Effects of Storage Time, Storage Temperature, and Packaging Method on Shelf Life of Brown Rice

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Cereal Chem. 63(3):247–251

ABSTRACT

Brown rice was stored either in heat-sealed two-ply laminated polyethylene bags, in sealed polyethylene bags sealed in metal cans, or in perforated bags in a metal can sealed under vacuum at 3, 22, or 38°C. Samples were evaluated each month for nine months for development of off-odors and off-flavors by sensory evaluation. Tests were also run to evaluate changes in conjugated diene hydroperoxide and free fatty acid levels. Storage of brown rice at 3°C resulted in lower levels of free fatty acids and less change in odor and flavor than at the higher temperatures. No advantage was found in placing the sealed polyethylene bag in a metal can or vacuum sealing the metal can compared to sealing in polyethylene bags. The combination of 3°C storage temperature and a sealed polyethylene bag provided the best shelf life for brown rice.

Brown (unmilled) rice has a higher nutrient content than milled rice (Kennedy 1980). However, direct consumption of brown rice only accounts for approximately 1.5% of domestic directly consumed rice (Holder and Smith 1978). Consumer preference for milled rice and short shelf life of dehulled unmilled rice have been implicated as deterrents to the amounts of brown rice packaged for direct consumption (Schutz and Fridgen 1974).

Various methods of brown rice storage have been tested to determine what temperature, atmosphere, and kind of packaging prolongs shelf life. Storage at cool temperatures has been shown to slow deterioration in brown rice and extend its shelf life (Mitsuda et al 1972, Sowbhagya and Bhattacharya 1976, Ory el al 1980). Brown rice stored under modified atmospheres such as carbon dioxide flushing and under vacuum have also been shown to undergo slow changes in odor and flavor (Ory et al 1980, Santoprete 1980).

Packaging can be used to influence the storage stability of brown rice. Various plastic films for storage of milled rice were studied by Tai et al (1981). A polyethylene and nylon combination film was found to be most suitable for long-term storage of milled rice both under vacuum and with carbon dioxide flushing.

This study was undertaken to determine the effect of storage time, storage temperature, and packaging method on the shelf life of brown rice.

MATERIALS AND METHODS

Rice Packaging and Storage

Long-grain Starbonnet brown rice was obtained from Pioneer Foods Industry, Inc., DeWitt, AR. The rice had been stored under unknown conditions for eight months before hulling. After hulling the rice was stored for one week in a commercial elevator at a temperature of less than 15°C. Two-ply polyethylene laminated film bags (Dazey Seal-A-Meal) were filled with 100-g portions of rice and were heat sealed. Three packaging methods for storage were used: 1) heat-sealed laminated bag (bag samples), 2) heat-sealed laminated bag sealed in a 211 × 304 metal can (can samples); and 3) punctured heat-sealed laminated bag sealed in a 211 × 304 metal can under 15.5 cm of vacuum (vacuum samples). The samples for each type of package were stored at three different temperatures for nine months: 3°C, room temperature (approximately 22°C), and 38°C. All samples were stored in the dark except during sample removal and periodic inspection. No humidity control was used for any of the storage treatments. Rice used as the control for sensory evaluations was stored at −12°C in polyethylene bags.

Sensory Evaluation

Sensory evaluation of the samples included both odor and flavor evaluations. The duo-trio method (Larmond 1977) was used to detect differences in odor and flavor between a control sample and the stored sample. A 20-member sensory panel composed of faculty, staff, and students from the Department of Food Science at the University of Arkansas judged the samples.

Only two samples randomly chosen from the nine storage treatments were evaluated on the same day. For both odor and flavor evaluations, all nine storage treatments were compared to the control over a two-week period within each month over the nine-month testing period. A reference sample and two coded samples were presented simultaneously for each of the two storage treatments. The panelists received four duo-trio tests at each setting—two for odor and two for flavor—and the tests were presented in succession. Half the time the stored sample was used as the reference and half the time the control sample was used as the reference. A three-digit random number code was used to identify the samples, and the order of sample presentation was randomized. Panelists were asked to rinse their mouths with water between duo-trio flavor tests.

Fluorescent lights in the testing area were covered with red cellophane, and containers used in odor evaluations were covered with cheese cloth to mask any possible color differences in the rice. Testing was conducted either in the midmorning or midafternoon in individual booths. Sensory evaluation data were tabulated by recording the number of correct responses out of the total, and tables of significance were used to analyze the data (Larmond 1977).

Panelists were asked to evaluate odor first because odor is the first stimulus perceived in acceptance of a food product. For the odor evaluation, plastic 3.4 × 6 cm containers with plastic snap-on lids were filled to within 1.5 cm of the top with raw rice. The sides of the containers were covered with brown construction paper, and the mouth of the container was covered with cheesecloth to further mask visual differences. The panelists removed the lid and smelled the samples to evaluate the odor.

To evaluate flavor, 120 g of rice from each of the storage treatments and 240 g of control sample were cooked. Sixty grams of uncooked brown rice and 120 ml of distilled water were measured into 250-ml beakers. Two beakers of rice from each storage treatment and of the control sample were placed in one of two Toshiba automatic rice cookers, model RC-100A (Toshiba Corp., Japan). Each rice cooker contained 400 ml of distilled water and was connected to an automatic timer. The rice was cooked 40 min and left to stand 15 min after the cooker was shut off. The pans of the rice cookers were removed from the heating element and placed in a 60°C water bath and were covered except when serving. Rice portions of approximately two teaspoons each were placed on coded 23-cm white plastic plates and served with plastic spoons.

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Analytical Evaluation

To measure brown rice stability, analytical tests were conducted on moisture, vacuum, conjugated diene hydroperoxides (CDHP), and free fatty acids (FFA). All analytical tests were conducted monthly except for the FFA analysis which was conducted on the samples that had been accumulated and stored at −12° C until the end of the nine months. The chemical analyses were analyzed as factorials by analysis of variance using the SAS statistical package (SAS Institute, Inc., Cary, NC). Significant differences between means were separated by the least significant difference (Snedecor and Cochran 1971). Simple correlations for all data, including the sensory data, were calculated (Steel and Torrie 1960). Moisture levels of the samples were determined after four months and each subsequent month of storage using a Delmhorst crop moisture detector model G-6C. Vacuum was determined on the cans sealed in a vacuum using a Marshalltown (USA) vacuum gauge.

CDHP content was determined by the method of St. Angelo et al (1972). The samples were ground in a Udy cyclone sample mill (Udy Corp., Boulder, CO) to pass through a 20-mesh screen. Duplicate ground samples of approximately 2 g were extracted with high-performance liquid chromatography grade hexane for 30 min, and the amount of oil in the extract was determined from a 5-ml aliquot. A Varian 640 double-beam spectrophotometer was used to determine absorbancy at 234 nm using hexane as the reference. An A_s of 24,500 mol·liter^{-1}·cm^{-1} was used to calculate the concentration of conjugated diene hydroperoxides in micromoles per gram of oil (Johnston et al 1961). Free fatty acids content of the rice samples was determined by the AOCS official method with modifications (AOCS 1982). Samples were prepared by grinding approximately 20 g of each sample in a cyclone sample mill. Each sample was extracted with 125 ml of petroleum ether for 1 hr with constant stirring. The samples were filtered through Whatman No. 1 filter paper, and duplicate 50-ml samples were taken. A 5-ml aliquot was taken to determine the oil content of the filtrate. After petroleum ether was evaporated under a hood, approximately 30 ml of neutralized 99% ethanol with 1 ml phenolphthalein indicator was added to the oil sample. The sample was titrated with 0.01 *N* NaOH until a faint pink color persisted for 1 min. Free fatty acids content was calculated as oleic acid and expressed as percent of oil.

RESULTS AND DISCUSSION

Sensory Evaluation

The detection of differences between odors of the control and the stored rice samples was not consistent throughout the nine months of storage. A difference in odor once detected was not necessarily noted throughout the remainder of the storage period. When the samples were stored at 3° C, a difference in odor was detected at month 3 for bag and vacuum samples (Table I). Differences in odor also were detected for the bag samples at months 5, 6, and 9 of storage and for the vacuum samples at months 4 and 7. A difference in odor was detected in the can samples only at month 7 of storage. When samples were stored at 22° C a difference in odor was detected in the bag and can samples from the first month throughout the test period with the exception of month 5. A difference in odor was detected in the vacuum samples beginning at month 3 and continuing through month 8; no difference was detected in month 9. A difference in odor from the control sample was found for most of the nine months for all packaging methods. The bag sample at month 3 and vacuum sample at month 9 were shown to be not significantly different from the control sample.

There was no difference in flavor detected at 3° C storage for the bag sample up to month 8 or after month 4 for the can sample (Table II). The vacuum samples differed from the control sample in flavor at months 4, 6, 7, and 9. Samples stored at 22° C did not show a consistent difference from the control sample in flavor, except all three packaging methods were different from the control at month 9. At the 38° C storage temperature, the can samples were different in flavor for months 3–9. Differences in flavor from the bag samples were found from months 5 to 7 and for the vacuum samples at months 6 and 9.

Fewer differences were detected in flavor evaluation than in odor evaluations. Changes in flavor and odor seemed to be slowed by storage at cooler temperatures, and the effect of temperature appeared to be greater on odor than on flavor. A difference in odor was noted beginning at month 1 for some samples stored at 22° C and 38° C and was consistent for most of the storage period, whereas differences in flavor detection were less often in the same samples. Odor differences may have been more readily detected because some of the volatiles responsible for the sensory changes were lost when the rice was cooked. D. Kohlwey (*personal communication*) suggested that much of the oxidized flavor was lost in the cooking of brown rice flour. Ory et al (1980) reported that no rancid or off-odors developed in brown rice stored for seven months of storage at 4 and 24° C in plastic and laminated films with and without CO_2. The results of the duo-trio test shown in Table I indicated that a difference in odor was detected between some of the stored and control samples, but the results do not indicate whether the difference was specifically rancidity or off odor. The use of a control sample could account for detectable differences in this study. Ory et al (1980) sampled on a two-month schedule; in this study, monthly sampling was conducted. Because of the inconsistency of detection of differences, it is conceivable that differences were missed in the study by Ory et al.

Analytical Evaluation

The moisture content of the samples did not vary with storage time, packaging method, or temperature. A moisture level of 11.4

TABLE I
Number of Correct Responses[a] for Odor Differences of Brown Rice as Measured by the Duo-Trio Test

Storage Temperature/ Packaging Method	Months of Storage 1	2	3	4	5	6	7	8	9
3°C									
Bag	14	12	15	13	16	17	11	11	17
Bag + can	13	13	13	13	13	10	18	13	13
Bag + can + vacuum	9	11	15	17	12	14	16	8	13
22°C									
Bag	16	17	16	18	10	17	16	17	18
Bag + can	16	17	18	15	14	16	15	17	15
Bag + can + vacuum	12	13	19	15	18	18	15	16	12
38°C									
Bag	20	19	14	18	17	17	20	19	19
Bag + can	18	16	18	15	18	19	16	20	17
Bag + can + vacuum	16	17	16	18	18	17	18	18	14

[a]Number of correct responses are out of a total of 20 judgments. Fifteen correct judgments were the minimum needed for a significant difference ($P < 0.05$).

TABLE II
Number of Correct Responses[a] for Flavor Differences of Brown Rice as Measured by the Duo-Trio Test

Storage Temperature/ Packaging Method	Months of Storage 1	2	3	4	5	6	7	8	9
3°C									
Bag	10	9	10	14	8	11	12	11	19
Bag + can	17	13	16	12	14	12	13	14	12
Bag + can + vacuum	10	11	10	16	13	15	15	14	15
22°C									
Bag	13	16	12	14	12	14	13	12	15
Bag + can	10	11	16	12	15	11	11	15	16
Bag + can + vacuum	12	12	12	12	12	14	11	11	16
38°C									
Bag	11	12	11	13	17	15	18	14	14
Bag + can	10	11	15	15	15	15	18	18	17
Bag + can + vacuum	10	14	13	14	12	16	12	12	16

[a]Number of correct responses are out of a total of 20 judgments. Fifteen correct judgments were the minimum needed for a significant difference ($P < 0.05$).

±0.2% was maintained in all samples from month 4 through month 9. A vacuum of 15.5 cmHg was found in the samples sealed under vacuum.

The results of the analysis of variance conducted on the chemical tests for conjugated diene hydroperoxides (CDHP) and FFA in the stored brown rice showed that all main effects and interactions were significant at the 0.05 level. Extended storage resulted in fluctuating CDHP and FFA values. Ory el al (1980) reported that the CDHP level of stored brown rice peaked at five months of storage, then decreased at seven months, whereas FFA levels steadily increased throughout the storage period. CDHP levels showed fluctuation in this study (Table III) with peaks occurring at months 2 and 7. FFA values also had fluctuating peaks at month 3 and month 9. CDHP did not increase as the storage temperature increased from 3 to 22°C but did increase with the change of temperature from 22 to 38°C, whereas FFA levels increased with each increase in temperature. As a main effect, packaging method showed a difference in CDHP levels between bag and vacuum samples with can samples not differing from either. FFA level for bag samples was lower than levels for can or vacuum samples, which were not different.

Interactions between storage time and storage temperature (Fig. 1) show that CDHP values for each storage temperature fluctuated in different patterns as storage time progressed. CDHP values increased between months 1 and 2 and decreased between months 2 and 3 regardless of the storage temperature. CDHP values for all storage temperatures increased sharply between months 6 and 7 and declined sharply between months 8 and 9. The percentage of FFA in oil (Fig. 2) also showed similarities and dissimilarities. The percentage of FFA for all three storage temperatures increased between months 1 and 3 and decreased between months 3 and 4. Beyond month 4 the patterns for percentage of FFA were dissimilar. Except for month 1 (when samples stored at 22 and 38°C were not different), month by month comparison showed samples stored at 3°C had a lower percentage of FFA than those stored at 22°C, which in turn had lower FFA levels than the samples stored at 38°C.

Interactions between storage time and packaging method showed much fluctuation in CDHP pattern as storage time increased (Fig. 3). As previously mentioned for storage temperature, there were periods when CDHP values from samples

TABLE III
Main Effects of Storage Time, Storage Temperature, and Packaging Method on Levels of Conjugated Diene Hydroperoxides (CDHP) and Free Fatty Acids (FFA) in Brown Rice

Variable	CDHP[a] (μmol/g oil)	FFA[a] (%)
Storage time (months)		
1	20.8	6.81
2	21.7	7.42
3	19.7	9.17
4	19.8	8.53
5	19.7	8.73
6	20.4	8.95
7	23.0	8.31
8	22.4	9.06
9	19.9	9.67
LSD (0.05)	0.96	0.146
Temperature (°C)		
3	20.2	5.81
22	20.0	8.31
38	21.9	11.58
Packaging method		
Bag	21.0	7.67
Bag + can	20.8	8.92
Bag + can + vacuum	20.3	8.97
LSD (0.05)	0.55	0.084

[a] Means within main effect block pooled over other variables.

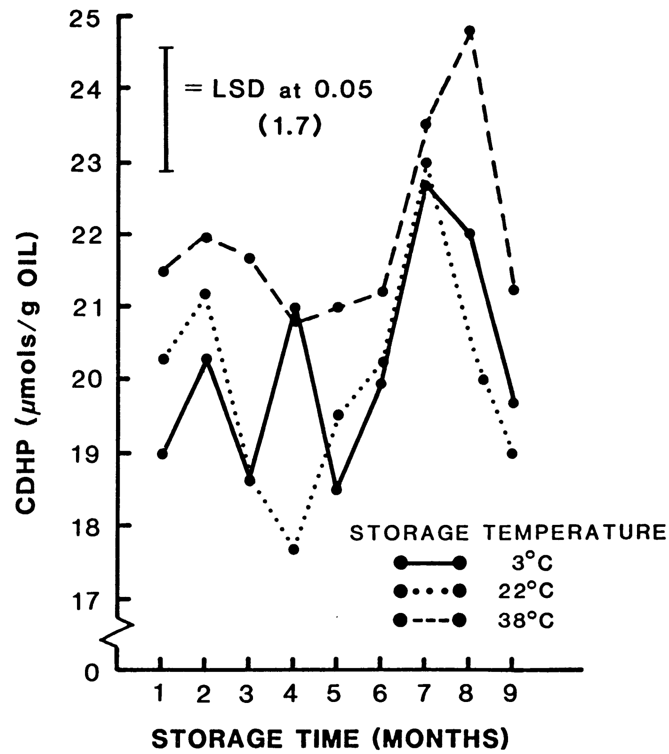

Fig. 1. Interactive effects between storage time and storage temperature pooled across packaging methods on levels of conjugated diene hydroperoxides (**CDHP**) in brown rice.

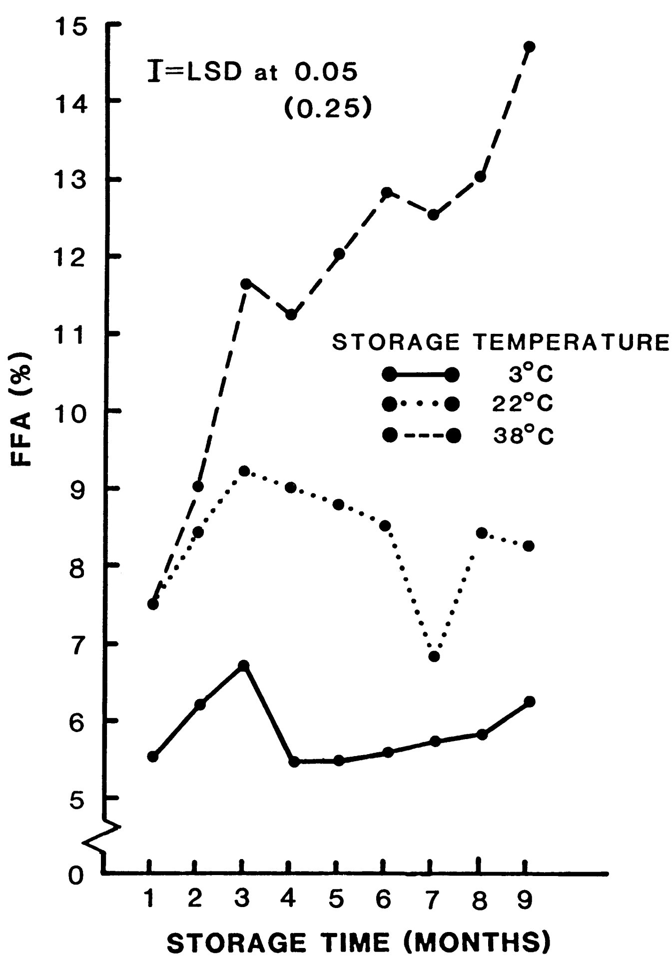

Fig. 2. Interactive effects between storage time and storage temperature pooled across packaging methods on levels of free fatty acids (**FFA**) in brown rice.

of all three packaging methods exhibited similar graphic patterns. The CDHP values for all three packaging methods decreased between months 2 and 3, increased between months 6 and 7, and decreased between months 8 and 9. Other than for these periods, the CDHP values were not meaningful except that a cyclic pattern was displayed for each packaging method as storage time increased. After month 3, the samples packaged in the bags alone had lower FFA levels in the oil (Fig. 4) than did the samples in either of the two other packaging methods. The percentage of FFA in the samples for all three packaging methods fluctuated greatly as storage time increased.

Interactions between storage temperature and packaging methods (Fig. 5) showed that bag and vacuum samples displayed somewhat similar cyclic patterns in CDHP values as the temperature increased, whereas the CDHP values of samples packaged in cans increased as the storage temperature increased. The percentage of FFA (Fig. 6) in samples from all three packaging methods increased as storage temperature increased from 3 to 22° C but decreased in the bag samples as the temperature increased from 22 to 38° C, whereas the percentage of FFA in the can and vacuum samples continued to increase. The FFA levels for all three packaging methods were lowest when the rice was stored at 3° C. Although storage at 38° C greatly increased the FFA level of the bag samples, the increase was much more dramatic in the can and vacuum samples.

Increases in CDHP and FFA levels from increased temperatures have been previously reported (Mitsuda et al 1972, Sowbhagya and Bhattacharya 1976, Ory et al 1980). Data collected in this study showed that CDHP levels increased in samples packaged in cans but fluctuated in samples packaged in bags and vacuums (Fig. 5). FFA levels of samples packaged in cans and vacuums increased while levels for samples packaged in bags initially increased, then decreased as the storage temperature increased. Data shown in Figure 1 indicate that CDHP levels fluctuated at different rate cycles as storage time increased; therefore, from a specific sampling (month 4) samples stored at 3° C contained a higher CDHP level than did samples stored at 22° C. At month 7 there were no differences in CDHP among samples stored at all three temperatures. The previously reported storage temperature effect on the level of FFA held true for this study (Fig. 2) but increased storage time did not always result in increased FFA levels.

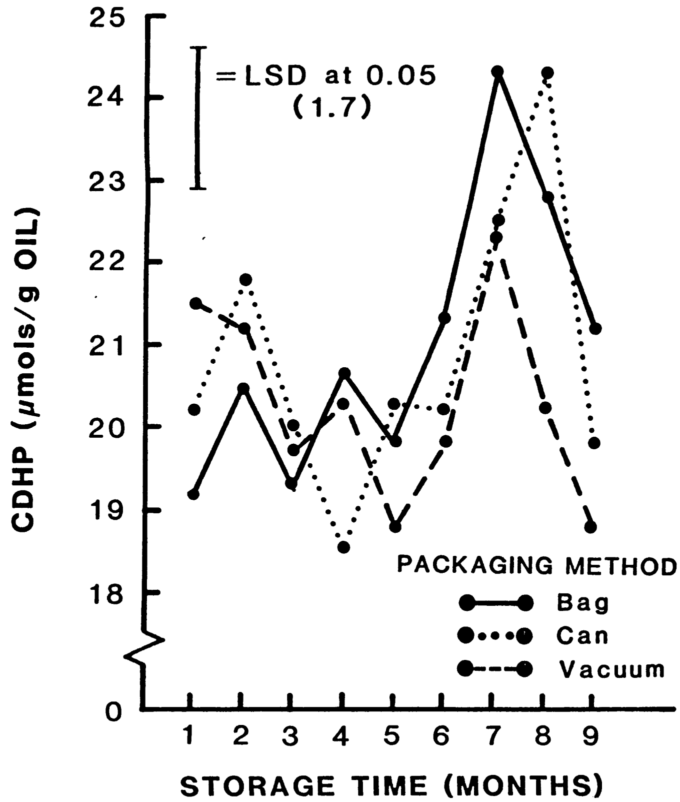

Fig. 3. Interactive effects between storage time and packaging method pooled across storage temperatures on levels of conjugated diene hydroperoxide (**CDHP**) in brown rice.

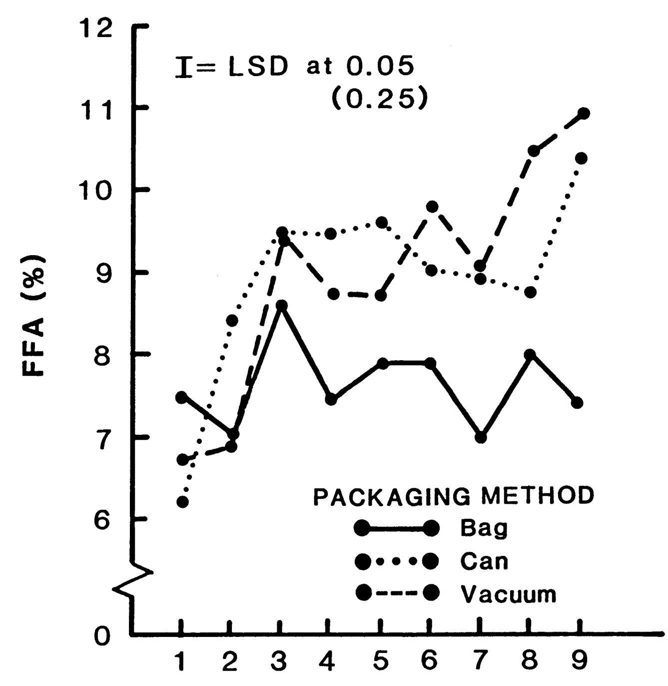

Fig. 4. Interactive effects between storage time and packaging method pooled across storage temperatures on levels of free fatty acids (**FFA**) in brown rice.

Relationship of Sensory and Analytical Evaluation

Simple correlations for sensory evaluations, CDHP, and FFA showed some significant relationships; however, none were strong enough to be meaningful as single predictors (Table IV). The most significant relationship was between percentage of FFA and odor evaluations. Although this relationship was statistically significant, FFA levels accounted for only 18% of the variation in odor responses, which was too low for practical consideration. Data in this study did not explain the sporadic detection of off-odor and

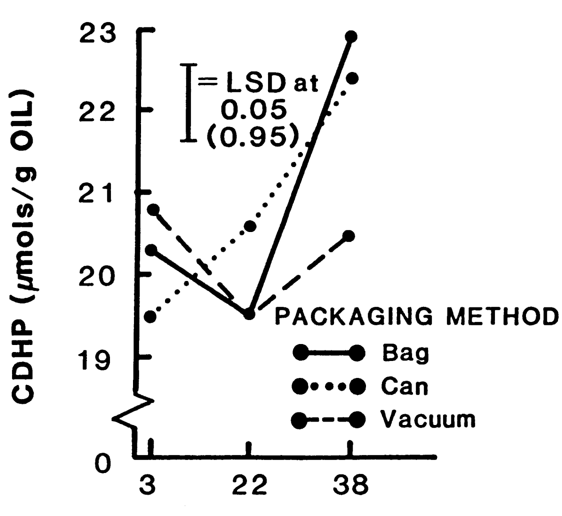

Fig. 5. Interactive effects of storage temperature and packaging method pooled across storage times on levels of conjugated diene hydroperoxide (**CDHP**) in brown rice.

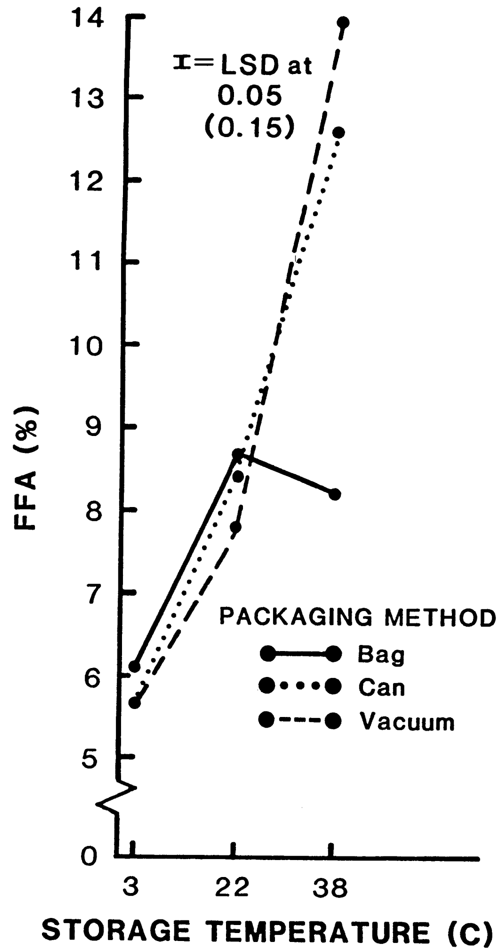

Fig. 6. Interactive effects of storage temperature and packaging method pooled across storage times on levels of free fatty acids (**FFA**) in brown rice.

off-flavor as storage time increased. Hydroperoxides are not responsible for rancidity, off-odors, and off-flavors, but secondary products such as volatiles, polymers, and oxygenated compounds contribute to flavor deterioration (Lundberg 1962, Gardner 1975, DeMan 1980). Therefore direct cause and effect for odor and flavor changes could not be determined.

CONCLUSION

The storage of brown rice samples at 3°C resulted in fewer samples being rated as different in odor than samples stored at either 22 or 38°C. Evaluation of flavor differences showed samples stored at 3 and 22°C were similar in the number of samples detected as different whereas samples stored at 38°C were much more often detected as being different from the control. No difference was noted in the number of samples detected as being different in odor development between the packaging methods, but the frequency of samples detected as being different in flavor was higher in samples stored in cans than samples stored in either bag or vacuum. CDHP levels varied regardless of storage temperature and packaging method as the storage time increased and the cyclic patterns of fluctuation were of uneven length. The free fatty acid levels were more consistent. Free fatty acid levels increased rapidly as the storage temperature increased. Samples stored in bags contained lower levels of FFA than did samples stored in cans or under vaeuum. CDHP and free fatty acid levels of the stored brown rice were not useful in predicting the development of off-odors or off-flavors. The best storage time and packaging method for brown rice in this study were 3°C storage temperature and polyethylene film bag.

TABLE IV
Simple Correlation Coefficients for Odor, Flavor, Conjugated Diene Hydroperoxides (CDHP), and Free Fatty Acids (FFA) of Stored Brown Rice[a]

	Odor	Flavor	CDHP	FFA
Odor	1.00			
Flavor	0.257*[b]	1.00		
CDHP	0.269*	0.254*	1.00	
FFA	0.424**	0.243*	0.146	1.00

[a] $n = 81$.
[b] *, ** Significant at the 5 and 1% levels, respectively.

LITERATURE CITED

AMERICAN OIL CHEMISTS SOCIETY. 1982. Official and Tentative Methods. 3rd ed. The Society: Champaign, IL.

DeMAN, J. M. 1980. Principles of Food Chemistry. Avi Publ. Co.: Westport, CT.

GARDNER, H. W. 1975. Decomposition of linoleic acid hydroperoxides. Enzymic reactions compared with nonenzymic. J. Agric. Food Chem. 23:129.

HOLDER, S. H., and SMITH, A. 1978. An analysis of U.S. rice distribution patterns. USDA ESCS Agric. Econ. Rep. No. 413. USDA: Washington, D.C.

JOHNSTON, A. E., ZILCH, K. T., SELKE, E., and DUTTON, H. J. 1961. Analysis of fat oxidation products by countercurrent distribution method. V. Low-temperature decomposition of methyl linoleate hydroperoxide. JAOCS 38:367.

KENNEDY, B. M. 1980. Nutritional quality of rice endosperm. Page 462 in: Rice Production and Utilization. B. S. Luh, ed. Avi Publ. Co.: Westport, CT.

LARMOND, E. 1977. Laboratory methods for sensory evaluation of food. Publ. 1637. Canada Dept. Agric.: Ottawa, Canada.

LUNDBERG, W. 0. 1962. Mechanisms. Page 31 in: Symposium on Foods: Lipids and Their Oxidation. Avi Publ. Co.: Westport, CT.

MITSUDA, H. F., KAWAI, F., and YAMAMOTO, A. 1972. Underwater and underground storage of cereal grains. Food Teohnol. 26(3):50.

ORY, R. L., DELUCCA, A. J., ST. ANGELO, A. J., and DUPUY, H. P. 1980. Storage quality of brown rice as affected by packaging with and without carbon dioxide. J. Food Prot. 43:929.

SANTOPRETE, G. 1980. Preservation of slightly milled rice. Riso 29:61.

SCHUTZ, H. G., and FRIDGEN, J. D. 1974. Consumer preference research on rice: Ranking description for improved products. Food Prod. Develop. 8(1):75.

SNEDECOR, G. W., and COCHRAN, W. G. 1971. Statistical Methods. The Iowa State University Press: Ames, IA.

SOWBHAGYA, C. M., and BHATTACHARYA, K. R. 1976. Lipid autoxidation in rice. J. Food Sci. 41:1018.

ST. ANGELO, A. J., ORY, R. L., and BROWN, L. E. 1972. A comparison of minor constituents in peanut butter as possible source of fatty acid peroxidation. J. Am. Peanut Res. Educ. Assoc. 4:186.

STEEL, R. G. D., and TORRIE, J. H. 1960. Principles and Procedures of Statistics. McGraw-Hill: New York.

TAI, C. C., LI, K. H., GUO, M. S., LI, C. F., CHAO, R. S., and CHEN, S. C. 1981. Storage of milled rice in plastic bags flushed with carbon dioxide or in vacuum. Food Ind. Res. Dev. Inst., Res. Rep. No. E-18. (In Food Sci. and Technol. Abstr. 1983. 15(1):1M41).

[Received September 25, 1985. Revision received November 26, 1985. Accepted December 2, 1985]