

Sensory Quality of Cooked Long-Grain Rice as Affected by Rough Rice Moisture Content, Storage Temperature, and Storage Duration

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ABSTRACT

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The effects of postharvest conditions (i.e., rough rice moisture content, storage temperature, and storage duration) on sensory quality of one long-grain rice cultivar grown in Arkansas (Cypress) were evaluated using a professional descriptive sensory panel. Eight textural (adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, particle size, toothpack, and loose particles) and six flavor attributes (overall rice

impression, sulfur, starch, grainy, metallic, and cardboard) were identified as most important in describing the sensory characteristics of cooked Cypress rice. Postharvest conditions had significant effects on rice sensory quality, and regression models illustrated the effects of each postharvest variable and their interactions.

Until recently, studies of the relationship between postharvest handling of rough rice and sensory quality of milled cooked rice have been limited in scope and number. As rice consumption continues to expand and markets become more competitive, there is an increasing need for quantitative data regarding the effects of postharvest handling on sensory characteristics of cooked rice. Sensory evaluation techniques have been used to assess the effects of postharvest handling on cooked rice quality (Okabe 1979, Juliano and Perez 1983, Chrastil 1990, Rousset et al 1995). However, these studies only provided information on the effects of single postharvest variables (i.e., rough rice moisture content, drying conditions, or storage duration), falling short of evaluating possible interactions between these postharvest variables. Champagne et al (1997, 1998) and Lyon et al (1999) have reported interactive effects of drying conditions, moisture content, and degree of milling on both texture and flavor profiles of rice. However, the effect of storage conditions on sensory quality of cooked rice remains to be thoroughly investigated using a reliable sensory tool.

Descriptive profiling is the most sophisticated sensory methodology available and provides the tool to determine the intensity of a number of specific sensory characteristics (Stone and Sidel 1993). Sensory profiling is also useful in evaluating sensory changes over time with respect to processing conditions and shelf life (Meilgaard et al 1991). The Spectrum methodology (Sensory Spectrum, Chatham, NJ) is a sensory profiling method designed to provide universal sensory intensities, especially adequate to provide reliable results for shelf life studies. The method relies on common commercial food references used as anchors for each of the specific sensory attributes studied and provides absolute sensory intensities that can be compared even if testing dates are spread throughout long periods of time.

The objective of this investigation was to study the effects of postharvest variables of rough rice moisture content, storage temperature, and storage duration on the sensory characteristics of one of the predominant long-grain rice cultivars grown in Arkansas.

MATERIALS AND METHODS

Postharvest Treatments

Long-grain rice cultivar Cypress was harvested from the University of Arkansas Rice Research and Extension Center in Stuttgart, AR, in September 1996 with a harvest moisture content of

19.1% (wb). The rice was immediately transported to the Biological and Agricultural Engineering laboratory (Fayetteville, AR) and cleaned (dockage tester, Carter-Day Co., Minneapolis, MN). Rice samples were dried using a parameter control generator unit in a laboratory-scale dryer at 43.3°C and 38.2% rh for 75 min. After drying, rice samples were spread 0.5 in. deep in wooden framed wire-mesh trays and allowed to equilibrate in air-controlled chambers until reaching moisture contents (mc) of 10 ± 0.2 , 12 ± 0.2 , and $14 \pm 0.2\%$. Equilibrated rice samples were then divided into three airtight plastic buckets and subsequently stored at 4, 21, and 38°C. Samples were removed from storage and allowed to equilibrate to room temperature (21°C) before milling at 0, 6, 12, 24, and 36 weeks. A sample sheller (McGill husker) was used to remove the rice hulls and a mill (McGill No. 2) was used to remove the bran. Samples were milled to a constant degree of milling (DOM = 90) measured by a milling meter (MM-1B, Satake). A DOM of 90 for the cultivar studied was equivalent to a whiteness of 40 ± 2 as reported by Champagne et al (1997, 1998) and Lyon et al (1999).

TERM	DEFINITION	REFERENCE
AROMA:		
SULFURY	Aromatic associated with hydrogen sulfide.	Boiled egg yolks, 2–3 days old, placed in a reference jar for sniffing.
STARCHY	Aromatic associated with the starch of a particular grain source.	Rice flour paste; rice flour in water (1:1).
GRAINY	General term used to describe the aromatics of raw grains that cannot be tied to a specific grain by name.	Rice Krispies, Shredded Wheat, and Multi Grain Cheerios crushed and placed in a reference jar for presentation.
AROMATICS:		
OVERALL RICE IMPRESSION	Sum of total sensory impressions of the food in the mouth including aromatics, basic tastes, and feeling factors.	Uncle Ben's converted rice = 5.0
STARCHY	Same as for aroma.	
CARDBOARD	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Wet cardboard presented in a reference jar.
METALLIC	Aromatic associated with metals, tin, or iron or the flat chemical feeling factor stimulated on the tongue by metal coins.	Dole Pineapple slices removed (can only) and can passed for sniffing.
GRAINY	Same as for aroma.	
AFTERTASTE (30sec):		
STARCHY	Same as for aroma.	
METALLIC	Same as for aromatics.	

Fig. 1. Vocabulary for sensory flavor attributes of cooked rice. Intensities based on a modified Spectrum universal aromatic scale (Meilgaard et al 1991). Soda note in soda cracker is 3.0, cooked apple in applesauce is 7.0, and cooked grape note in grape juice is 14.0.

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Sensory Methodology

Nine panelists, trained in descriptive analysis techniques according to the Spectrum methodology, and with three years of experience in descriptive analysis, developed flavor and texture profiles for cooked long-grain rice. Four 3-hr orientation sessions were necessary for the panel to develop the rice lexicon and test methodology necessary to describe both flavor and texture characteristics of cooked Cypress rice. The flavor portion of the evaluation was conducted in three distinct stages (Fig. 1). Sulfury, starchy and grainy were evaluated as *aromas* by sniffing the samples. Overall rice impression, starchy, cardboard, metallic, and grainy were evaluated in the *aromatics* stage, while product was chewed up to eight times. Finally, starchy and metallic notes were evaluated 30 sec after expectoration in the *aftertaste* stage.

Eight textural attributes were identified as adequately describing the texture profile of cooked Cypress rice (Fig. 2). The methodology developed for the evaluation of texture characteristics of cooked rice was organized in four consecutive stages. Adhesiveness to lips was evaluated first as a *surface characteristic* by compressing the sample between dry lips and evaluating the degree to which the sample adhered to the lips. After the *first chew*, hardness was assessed by compressing the sample between molars and evaluating the force required to bite through the sample. Cohesiveness of mass after three and eight chews, roughness of mass toothpull, and particle size were evaluated during the *chewdown* stage of the evaluation. Finally, toothpack and loose particles were evaluated after expectoration of the product or the *residual* stage. Sensory scores were given by panelists using paper ballots and numbers between 0 and 15 (Meilgaard et al 1991). Intensities for flavor and texture attributes were assessed by comparison with

carefully chosen references anchored on specific attribute scales. Lists of the references used for both flavor and texture attributes are provided in Figs. 1 and 2, respectively.

Samples were cooked for 20 min in household steam rice cookers (model SR-W10FN, National) with a rice to water ratio of 1:2 (v/v) and immediately mixed and fluffed using a plastic fork. Samples were presented at $71 \pm 1^\circ\text{C}$ in preheated glass bowls insulated with Styrofoam cups and covered with watch glasses. Panelists were instructed to monitor temperature during the test using digital thermometers and to complete the evaluation before the temperature of the sample reached $60 \pm 2^\circ\text{C}$. Flavor evaluation was performed first. The order of sample presentation was randomized across treatments but not randomized across panelists because of limited sample availability and the importance of serving temperature. In addition, the samples were evaluated twice by each of the panelists on two separate days. A reference rice sample was presented as a warm-up sample at the beginning of each session. Samples were presented monadically in individual booths featuring incandescent lighting and positive pressure. Panelists were allowed a 10-min break between each sample evaluation and interacted to clean their palate with unsalted soda crackers and water.

Statistical Data Analysis

The experiment was treated as a 3×3 full-factorial design with repeated measures over time. Independent variables were rough rice storage (10, 12, or 14% mc) and rough rice storage temperature (4, 21, or 38°C). The sensory evaluation was conducted after 0, 6, 12, 24, and 36 weeks of storage. Panel performance was monitored for use of scales, repeatability, and discrimination using Grapes, a statistical analysis macro (SAS Institute, Cary, NC) (Schlich 1994) (data not shown). Sensory data were analyzed for the various sampling times by a treatment \times subject design (Stone and Sidel 1993) using PROC MIXED (SAS) and least square differences calculated to evaluate significant differences between treatments (data not shown). This analysis was performed to determine which sensory attributes exhibited the significant treatment effects necessary to evaluate meaningful regression models. Sensory intensities were predicted using multiple regression models including variables such as rough rice moisture content, storage temperature, storage duration, quadratic terms, and interactions. PROC STEPWISE (SAS) was used to determine regression models including only significant variables ($P < 0.10$).

RESULTS AND DISCUSSION

Aroma

Sulfur note intensities were significantly affected by both storage temperature and duration (Fig. 3a, $R^2 = 0.68$). Intensities increased with storage duration from 0.2 at 0 weeks to 1.0 after 36 weeks for samples stored at 4°C . As storage temperature increased, sulfur notes increased less and less over time and barely increased for samples stored at 38°C . Volatilization of sulfur compounds at higher temperatures is a possible explanation for this result. Champagne et al (1997) reported that sulfur-like notes were higher in samples dried to 15% mc than in samples dried to 12% mc. This result was not confirmed by our studies. However, the highest storage moisture content in the present study was 14%. Starchy aroma intensities were mainly influenced by rough rice storage moisture content and storage duration (Fig. 3b, $R^2 = 0.42$). Starchy aroma notes decreased with increasing storage duration. In addition, starchy aroma was consistently higher for samples stored at 12% mc than for samples stored at either 10 or 14% mc. This is in partial agreement with Champagne et al (1997), who reported higher starchy notes in samples with lower moisture contents. Grainy aroma, described by the panelists as a raw grain aroma, was affected by both storage temperature and duration (Fig. 3c, $R^2 = 0.68$). Overall, grainy notes consistently decreased with time for the first 25 weeks of storage and increased during subsequent storage. The effects of storage temperature on

TERM	DEFINITION	TECHNIQUE	REFERENCE	
SURFACE:				
ADHESIVENESS TO LIPS	The degree to which the sample adheres to the lips.	Compress sample between lips, release, and evaluate.	Tomato	0.0
			Nougat	4.0
			Bread stick	7.5
			Pretzel rod	10.0
			Rice Krispies	15.0
FIRST BITE:				
HARDNESS	The force required to compress the sample.	Solids - Compress or bite through sample 1 with molars or incisors.	Cream cheese	1.0
			Egg white	2.5
			American cheese	4.5
			Beef frankfurter	5.5
			Olive	7.0
			Peanut	9.5
			Almond	11.0
			Carrot	11.0
Life Savers	14.5			
CHEWDOWN:				
COHESIVENESS OF MASS after 3 or 8 chews	The amount the chewed sample holds together.	Chew sample with molars 3 times or 8 times and evaluate.	Licorice	0.0
			Carrots	2.0
			Mushrooms	4.0
			Beef frankfurter	7.5
			American cheese	9.0
			Brownie	13.0
			Dough	15.0
ROUGHNESS OF MASS	The amount of roughness perceived in the chewed sample.	Chew sample with molars 8 times and evaluate.	Unchewed Jello	0.0
			Orange peel	3.0
			Cooked oatmeal	6.5
TOOTHPULL	The force required to separate the jaws during mastication.	Chew sample up to 3 times and evaluate.	Clam	3.5
			Caramel	5.0
			Jujubes	15.0
PARTICLE SIZE	The amount of space the particle fills in your mouth.	Place sample in center of mouth and evaluate.	Rice grain	0.5
			Tic Tac	2.5
			M & M (plain)	4.0
			Mike & Ikes	6.0
			Cherry Bite	11.0
			Spearmint leaf	13.0
TOOTHPACK	The amount of product packed into the crowns of your teeth after mastication.	Chew sample up to 8 times, expectorate, and feel the surface of the crowns of the teeth with tongue.	Captain Crunch	5.0
			Heath Bars	10.0
LOOSE PARTICLES	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample up to 8 times with molars, swallow and evaluate.	Carrot	10.0

Fig. 2. Vocabulary for sensory texture attributes of cooked rice.

grainy aroma were noticeable only after 12 weeks of storage, when grainy aroma increased slightly with increasing storage temperature. It is possible that the perception of grainy notes included that of raw grain as well as of off flavors developing during storage, especially in samples stored at higher temperatures.

Aromatics

Overall rice impression was not explained by the variables studied ($R^2 = 0.15$). However, this result is not surprising because this attribute is defined as the sum of all sensory flavor notes or the total flavor impact. Because some flavor notes decreased with time while others increased, the overall impact may have been similar even if the individual attributes differed in intensity. The starchy note perceived in the aromatic phase of the evaluation was poorly predicted by the variable studied ($R^2 = 0.33$) and will not be discussed here. Cardboard notes, an indicator of slightly oxidized fats and oils, were mostly affected by storage temperature and duration (Fig. 3d, $R^2 = 0.43$). Overall, cardboard notes increased with storage duration. This result was expected because oxidation has more time to occur as storage duration increases. However, oxidation notes were overall fairly low in intensity. Samples stored at 4°C showed little increase in cardboard notes

over time, while samples stored at 38°C showed greater cardboard intensities. After 36 weeks of storage, oxidation notes were two to three times higher in samples stored at 38°C than in samples stored at 4°C. The perception of metallic notes in the samples was mainly influenced by storage temperature and storage duration (Fig. 3e, $R^2 = 0.68$). Overall, metallic notes decreased with increasing storage duration and storage temperature. A synergistic effect (i.e., significant interaction) was found between storage duration and storage temperature. The perception of grainy in the aromatic phase of descriptive profiling followed the same trend observed in the aroma phase of the evaluation (Fig. 3f, $R^2 = 0.72$).

Aftertaste

Starchy aftertaste was affected by rough rice storage moisture content, storage temperature, and storage duration (Fig. 3g and h, $R^2 = 0.65$). Starch notes decreased with increasing storage temperatures and increased with increasing storage duration. The effect of storage moisture content on starchy aftertaste was not apparent during the first 15 weeks of storage. Subsequent storage showed that samples stored at 10% moisture exhibited higher aftertaste starch notes. Metallic aftertaste was mostly affected by storage moisture content and storage duration (Fig. 3i, $R^2 = 0.83$).

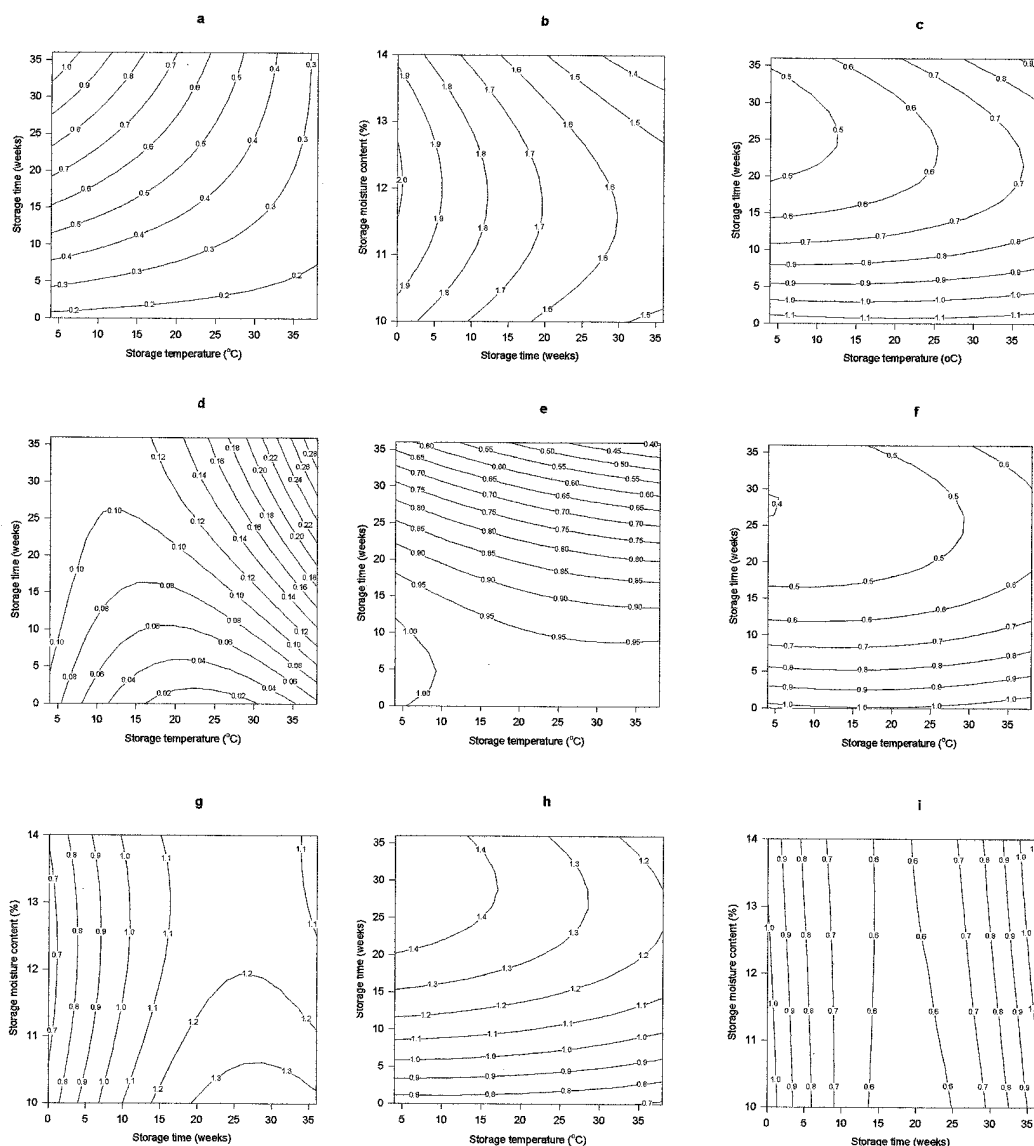


Fig. 3. Contour plots for the effects of rough rice moisture content, storage temperature, and storage duration on cooked rice flavor profiles. Aroma profiles: sulfury, starchy, and grainy (a–c, respectively); aromatic profiles: cardboard, metallic, and grainy (d–f, respectively); aftertaste profiles: starchy (g and h) and metallic (i).

Increasing rough rice storage moisture content slightly decreased the perception of the metallic notes in the samples. Metallic notes decreased with increasing storage duration up to 15 to 20 weeks of storage and increased during subsequent storage, exhibiting similar intensities after 36 weeks of storage as for 0 weeks.

Surface Characteristics

Storage temperature and duration significantly affected adhesives to lips, an indicator of rice stickiness (Fig. 4a, $R^2 = 0.58$). Increasing storage temperatures decreased rice stickiness. Tamaki et al (1993) reported similar results on Japanese rice cultivars using instrumental measurements. In the present study, rice stickups reached a maximum after 20 weeks of storage and decreased significantly after 36 weeks of storage. A significant interaction was found between storage temperature and duration. A shorter storage duration was necessary for the samples stored at higher temperature to reach the maximum perceived stickiness. This result is in partial contradiction with results obtained by Tamaki et al (1993), who reported that rice stickiness measured by instrumental methods decreased consistently during the first 90 days of storage regardless of storage moisture content or storage temperature. In addition, Champagne et al (1998) reported a decrease in adhesiveness with increasing rough rice moisture contents. No significant effect of rough rice moisture content was reported in this study.

First Chew

Hardness was affected by storage duration and rough rice storage moisture content (Fig. 4b, $R^2 = 0.38$). Cooked kernel hardness

decreased with increasing storage moisture content and reached a maximum between 15 and 22 weeks of storage depending on the rough rice storage moisture content. A significant interaction was found between rough rice moisture content and storage duration. Increasing rough rice moisture contents delayed the perception of maximum hardness. These results are in partial disagreement with results published by Champagne et al (1998), who reported no difference in hardness as rough rice moisture content increased. However, Lyon et al (1999) reported that samples dried to 15% mc were less chewy than those dried to 12% mc. In addition, results are in agreement with a study by Tamaki et al (1993), who reported that rice stored at 12% mc was initially found to be harder than rice stored at 15 or 18% mc.

Chewdown

Cohesiveness of mass after three chews (COM_1) was affected by storage temperature and duration (Fig. 4c, $R^2 = 0.53$). COM_1 decreased with increasing storage duration during the first 25 to 30 weeks of storage and increased slightly from 24 to 36 weeks. Changes in COM_1 were most rapid during the first 15 weeks of storage and increasing storage temperatures slightly decreased the sensory intensities of COM_1 . Cohesiveness of mass after eight chews (COM_2) was affected by the same postharvest variables (i.e., storage temperature and duration) (Fig. 4d, $R^2 = 0.74$). COM_2 reached a maximum after 20–25 weeks of storage and then decreased. The maximum COM_2 was reached faster for samples stored at higher temperatures. Roughness of mass (Fig. 4e, $R^2 = 0.54$) slightly increased with increasing storage temperatures. Overall,

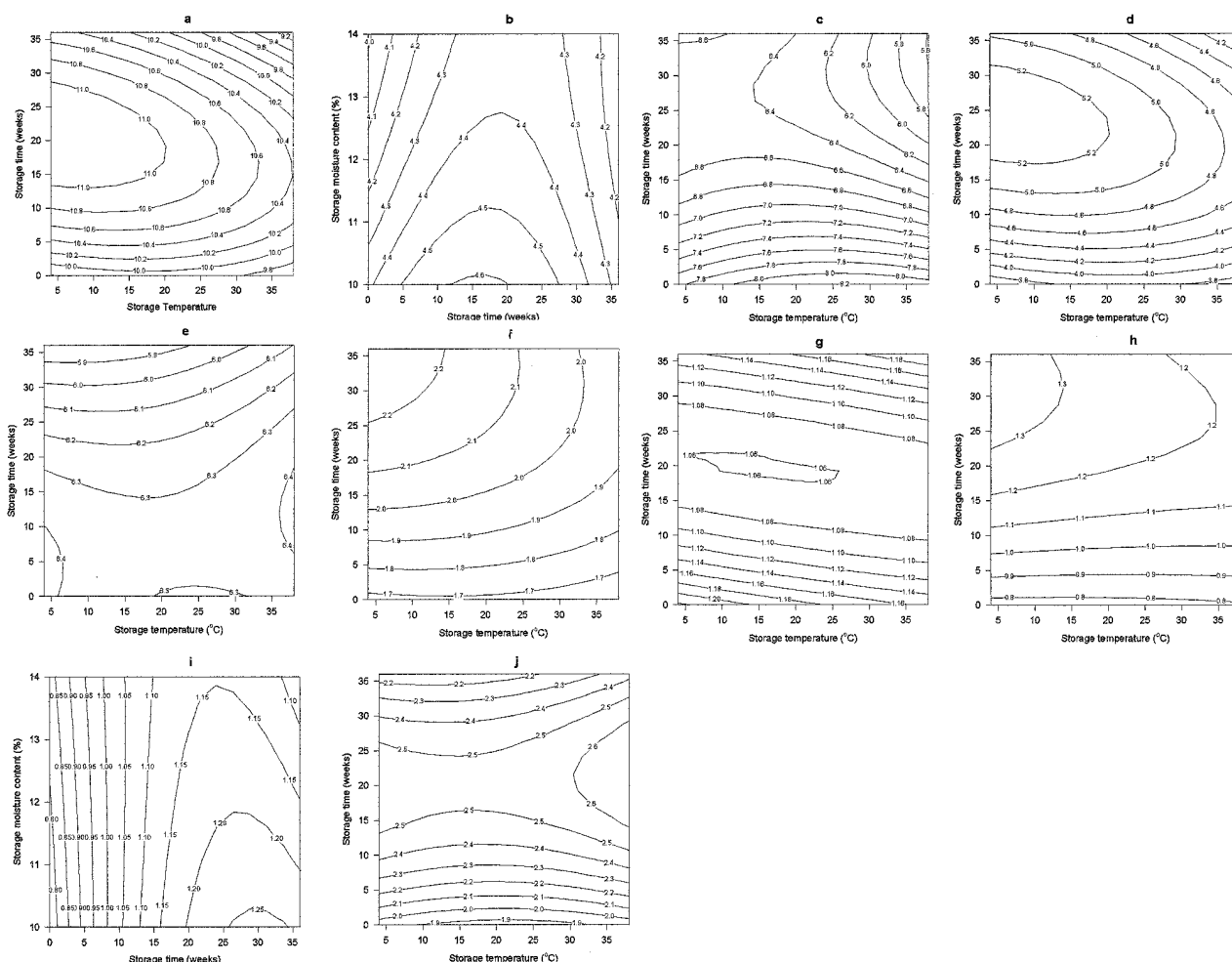


Fig. 4. Contour plots for the effects of rough rice moisture content, storage temperature, and storage duration on cooked rice texture profiles: adhesiveness to lips (a), hardness (b), cohesiveness of mass after three chews (c), cohesiveness of mass after eight chews (d), roughness of mass (e), toothpull (f and g), particle size (h), toothpack (i), loose particles (j).

roughness of mass decreased over time. Toothpull was affected by storage moisture content, storage temperature, and storage duration (Fig. 4f and g, $R^2 = 0.50$). Toothpull decreased with increasing storage moisture content and increased with increasing storage duration with the most rapid changes occurring during the first 15 weeks of storage. Toothpull slightly decreased with increasing storage temperatures. Particle size was most affected by storage temperature and storage duration (Fig. 4h, $R^2 = 0.41$). Particle size decreased to a minimum after 17–22 weeks, with samples stored at higher temperatures reaching the minimum faster. Overall, increasing storage temperature slightly decreased perceived particle size.

Residual

Toothpack was affected by storage temperature, storage duration, and storage moisture content (Fig. 4i, $R^2 = 0.79$). Toothpack increased with storage duration. However, most rapid changes occurred during the first 10–15 weeks of storage. Increasing storage temperatures and rough rice moisture content slightly decreased toothpack. Storage temperature and storage duration most affected loose particles (Fig. 4j, $R^2 = 0.75$). Loose particles increased to a maximum after 20 weeks of storage and subsequently decreased as storage duration increased. The effect of storage temperature was slight and seen most after 25 weeks of storage where increasing storage temperatures increased sensory intensities for loose particles.

SUMMARY AND CONCLUSIONS

Postharvest conditions had very significant effects on cooked rice quality evaluated by sensory evaluation. The significance of these findings is twofold. First, loss of quality during storage can be significant under specific storage conditions. Second, this data shows that rice quality can be optimized by carefully controlling some of the postharvest conditions such as rough rice storage moisture content, storage temperature, and duration. It is probably not very realistic at this point to forecast that rough rice storage temperature can be monitored in the United States. However, it seems that optimizing postharvest parameters such as rough rice

storage moisture content as a function of the predicted storage duration would help optimize U.S. rice quality for rice destined to consumer or processing markets. The data presented represents only the 1996–1997 crop, and additional data is being generated on the 1997–1998 crop so that storage recommendations to optimize rice quality can be formulated.

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