Storage Stability of Flour-Blasted Brown Rice

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ABSTRACT

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Brown rice was blasted with rice flour rather than sand in a sand blaster to make microperforations so that water could easily penetrate the brown rice endosperm and cook the rice in a shorter time. The flour-blasted American Basmati brown rice, long-grain brown rice, and parboiled long-grain brown rice samples were stored in Ziploc storage bags under atmospheric conditions and in vacuum-packed bags. They were periodically tested for over 10 months for changes in water absorption, free fatty acid (FFA), peroxide value (POV), viscosity changes of flour using the Rapid ViscoAnalyser (RVA), and texture of whole cooked kernel using a texture analyzer during cooking. Flour-blasted brown rice absorbed less water but needed less cooking time than its counterpart that was not flour-blasted. There was an increase in FFA, POV, peak viscosity (PV), final viscosity (FV), breakdown viscosity (BD), and setback viscosity (SB) during storage of flour-blasted brown rice for 300 days, but no change was observed in texture (hardness, gumminess) and water absorption. The combined coefficient of correlation (including all types of rice) between FFA and FV is $r = 0.86$ and between FFA and SB is $r = 0.90$ at $P < 0.0001$.

An environmentally friendly process for quick-cooking brown rice has been developed that involves blasting the rice with a high velocity abrasive particulate (parboiled rice flour) to create microperforations (i.e., nicks, holes, or cuts) in the water-resistant outer bran layers that, in turn, allow water to more quickly penetrate the layers, resulting in faster cooking times (Guraya 2003). An earlier study reports the optimal conditions for producing a quick-cooking brown rice (Guraya 2011).

Putting microperforations in the outer bran layers has potential for increasing the susceptibility of the rice lipids to hydrolytic and oxidative deterioration. In the intact rough rice kernel, lipases are dormant because the enzyme and its substrates (lipids) are not in contact due to compartmentalization (Shastry and Rao 1971). Dehulling rice disrupts these outer layers, lipids diffuse to make contact with lipases, and the hydrolysis of triglycerides to free fatty acids (FFA) proceeds (Champagne et al l993). These FFA serve as the preferential substrate in subsequent lipoxygenase-initiated oxidation (Barnes and Galliard 1991). Thus, by creating microperforations, the flour-blasting process would be expected to further disturb the compartmentalized lipids and, consequently, accelerate the hydrolytic and oxidative reactions to a certain extent. The purpose of this study was to determine the extent that flour-blasting increases the susceptibility of the rice to lipolytic hydrolysis and oxidation by measuring FFA and determining POV values, respectively, in rice stored in air and under vacuum. Percent water absorption during cooking, changes in texture and viscosity were also studied to determine the indirect effect of oxidation products of rancidity on the starch granules inside the rice during storage.

MATERIALS AND METHODS

Statistical Analyses

The experiment was laid out on a completely randomized 3×2×2×7 factorial design, with rice type (American Basmati brown rice, long-grain brown rice, parboiled long-grain brown rice), blasting (no blasting and flour-blasting), packaging (vacuum and Ziploc storage bags), and storage time (0, 14, 30, 60, 120, 180, and 300 days) as main factors. The experiment was replicated twice. Analysis of variance (ANOVA) was used to evaluate main factor and factor-interaction effects. Significantly different means were identified by Tukey's HSD test. All statistics were analyzed using JMP software v.7 (SAS Institute, Cary, NC). All sample analyses were replicated twice.

Samples

Long-grain brown rice (nonparboiled) was obtained from Lundberg Farms (Richvale, CA). Long-grain brown rice (parboiled) was obtained from Riceland Foods (Stuttgart, AR). American Basmati brown rice was obtained from RiceTec (Alvin, TX). The samples used for this study were the same as in Guraya (2011).

Flour-Blasting

Parboiled rice flour (RP-100) was purchased from Riviana (Houston, TX) and passed once through a pin-mill (Alpine sieveless impact stud mill, Augsburg, Germany) to obtain an average particle size of 124 μm. This was determined to be optimum in Guraya (2011). A portable, suction-feed bench-top abrasive blasting cabinet (model 99-1982, Econoline Abrasive Products Division, Spectra Products, Grand Haven, MI) was used for blasting. Samples (120 g) of the rice types were placed on a U.S. standard 12-mesh screen (with an opening of 0.1651 cm) below an 8-mesh screen (with an opening of 0.2362 cm). The top screen was bigger to allow for maximum exposure to blasting media while preventing the brown rice from being blown away. The bottom screen size was selected so that rice would not fall through. A constant air pressure of 413 kPa was used to flour-blast Basmati brown rice for 40 sec and parboiled and nonparboiled long-grain brown rice for 50 sec. The screen was held at an angle of ≈45° and agitated such that the exposure to the particles in the air and the turbulence resulting from the air pressure randomly moved the rice kernels. Thus, all sides of the rice would be evenly exposed to the particles. The control was not flour-blasted.

A total of 56 batches of rice, each weighing 120 g, were flour-blasted for each rice type. A total of 28 batches from these 56 batches were vacuum-packed and the remaining 28 batches were placed in Ziploc storage bags in air at atmospheric pressure. An additional 56 batches of each rice type, each weighing 120 g were not flour-blasted and were used as controls. A total of 28 batches out of the 56 bags of control were vacuum-packed and the rest of the 28 bags were placed in Ziploc storage bags. Bagged samples were stored under ambient temperature (≈25°C) to simulate actual market shelf-storage conditions. Sample bags of treated rice and control samples were removed in duplicate for analysis after 0, 14, 30, 60, 120, 180, and 300 days of storage and placed in a freezer at –80°C until analyzed to stop all biological activity.

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% Water Absorption

A 10-g sample of each type of untreated and treated brown rice was placed on double-layered cheesecloth (20 × 38 cm), which was then loosely folded and tied with a string. At the same time, the treated or flour-blasted samples were placed in a boiling water bath (400 mL of water/10 g of brown rice) and cooked for 25 min. Control or untreated samples were cooked for 55 min. The cooking times were determined as optimum in the previous study (Guraya 2011).

The percent water absorbed in treated and control samples was measured previously. Guraya (2011) consulted with several private companies interested in the microperforation technology and adapted their methods for the absorption rate. Very little solids loss during cooking of brown rice is expected because it is covered with wax and bran layers. Therefore, we did not look for solids loss during cooking of brown rice.

Fat Extraction

Rice kernels (25 g) were ground in a cyclone mill (Udy, Fort Collins, CO) with an 0.8-mm screen. Ground sample (20 g) was weighed into a 400-mL Omni blender stainless vessel and 100 mL of petroleum ether (type 37, 60°C) was added (Lam and Proctor 2001). The vessel was capped with a matching screw-type assembly with cutting and blending blades. Blending was continued for 2 min in the Omni mixer. The petroleum ether extract of the rice flour sample was passed over the Whatman #4 filter paper. The residue on the paper was added back to the stainless steel extraction vessel and an additional 100 mL of petroleum ether was added for extraction. This process was repeated two more times. The solvent collected from all three extractions was pooled together and evaporated using a rotary evaporator at 40°C. This method of fat extraction was more rapid and accurate than using the Soxhlet apparatus. The oil was collected and flushed with nitrogen to prevent oxidation and stored at –80°C until analyzed.

FFA

FFA was measured using the colorimetric method applied on rice oil by Lam and Proctor (2001) but originally developed by Walde (1990) and Walde and Nastruzzi (1991).

POV

The POV was determined by measuring the amount of iodine formed by the reaction of peroxides formed in fat or oil with iodide ion (Takagi et al 1977). POV is expressed as milliequivalents of oxygen/kg of oil. The frozen sample of extracted oil was thawed momentarily to remove a certain amount of oil for the test and then flushed again with nitrogen and returned to the freezer (–80°C) until further use. The test determines oxidative deterioration of fat and gives a very good indication as to what stage the fat deterioration has occurred.

Texture Analysis

Texture analysis was performed previously by Guraya (2011). Hardness and gumminess were also measured.

Pasting Properties

Rice flour pasting properties were determined using a Rapid ViscoAnalyser (RVA model 3D, Newport Scientific, Warriewood, NSW, Australia) according to Approved Method 61-02.01 (AACC International 2010). Brown rice (10 g) was removed from storage and ground in a Udy cyclone mill fitted with an 0.8-mm screen. Moisture content of the ground rice flour was measured using Official Method 945.15 (AOAC 1990). Each rice sample (3 g, db) was mixed with 25 g of distilled water in a RVA sample container. The temperature was set at 50°C, and the 12.5-min test profile was 1) hold at 50°C for 1 min; 2) linearly ramp up to 95°C in 3.8 min; 3) hold at 95°C for 2.5 min; 4) linearly ramp down to 50°C in 3.8 min; and 5) hold at 50°C for 1.4 min. Peak viscosity (PV), final viscosity (FV), breakdown viscosity (BD), and setback viscosity (SB) were determined from the RVA data.

RESULTS AND DISCUSSION

The main objective of developing any new process for decreasing the cooking time of brown rice is to understand and ensure that the water absorption stays consistent during sale and use of instant or reduced cook time brown rice. In a commercial situation, the buyer expects the rice to absorb a certain amount of water and the instant quick cook product is priced accordingly to the convenience associated with preparation time. With higher water absorption, less rice is needed per person, which translates into a higher profit margin. Previously (Guraya 2011), we demonstrated that flour-blasting rice reduces its cooking time by penetrating the pericarp and presumably testa, which are responsible for inhibiting water absorption of brown rice during cooking due to the presence of wax in these layers (Bechtel and Pomeranz 1977). These layers have to be penetrated to allow absorption of water with a subsequent increase in the rate of hydration and reduction of cooking times. Figures 1, 2, and 3 show the effect of storage time on the water absorption of American Basmati, long-grain, and parboiled rice, respectively, during cooking and the effect of packaging. The initial moisture content of nonparboiled long-grain brown rice, parboiled long grain brown rice, and American Basmati brown rice was 13.73, 13.85, and 13.57%, respectively, and did not change during storage. Table I shows that, except for packaging, the type of rice, type of blasting, and length of storage had a significant effect ($P < 0.01$) on %water absorption. There was no significant difference between % water absorption of nonparboiled long-grain brown rice, and parboiled long-grain brown rice, but American Basmati brown rice was significantly different (Table II). Overall, blasting had a significant effect on % water absorption with subsequent increase in hydration and decrease in cooking times of flour-blasted brown rice. During cooking of untreated (control) brown rice, the core took longer to hydrate and cook, unlike the flour-blasted brown rice where the rice hydrates faster and therefore cooks to completion faster. The core of untreated brown rice is the last to get cooked; it is farthest from the water and heating source necessary for gelatinization of starch.

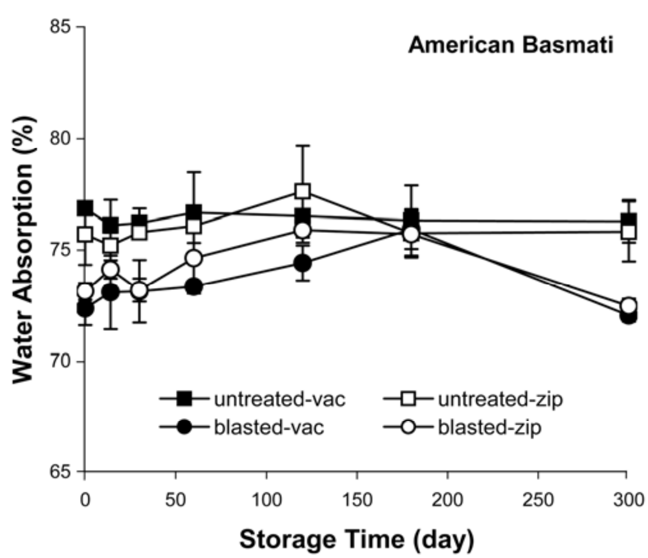

Fig. 1. Effect of storage time on % water absorption during cooking of treated American Basmati brown rice previously stored in Ziploc storage bags (○); untreated American Basmati brown rice previously stored in Ziploc storage bags (□); treated American Basmati brown rice previously stored in vacuum-packed cryovac bag (●); untreated American Basmati brown rice previously stored in vacuum-packed cryovac bags (■).

Meanwhile starch granules continue to absorb water and swell so the granules on the outer periphery are more swollen than on the inside. There is probably a moisture gradient from the outside to the center of the kernel that forms as moisture transfers from the outside to the inside of the brown rice to cook the core. This is not the case with flour-blasted brown rice where hydration is not hindered by the bran layer. The fissures created by flour-blasting significantly facilitate the movement of moisture from the outside to the inside, and therefore the cooking process is much faster than the control as there is no barrier to moisture penetration from the beginning. This explains the difference in the % water absorption between the flour-blasted and untreated brown rice. The combined data for all three brown rice types (Table II) shows that there was no difference in % water absorption between rice samples stored for different lengths of time. The % water absorption (73.5%) for rice stored during 60 days is not significantly different than for rice stored for 120 days (73.0%) or for rice stored for 180 days (73.8%) or for 300 days (73.1%). Indudhara Swamy et al (1978) reported an increase in water uptake after cooking up to one year in storage, after which the uptake decreased. ANOVA (Table I) shows that rice type, storage time, and blasting were the three most important factors affecting the absorption at $P < 0.01$ but the packaging type was not significant even at $P < 0.05$, which further confirms observations in Figs. 1, 2, and 3, and Table I. Also, there was no significant effect in % water absorption due to packaging.

Rice lipids are usually stable in intact spherosomes in the cell. However, when the lipid membrane is destroyed by phospholipase, physical injury, or high temperature, lipid hydrolysis is initiated by the action of lipases (Takano 1989). Figures 4, 5, and 6 show the effect of flour-blasting and no flour-blasting on lipolysis over time. Lipolysis that occurs without any flour-blasting is probably due to surface bacteria that produce lipases or due to damage during the dehulling process, thereby breaking the lipid membrane between the fat and the enzymes, which in turn mix with each other, causing lipolysis. Figures 4, 5, and 6 show the effect of time of storage in both treated and untreated rice samples on the formation of FFA. In American Basmati brown rice and long-grain brown rice, there is a distinct noticeable difference in the FFA formed during storage as compared to the parboiled long-

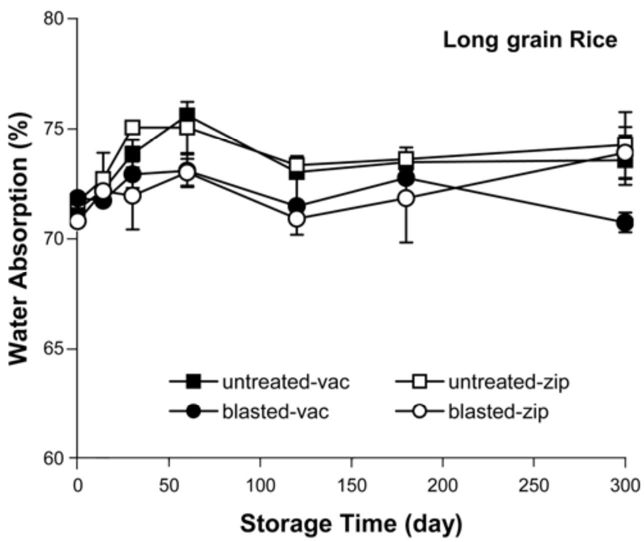

Fig. 2. Effect of storage time on absorption (%) of water during cooking of treated long-grain brown rice previously stored in Ziploc storage bags (○); untreated long-grain brown rice previously stored in Ziploc storage bags (□); treated long-grain brown rice previously stored in vacuum-packed cryovac bags (●); untreated long-grain brown rice previously stored in vacuum-pack cryovac bags (■).

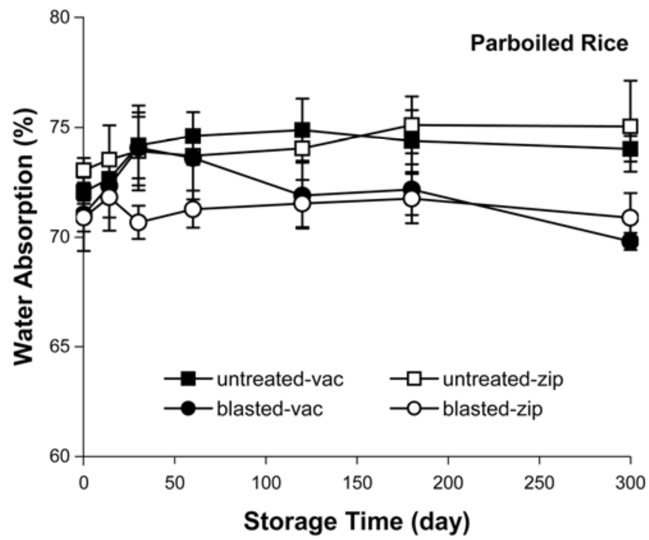

Fig. 3. Effect of storage time on % water absorption during cooking of treated parboiled brown rice previously stored in Ziploc storage bags (○); untreated parboiled brown rice previously stored in Ziploc storage bags (□); treated parboiled brown rice previously stored in vacuum-packed cryovac bags (●); untreated parboiled brown rice previously stored in vacuum-packed cryovac bags (■).

TABLE I
***F*-Values from Four-Factorial Analysis of Variance of Rice Physicochemical Properties[a,b]**

Variation	FFA	POV	PV	FV	BD	SB	Hardness	Gumminess	Water Absorption
Rice type (R)	6,187.3**	1,329.0**	103,831.5**	120,276.1**	54,227.3**	90,991.5**	112.7**	15.3**	92.9**
Blasting (B)	1,892.4**	11.5**	440.0**	1,787.9**	277.0**	2,534.9**	81.6**	360.1**	194.8**
Packaging (P)	1.3ns	142.5**	6.8*	17.2**	0.1ns	9.6**	6.3*	2.7ns	0.1ns
Storage (S)	404.7**	582.2**	166.6**	870.2**	50.3**	1,141.1**	2.3*	2.38*	6.7**
R×B	332.6**	0.2 ns	159.6**	566.0**	141.3**	796.3**	30.8**	27.7**	4.6*
R×P	23.4**	8.7**	102.7**	127.1**	15.8**	73.1**	5.8**	2.9ns	3.8*
R×S	89.3**	119.4**	62.0**	245.0**	21.5**	322.6**	8.4**	5.2**	4.4**
B×P	15.8**	0.8 ns	28.3**	1.0ns	47.6**	2.8ns	1.6ns	0.3ns	0.4ns
B×S	99.9**	8.9**	49.4**	80.5**	23.5**	101.4**	5.4**	2.2ns	5.0**
P×S	3.2**	30.9**	90.4**	45.1**	27.8**	8.8**	8.5**	1.4ns	3.0*
R×B×P	25.9**	5.0**	42.6**	10.2**	34.0**	4.8*	22.5**	3.5*	5.6**
R×B×S	21.0**	8.4**	31.3**	35.4**	17.4**	38.3**	13.6**	3.7**	1.3ns
R×P×S	4.4**	16.7**	102.5**	51.2**	36.2**	13.2**	11.0**	5.2**	3.7**
B×P×S	5.9**	10.2**	9.3**	14.8**	7.5**	15.6**	5.1**	5.2**	1.5ns
R×B×P×S	8.2**	4.7**	24.0**	17.9**	8.2**	9.2**	12.5**	4.7**	1.7ns

[a] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD breakdown viscosity; SB, setback; RVU, measured as Rapid ViscoAnalyser units.
[b] **,* Indicate significance at $P < 0.01$ and $P < 0.05$, respectively; ns, not significant.

grain brown rice. This is due to the parboiling process that inactivates the lipase in the brown rice, resulting in decreased production of FFA due to lipolytic hydrolysis (Viraktamath and Desikachar 1971; Desikachar 1977). During the initial storage stages of American Basmati brown rice and long-grain brown rice, a low rate of FFA formation was observed but the rate gradually increases later in storage (Figs. 4 and 5). The FFA values for flour-blasted brown rice for all rice types were higher as compared to untreated samples during storage except for the first 50 days, which may be due to the time it takes for the oil and enzymes to migrate to appropriate sites and cause significant oxidation. The FFA values for untreated long grain brown rice and parboiled long grain brown and American Basmati rice did not change much over storage as compared to their flour-blasted counterparts for both packaging types. The increase in FFA during storage of brown rice has been reported in a number of studies (Shin et al 1986; Nishiba et al 2000). Table II shows that average FFA values were higher for long-grain brown rice and American Basmati brown rice; whereas, parboiled long-grain brown rice produced at least five times less FFA during storage. ANOVA (Table I) shows that, overall, type of packaging had no effect on the formation of FFA during storage of flour-blasted or untreated brown rice and all other treatments had a significant effect on the production of FFA. As expected, blasting (Table II) should increase lipolysis by damaging the lipid membrane. Storage would also increase lipolysis by allowing time for the enzymes and oil to mix with each other, causing lipolysis. Table II shows that FFA increased significantly with time over all rice types, and the mean FFA production of all rice types significantly differed between untreated and blasted brown rice types combined together (Table I).

Figures 7, 8, and 9 show the POV during storage of the three different rice types. The method measures the active oxygen present in the sample, thus identifying the oxidative status of the oil fraction present (Takagi et al 1977). The most interesting behavior shown in these figures for all treatments with American Basmati brown rice and long-grain brown rice types is that the POV peaks at ≈180 days and then decreases to approximately the starting levels. But in parboiled brown rice, the POV continued to increase during the whole storage period (Fig. 9). This would probably mean that for American Basmati brown rice and long-grain brown

TABLE II
Summary of Means (by factor) for Physicochemical Properties of Brown Rice[a,b,c]

Factor	FFA (%)	POV (meq/kg)	PV (RVU)	FV (RVU)	BD (RVU)
Rice type					
American Basmati	10.8a	144.4b	137.6b	306.2a	19.0b
Long grain rice	7.9b	86.0c	219.3a	291.1b	97.9a
Parboiled rice	1.5c	291.9a	29.6c	46.6c	5.2c
Blasting					
Untreated	5.2b	168.4b	125.2b	204.4a	38.6b
Flour-blasted	8.2a	179.8a	132.4a	224.9a	42.8a
Packaging					
Vacuum	6.8a	194.2a	129.3a	215.7a	40.7a
Ziploc	6.7a	154.0b	128.4b	213.6b	40.7a
Storage time					
0 day	4.1g	51.8f	125.9c	192.5e	38.4e
14 days	5.1f	59.4f	119.5d	189.7f	38.6de
30 days	5.7e	100.8e	125.8c	207.4d	41.4b
60 days	6.7d	201.5d	130.3b	217.3c	40.4c
120 days	8.0c	241.5b	131.1b	224.6b	41.9b
180 days	8.4b	341.3a	138.3a	235.2a	45.0a
300 days	9.1a	222.6c	130.2b	236.0a	39.4d

[a] For each factor, values followed by the same letters are not significantly different at $P < 0.05$.
[b] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD breakdown viscosity; RVU, measured as Rapid ViscoAnalyser units.
[c] Results were averaged across treatments.

TABLE II (*continued*)
Summary of Means (by factor) for Physicochemical Properties of Brown Rice[a,b,c]

Factor	SB (RVU)	Hardness (g force)	Gumminess (g force)	Absorption (%)
Rice type				
American Basmati	187.6a	4219.5c	1205.0b	74.5a
Long grain rice	169.7b	4804.1b	1352.3a	72.0b
Parboiled rice	22.3c	4987.7a	1214.3b	72.3b
Blasting				
Untreated				
Flour-blasted	117.8b	4867.5a	1488.2a	74.1a
Packaging	135.3a	4473.4b	1026.2b	71.8b
Vacuum				
Ziploc	127.1a	4725.1a	1277.3a	72.9a
Storage time	126.0b	4615.8b	1237.1a	72.9a
0 day				
14 days	105.0g	4682.8b	1304.3a	72.2d
30 days	108.6f	4710.9ab	1245.5ab	72.5cd
60 days	122.0e	4608.4b	1165.0b	72.5cd
120 days	128.5d	4609.6b	1295.1a	73.5ab
180 days	135.3c	4628.6b	1256.1a	73.0bc
300 days	142.0b	4607.4b	1236.4ab	73.8a

[a] For each factor, values followed by the same letters are not significantly different at $P < 0.05$.
[b] SB, setback viscosity; RVU, measured as Rapid ViscoAnalyser units.
[c] Results were averaged across treatments.

rice, the peak POV observed at 180 days of storage might be the maximum for these values under these conditions. After that, the peroxides are likely broken down faster to further break down products responsible for rancidity. Because the parboiled brown rice is more stable, it has not reached that maximum where the equilibrium has shifted toward the formation of further break down products responsible for rancidity. An increase in POV was observed during storage of brown rice by Barber (1972). The POV, FFA contents, and carbonyl values have been adopted as indices for determining maximum storage periods (Suzuki et al 1996).

Table I shows that all main factors (i.e., rice type, blasting, packaging, and storage length) had a significant effect on the production of POV. The POV peaked after 180 days of storage for nonparboiled long-grain brown rice and American Basmati brown rice (Figs. 7 and 8) but never peaked for parboiled long-grain brown rice (Fig. 9) throughout the study, which shows that the oxidation process had not reached its maximum. Table II shows the POV mean values of the long-grain brown rice displayed the lowest value, followed by American Basmati brown rice, and then parboiled long-grain brown rice, over time and treatments. Overall POV mean value for parboiled long-grain brown rice was drasti-

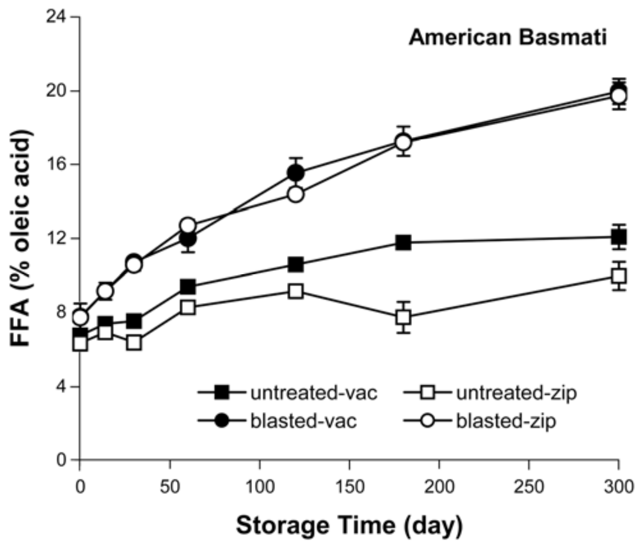

Fig. 4. Effect of storage time on formation of FFA (%) from total fats present in treated American Basmati brown rice previously stored in Ziploc storage bags (○); untreated American Basmati brown rice previously stored in Ziploc storage bags (□); treated American Basmati brown rice previously stored in vacuum-packed cryovac bags (●); untreated American Basmati brown rice previously stored in vacuum-packed cryovac bags (■).

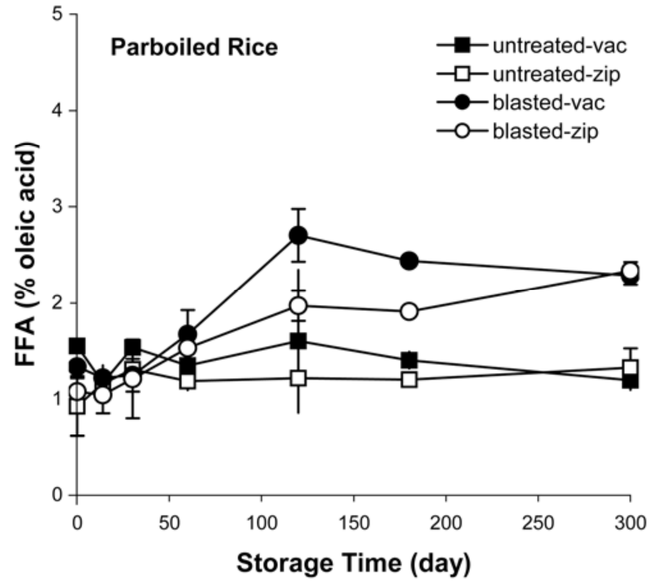

Fig. 6. Effect of storage time on formation of FFA (%) from the total fats present in treated parboiled brown rice previously stored in Ziploc storage bags (○); untreated parboiled brown rice previously stored in Ziploc storage bags (□); treated parboiled brown rice previously stored in vacuum packed cryovac bag (●); untreated parboiled brown rice previously stored in vacuum-packed cryovac bags (■).

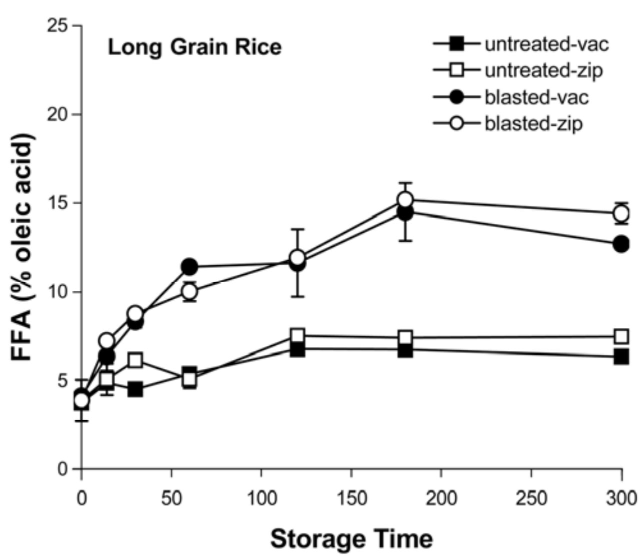

Fig. 5. Effect of storage time on formation of FFA (%) from the total fats present in treated long-grain brown rice previously stored in Ziploc storage bags (○); untreated long-grain brown rice previously stored in Ziploc storage bags (□); treated long-grain brown rice previously stored in vacuum-packed cryovac bags (●); untreated long-grain brown rice previously stored in vacuum-packed cryovac bags (■).

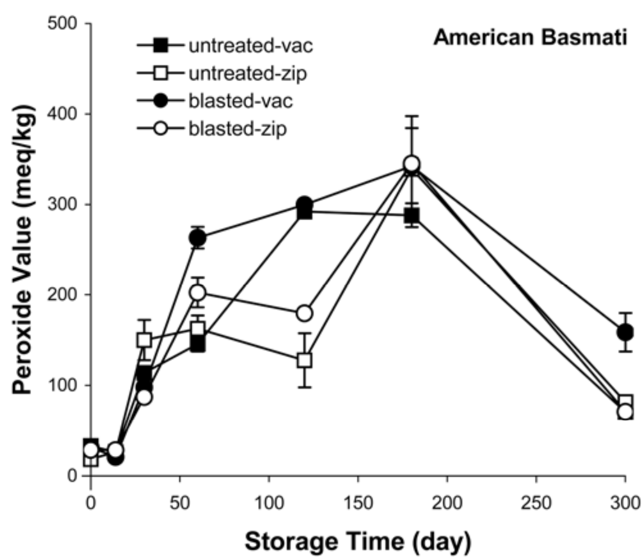

Fig. 7. Effect of time of storage on formation of peroxides from the FFA due to the oxidation in treated American Basmati brown rice previously stored in Ziploc storage bags (○); untreated American Basmati brown rice previously stored in Ziploc storage bags (□); treated American Basmati brown rice previously stored in vacuum-packed cryovac bags (●); untreated American Basmati brown rice previously stored in vacuum-packed cryovac bags (■).

cally higher (twice as high) as that for American Basmati brown rice and three times higher as that for nonparboiled long-grain brown rice. The flour-blasting treatment, the type of packaging, and the length of storage resulted in POV mean values that were significantly different at $P < 0.05$ (Table II). ANOVA (Table I) shows that the F-values were significant at $P < 0.01$ for all four factors (rice type, blasting treatment, packaging type, and storage length). ANOVA also shows that all three-way and four-way interactions are significant at $P < 0.01$, which means that all these factors are strongly interacting with each other, contributing to an increase in the production of FFA and POV. Changes observed during storage of flour-blasted and untreated brown rice suggest that two types of processes are affecting the lipids, one that involves hydrolysis of lipids to produce FFA and another that results from oxidation of FFA and other lipids to produce hydroperoxides.

The analysis of the RVA factor is shown in Table II. The hypothesis was that rancidity of different types of brown rice would increase with length of storage, leading to the production of FFA and other breakdown products that would affect the pasting properties of the flour. We hypothesized that the production of FFA could interfere by binding tightly into the hydrophobic region of the amylose helix, therefore hampering gelatinization and pasting of the starch granule, entangling starch molecules and leading to less swelling, more opacity, and "short" viscosity, and inhibiting recrystallinization (retrogradation), and affecting setback viscosity. Glabe (1939) showed that increased viscosity with increasing pH from 5.5 to 6.95 of fat acidity. Mitchell and Zillmann (1951) showed both increased viscosity at different FFA contents and the type of FFA that affects the stability of the starch granule. The high viscosity could be explained by the increased granule size in these mixtures and also due to formation of a fatty acid-lipid complex. Similar observations were made by Yamatsu et al (1964) and Yamatsu and Moritaka (1964).

The blasting had a significant effect ($P < 0.05$) on the PV, BD, and SB, but not the FV (Table II). The PV, BD, SB, and FV were significantly different for different rice types at $P < 0.05$ (Table II). The packaging type had a significant effect ($P < 0.05$) on the PV, FV, and SB, but not the BD (Table II). The time of storage had a significant effect on PV, BD, SB, and FV. Generally the PV, FV, BD, and SB increased with storage (300 days), suggesting that the viscosity for all measurements increased over time except for PV and BD, which decreased after six months of storage (Table II). Villereal et al (1976) also observed an initial increase in amylo-

TABLE III[a,b]

Combined Correlation Matrix for Physicochemical Properties of American Basmati, Long Grain Rice, and Parboiled Rice ($n = 168$)

	FFA	POV	PV	FV	BD	SB	Hardness	Gumminess	Absorption
FFA	1.00								
POV	–0.20*	1.00							
PV	0.62**	–0.51**	1.00						
FV	0.86**	–0.45**	0.87**	1.00					
BD	0.31*	–0.41**	0.89**	0.57**	1.00				
SB	0.90**	–0.41**	0.84**	0.99**	0.53**	1.00			
Hardness	–0.40**	0.15ns	–0.15ns	–0.33*	0.04ns	–0.34*	1.00		
Gumminess	–0.21*	–0.03ns	0.13ns	0.03ns	0.15ns	–0.01ns	0.67**	1.00	
Absorption	0.18*	0.04ns	–0.03ns	0.18	0.20*	–0.25*	0.21*	0.10ns	1.00

[a] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD, breakdown viscosity; SB, setback.
[b] **,* Indicate significance at $P < 0.001$ and $P < 0.01$, respectively; ns, not significant.

TABLE IV

Correlation Matrix for Physicochemical Properties of American Basmati ($n = 56$)[a,b]

	FFA	POV	PV	FV	BD	SB	Hardness	Gumminess	Absorption
FFA	1.00								
POV	0.42*	1.00							
PV	0.41*	0.42*	1.00						
FV	0.81**	0.58**	0.80**	1.00					
BD	0.37*	0.52**	0.91**	0.74**	1.00				
SB	0.88**	0.61**	0.62**	0.96**	0.61**	1.00			
Hardness	–0.07ns	–0.28*	–0.24ns	–0.15ns	–0.36*	–0.11ns	1.00		
Gumminess	–0.35*	–0.12ns	–0.24ns	–0.24ns	–0.22ns	–0.22ns	0.56**	1.00	
Absorption	–0.26ns	0.16ns	–0.19ns	–0.23ns	–0.17ns	–0.09ns	0.02ns	0.28*	1.00

[a] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD, breakdown viscosity; SB, setback.
[b] **,* Indicate significance at $P < 0.001$ and $P < 0.01$, respectively; ns, not significant.

TABLE V

Correlation Matrix for Physicochemical Properties of Long Grain Rice ($n = 56$)[a,b]

	FFA	POV	PV	FV	BD	SB	Hardness	Gumminess	Absorption
FFA	1.00								
POV	0.42*	1.00							
PV	0.59**	0.38*	1.00						
FV	0.83**	0.43*	0.80**	1.00					
BD	0.62**	0.37*	0.81**	0.56**	1.00				
SB	0.90**	0.44**	0.70**	0.97**	0.58**	1.00			
Hardness	–0.36*	0.18ns	–0.04ns	–0.11ns	–0.25ns	–0.19ns	1.00		
Gumminess	–0.53**	0.15ns	–0.13ns	–0.28*	–0.36*	–0.40*	0.88**	1.00	
Absorption	–0.09ns	0.03ns	0.00ns	0.15ns	–0.06ns	–0.15ns	0.06ns	0.23ns	1.00

[a] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD, breakdown viscosity; SB, setback.
[b] **,* Indicate significance at $P < 0.001$ and $P < 0.01$, respectively; ns, not significant.

graph peak viscosity of slurries made from aged rice during the first six months of storage, followed by a steady decrease during the subsequent three years of storage of rough and milled rice. Shibuya and Iwasaki (1984) made similar observations and found that PV and BV decreased after seven months of storage of milled rice. Because we do not know the date of harvest for the rices used in our study, it would be difficult to relate these changes to rice used in other studies where the date of harvest and the type of cultivar were included among the parameters. This study only reflects what changes occurred as a result of flour-blasting and storage of the type of rice used for the study on viscosity changes.

The two parameters measured using the texture analyzer were hardness and gumminess. The gumminess of blasted brown rice was markedly and significantly lower than that of untreated brown rice (Table II). Gumminess was significantly affected by rice type, blasting, and time of storage at $P < 0.05$ (Table I). Hardness of blasted brown rice was significantly lower than untreated brown rice (Table II). Hardness was significantly affected by rice type, blasting, packaging, and time of storage at $P < 0.05$ (Table I). The vacuum-packed brown rice was significantly harder than rice in Ziploc bags at $P < 0.05$ (Table II).

The combined coefficient of correlation (*r* value) matrix is presented in Table III, which takes into account the three brown rice types. The two most important correlations are between FFA and FV (0.86 at $P < 0.0001$) and FFA and SB (0.90 at $P < 0.0001$). The third, less linear but just as significant, correlation is between FFA and FV (0.62 at $P < 0.0001$). The second most important relationship, not as linear but very significant ($P < 0.0001$) is between POV and PV (–0.51), FV (–0.45), BD (–0.41), and SB (–0.41).

The coefficient of correlation matrix for physiochemical properties of American Basmati brown rice is presented in Table IV. The two similar important correlations, as discussed previously, are between FFA and FV (0.81 at $P < 0.0001$) and FFA and SB (0.88 at $P < 0.0001$). The second most important relationship, not as linear but very significant ($P < 0.0001$), is between POV and FV (0.58), BD (0.52), and SB (0.61). The other correlations are between viscosity parameters and are of less importance.

The coefficient of correlation matrix for physiochemical properties of long-grain rice is presented in Table V. The two similar important correlations as noted above are between FFA and PV (0.59), FV (0.83), BD (0.62), SB (0.90), and gumminess (–0.53) at $P < 0.0001$. This is probably due to the effect of FFA and its binding to starch. The second most important relationship, not as linear but very significant ($P < 0.0001$), is between POV and SB (0.44). The other correlations are between viscosity parameters and are of less importance (Table IV).

The coefficient of correlation matrix for physiochemical properties of parboiled rice is presented in Table VI. There is only one important relationship between FFA and POV (0.51 at $P < 0.0001$), primarily because of inactivated lipases in parboiled brown rice with most oxidation due to auto-oxidation. The other correlations are between viscosity parameters and are of less importance.

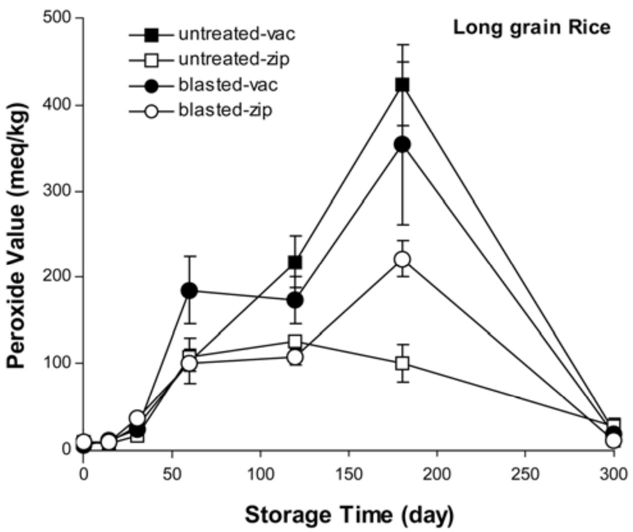

Fig. 8. Effect of storage time on formation of peroxides from the FFA due to the oxidation in treated long-grain brown rice previously stored in Ziploc storage bags (○); untreated long-grain brown rice previously stored in Ziploc storage bags (□); treated long-grain brown rice previously stored in vacuum-packed cryovac bags (●); untreated long-grain brown rice previously stored in vacuum-packed cryovac bags (■).

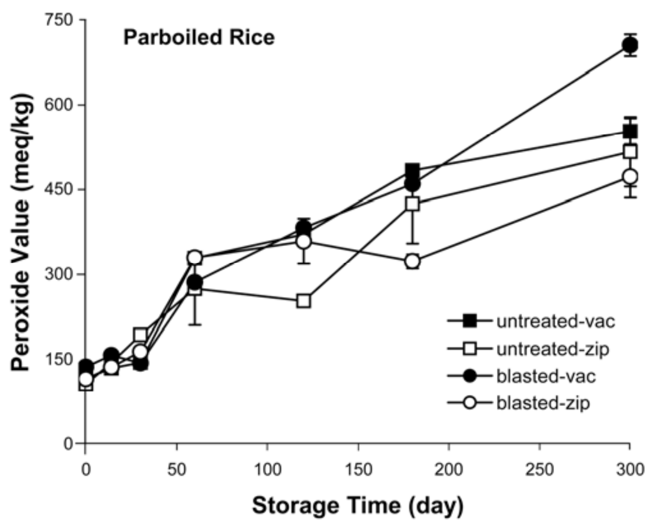

Fig. 9. Effect of storage time on formation of peroxides from the FFA due to oxidation in treated parboiled brown rice previously stored in Ziploc storage bags (○); untreated parboiled brown rice previously stored in Ziploc storage bags (□); treated parboiled brown rice previously stored in vacuum-packed cryovac bags (●); untreated parboiled brown rice previously stored in vacuum-packed cryovac bags (■).

TABLE VI
Correlation Matrix for Physicochemical Properties of Parboiled Rice (n = 56)[a,b]

	FFA	POV	PV	FV	BD	SB	Hardness	Gumminess	Absorption
FFA	1.00								
POV	0.51**	1.00							
PV	–0.20ns	–0.14ns	1.00						
FV	–0.27ns	–0.17ns	0.94**	1.00					
BD	–0.35*	–0.11ns	0.66**	0.74**	1.00				
SB	–0.34*	–0.17ns	0.71**	0.90**	0.83**	1.00			
Hardness	–0.06ns	0.12ns	–0.05ns	0.06ns	0.06ns	0.16ns	1.00		
Gumminess	–0.36*	0.06ns	0.06ns	0.18ns	0.24ns	0.31*	0.58**	1.00	
Absorption	–0.21ns	0.13ns	0.24ns	0.23ns	0.25ns	0.17ns	0.21ns	0.12ns	1.00

[a] FFA, free fatty acid; POV, peroxide value; PV, peak viscosity; FV, final viscosity; BD, breakdown viscosity; SB, setback.
[b] **,* Indicate significance at $P < 0.001$ and $P < 0.01$, respectively; ns, not significant.

CONCLUSIONS

Flour-blasting of brown rice leads to a decrease in the % water absorption during cooking. This is not due to storage effects but rather due to flour-blasted brown rice cooking faster, thereby not getting overcooked and absorbing too much water. Regular brown rice takes ≈55 min to cook and the core of the kernel is the last to get cooked. Meanwhile, already cooked starch granules continue to absorb water and swell so that the granules on the outer periphery are more swollen than those on the inside. This leads to the observed difference in the % water absorption between the flour-blasted and untreated brown rice samples. To prevent rancidity, the formation of FFA needs to be controlled and there are several different options that can be used. These include antioxidants, coatings, and a combination of the two options. Another alternative to prevent rancidity involves the use of parboiled brown rice because the lipases have been inactivated, therefore slowing down the formation of FFA as shown in our study.

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