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QUALITY PRESERVATION OF MOIST PADDY UNDER HERMETIC CONDITIONS

J.E. DONAHAYE,[1]* S. NAVARRO,[1] S. ANDALES,[2] ANGELITA M. DEL MUNDO,[3] FILIPINAS CALIBOSO,[2] GLORY SABIO[2] ANGELINA FELIX[3], MIRIAM RINDNER,[1] A. AZRIELI[1] and R. DIAS[1]

[1]Department of Stored Products, Agricultural Research Organization, The Volcani Center, Bet Dagan 50250, Israel [e-mail: jondon@netvision.net.il]*
[2]Bureau of Postharvest for Research and Extension (BPRE), CLSU Compound, Nueva Ecija, Philippines
[3] Institute of Human Nutrition and Food, College of Human Ecology, University of the Philippines, Los Banos, Laguna, Philippines

ABSTRACT

Two laboratory studies were carried out to evaluate the influence of hermetic storage on the quality conservation of paddy at different water activities. Five moisture content (M.C.) levels of paddy were used, namely, 14, 15, 16, 17 and 18% w.b., approximately corresponding to the following water activities: 0.75, 0.80, 0.85, 0.88 and 0.90 a_w. Quality evaluations were carried out after five storage periods, namely: 0, 1, 2, 3, 4 weeks for the first experiment and seven storage periods, namely 0, 1, 2, 3, 4, 5, 6 months for the second experiment. The entire study was undertaken at room temperatures of ~ 29° to 30°C prevailing in the Philippines. Cooked rice aroma, taste, tenderness, cohesiveness, color and gloss were found to be negatively correlated with moisture content (m.c.) and storage duration of the paddy. The poor acceptability and preference-scores for cooked milled rice samples from paddy stored hermetically at 16% to 18% m.c. was primarily dictated by the presence of fermented smell in these samples. In the raw form, wholeness of grains and color were found to have a significant negative correlation with m.c. and storage duration. Analysis of microfloral loads and bacteria revealed an increase in bacterial counts for the paddy held at 17% and 18% m.c.

Field trials using sealed flexible storage structures of 10 tons capacity were undertaken. It was clearly demonstrated that the rates of oxygen depletion in hermetically sealed 18% m.c. paddy could prevent mold proliferation. The effects of hermetic storage upon paddy quality were also evaluated using cooking and acceptability parameters obtained after 1, 3 and 6 months of storage. The findings indicated that after 1 month, quality of sealed paddy stored at 18% m.c. had not deteriorated perceptibly. However, further evaluations made on paddy stored hermetically for 1, 3 and 6 months under both laboratory and field conditions confirmed that after the first month of storage the quality of moist paddy (16-18% m.c.) deteriorated progressively and the grain was no longer acceptable to the taste panels.

INTRODUCTION

This study formed part of a project aimed at providing a solution to the acute problem in far-eastern Asia where paddy-rice is harvested at high moisture contents (m.c.) during the monsoon season. The paddy must then be dried rapidly to a safe m.c. in order to prevent it from molding and rotting. However, when quick-dried from about 30% to the required "safe" m.c., the grains suffer stress that results in cracking and breakage. To overcome this, a two-stage drying procedure has been advocated where the paddy is initially dried to an intermediate m.c. of 18%, at which stage, yeast and bacterial activity are suppressed, followed by a second stage drying from 18 to 14% m.c. to prevent the development of storage molds (Quitco, 1983; Mendoza and Quitco, 1984). Unfortunately, most farmers do not have flash dryers and consequently are obliged to sell their grain directly to the traders. Even where flash dryers are available, the paucity of second stage dryers creates a serious bottleneck at harvest time that results in considerable quality degradation.

The objective of this project was to develop a technology that would enable farmers to overcome this bottleneck at the second drying stage by providing them with a means of storing the intermediate m.c. paddy under tightly sealed conditions and thereby prevent spoilage for prolonged periods until drying by sun or machine is again an available option.

Flexible sealed plastic storage structures have already been developed and have proven suitable for outdoor storage of dry paddy (Navarro *et al.* 1996; Navarro *et al.* 1998a; Navarro *et al.* 1998b). However, before field trials could be carried out to evaluate the hermetic storage of intermediate m.c. paddy, it was deemed essential that this should be preceded by laboratory trials under controlled conditions that would include a comprehensive evaluation of quality parameters. These trials were undertaken both in the Philippines and in Israel and some aspects of the study have been published elsewhere (Donahaye *et al.*1998). The studies described below were carried out in the Philippines at the laboratories of the Bureau of Postharvest for Research and Extension (BPRE) at Munos, Nueva Ecija, and at the Institute of Human Nutrition and Food, University of the Philippines, Los Banos, (UPLB).

MATERIALS AND METHODS

Laboratory procedures

The sealed storage of paddy at intermediate moisture contents under laboratory conditions was undertaken at the Physical Laboratory of the BPRE. Two experiments were performed. The first was carried out over a 4 week period from January 15 to February 12, 1997, while the second experiment lasted for a duration of six months from October 7, 1997 to April 7, 1998. The objective of both experiments was to evaluate the time limits up to which hermetic storage can protect the paddy from quality deterioration.

Experimental stock. The rice variety IR-64, which is one of the most widely planted varieties in the Philippines, was used throughout. The experiments were undertaken at ambient laboratory conditions. Five moisture levels were investigated namely: 14, 15, 16, 17 and 18% m.c. (w.b.), which are approximately equivalent to water activities (a_w) of 0.75, 0.80, 0.85, 0.88 and 0.90, respectively. To achieve homogeneity, the paddy for each trial was obtained from batches that were harvested from a single farm plot. The paddy-stock was cleaned to 100% purity and then mixed thoroughly and divided into five equal lots that were conditioned to 14, 15, 16, 17 and 18% m.c., respectively.

Conditioning was done by adding distilled water to the different lots in quantities calculated to produce the required moisture contents, and each lot was then mixed thoroughly by rotation in capped plastic drums. The drums were then tightly sealed with circular metal band-clamps and transferred to a refrigerator at 2±1°C to suppress microfloral development during the equilibration process. Each drum was rotated and shaken for 2 to 3 minutes daily. After two weeks, the m.c. of each lot was checked twice weekly by the oven method until readings became constant. If the m.c. after stabilization differed from the target m.c. by more than 0.2%, an additional correction was made, either by adding a calculated amount of water, or by spreading the paddy on a flat surface to enable partial drying. Target moisture contents were reached after 2 to 4 weeks.

Experimental set-up. The lots of paddy conditioned to their targeted moisture contents were divided into 1.5 kg aliquots and placed in 3.5-L glass jars equipped with screw-on metal lids and gasket seals. To enable gas sampling, a hole was drilled in each lid through which plastic tubing was inserted and sealed to the lid with silicon sealer. Before closing, the rims of the jars were smeared with a thin layer of silicon grease to achieve a tight seal. In addition, part of the paddy-lot at 14% m.c. was placed in jars covered with filter paper to simulate unsealed storage conditions so as to provide control data. The jars were stored at ambient laboratory temperatures (averaging 28.7ºC and 29.8ºC during the first and second experiments respectively), for the desired storage durations, namely 0, 1, 2, 3, and 4 weeks in the first experiment, and 0, 1, 2, 3, 4, 5, and 6 months in the second experiment. Three replicates were used for each m.c. at each storage period.

The effects of the sealed storage on paddy quality were assessed by comparative analysis of samples taken at the beginning, and at the end of each storage period.

The storage parameters: To ascertain that sealed conditions were maintained during storage, the oxygen (O_2) and carbon dioxide (CO_2) concentrations were monitored using a "David Bishop OxyChek 2" analyser, and a "Gow Mac gas analyzer Model 20-600", respectively. These measurements were carried out at the end of each storage period. Ambient temperatures and relative humidities in the laboratory were monitored using an “ACR” data logger. Final moisture contents of the paddy samples were determined using an "OHAUS Grainweigh MB 301" instrument, while water activity was measured using a "Novasina MS1 Defensor".

Field trial procedures

Two outdoor trials were carried out at the BPRE campus.

In the first trial, the paddy used was freshly harvested IR-64 variety certified seed from a single farm lot. The m.c. ranged from 20.6 % to 21.3%. A day after receipt, the stock was sun dried to 17.0 to 18.3% m.c. The following day, two hundred and six bags were stacked and sealed in a 15 m^3 capacity "Volcani Cube®" according to a standard procedure developed earlier (Navarro *et al.*, 1996). In addition, two control stacks of 14% m.c. and 18% m.c. paddy were piled on wooden pallets and covered with ordinary white tarpaulin sheets only. Storage duration was for one month.

In the second trial five hundred bags of freshly harvested IR-64 variety certified seeds were purchased. The m.c. of the stock at procurement was 22.0% to 24.0%, and after mechanical drying ranged from 17.8% to 18.4%. A non-laminated and a laminated Volcani Cube were used to store the paddy. Two stacks of 18% m.c. and 14% m.c. paddy served as controls. All the Volcani Cubes whether laminated or not were covered with reflective awnings, whereas the control stacks were covered only with tarpaulins. Storage duration of one Volcani Cube and one control stack was for three months, and for the others, six months.

Storage parameters: Six thermocouple cables and two plastic tubes were installed at different locations inside the cubes to monitor grain temperatures and gas concentrations respectively. Changes in CO_2 and O_2 concentrations were measured daily.

Sampling: Initial samples were collected during the building of the stacks and final samples were collected at the end of the storage periods and analyzed at BPRE and UPLB as described below.

The samples for sensory evaluation were obtained as a composite sample of paddy withdrawn from bags in the 4th layers of the stacks. In addition, for the second trial, seven milled rice samples from the seven different layers of the Volcani cubes were sent to UPLB for both the 3 and 6 month quality evaluations. From each stack, a 3 kg composite sample of paddy was obtained from each layer, dried to 14% and milled, and 2 kg were sent to UPLB for evaluation of cooking parameters and sensory qualities.

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Quality evaluations undertaken at BPRE

Percent yellow kernels and Minolta b value.* Percent yellow kernels were determined from the ratio of the visually yellow kernels to the total samples. The Minolta b* value, a measure of the degree of yellowness of a substance, was measured using the "Minolta Chroma Meter CR-110".

Percent milling and headrice recovery: Percent milling and headrice recovery were determined from 200 g paddy sub-samples using a "Satake Grain Testing Mill". However, before milling, wet samples were dried using an "EUROTHERM Laboratory Mechanical Dryer".

Microfloral load: Isolation of fungi and assessment of microfloral load were carried out by direct plating. Ten paddy seeds randomly taken from each replicate were immersed in a 10% solution of sodium hypochlorite (NaOCl). After one minute, the solution was decanted, and the seeds were immediately rinsed with sterile water. These were then plated equidistantly using disinfected forceps on the following media: Dichloran Rose Bengal Chloramphenicol Agar (DRBC), AFPA agar, Dichloran Chloramphenicol Peptone Agar (DCPA), and Dichloran 18% Glycerol (DG18). As the name suggests, AFPA is for the isolation of *Aspergillus flavus* and *A. parasiticus* while DCPA is for *Alternaria, Fusarium* and other field fungi. *Eurotium* species can be isolated by DG18, while DRBC was the medium chosen for the isolation of *Penicillium* and other storage fungi. The media were incubated for 7 d at 30ºC.

Isolation and enumeration of bacteria were done by adding one g of paddy to 9 mL of sterile phosphate buffered saline in a test tube. The mixture was shaken for five minutes using a vortex apparatus. Afterwards, one mL of the liquid solution was diluted eight times. From each dilution, 0.1 mL of the suspension was plated on a solidified Tryptone Glucose Yeast extract Agar (TGYA). Growth of bacteria was evaluated after 24-48 hours of incubation at 30ºC. For purification, isolated single colonies of bacteria were transferred to TGYA slant.

Quality evaluations undertaken at UPLB

Two kg of freshly milled rice samples from each treatment were sent in sealed polyethylene bags from BPRE to UPLB at the beginning of the trials, and later, immediately after every sampling period.

Cooking trials: Replicated cooking trials (Del Mundo, 1991) were conducted on the same day that the samples were received from PBRE to measure optimum cooking water, height increase and cooking time.

Sensory evaluations: These were conducted the following day employing consumer panels. Fifty panelists and 30 panelists were chosen for the first and second laboratory experiments, and consisted of UPLB staff, while the field trials consisted of two groups of 50 panelists each, staff (UPLB) and farmers (BAY). The panelists were chosen based on their age (16-60 years old), and availability in all sessions.

Cooked sensory qualities such as aroma, color, flavor, tenderness, cohesiveness and gloss were compared among the experimental samples. The cooking and sensory assessments are not described in detail here but were conducted following the procedures of Del Mundo (1991).

Data calculation and analysis: The means of the replicated trials for the cooking parameters namely height increase and cooking time were computed for each sample. Raw data on the sensory evaluations of cooked rice were decoded and tabulated prior to data processing. Acceptability was calculated by dividing the number of "yes" responses by the total number of responses and multiplying the dividend by 100. A percent acceptability of 75% and above was considered acceptable. Preference score was expressed in scores of ranked data, following the procedure of Larmond (1985).

The total preference score obtained was divided by the number of judgments. This was done to make values comparable between presentations and panel size. A preference score of 1.03 was the highest attainable score. All positive preference scores were accepted.

Tests of normality were performed for all data gathered to identify the method of statistical analysis. Data on height increase, cooking time, percent acceptability and preference scores, which followed normal distribution, were subjected to analysis of variance using the F-test to determine treatment effects. The Duncan multiple range test was used to locate significant differences. On the other hand, the numeral scores of the descriptions for each sensory characteristic were found to deviate from the normal distribution curve. Differences across m.c.'s and storage durations were therefore analyzed using the Kruskal-Wallis 1-way ANOVA and the Friedman two-Way ANOVA, analyses respectively. Correlation among the different cooking parameters and sensory data was analyzed using the Spearman correlation and path analysis.

RESULTS AND DISCUSSION

Laboratory experiments

Yellowing and b value*: Changes in percent yellow kernels over the 28 day period of the first experiment, as visually assessed, and as measured by the Minolta Chroma meter, indicate an increasing trend in grain yellowing in all m.c. levels as storage progressed. In the second experiment of six months duration, levels of yellowing in all treatments were still acceptable at the end of six months, and under the 2% maximum yellowing limit set for Grade 1 milled rice by the National Food Authority (NFA) standards, except for paddy at 17% and 18% m.c., which were downgraded to Grade 2 (>2-4% maximum yellows) after 4 months storage at 17% m.c. and 5 months storage at 18% m.c.

Milling and headrice recovery: It was noted that from the start of the laboratory experiments, the milling and headrice recoveries were low. This condition could be brought about by grain conditioning which includes re-wetting and storage at very low temperature (2 ± 1°C). This process probably caused moisture stress leading to kernel fissuring and breakage.

Microfloral load: In the first laboratory experiment, the dominant fungal species observed from the samples prior to storage were *Aspergillus flavus* and *Fusarium oxysporum*. Other species observed but at low incidence were *A. fumigatus*, *Eurotium amstelodami*, *Fusarium poae* and *Syncephalastrum racemosum*. Fungal species such as *Eurotium chevalieri* and *Fusarium semitectum* were also isolated during the intermediate sampling periods.

The average initial infection in the various m.c. treatments ranged from 21% to 26%. After 28 days of storage, changes in total percent infection varied with m.c. levels. Average total percent infection in paddy at the lower moisture contents of 14% (sealed and unsealed), 15% and 16% increased, whereas for paddy at 17% and 18% m.c., they decreased to 18% and 13%, respectively.

The paddy samples conditioned to 17 and 18% m.c., were observed to have high initial infections of *A. flavus* (90 - 100%) and *F. oxysporum* (96.7-100%). whereas, paddy conditioned at 14, 15 and 16% were also found infected by *A. flavus* (10 - 70%), *A. fumigatus* (0-16.7%), *E. amstelodami* (0 - 6.7%), *F. poae* (0-6.7%), *F. oxysporum* (0 - 60%) and *S. racemosum* (0 - 3.3%).

At the end of the experiment, fungal infection in sealed paddy samples at 17 - 18% m.c. were significantly reduced. Percent fungal infection with *A. flavus* was reduced to 3.3 - 30% and with *F. oxysporum* to 0%. Fungal infection in the sealed paddy samples at 14, 15 and 16% MC did not significantly change, perhaps because the O_2 remained at slightly higher levels during storage period.

Results of the microbial analysis in the second laboratory trial (6 month duration) showed that initially, nine fungal species were found infecting the paddy, the most common species at all m.c. levels being *A. flavus, E. chevalieri, E. amstelodami, Mucor circinelloides* and *F. oxysporum*. Other less frequent fungi were *A. niger, A. fumigatus, Curvularia lunata* and *Neosatorya fischeri*. During the first three months, *Eurotium* species and *N. fischeri* were noted to be infecting paddy at the lower moisture contents (14% to 16%), while *A. oryzae* and *Penicillium citreonigrum* prevailed in paddy at 15% to 18% m.c. For the 4th and 5th months, *Aspergillus ochraceous* was prevalent in paddy at 15% to 17% m.c., while *E. amstelodami* and *E. chevalieri* remained infecting paddy at the lower moisture contents (14% and 15%).

It was shown that *A. flavus* was present at all moisture contents throughout the storage time. However, after 6 months, growth of *Eurotium* sp. and *N. fischeri* were suppressed. Non suppression of *Byssochalmys nivea* and *Penicillium* was observed at 18% m.c., implying that the modified atmosphere obtained by hermetic storage did not affect these species.

Bacterial populations rose sharply after a month of storage in paddy held at 18% m.c., while in the paddy at 17% m.c. this occurred after 2 months of holding. As a result, a strong foul odor developed in these grains.

Cooking trials. In the first laboratory experiment, the optimum cooking water of the milled rice from the paddy samples at the different moisture contents as well as that of the unsealed control were the same throughout the four weeks of storage. Each 80 g milled rice sample required 100 mL (1:1.25) cooking water.

Mean height increase across storage time was highest for the 17% m.c. sample (160.6%) and lowest for the control at 14% m.c. (143.8%). The height increase of all treated samples did not vary significantly but the control was significantly lower. A significantly greater height increase of the samples stored for 14, 21 and 28 days was shown, compared to that of the initial samples, and after 7 days of storage. A positive relationship between % height increase of milled cooked rice and storage duration of its paddy was established. This trend corroborates the earlier findings of del Mundo (1995) where it was found that the % height increase of milled cooked rice var: IR64 stored for 12 months as paddy was higher than that of samples stored as paddy for only three months.

Statistical analysis indicated that differences in cooking time of each treatment from 0 to 28 days of storage were insignificant. However, m.c. was found to directly affect cooking time, revealing a negative correlation. The highest mean cooking time (13.8 minutes) was recorded for the treated sample of 14% m.c., while the treated samples of 15% to 18% had lower cooking times ranging from 12.7 min to 13.4 min.

TABLE 1
Percent acceptability of milled cooked rice stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	% Acceptability			
Storage time	0 day ns	30 days ns	60 days**	90 days**
Control (14%m.c.) ns	98.0	96.0	96.0	94.0
Hermetic				
14% m.c. ns	100.0	96.7	96.7	96.7
15% m.c. **	93.3	93.3	93.3	80.0
16% m.c. **	96.7	96.7	90.0	73.3
17% m.c. **	90.0	90.0	60.0	43.3
18% m.c. **	93.3	90.0	56.7	30.0

ns - not significant at 5% level
** - significant at 5% level

Sensory evaluation: In the first and second laboratory experiments, for cooked rice, aroma, taste, tenderness, cohesiveness, color and gloss were negatively correlated with m.c. and storage duration. These characteristics became inferior at higher m.c levels and at longer storage periods. Among these attributes, aroma and flavor had the strongest negative correlation with m.c. and storage duration.

Table 1 and Table 2 reveal the poor acceptability and preference for cooked milled rice samples from paddy stored at 16% to 18% m.c. This was primarily dictated by the presence of fermented smell in these samples.

TABLE 2
Mean preference scores of milled cooked rice stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	Mean preference score			
Storage time	0 day **	30 days**	60 days**	90 days**
Control (14% m.c.) ns	0.06	0.42	0.34	0.37
Hermetic				
14% m.c. ns	0.49	0.51	0.51	0.68
15% m.c. ns	0.01	0.09	0.22	0.11
16% m.c. **	0.06	0.08	- 0.17	- 0.01
17% m.c. **	- 0.27	- 0.29	- 0.17	- 0.58
18% m.c. **	- 0.37	- 0.52	- 0.70	- 0.90

ns - non significant at 5% level
** - significant at 5% level

Acceptability scores above 75.0% are considered as being acceptable. Using this criterion it can be seen that after 30 days all moisture contents were still acceptable whereas after 60 days storage the 17% and 18% m.c., samples were unacceptable, and after 90 days the 16% m.c., sample was unacceptable. In the first laboratory experiment, all samples were rated acceptable at storage periods of 7, 14 and 21 days. Although considered as acceptable in the "Acceptability" evaluation, preference scores of the 17% and 18% m.c., samples revealed negative values even from the initial samples.

In the milled uncooked form, (Tables 3 and 4), wholeness of grains and color were found to have a significant negative correlation with m.c. and storage duration. Milled rice samples from paddy stored at lower moisture contents had a whiter shade of color and a higher proportion of whole grains compared to milled rice samples from paddy stored at higher moisture contents. As the durations of paddy storage increased and at the higher moisture contents, color of the rice tended towards a creamy to grayish shade and broken grains became more evident.

TABLE 3
Percent acceptability of milled raw rice, stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	% Acceptability			
Storage time	0 day ns	30 days ns	60 days**	90 days**
Control (14% m.c.) ns	96.0	100.0	96.0	96.0
Hermetic 14% m.c. ns	96.7	100.0	96.7	100.0
15% m.c. ns	90.0	96.7	93.3	93.3
16% m.c. ns	93.3	96.7	80.0	80.0
17% m.c. ns	93.3	93.3	80.0	70.0
18% m.c. **	86.7	86.7	76.7	63.3

ns - not significant at 5% level
** - significant at 5% level

TABLE 4
Mean preference scores of milled raw rice stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	Mean preference score			
Storage time	0 day **	30 days**	60 days**	90 days**
Control Sample (14% m.c.) ns	0.38	0.42	0.31	0.47
Hermetic 14% m.c. ns	0.51	0.49	0.48	0.79
15% m.c. ns	0.03	0.04	0.14	0.17
16% m.c. ns	-0.20	-0.04	- 0.01	- 0.21
17% m.c. ns	- 0.27	- 0.45	- 0.47	- 0.62
18% m.c. ns	-0.72	-0.77	-0.76	-0.86

ns - not significant 5% level
** - significant at 5% level

In the first experiment of one-month duration, correlation analysis revealed a positive relationship between % acceptability and length of storage. The acceptability of the milled cooked rice increased as duration of paddy storage lengthened to 28 days except for the 18% m.c. sample stored for 28 days. No correlation was established between % acceptability and moisture content. The second laboratory experiment showed that this absence of correlation was not sustained for longer storage durations.

Differences in preferences scores can be explained by the variations observed in terms of the sensory characteristics. The control, and the treated sample of 14% m.c. had positive preference scores compared to the other samples because these two samples were described better in terms of the various sensory characteristics compared to the other treatments. It was found that aroma, color and gloss were the characteristics most affected by m.c. and length of paddy storage. Both aroma and color were negatively correlated to m.c. whereas a, positive relationship was obtained between storage duration, aroma color and gloss. Not all the panel scores can be provided here, but Tables 5 and 6 showing the evaluation of aroma in cooked rice serves to illustrate this point.

TABLE 5
Mean aroma scores of milled cooked rice, stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	Mean value			
Storage time	0 day**	30 days**	60 days**	90 days**
Control (14% m.c.) ns	4.58	4.38	4.02	4.04
Hermetic				
14% m.c. ns	4.53	4.87	4.60	4.30
15% m.c. ns	4.47	4.43	4.30 (1)	3.33 (7)
16% m.c. **	4.30	4.17	3.87 (4)	2.86 (9)
17% m.c. **	4.10	4.23	2.30 (17)	1.77 (19)
18% m.c. **	3.90	4.03	2.06 (19)	1.37 (26)

ns - no significant difference at 5% level of significance
** - with significant difference at 5% level of significance
( ) - number of judges out of the 30 panelists who described the sample as having off odor

Field trials

Yellowing and b value:* In Trial 1, the average initial yellow kernels of the sealed stack and the two control stacks were 0.13%, 0.09% and 0.06%, respectively. After 31 days of storage, yellow kernels in the sealed stack significantly increased to 0.66%, the highest level being at the dampened topmost layer, which increased to 1.26%. In the control stacks, the yellow kernels significantly increased to 0.33% and 0.49%, respectively. As in the laboratory experiments, increase in yellow kernel levels did not exceed the 2% maximum limit set by NFA for Grade 1 milled rice (Anon. 1996). Also, the average b* value of the sealed stack increased from 9.6 to

10.6, while in one control stack the b* value at 9.7 did not change, while in the other it increased to 10.2.

TABLE 6
Mean aroma scores of milled uncooked rice, stored as paddy at different moisture contents and for different storage durations, (second laboratory experiment)

	Mean value			
Storage time	0 day ns	30 days**	60 days**	90 days**
Control (14% m.c.) ns	4.28	3.94	4.30	4.10
Hermetic				
14% m.c. ns	4.40	4.50	4.20	4.27
15% m.c. ns	4.20	4.03	4.00	4.17 (1)
16% m.c. ns	3.87	3.67	3.60 (3)	3.63 (3)
17% m.c. ns	3.97	3.93	3.63 (4)	2.80 (10)
18% m.c. ns	3.53	3.83	3.20 (8)	3.00 (8)

ns - no significant difference at 5% level of significance
** - with significant difference at 5% level of significance
( ) - number of judges out of the 30 panelists who described the sample as having off odor

Numerical Score:	Equiv. Aroma Description
1	With off odor
2	No aroma
3	Weak aroma
4	Moderately aromatic
5	Aromatic

In Trial 2, the same trend was observed. For the sealed stack opened after 93 days, average yellow kernels had increased from 0.9% to 1.1% and the b* value from 9.6 to 10.8. During the same period, yellow kernels and b* value in the two control stacks increased from 0.9% to 6.5% and from 9.7 to 11.2, respectively, and from 1.2% to 2.4% and from 9.5 to 10.2, respectively.

After 180 days of storage, the sealed stack was found to be heavily damaged, with an increased average yellow kernel and b* value from 1.2% to 25.3% and from 9.8 to 14.3, respectively at the top layer of the stack. Yellow kernel and b* value also increased from 1.0% to 14.4% and from 9.9 to 12.8, respectively at the middle layer of the stack. Yellowing and b* values in the control stacks also increased to 7.5%

and 11.9 and 2.6 % and 11.2, respectively. These observations in both field trials confirm the laboratory findings.

Milling and head-rice recovery: In Trial 1, after 31 days storage, average milling recovery of the sealed stack had decreased from 65.1% to 59.7% while in the control stacks it had decreased from 65.2% to 60.0% and 65.7% to 60.1% respectively. Likewise, head-rice recovery of the sealed stack decreased from an initial 80.7% to 65.9%, 62.4% and 38.8% at the bottom, middle and top layers, respectively while in the control stacks it decreased from 79.7% and 80.6% to 69.1% and 67.8%, respectively. The marked decrease at the top layer of the sealed stack may be attributed to an increase in m.c. as a result of convection currents to the surface and condensation.

In Trial 2, in contrast to Trial 1, the average milling recovery of the sealed stack increased from 65.0% to 66.4% after 93 days of storage and in the two control stacks it increased from 64.7% to 67.3% and from 66.1% to 67.7%. This may be attributed to biological aging, which usually occurs after 1-3 months of storage After 180 days storage, the average milling recovery of the sealed stack decreased from 65.6% to 59.8%, while head-rice recovery decreased from 80.2% to 79.1%. In contrast, milling and head-rice recovery of the control stacks increased to 65.6% and 90.2%, and 67.0% and 89.6%, respectively, and this may be attributed to a drying phenomenon since these small stacks under tarpaulins were exposed to prevailing winds, and "dried-out during" the dry season.

Microfloral load: In Trial 1, the initial fungal infections in the sealed stack, and control stacks were 12%, 12% and 10%, respectively. After 30 days, fungal infection in the sealed stack had decreased to 3% while the total percent fungal infection in the control stacks had increased to 15% and 20%, respectively.

In Trial 2, the stocks of paddy were initially found to be infected with *A. flavus, Curvularia lunata*, *P. citrinum* and *Neosatorya fischeri*. Overall, the final results indicated that after three months of gas-tight storage, the percentage occurrence of the above fungi had significantly decreased while after 6 months storage, the atmosphere inside the cube was able to suppress totally the growth of *A. flavus, C. lunata, P. citrinum* and *N. fischeri*.

However, bacterial counts revealed a significant increase in the top layer of the paddy stored for 3 months. Visual observation showed that microbial growth was high especially in the peripheries and topmost layer of the bag. This was probably due to the increase in moisture as evidenced by moisture migration to the uppermost layer of the stack.

From the paddy stored for 6 months, it was noted that the population of bacteria had significantly decreased. Possibly the prolonged high CO_2 concentration was detrimental to the growth of bacteria since most food spoilage organisms appear to be sensitive to high levels of CO_2 (Pitt and Hocking, 1997). However, these findings did not correspond with those of the laboratory trials where bacterial counts were still high after 6 months.

Cooking trials: Initial samples from all stacks showed that the optimum rice to water ratio was 1:1.25 (80 g milled rice to 100 mL water). This ratio did not change during storage. There was no significant difference in percent height increase of the cooked rice among samples during each storage period. Percent height increase ranged from 146.9% to 221.4%. Cooking time ranged from 15.4 to 18.4 min revealing an insignificant increasing trend in cooking time as paddy storage was prolonged.

Sensory evaluation: The many parameters examined separately by the consumer panels in their sensory evaluation of the paddy stored in the field trials are summarized by the acceptability and preference, and aroma, scores of the cooked rice samples given in Tables 7 to 9. The initial samples from the control stacks and from the sealed Volcani cubes were similar. After three months of storage, the tenderness and cohesiveness of the cooked rice from the different set-ups remained similar. There were also no significant differences in uncooked milled rice qualities such as wholeness of grains, grain translucency and grain brittleness across storage set-ups and duration. However, samples taken from the Volcani cube that was opened after 3 months had become inferior in terms of the other characteristics. There was a decrease in the overall rating for cooked rice flavor, color and gloss from initial time to third month of paddy storage. Similarly, the rating for uncooked milled rice color and gloss consistently declined after three and six months for the paddy stored in the Volcani cubes.

After 3 months, aroma of the sample from the Volcani cube was significantly inferior to the control samples (which had rapidly dried due to ambient ventilation as explained previously). Off odor, specifically a fermented smell was perceptible in both the cooked and uncooked milled rice. After six months storage, the milled cooked rice of samples taken from the Volcani cube were no longer presented for sensory evaluation due to a highly distinct fermented smell recorded during the cooking trials.

The sensory panels gave a mean of 35% acceptability for the cooked rice, and 51.6% for the milled uncooked rice for samples taken from Volcani cube after three months storage. These percentages were significantly lower than the acceptability of controls. After six months of storage, only three judges from the panels indicated acceptability for the raw sample of wet paddy stored in the Volcani cube

For preference scores, which rank the choice levels, the samples taken from the Volcani Cubes after 3 and 6 months received a consistent negative score in the cooked form as opposed to the control samples. Similarly, there was a notable decrease in preference score of uncooked milled rice from the initial test to 3 and 6 months storage. Scores for color, gloss, flavor, tenderness, cohesiveness, wholeness, brittleness, and translucency of the samples were also made, but although of value in themselves, they are not presented here, as they are subservient to the scores for acceptability and preference.

TABLE 7
Percent acceptability of milled cooked rice, stored as paddy at 14% and 18% moisture contents under field conditions - Trial 2

Set-up /samples	% Acceptability / Storage period / Panel					
	Initial samples		Three months		Six months	
	UPLB	BAY	UPLB	BAY	UPLB	BAY
Conventional Set-up						
14% m.c.	96.7	90.0	90.0	100.0	90.0	90.0
18% m.c.	100.0	93.3	80.0	83.3	73.3	83.3
Volcani cubes (18% m.c.)						
Stack 1	96.7	90.0	23.3	46.7	-	-
Stack 2	100.0	90.0	-	-	**	**

- no evaluation as per BPRE sampling design
** not evaluated due to a very strong fermented smell (off odor) established during cooking trials

TABLE 8

Mean preference of milled cooked rice, stored as paddy at 14% and 18% moisture contents under field conditions - Trial 2

Set-up/Samples	Mean Preference Score / Storage Period / Panel					
	Initial samples		Three months		Six months	
	UPLB	BAY	UPLB	BAY	UPLB	BAY
Conventional set-up						
14% m.c.	0.07	0.09	0.51	0.51	0.11	0.06
18% m.c.	0.16	0.18	0.28	0.06	-0.11	-0.06
Volcani cubes (18% m.c.)						
Stack 1	-0.25	-0.14	-0.79	-0.44	-	-
Stack 2	-0.18	-0.12	-	-	**	**

- no evaluation as per BPRE sampling design

** not evaluated due to a very strong fermented smell (off odor) established during cooking trials

TABLE 9
Mean aroma scores of milled cooked rice, stored as paddy at 14% and 18% moisture contents under field conditions - Trial 2

Set-up /Samples	Mean value / Storage period / Panel					
	Initial samples		Three months		Six months	
	UPLB	BAY	UPLB	BAY	UPLB	BAY
Conventional set-up						
14% m.c	4.0	4.4	3.5	4.2	3.6	4.0
18% m.c	4.0	4.5	3.3	3.6	3.2	4.0
Volcani cubes (18% m.c.)						
Stack 1	4.0	4.0	1.5	2.0	-	-
Stack 2	4.0	4.0	-	-	**	**

- no evaluation as per BPRE sampling design
** not evaluated due to a very strong fermented smell (off odor) established during cooking trials

CONCLUSIONS

From the above laboratory and field trials, it was agreed among the project investigators that the following storage durations can be recommended for intermediate m.c. storage of paddy in hermetically sealed Volcani Cubes:

For 18% and 17% m.c. paddy, storage can be prolonged for one month. Perception of a fermented smell was very evident in the cooked form after 2 months. Other cooked qualities such as flavor, color and gloss as well as the raw qualities of color, wholeness of grains and translucency became inferior beyond one month of paddy storage.

For 16% m.c. paddy, storage can be extended to two months. Significant negative changes in cooked rice aroma as well as in such qualities as color and gloss in both cooked and raw forms were observed at above two months of paddy storage. Other sensory qualities changed slightly after more than two months of storage.

For 15% m.c. paddy, storage can be extended to three months. Slight changes in sensory qualities with an off-odor slightly perceptible in the cooked form were noted after three months of storage.

The hermetic storage under hypoxic conditions of about 1% O_2 or less, needed to arrest mold development, can be obtained using a well sealed standard Volcani cube. The moisture migration phenomenon experienced in outdoor storage, which is exacerbated at intermediate m.c.'s, can be strongly reduced using reflective covers, provided they are correctly placed over the cubes.

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