked kernels)	– 0.407**	– 1.574*
DamageK (damaged kernels)	3.698	1.635
ChalkyK (chalky kernels)	1.048**	0.167
FermentK (fermented kernels)	0.559	– 2.783*
Moisture	0.670	
Impurity		– 0.129
Harvest (timeliness in harvesting)	– 1.796	2.381*
Handle (timeliness in handling)	– 1.608	– 2.067*
Thresh (threshing method)	8.421	0.504
Clean (cleaning method)		– 2.394
Dry (method and timeliness of drying)		– 0.607
Region (Central Luzon or Bicol)	– 2.946	5.564*
MDHVHA (man-hours harvesting/ha)	0.074	0.780*
MDTHHA (man-hours threshing/ha)	– 0.509	
MDDRHA (man-hours drying/ha)		29.687
ETHV (hours elapsed from harvesting to threshing)	0.0022	0.002
ETDR (hours elapsed from harvesting to drying)		0.0009*
MDHVHA x Harvest	– 0.00036*	– 0.0003*
MDDRHA x Dry		– 0.0008*
Harvest x Moisture	0.172	
Thresh x Moisture	– 0.431	
Thresh x DamageK	– 0.991	
Dry x FermentK		0.892*
ETTH x FermentK		– 0.00016
Dry x DamageK		– 0.836*
Clean x Impurity		0.312
Thresh x CrackK		0.166
Dry x CrackK		0.229*
R^2	0.310**	0.398**
F-value	6.40	6.31
PR > F	0.0001	0.0001

[a]** = highly significant at .01 level, * = significant at ≤.10 level.

in grade of milled rice (Table 8). Of the interaction terms considered, elapsed time from harvesting to threshing by elapsed time from threshing to drying (ETHVTH) and timeliness in handling by moisture content (HANDMC) were significant.

The R^2 value obtained in the model was low indicating that other relevant variables were omitted. However, the F-test indicates the total model is highly significant.

In drying, all postproduction tasks from harvesting to drying were significantly associated with grade of milled rice. Labor inputs and delays in the performance of subsequent postproduction tasks likewise had significant impact on grade. Among the interaction terms, degree of fermentation and cracking combined with alternative tasks significantly influenced variability in rice grade (Table 8).

The following variables showed positive association with grade of milled rice indicating they contribute to an increase in numerical grade (which indicates *reduced* market quality of milled rice): a) moisture content (MC); b) timeliness in harvesting (harvest); c) man-hours drying (MDDRHA);

Table 8. Summarized result of the functional relation between grade of milled rice and combined explanatory variables in threshing and drying operations, Philippines, 1975-77.

Explanatory variables	Grade of milled rice[a] (b-values)	
	Threshing	Drying
Intercept	0.327	0.751
Moisture	0.077**	0.053**
CrackK (cracked kernels)		-0.033
FermentK (fermented kernels)	0.084*	0.050
Harvest (timeliness of harvest)		0.631**
Handle (timeliness of handling)	- 0.738*	-1.049**
Thresh (threshing method)		0.094
Clean (cleaning method)	- 0.047	
Dry (method and timeliness of drying)		0.086
Region (Central Luzon or Bicol)	- 0.778**	-0.692**
MDHVHA (man-hours harvesting/ha)	- 0.005	-0.042
MDTHHA (man-hours threshing/ha)		0.003
MDDRHA (man-hours drying/ha)		1.051
ETHV (hours elapsed from harvesting to threshing)	- 0.0001*	-0.0001
ETTH (hours elapsed from threshing to drying)	- 2.70E-05	-0.0002*
ETDR (hours elapsed from harvesting to drying)		0.0002
Lodge (lodging index of variety)		0.036
Maturity (maturity days)	0.010*	0.014*
ETHV × ETTH	1.64E-08*	4.01E-08**
ETHV × ETDR		-2.55E-08**
MDHVHA × Harvest	9.78E-06	2.69E-05**
MDTHHA × ETTH		-8.59E-06**
Harvest × Moisture		-0.028**
Handle × Moisture	0.033*	0.044**
Harvest × FermentK		-0.049*
Handle × FermentK	0.008	
ETHV × FermentK		-2.28E-05*
ETTH × FermentK	- 8.41E-06	
Dry × FermentK		-0.037*
Moisture × FermentK		0.008*
Moisture × CrackK		-0.003*
Thresh × CrackK		-0.020*
Handle × CrackK		0.018*
Dry × CrackK		0.013*
R^2	0.394**	0.580**
F-value	10.64	9.75
PR > F	0.0001	0.0001

[a]** = highly significant at .01 level, * = significant at ≤.10 level.

d) maturity; e) moisture by fermented kernels (MCFERK); f) moisture by cracked kernels (MCRACK); g) man-hours by elapsed time in harvesting to threshing (MDETHV); h) timeliness in handling by moisture content (HANDMC); i) timeliness in handling by cracked kernels (HANDCRAK); and j) timeliness and method of drying by cracked kernels (DRYCRAK).

Factors influencing threshing loss, rice recovery, and grade

Harvest. The timing of harvest and the moisture content of paddy both determine the ease with which rice shatters. The timing of harvest also influences prethreshing handling and milling.

Handling. The fewer times paddy is handled before threshing, the lower the losses. Samson and Duff (8) noted zero handling loss and low threshing losses when rice was threshed immediately after harvest. They reported that each additional handling step embodied 1-2% loss particularly for varieties with high shattering characteristics.

Timeliness in harvesting and handling. Early harvesting means a large percentage of immature and unfilled kernels. Delayed harvest, on the other hand, reduces yield due to shattering and attack from birds, rodents, and insects. It also reduces head rice recovery because the grain cracks while the harvested stalk paddy is left in the field loose or bundled, piled, and/or stacked awaiting threshing. According to Kunze and Calderwood (5), cracks are caused by rapid moisture adsorption or desorption through the grain surface readsorbing moisture from the environment, and/or the grain surface adsorbing moisture from the center of the kernel. Under certain conditions, temperature changes may lead to cracking. Cracked kernels usually break during harvesting, handling, and processing.

As noted in Table 4, timely harvesting and handling produced significantly higher head rice recovery than delayed operations. Table 4 also showed significantly fewer cracked kernels from samples collected in timely operations.

The stacking method also influences dryness of cut paddy in the field. An experiment in Surinam (9) showed that harvested paddy spread on the stubble dried very quickly and after 3 d resulted in a sudden decrease in percentage of whole grains due to remoistening during the night. In comparison, harvested paddy stacked upright in sheaves dried more slowly with practically no decrease in whole grain recovery even after 8 d of stacking.

In a third stacking method, covered sheaves, drying was so slight that after 8 d, moisture content remained far above the critical point for sun cracking. Consequently the percentage of whole grains remained unchanged.

These results partly explain the inconsistent behavior of timeliness in harvesting and handling as it relates to the amount of head rice, total milling yield, and milled rice grade.

Threshing. The threshing method will contribute to losses if it results in grain cracking. Mechanical threshers may excessively break grain if used improperly or fed with poor quality paddy. The field trials indicated this with significantly higher percentage of head rice in systems using the threshing frame (*hampasan*) over that of the axial-flow thresher (Table 4).

Interaction between cleaning method and inferior-quality characteristics. The farmer's practice of threshing high moisture paddy reduced percentage of head rice and total milling yield. The negative association between percentage of head rice in threshing observation and total milling recovery in samples obtained during threshing and drying is captured by the interaction term, method of threshing by moisture content (THRHMC). Similarly, when low quality paddy is threshed by machine, a negative association is obtained between total milling recovery and the interaction between threshing method and broken kernels

(THRHBROK). The negative sign was significant for drying but not for threshing, again confirming the general observation that the impact of qualitative factors on the final product is most pronounced in the drying stage (Table 6).

Moisture content. Milling quality is influenced by the moisture content of paddy at harvest, during drying and storage, and at milling (4). Rice with high milling quality must be harvested at the right stage of maturity, properly dried, stored, and milled under moisture conditions optimum for least breakage. The optimum moisture content for harvest is 21-24% and the high value for safe storage and milling is 14% (1).

In the field trials, the moisture content of newly harvested paddy was 18-25% (wet basis) during the dry season and 20-30% (with some samples exceeding 30%) during the wet season. Under these conditions, paddy deteriorates quickly, losing quality through damaged, discolored, and germinated kernels.

Cracked kernels. Cracked or broken grains, caused by intermittent drying and rewetting while in stacks (7), rough handling, or improper drying, easily break during milling. Cracked kernels is usually inversely related to percentage of head rice and total milling recovery, and directly or positively associated with grade of milled rice.

Damaged kernels. Grains discolored or weakened by water, insects, heat, or any other means are classified as damaged kernels. This variable may exhibit either a positive or negative association with rice recovery and grade depending on the source and degree of damage.

Chalky kernels Chalkiness in the rice grain can be caused by varietal and environmental factors. Starch granules in chalky areas are less densely packed with more spaces in between the granules than those in translucent areas (3). These chalky areas contribute to grain breakage during milling because they are softer than the translucent portions (6). Chalky kernels were negatively associated with variability in percentage of head rice and milling yield and positively related to the numerical grade of milled rice. The significant positive association of chalky kernels with percentage of head rice in both threshing and drying operations may, however, indicate a safe range of chalkiness that does not lead to breaking if grain is milled at the right moisture, temperature, and hulling efficiency.

Fermented kernels. The results reveal divergent relationships between fermented kernels and threshing and drying. In threshing, fermented kernels significantly positively associated with percentage of head rice and total milling yield. Conversely, in drying, fermented kernels and percentage of head rice and total milling yield were negatively associated (Table 6, 7). The values were also significant in both models for drying, indicating the impact of fermented kernels on head rice, and total milling recovery is especially pronounced in the drying stages.

Other varieties. Off-varieties which differ distinctly from the target grain variety influence variability in percentage of head rice. Uniformity in kernel size indicates varietal purity. Significant quantities of off-varieties may result in a higher proportion of brokens.

Impurities. Foreign materials such as straw, chaff, weed seeds, dirt, stones, etc. get mixed with the grain in postproduction stages. During harvesting, tall grasses in weedy fields are likely to be cut and get mixed with the paddy. Foreign materials get mixed in when cut paddy is stacked on the stubble, dikes, or levees without using underlays. These impurities increase threshing loss. Stones and other sharp objects can damage the threshing, cleaning, and processing equipment. Impurities can, therefore, reduce the quantity of usable rice, lower its milling yield, and affect its nutritional value.

Brokens. After paddy is cut, delays while the material is stacked in the field may subject the grain to alternate rewetting and drying causing cracks. Cracked grains break easily during milling. Although the percentage of broken kernels is a measure of quality rather than quantity, the variable seems to function as a reasonable proxy for loss in quantity as well. The same unfavorable conditions and practices which lead to broken kernels during milling also contribute to physical losses during harvesting and threshing.

SUMMARY AND CONCLUSIONS

Improved postproduction technology using axial-flow threshers and mechanical dryers produced lower physical losses and significantly higher head rice recoveries than did traditional systems. In the loss response functions, inferior-quality characteristics such as levels of impurities, and cracked, fermented, damaged, and chalky kernels were associated with lower quantity, quality, and market grade of milled rice. Timeliness in performing postproduction tasks, as well as the type of machine or equipment used, also influenced rice recovery and grade.

Although the validity of the results are restricted to Central Luzon and Bicol Region, they do permit general conclusions about postproduction systems in other regions. Each operation in the postproduction chain can influence physical loss and quality deterioration of paddy/or milled rice. Timeliness is a critical factor conditioning postproduction losses. To preserve quantity and quality of grain, cultural practices must be changed to shorten the period between harvesting and storage. Intermediate postharvest machineries such as threshers and dryers can reduce physical loss and quality deterioration in grain. Finally, in view of the complexity and interdependency of operation, modification in more than one element of the system is normally required to maximize benefits from these changes.

AREAS FOR FUTURE RESEARCH

The present analysis of physical and quality losses is confined only to variables identified and measured during Bicol and Central Luzon field trials. It fails to capture all sources of variation in postharvest losses because the research ad-

dressed only those items within the management control of the farmer. Other variables were excluded from the analysis due to data limitations and time and manpower constraints. These include effect of adverse weather conditions, alternative levels of efficiency and management of other post-production systems, farmers' attitudes toward losses, and the trade-offs between loss reduction and other factors.

Research should also include variables affecting postharvest performance related to genetic modification in the rice plant itself. Such research at IRRI falls under the mandate of the Genetic Evaluation and Utilization program, specifically under Grain Quality. The major objective of this research is to explore differences in varietal characteristics which lead to improved grain quality and nutrition. Major variables in this area and their possible effects on postharvest performance are listed below:

Variable	*Hypothesized effects*
Reduce % immature grain	Increased head rice and milling recovery
Reduce % hull weight	Increased grain yield and milling recovery
Reduce hull thickness	Increased grain yield Reduced resistance to insect infestation
Increase hull thickness/ grain hardness	Increased varietal resistance to stored rice insects
Improve resistance to fissuring	Improved head rice and milling recovery
Reduce chalkiness	Reduced brokens and increase head rice recovery
Raise protein content	Increased milling and head rice recovery due to improved grain resistance to abrasive milling

High yielding varieties have undoubtedly increased total grain production, but with some trade-offs. The short season, photoperiod-insensitive varieties permit multiple cropping with increased yields per hectare and per year. The photoperiod insensitivity of these varieties, however, means they will mature during the wet season when the environment for postharvest handling is often suboptimal. Conditions are present which produce cracking, fermentation, yellowing and subsequent grain spoilage, and low milling and head rice recoveries.

Improvements in techniques and hardware can only partially mitigate these problems. In addition, the costs to the farmer can be high and the benefits uncertain. Genetic improvements which *build in* improved characteristics leading to higher milled and head rice recoveries would greatly complement the efforts of engineers and may sometimes even be a necessity for overcoming second generation postharvest problems.

IRRI's strength in varietal improvement should be harnessed and exploited to fully ensure that the higher yield and quality potentials of the improved varieties reach the consumers' table.

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Appendix 1. Criteria prescribed by the Philippine Grades and Standards for paddy and milled rice.

Moisture content, the amount of water held by the grain. Moisture content is usually expressed as a mass of water per unit mass of wet grains (wet weight basis) or mass of water per unit mass of dry grains (dry weight basis). Moisture content wet weight basis, which is usually used in trade and industry, was used in this study.

Foreign material, all impurities other than rice which include weed seeds, straw, chaff, stalks, stone, sand, dirt, etc.

Other varieties, rice kernels of varieties other than the one being analyzed.

Cracked kernels, kernels that have seed coats cracked by mechanical means or by drying too rapidly with excessive heat.

Damaged kernels, kernels or pieces of kernels of rice which are distinctly discolored or damaged by water, insects, heat, or any other means.

Fermented kernels, yellowish milled rice due to fermentation or heat.

Chalky and immature kernels, kernels that are undeveloped, shrivelled, and with 50% or more white portion. The chalky spots may be referred to as *white belly*, *white core*, or *white back* depending on the location of chalk on the kernel.

Red kernels, kernels with any degree of redness. The red seed coat (pericarp) is usually a firmly adhering bran.

Head rice, whole kernels and those not less than 3/4 of the size of a whole kernel.

Brokens, milled rice smaller than head rice but larger than brewers' rice or *binlid*.

Brewer's rice or *binlid*, portions of a kernel that will pass through a 4/64 sieve (1.587 mm).

Appendix 2. Standard grade requirements for Philippine milled rice.

Item	Premium grade (%)	Grade 1 (%)	Grade 2 (%)	Grade 3 (%)
Head rice	95 min	85 min	75 min	65 min
Brokens	4 max	12 max	20 max	28 max
Brewer's rice	1 max	3 max	5 max	7 max
Yellow and damaged	0.5 max	1 max	2 max	4 max
Chalky and immature	2 max	4 max	6 max	8 max
Paddy (no./100 g)	none	1 max	2 max	3 max
Other varieties	2 max	4 max	6 max	8 max
Red kernels	none	0.5 max	1.0 max	1.5 max
Foreign matter	none	0.25 max	0.5 max	1 max
Moisture content		Not greater than 14%		

Appendix 3. Definitions of variables used in the loss response functions.

To analyze the loss functions, the models considered a combination of quantity- and quality-oriented variables. Four measures were used as dependent variables in each model: threshing loss, total milling recovery, percentage of head rice, and milled rice grade. These variables are defined as follows:

THLOSS = amount of threshing loss per hectare, in kg;
MILLREC = total milling recovery expressed, in percent;
HDRICE = percentage of head rice in milled product; and
GRADE = numerical market grade of milled rice.

The independent variables considered in the model include post-production inputs, inferior-quality characteristics of paddy and milled rice, varietal characteristics, and interaction terms.

Inferior quality characteristics include

MC = moisture content, in percent
CrackK = percentage of cracked kernels
Othervar = percentage of other varieties of rice mixed with the grain under consideration
FermentK = percentage of fermented kernels
DamageK = percentage of damaged kernels
ChalkyK = percentage of chalky kernels
Redkernels = percentage of red kernels
Impurity = sum of percentage of chaff and weed seeds
Brokens = percentage of broken kernels in milled rice

Postproduction input variables include

PLTSIZE = area of plot included in the trials, in square meter
MDHVHA = man-hours harvesting per hectare
MDTHHA = man-hours threshing per hectare
MDDRHA = man-hours drying per hectare
ETHV = hours of elapsed time from harvesting to threshing
ETTH = hours of elapsed time from threshing to drying
ETDR = hours of elapsed time from harvesting to drying
Harvest = timeliness in harvesting
Thresh = alternative methods of threshing (mechanized vs traditional)
Handle = timeliness in handling
Clean = alternative methods of cleaning (traditional vs mechanical)
Dry = timeliness and method of drying
Region = Central Luzon or Bicol Region

Interactions between two independent variables include

ETHVDR = delay in harvest by delay in drying
ETHVTH = delay in harvest by delay in threshing
MDETTH = man-hours threshing by delay in threshing
MDETHV = man-hours harvesting by delay in harvesting
MDETDR = man-hours drying by delay in drying
MCRACK = moisture by cracked kernels
MCFRMENT = moisture by fermented kernels
CLENIMPU = clean by impurities
OVARED = other varieties by red rice
DAMCHALK = damaged kernels by chalky kernels
ETTHFERK = elapsed time from threshing to drying by fermented kernels
ETHVFERK = elapsed time from harvesting to threshing by fermented kernels
DRYFERK = dry by fermented kernels
THRHCRAK = thresh by cracked kernels
HANDCRAK = handle by cracked kernels
DRYCRACK = dry by cracked kernels
DRYDAM = dry by damaged kernels
HARVMC = harvest by moisture content
HARVFERK = harvest by fermented kernels
THRHMC = thresh by moisture content
THRHDAM = thresh by damaged kernels
HANDMC = handle by moisture content
HANDFERK = handle by fermented kernels
THRHBROK = thresh by broken kernels
THRHIMPU = thresh by impurities

The general Linear Models used in the physical and quality deterioration loss response functions were of the forms

(4-1) THLOSS = f (PLTSIZE, MDHVHA, ETHV, ETTH, thresh, clean region, ETHVTH, brokens, impurity, THRHBROK, THRHIMPU)

(4-2) HDRICE (Threshing) = f (crackK, damageK, chalkyK, fermentK, MC, harvest, handle, thresh, region, MDHVHA, MDTHHA, ETHV, HARVMC, THRHMC, THRHDAM, MDETHV)

(4-3) HDRICE (Drying) = f (ChalkyK, impurity, crackK, fermentK, damageK, harvest, handle, thresh, clean, dry, region, MDHVHA, MDDRHA, ETHV, ETDR, MDETHV, MDETDR, DRYFERK, ETTHFERK, DRYDAM, CLENIMPU, THRHCRAK, DRYCRAK)

(4-4) MILLREC (Threshing) = f (MC, chalkyK, impurity, crackK, fermentK, damageK, othervar, harvest, thresh, MDTHHA, ETTH, MDETTH, ETTHFERK, CLENIMPU, THRHCRAK, HANDCRAK, THRHBROK, MCRACK, THRHMC)

(4-5) MILLREC (Drying) = f (MC, chalkyK, impurity, crackK, fermentK, damageK, othervar, harvest, thresh, MDTHHA, ETTH, MDETTH, ETTHFERK, CLENIMPU, THRHCRACK, THRHBROK, MCRACK, THRHMC)

(4-6) GRADE (Threshing) = f (MC, fermentK, handle, clean, region, MDHVHA, ETHV, ETTH, maturity, ETHVTH, MDETHV, HANDMC, HANDFERK, ETTHFERK)

(4-7) GRADE (Drying) = f (MC, crackK, fermentK, harvest, handle, thresh, dry, region, MDHVHA, MDTHHA, MDDRHA, ETHV, ETDR, lodge, maturity, MCRAK, MCFRMENT, ETHVTH, ETHVDR, MDETHV, MDETTH, HARVMC, HARVFERK, ETHVFERK, DRYFERK, THRHCRACK, HANDCRAK, DRYCRAK)

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