Characterization of the sensory, chemical, and microbial quality of microwave-assisted, thermally pasteurized fried rice during storage

María Laura Montero, Shyam Sablani, Juming Tang, and Carolyn F. Ross

Abstract: Companies producing ready-to-eat (RTE) meals are looking for processing alternatives that allow them to gain presence in the supermarket chill section. Microwave-assisted pasteurization systems (MAPS) offer the potential to produce safe, high-quality foods. This research examined sensory, physical, chemical, and microbial changes in fried rice processed with MAPS and stored at 7 °C over a 6-week storage period. Additional fried rice samples (cooked but not MAPS-processed) were stored at –31 °C and were used as the control. Randomly selected trays of each type of rice were analyzed at 1, 4, and 6 weeks of storage. Aroma, appearance, taste/flavor, texture, mouthfeel, and aftertaste were evaluated by a semitrained sensory panel with rate-all-that-apply questions. The type of rice treatment (MAPS or control) significantly influenced sensory attributes ($P < 0.05$), with firm texture attribute of the egg being more intense in the MAPS-rice compared to the control. In addition, storage time affected the sensory modalities of both rice samples, including aroma, appearance, and taste/flavor ($P < 0.05$). No spoilage-associated sensory attributes were detected in the MAPS-rice during storage. At each examination point, various physical, chemical, and microbial analyses were conducted for the MAPS- and control rice. From the physical and chemical perspective, the MAPS-rice did not present relevant changes over the period tested. Microbial growth was the main cause of spoilage of the MAPS-rice; however, MAPS was able to extend the regular 5-day shelf life of a chilled fried rice meal to 6 weeks, demonstrating the potential of this technology for the RTE industry.

Keywords: fried rice, microwave processing, sensory evaluation, shelf life

Practical Application: The findings of this study indicate that, by applying microwave technology to RTE fried rice, the shelf life can be extended from 5 to 7 days up to 42 days (6 weeks) when stored at 7 °C. This temperature closely mimics that of consumers' refrigerators in the United States. This study also shows the potential of working with a semitrained panel and RATA questions when characterizing sensory changes during storage.

1. INTRODUCTION

Ready-to-eat-(RTE) meals are products that are precooked, packaged, and ready for consumption without additional preparation and cooking beyond simple heating (Huang & Hwang, 2012). They have emerged as the next big trend in the food sector and represent a promising option to meet current consumers' needs. The percentage of consumers who mentioned that convenience had a significant impact on their food purchase decision rose almost 50% from 2017 to 2018 (International Food Information Council, 2018; Sloan, 2019).

For enhanced growth in all market sectors in the food industry and especially the RTE sector, advances in product quality, convenience, and stability are required. Conventional food processing and stabilization technologies, such as cook-chill, retort, and freezing, are of only limited use in producing high-quality meals with extended shelf life (Stanley & Petersen, 2017). Microwave (MW) processing, one of the emerging thermal food technologies, offers several advantages over conventional methods, including reduced thermal degradation of heat-sensitive ingredients and improved food quality (Auksornsri & Songsermpong, 2017; Peng et al., 2017). Pasteurization of RTE using MW processing to enhance their shelf life has been recognized for many years, and the potential of the method has been validated (Ahmed & Ramaswamy, 2007; Tang, Hong, Inanoglu, & Liu, 2018). A microwave-assisted pasteurization system (MAPS) shortens the time for the product to reach the target temperature. Unlike in conventional heat treatments, the generation of volumetric heat makes it possible to increase the heat transfer rate and reduce the total heating time three to five times (Auksornsri & Songsermpong, 2017; Tang, 2015). MAPS-reduced heating time improves product quality compared to conventional hot water heating (Tang, 2015).

Convenient, processed rice products are increasingly needed in modern lifestyles (Lu & Collado, 2019) and to address the dietary preferences of more than 50% of the world's population (The Global Rice Science Partnership, 2013). Food trends, such as the replacement of home meals, reduced preparation on-site in restaurants, and growing interest in a wide variety of ethnic foods, have given food processors the opportunities to offer both consumers and foodservice customers finished meals, with increased usage of rice (Wilkinson & Champagne, 2004). Rice-based products are often cooked, steamed, puffed, extruded, or fried (Bhattacharya, 2011). Rice can take the form of noodles, breakfast cereals,

JFDS-2020-0613 Submitted 4/14/2020, Accepted 6/27/2020. *Authors Montero and Ross are with School of Food Science, Washington State University, Pullman, WA 99164, U.S.A. Authors Sablani and Tang are with Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164, U.S.A. Direct inquiries to author Ross (E-mail: cfross@wsu.edu).*

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crackers, extruded snacks, chips, flour, entrées, and RTEs (Pallas, 2016; Wilkinson & Champagne, 2004).

With the increasing popularity of RTEs, rice is often selected to produce rice-based products, including shelf-stable, chilled, and frozen products (Auksornsri, Tang, Tang, Lin, & Songsermpong, 2018; Yu, Turner, Fitzgerald, Stokes, & Witt, 2017). However, cooked rice is highly perishable (Ali, Hasan, Islam, & Islam, 2008). Thus, processing methods developed to extend the shelf life of rice have many applications and economic ramifications. Recent advances have focused on extending the shelf life of rice-based RTEs via additional postcooking processing steps, such as high temperature, which destroys bacteria and their spores, or freezing, which prevents spore germination and bacterial growth (Yu et al., 2017).

However, to date, few studies have investigated the effect of MW processing on the sensory, physico-chemical properties of rice (Auksornsri & Songsermpong, 2017), and no previous study has focused on RTE fried rice. According to Yu et al. (2017), the mechanism that causes deterioration in physical and sensory properties, such as texture and flavor, during the processing of RTE rice is poorly understood.

Thus, this study sought to evaluate the effect of MAPS as compared to simple freezing on the sensory, physical, chemical, and microbial changes of fried rice stored at 7 °C over 6 weeks. The average shelf life of a chilled RTE is 5 to 7 days (Huang & Hwang, 2012); therefore, this extension in shelf life (up to 42 days) represents a major benefit for companies and consumers. In addition, the selected storage temperature reflects the temperature at which 10% of American consumers store their food (Peng et al., 2017).

2. MATERIALS AND METHODS

2.1 Materials

Long grain Jasmine rice (Kirkland Signature, Seattle, WA, USA), soybean oil (Kirkland Signature), salted sweet cream butter (Kirkland Signature), ground Himalaya pink salt (Kirkland Signature), ground white pepper (McCormick, Hunt Valley, MD, USA), 100% organic granulated onion (The Spice Hunter, San Luis Obispo, CA, USA), chicken flavor bouillon (Knorr, Englewood Cliffs, NJ, USA), soy sauce (Kikkoman, San Francisco, CA, USA), eggs (Safeway brand, Pleasanton, CA, USA), and fresh green onion (Safeway brand) were used for the preparation of the fried rice. Additional materials used in the determination of the volatile compound profile of the fried rice samples were sodium phosphate monobasic monohydrate (SPMM) (ACS grade, VWR Life Science, Radnor, PA, USA); nonanal (N0296, CAS 124-19-6, Tokyo Chemical Industries Co., America, OR, USA) with a purity of >95%; and ethanol (100% ethyl alcohol, Koptec, PA, USA).

2.2 Fried rice preparation

The fried rice was prepared, and the control samples were frozen in industrial scale food preparation facilities at Banzai Sushi (Seattle, WA, USA), a company that produces frozen RTE meals and sushi products for retail markets. The formulation is presented in Table 1.

Table 1–Fried rice formulation.

Ingredients	Amount (g)	Percentage (%)
Cooked rice	6,356	65.25
Soybean oil	210	2.16
Salted sweet cream butter	84	0.86
Soy sauce	168	1.72
Onion powder	14	0.14
White pepper	4.2	0.04
Salt (added to rice)	14	0.14
Chicken flavor	14	0.14
Eggs (raw)	2,100	21.56
Butter (added to eggs)	238	2.44
Salt (added to eggs)	14	0.14
Green onions (raw)	525	5.39
Total	9,741.2	100.00

2.2.1 Cooking. 3.3 kg of raw long-grain Jasmine rice and 4.5 kg of hot water were mixed together. All the other ingredients, except for the egg and green onions, were then added to the hot water and rice and mixed until they were evenly distributed. The mixture was cooked at 100 °C for 15 min in a gas cooking tunnel used specifically for rice. As the rice was being prepared, the egg was cooked in small batches and the green onions were chopped. The prepared scrambled eggs and green onions were added to the rice. In total, three batches of this rice were processed and mixed together into one large batch.

2.2.2 Control preparation. From this final large batch, forty 250 g trays were prepared and frozen at −45.5 °C in liquid nitrogen in a freezing tunnel to serve as the control. The 40 frozen trays were temporarily packaged in individual Ziploc plastic bags and stored in coolers with dry ice before being sealed.

2.2.3 Preparation of the MAPS samples. The rest of the prepared rice was packaged in 1.5 kg plastic bags and stored in coolers at 4 °C.

2.2.4 Transport. Both sets of samples, the control and those to be processed via MAPS, were shipped in coolers to Pullman, WA, USA. The transit time was 6 hr.

2.3 MAPS-processing

On the day following cooking, the nonfrozen fried rice samples were processed in a pilot-scale, MAPS in the Food Processing Pilot Plant at Washington State University, Pullman, WA, USA. A detailed description of MAPS can be found in Tang et al. (2018). Before processing, 250 g of the rice was weighed into polypropylene and EVOH trays (Silgan PFC) and sealed with a lid film with the same composition reported by Barnett, Sablani, Tang, and Ross (2019), under the following conditions: 200 °C for 4 s under a 65 mbar vacuum with a 400 mbar nitrogen flush. The MAPS was designed to achieve a minimum 90 °C for 10 min ($F_{90\,°C}$ = 10 min) at the cold spot in the food trays. This processing condition should result in more than a 6-log reduction of nonproteolytic *Clostridium botulinum* spores (Peng et al., 2017). The procedures for processing are described in Auksornsri et al. (2018). Two batches of 16 trays each were processed. After being processed, the trays were stored at 7.3 ± 2 °C. A Temperature Data Logger (SUPCO, Bronx, NY, USA) was used to track the temperature. The storage temperature was selected because research showed that approximately 10% of consumers' refrigerators in the United States are above 7.2 °C, and thus this temperature would mimic realistic storage conditions (Peng et al., 2017).

2.4 Control storing

The control samples were sealed under identical conditions as those of the MAPS-samples and stored at −31 °C. The storage conditions for the control samples were selected to ensure minimal product changes over the length of the study.

Trays of each type (MAPS and control) were randomly selected and analyzed for sensory and physico-chemical properties at 1 (day 7), 4 (day 28), and 6 (day 42) weeks of storage, after which the aerobic plate count (APC) values reached 10^5 to 10^6.

2.5 Microbial analysis

At weeks 1 and 6, microbial analyses were performed. Trays of both rice samples were randomly selected and sent to Microchem Laboratories (Seattle, WA, USA). The following analyses from AOAC International Official Methods of Analysis were used to detect spoilage: APC, yeasts, and molds as well as total coliform. The samples were also screened for *Bacillus cereus* (Local Instruction)*; Salmonella*; *Listeria monocytogenes;* and *E.* coli O157:H7.

2.6 Sensory evaluation

The present study protocol received the approval of the WSU Institutional Review Board for conducting tests with human subjects, under the title *Consumer preferences of fried rice IRB #16994.*

Rate-all-that-apply (RATA) questions were used for the sensory evaluation. This method is a variation of check-all-that-apply questions in which consumers indicate whether terms from a list apply to describe a given product and if so, to rate the intensity of the terms (Vidal, Ares, Hedderley, & Jaeger, 2018). This methodology has been reported as a valid and reliable sensory profiling tool suitable for small semitrained panels (11 assessors) (Giacalone & Hedelund, 2016).

In this study, RATA questions for the fried rice were divided into six sections: aroma, appearance, taste/flavor, texture, mouthfeel, and aftertaste. The terms used for each of the sensory modalities were defined based on pilot work and previous rice and quinoa studies (Pramudya & Seo, 2018; Wu, Ross, Morris, & Murphy, 2017). A small, semitrained panel ($n = 8$; 6 females, 2 males, ages 23 to 45) evaluated the sensory profile of the MAPS-rice and the control. The rice samples were tested by all assessors at weeks 1, 4, and 6 of storage.

All the assessors of the semitrained panel had previous experience in conducting sensory evaluation and had been part of multiple descriptive panels run at the WSU Sensory Evaluation Facility. In an orientation session, the paper-based ballot was presented to the assessors. The ballot comprised the six different sensory modalities previously mentioned. All the terms and the three-point intensity scale were discussed with the assessors and the ballot was tested with MAPS-fried rice processed during pilot trials but following the same processing conditions as the ones used for the present study.

During the orientation session, it was also clarified that some of the sensory modalities were more conveniently evaluated overall (aroma, flavor/taste, mouth feel, and aftertaste) and the other ones, the main ingredients of the fried rice, were more easily assessed individually. A final point was made that in assessing "high," "medium," and "low" in the color attributes for egg and green onions, assessors were to focus on the intensity of the color rather than the number of the items of that color in the sample. Thus, a rating of "medium" intensity for an *olive-green* onion was an evaluation of the medium-level intensity of the *olive-green* color. Following this first session, question design and data acquisition were finalized with Compusense® Cloud (Guelph, ON, USA) software. The WSU Sensory Evaluation Facility is a member of the Compusense Academic Consortium. A second orientation session was conducted to present standards to clarify some of the aroma attributes, specifically *oily, buttery, sesame, soy*, and *nutty*. The standards presented to the assessors were the ones reported by Wu et al. (2017).

For each session, the control trays were thawed in water at room temperature for 1.5 hr before the warming step. Each fried rice tray (250 g) was warmed at 45 to 50 °C for 30 min (15 min on each side, top and bottom) with a food warmer (Glo-Ray HATCO Corp., Milwaukee, WI, USA). Then, the trays were opened, and the rice was carefully mixed. Seventeen to 20 grams of warmed rice was then portioned into styrofoam containers.

Evaluations were conducted in individual booths, under white lighting, with temperature and pressure control. The fried rice samples were coded with 3-digit codes and presented in monadic sequential, randomized, balanced order. All samples were evaluated at 40 ± 1 °C. A 30 s break was given between the evaluation of each sample. Filtered water and unsalted crackers were provided as palate cleansers.

Assessors evaluated six sensory modalities: first aroma, followed by appearance, taste/flavor, texture, mouthfeel, and aftertaste, checking the terms they considered appropriate for describing the rice samples (Figure 1). The list consisted of 5 to 16 terms, depending on the sensory modality. Assessors then rated the intensity of the selected terms, using a three-point structured scale (low, medium, and high).

2.7 Sensory data analysis

RATA results were analyzed by treating the RATA scores as continuous data and expanding the scale to 4 points (0, 1, 2, and 3 for absent, low, medium, and high, respectively) (Meyners, Jaeger, & Ares, 2016; Vidal et al., 2018). Repeated measures analysis of variance (ANOVA) using mixed models was conducted. Rice treatment and time and the interaction (rice treatment × time) were analyzed as the fixed factors, time as the repeated factor, and panelists as the subject factor.

Means were separated with Tukey's honest significant difference test (HSD). Principal component analysis (PCA) was used for data visualization and to elucidate the relationships among the rice sensory attributes and storage times. XLSTAT 2017 (Addinsoft, Paris, France) statistical software was used for all data analyses. If the terms were used at a frequency of 20% or less by the assessors, those terms were not considered for analysis. Out of the 76 terms (Figure 1) that comprised the complete list of attributes, 19 were not considered for analysis. The results from the assessors were validated by internal agreement on the rating of the intensity of one of the attributes. For each of the tested sensory modalities, several attributes were selected and checked/tracked so that the group average intensity did not differ by more than 0.50 between replicated MAPS-rice samples evaluated at a specific time point (1, 4, or 6 weeks). The rice samples were tested by the assessors in duplicate.

2.8 Physical analysis

2.8.1 Texture. Immediately following sensory analysis, samples were cooled to room temperature (20 °C). The textural profile analysis (TPA) of both rice types was performed with a TA-XT2i Texture Analyzer (Texture Technologies Corp., Hamilton, MA, USA) equipped with a 25 kg load cell. An acrylic probe (TA-11, $d = 2.54$ cm) compressed 6 grains of fried rice at 1.00 mm/s as the pretest, test, and post-test speeds. For each rice sample, the TPA was replicated eight times. A two-cycle compression force-versus-time program was used to compress the samples to 90% of the original cooked grain thickness before it was allowed to return to the original conformation and compress it again (Yu, Ma, & Sun, 2010).

2.8.2 Color change (ΔE). The color of both rice samples was measured with a spectrophotometer (CM-5, KONICA MINOLTA, Osaka, Japan). The measurement condition used was a 30 mm Petri dish. Approximately 30 g of each sample was spooned into a plastic Petri dish. For each rice sample, six measurements were performed. The total color change (ΔE) was

I. AROMA

Overall

Attribute	Low	Med	High
Oily			
Buttery			
Oxidized			
Roasted			
Burnt			
Grain like			
Metallic			
Nutty			
Earthy			
Sulfur			
Soy			
Sesame			
Off-aroma			
Other:			

II.APPEARANCE (by looking at)

Overall

Attribute	Low	Med	High
Oily			
Amount of ingredients beside rice			
Sheen/ Shiny			
Other:			

Rice

Attribute	Low	Med	High
Oily			
Loose grains			
Mushy			
Sheen/ shiny			
Light brown			
Other:			

Egg

Attribute	Low	Med	High
Shrivelled/ overcooked			
Cooked			
Light yellow			
Dark yellow			
Other:			

Green onions

Attribute	Low	Med	High
Shrivelled			
Light green			
Olive green			
Dark green			
Sheen/shiny			
Other:			

III. TASTE/ FLAVOR

Overall

Attribute	Low	Med	High
Sweet			
Salty			
Sour			
Umami			
Bitter			
Oily			
Oxidized			
Grain-like			
Sulfur			
Soy			
Sesame			
Off-flavor			
Other:			

IV. TEXTURE (by tasting)

Rice

Attribute	Low	Med	High
Soft			
Firm			
Separate/ loose particles			
Sticky			
Chewy/ gummy			
Other:			

Green onions

Attribute	Low	Med	High
Firm			
Soft			
Slippery			
Crunchy			
Mushy			
Other:			

Egg

Attribute	Low	Med	High
Firm			
Soft			
Rubbery			
Chewy			
Other:			

V. MOUTHFEEL

Overall

Attribute	Low	Med	High
Oily			
Greasy			
Mouthcoating			
Rough/ grainy			
Other:			

VI. AFTERTASTE

Overall

Attribute	Low	Med	High
Oily			
Bitter			
Soy			
Sesame			
Umami			
Other:			

Comments:____________________

Figure 1–Ballot of the rate-all-that-apply (RATA) question with the sensory attributes tested for the MAPS-rice and the control.

calculated from the $L^\star$, $a^\star$, and $b^\star$ values to describe the color changes that occurred in the rice over time by means of the methodology described by Aamir, Ovissipour, Rasco, Tang, and Sablani (2014).

2.8.3 Chemical analysis. To measure pH, 5 g of rice and 10 mL of Milli-Q water were mixed with an ultra-turrax (Tekmar, Model TR-10 Power control, Vernon, BC, Canada) (Code of Federal Regulations, 1998). The pH-meter (Accumet Basic AB15 Plus, Fisher Scientific, Loughborough, Leics, UK) was calibrated to buffer the reference standards pH 4.00 ± 0.01 and pH 7.00 ± 0.01 (VWR Chemicals, Radnor, PA, USA) before measurements. The pH of each sample was measured five times.

Table 2–Pathogens and spoilage-related microbial analyses conducted on the MAPS-rice and the control during 6-weeks of storage.

		Microorganism tested						
Time (weeks)	Treatment	*B. cereus* (CFU/g)	*Salmonella* (in 25 g)	*L. monocytogenes* (in 25 g)	*E. coli* O157:H7 (in 25 g)	Aerobic count (CFU/g)	Yeast and molds(CFU/g)	Total coliforms (CFU/g)
1	MAPS[a]	<10	Negative	Negative	Negative	<10	<10	<10
	Control	<10	Negative	Negative	Negative	$1.5{\star}10^4$	$7.0{\star}10^2$	10
6	MAPS	<10	Negative	Negative	Negative	$6.5{\star}10^6$	<10	<10
	Control	<10	Negative	Negative	Negative	$6.9{\star}10^2$	$4.5{\star}10^1$	<10

[a]MAPS-rice replicates 1 and 2 are represented as MAPS, and the cooked frozen fried rice is represented as control.

The moisture, fat, and salt contents were determined with the AOAC 934.01/950.46, AOAC 922.06, and AOAC 971.19/976.19 methods, respectively.

2.8.4 Analysis of volatile compounds. For the extraction, 25 g of the MAPS- or control rice was homogenized with a mortar and pestle for 1 min. In triplicate, 5 g of each homogenized rice sample was mixed with 5 mL of 25% (m/v) SPMM solution, with an ultra-turrax homogenizer (Tekmar, Model TR-10 Power control) at a speed of 70 for 1 min. The mixture was added to 20-mL septum glass vials (natural rubber orange/TEF transp.; 60° Shore, 1.3 mm, GERSTEL) and then manually sealed. An SPME fiber (50/30 μL DVB/CAR/PDMS; Supelco, PA, USA) was used to extract and absorb the volatile compounds (60 °C, 30 min, mixing speed = 750 rpm). The fiber was injected with an automatic autosampler (CombiPAL; CTC Analytics AG, Lake Elmo, MN, USA) into a gas chromatography (GC) system (6890N; Agilent Technologies, Santa Clara, CA, USA) coupled to a mass spectrometry system (5975C Agilent Technologies) with an HP-5MS column (30 m × 0.250 mm × 0.5 micrometer; Agilent Technologies) and desorbed at 250 °C for 5 min. The injection port was maintained at 250 °C in split less mode. Helium (99.999%) was used as a carrier gas and applied at a constant flow rate of 1.8 mL/min. The GC oven temperature was initially set at 40 °C, maintained there for 6 min, and then increased to 100 °C at a rate of 3 °C/min and maintained for 3 min. The temperature was increased to 230 °C at a rate of 5 °C/min and maintained for 10 min (Liu, Li, Chen, & Yong, 2017). Spectra were acquired over the m/z range of 41 to 450 amu and total ion chromatograms were determined for peak area integration.

During storage, nonanal was used as an external standard and tracked as an indicator of lipid oxidation in the fried rice samples (Ross & Smith, 2006). A standard curve was prepared. A specific volume of the nonanal solution was transferred into 20-mL septum glass vials and mixed with 25% (m/v) SPMM solution to obtain the desired concentration for each point of the standard curve (0.025 to 0.004 mg/mL); the final volume was 5 mL. Each standard was analyzed in duplicate. The mean values of the peak area for each point were calculated and then plotted in a graph as a function of the nonanal concentration. The following equation was obtained to calculate the nonanal concentration: Peak area = $5.0{\star}10^9$ nonanal Cn – $8.0{\star}10^6$ $R^2 = 0.9913$.

2.8.5 Physical and chemical data analysis. Data for hardness, ΔE, pH, and nonanal quantification were analyzed by repeated measures ANOVA using mixed models. Rice treatment and time and the interaction (rice treatment × time) were analyzed as the fixed factors, time as the repeated factor, and repetition as the subject factor. Means were separated by Tukey's HSD. XLSTAT 2017 (Addinsoft) statistical software was used for all data analyses.

3. RESULTS AND DISCUSSION

3.1 Microbial analysis

The microbial testing results for the MAPS-rice and the control are presented in Table 2. MAPS was effective in controlling yeasts, molds, and all the pathogenic bacteria tested in the fried rice over the 6 weeks of storage. In chilled food, a minimum of 6 log reductions in nonproteolytic *C. botulinum* spores or *L. monocytogenes* is required. A food product heated at 90 °C for 10 min and stored at ≤5 °C would have a maximum shelf life of ≤6 weeks (Peng et al., 2017). However, depending on the product's chemical composition and the barrier properties of the packaging materials, the shelf life could vary from 6 to 14 weeks at refrigerated temperatures (Sonar, Rasco, Tang, & Sablani, 2019).

After 6 weeks of storage at 7.3 ± 2 °C, the APC for the MAPS-rice reached values that ranged from 10^5 to 10^6 CFU/g. Generally, in solid foods, the APC should not exceed values of 10^7 CFU/g; otherwise, the product is spoiled (Fung, 2009).

3.2 Sensory evaluation

To understand the sensory changes that the two types of rice underwent during storage, the main effects (rice treatment and time) and their interaction (rice treatment × time) were analyzed. The rice treatment × time interaction was not significant; therefore, only the main effects of rice treatment and time were interpreted.

Rice treatment (i.e., MAPS-processed or control) significantly influenced some of the sensory attributes ($P < 0.05$), mainly texture of the egg and green onion.

The intensity score of the egg texture attribute *firm* was significantly higher ($P = 0.005$) for the MAPS-rice (2.00) than for the control (0.77). However, the intensity for *firm* for the MAPS-rice was medium. *Soft* attribute was significantly higher ($P < 0.0001$) for the control (1.19) than for the MAPS-rice (0.06). MW technology may have had a higher impact given that the rice was initially cooked and then processed through the MAPS system as compared to the control, which only underwent one cooking process.

The green onion texture attribute *crunchy* was perceived as significantly higher ($P = 0.002$) for the control (1.71) than for the MAPS-rice (0.52).

Additionally, for both the control and MAPS-rice, storage time had a significant effect on all sensory modalities, including aroma, appearance, taste/flavor, and texture ($P < 0.05$) (Table 3). The aroma-related attribute *nutty* aroma was perceived with a significantly lower intensity as the storage time increased.

When green onion appearance attribute was compared between 1 and 6 weeks of storage, *shiny* perception increased ($P < 0.0001$). The intensity of the dark yellow attribute of egg significantly increased across weeks 1 to 4; however, there was no significant

Integrated Food Science

Table 3–Means of sensory attributes intensities that significantly differed ($P < 0.05$) due to the effect of storage time.

Storage time (weeks)	Aroma Nutty	Eggappearance Dark yellow	Green onion appearance Sheen/shiny	Taste/flavor Grain-like	Green onion texture Slippery
1	1.50 a[A]	0.06b	0.00b	1.91b	0.00b
4	1.28 a	1.22a	1.69a	2.22ab	1.13a
6	0.00 b	1.22a	1.75a	2.69a	1.22a
P-value	<0.0001	<0.0001	<0.0001	0.000	<0.0001

[A]Different letters within a column (a, b) indicate that attribute intensities were different among storage times at $P < 0.05$ as determined using Tukey's HSD. These results range between 0 and 3 due to the use of a four point scale of 0, 1, 2, and 3 (absent, low, medium, and high). Mean values are collapsed over rice treatment, replicate, and panelists.

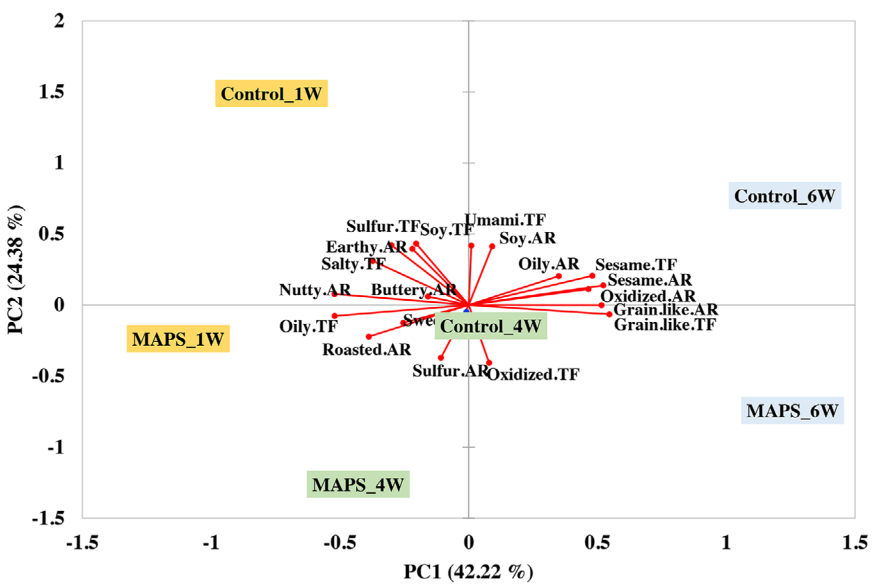

Figure 2–PCA biplot of aroma (AR) and taste/flavor (TF) attributes evaluated by a semitrained sensory panel ($n = 8$) of MAPS-rice and the control over a 6-week storage period. For each time point, MAPS-rice replicates 1 and 2 are represented as MAPS and cooked frozen fried rice replicates 1 and 2 are represented as control. The storage times of 1, 4, and 6 weeks are represented as _1W, _4W, and _6W following the sample name. Aroma attributes are followed by AR and taste/flavor attributes are followed by TF.

difference in the perceived intensity between 4 and 6 weeks of storage.

With respect to taste/flavor, *grain-like* intensity significantly increased ($P = 0.000$) as the storage time increased. Barnett et al. (2019) reported that as the storage time of MW-processed Cajun chicken pasta meals increased, increases in the intensities of some aroma, taste, and flavor attributes were observed. These increases may have resulted from potential water migration from the package (Zhang, Tang, Rasco, Tang, & Sablani, 2016), which left the sample more concentrated at later storage times.

The last sensory modality influenced by the time effect was green onion texture; perception of the attribute *slippery* increased from 1 to 4 weeks, but no difference was determined between 4 and 6 weeks of storage.

To interpret the aroma and taste/flavor results and changes over storage time, PCA was used (Figure 2). In this figure, the visual proximity of one or more of the attributes to a listed specific rice sample reflects the degree of association between the attribute and the sample (Wu et al., 2017). The first two principal components, PC1 and PC2, accounted for 66.6% of the total variance (42.22% and 24.38%, respectively). The first component (PC1) was characterized by a *nutty, sesame, sulfur*, and *soy* aroma and by *soy, umami, salty, and oxidize*d taste/flavors. The aroma attributes of principal component 2 (PC2) were primarily described as *buttery* and *earthy* and by *grain-like, sesame*, and *oily* taste/flavor attributes.

At 1 week of storage, MAPS-rice and the control were characterized by *earthy, nutty*, and *roasted* aroma. After 4 weeks of storage, the MAPS-rice was mainly characterized by roasted aroma and the control sample by *sulfur* aroma. At the final point of the study, MAPS-rice and the control were mainly characterized by the positive aroma characteristics of *roasted* and *nutty, soy, sesame, oily*, and *grain-like*. The MAPS-rice aroma profile did not present negative changes over a 6-week period of storage.

After 1 week of storage, the taste attributes of both rice samples were characterized by some basic tastes/flavors, such as *salty* and *oily*. After 6 weeks of storage, the taste/flavors of *grain-like, sesame*, and *umami* were the most characterized flavors in the MAPS-rice and the control.

Very few studies have evaluated RTE changes during storage using a comprehensive sensory profile and a rice-based product processed with MW technology. With a small consumer panel ($n = 30$), changes in the sensory quality of plain Jasmine rice were assessed after MW pasteurization, with consumer liking scores for all the attributes, including flavor, color, and overall liking, decreasing significantly over 30 days of storage (Auksornsri & Songsermpong, 2017). However, those findings vary from those of the present study. In our study, negative aroma attributes, often associated with consumer rejection, did not arise after 42 days (6 weeks) of storage despite the complexity of the fried rice, which contained more ingredients (scrambled egg, green onion, and spices) than the research samples in the study by Auksornsri and Songsermpong (2017). Therefore, the lack of spoilage-related aromas/flavors in the MAPS-rice at 6 weeks of storage suggests that applying MAPS will extend the shelf life of RTE fried rice.

Table 4–Effect of rice treatment (MAPS processing) on the hardness, adhesiveness, pH, and nonanal concentration mean values of MAPS-rice and control.

Treatment	Hardness (N)	Adhesiveness (N s)	pH	Nonanal concentration (mg/mL)
MAPS[A]	59.50 ± 8.77a	−0.26 ± 0.18a	6.74 ± 0.29a	0.0027 ± 0.0003a
Control	65.13 ± 10.61b	−0.408 ± 0.22a	6.82 ± 0.07b	0.0030 ± 0.0004a
P-value	<0.0001	0.071	<0.0001	0.130

[A]MAPS-rice replicates 1 and 2 are represented as MAPS, and cooked frozen fried rice is represented as control. Different letters (a, b) within a column indicate that the tested parameter was significantly different between MAPS and the control at $P < 0.05$ as determined using Tukey's HSD.

Table 5–Effect of storage time on the hardness, adhesiveness, pH, and nonanal concentration mean values of MAPS-rice and the control.

Storage time (weeks)	Hardness (N)	Adhesiveness (N s)	pH	Nonanal concentration (mg/mL)
1	51.01 ± 4.11a[A]	−0.23 ± 0.12a	6.88 ± 0.03a	0.0030 ± 0.0003 a
4	69.23 ± 5.62b	−0.34 ± 0.22ab	6.86 ± 0.05b	0.0030 ± 0.0004 a
6	66.71 ± 7.27b	−0.44 ± 0.22b	6.60 ± 0.33c	0.0025 ± 0.0001 b
P-value	<0.0001	0.003	<0.0001	0.002

[A]Different letters within a column (a, b) indicate that the tested parameter mean value was different among storage time at $P < 0.05$ as determined using Tukey's HSD.

3.3 Physical analysis

To understand the physical and chemical changes that the two types of rice underwent during storage, the main effects (rice treatment and time) and their interaction (rice treatment × time) were analyzed.

3.3.1 Texture. For texture analysis results, the rice treatment × time interaction was not significant; therefore, only the main effects of rice treatment and time were interpreted. Of the texture parameters recorded from the TPA curves, hardness and adhesiveness are reported. Other parameters, such as springiness and chewiness, did not present significant differences due to the effect of the tested variables. Hardness is defined as the maximum force of the first compression. Adhesiveness is measured as the negative work between the two cycles and represents the work necessary to pull the plunger from the sample (Friedman, Whitney, & Szczesniak, 1963).

Rice hardness, one of the most important textural attributes of cooked rice, has been reported as one of the texture parameters mainly affected during storage at freezing temperatures (Kwak, Kim, & Jeong, 2015; Yu et al., 2010). Rice adhesiveness has also been investigated as part of the texture profile of cooked rice (Park, Kim, & Kim, 2001; Yu et al., 2010; Zhu et al., 2011).

In Table 4 and 5, the hardness and adhesiveness values of the MAPS-rice and the control measured during a 6-week storage period are presented. Results are reported as mean values with their respective standard deviation values. Hardness values of the MAPS-rice and the control differed significantly when the effect of the rice treatment (MAPS vs. control) was analyzed (Table 4). The control presented significantly ($P < 0.0001$) higher hardness as compared to the MAPS-rice; 65.13 ± 10.61N and 59.50 ± 8.77N, respectively. For adhesiveness, the MAPS-rice did not present significant differences in the mean values ($P = 0.071$) as compared to the control. Based on the effect of the storage time (Table 5), hardness values after 6 weeks of storage were significantly higher ($P <$ 0.000). Meanwhile, the hardness values did not present significant differences between 4 and 6 weeks of storage. These results align with the sensory evaluation findings, in which texture-related attributes of the rice did not change significantly ($P < 0.05$) due to storage time. In the case of adhesiveness, the mean values significantly decreased ($P = 0.003$) as the storage time increased. These findings match those of Yu et al. (2010), the authors reported a decrease in the adhesiveness of cooked frozen rice during the first month of storage. They hypothesized that this could be caused by amylopectin retrogradation.

Yu et al. (2010) reported hardness values for Japonica rice exposed to medium-to-slow freezing rates of 63.93 up to 70.30 N after 30 days of storage at −18 °C. Those values are comparable with the ones reported in the present study for the fried rice samples after 4 and 6 weeks of storage. Yu, Ma, and Sun (2009) and Yu et al. (2010) have proposed that one main reason for the increase in hardness during storage may be amylopectin retrogradation. Starch retrogradation occurs when the molecules of gelatinized starch begin to reassociate in an ordered crystalline structure under low energy input, such as in cooling and freezing (Jung, Lee, Lee, & Kim, 2016; Perdon, Siebenmorgen, Buescher, & Gbur, 1999). Commonly, as storage time increases, the degree of retrogradation gradually increases. Consequently, textural changes during storage, such as changes in chewiness and increased hardness in cooked rice, are closely related to starch retrogradation. Thus, starch retrogradation has become an important quality parameter for the evaluation of the effects of prolonged storage (Jung et al., 2016).

Some important factors should be understood more to evaluate the application of freezing in the preservation of cooked rice and the impact of freezing on texture-related characteristics. Freezing is an effective method to extend the shelf life of cooked rice; however, it is energy intensive and affects cooked rice texture significantly when freeze-thawing occurs. For frozen rice, any kind of breakdown in the cold storage chain in transportation from the factory to the retailer and then to the consumer can lead to undesirable changes in the texture (Yu et al., 2017). While the changes in texture are understood to some extent, there is little information about the changes in volatile compounds, appearance, and flavor of rice after chilling and freezing (Yu et al., 2017). The current study focused on a way to work around the potential degradation caused by freezing. The study investigated how MAPS processing can obviate the need for freezing and thus eliminate the acquisition of undesirable characteristics (i.e., hardness increase) caused by freezing in rice.

3.3.2 Color change (ΔE). For the color change results, the rice treatment × time interaction was significant; therefore,

Table 6–MAPS-rice and the control moisture, fat, and salt content at 1 and 6 weeks of storage.

Properties	Treatment	Storage time (weeks) 1	6
Moisture content (%)	MAPS[A]	59.56 ± 1.41	60.91 ± 0.06
	Control	59.70	61.63
Fat content (%)	MAPS	7.05 ± 0.35	6.50 ± 0.14
	Control	6.50	ND
Salt content (%)	MAPS	0.47 ± 0.00	0.50 ± 0.02
	Control	0.47	0.51

[A]MAPS-rice replicates 1 and 2 are represented as MAPS, and frozen fried rice is represented as control.
ND, not determined.

the interaction was interpreted. The ΔE mean values of the MAPS-fried rice significantly increased ($P < 0.0001$) from 1.84 ± 0.72 at 1 week of storage to 3.08 ± 1.17 after 6 weeks of storage. There were no significant differences when the ΔE mean values between 1 and 4 weeks of storage (1.12 ± 0.44) were compared. The control presented the opposite trend when changes from 1 to 6 weeks of storage were compared. The ΔE mean values for the control decreased significantly ($P < 0.0001$) from 3.34 ± 0.29 to 1.06 ± 0.70. There were no significant differences between the ΔE mean values at 4 weeks of storage (2.08 ± 0.48) as compared to both ΔE mean values at 1 and 6 weeks of storage. Notably, most of the ΔE values obtained for both rice samples were less than or close to 2. According to Martin (2015), the minimum ΔE to detect a difference by human sight is approximately 2. Smaller differences can normally be detected in neutral colors, while more saturated colors require a slightly larger ΔE. Possibly, because the ΔE values are very close to the minimum threshold needed to detect a difference, a comparison of the ΔE and the sensory evaluation of the rice color showed that the panelists did not detect relevant color changes in the rice samples over the course of the study. There was no significant change in the color-related attribute of light brown in the rice.

3.3.3 Chemical analysis. For the pH analysis results, the rice treatment × time interaction was not significant; therefore, only the main effects of rice treatment and time were interpreted. The mean pH values of the MAPS-rice and the control are presented in Table 4 and 5. The pH values of the fried rice samples significantly differ (<0.0001) due to rice treatment (MAPS vs. control) (Table 4). Moulavi, Chaudhari, Nalawade, and Kanade (2018) reported pH values of fresh cooked white rice that ranged from 6.00 to 6.70 and those of brown rice from 6.20 to 6.80. The pH values obtained for the MAPS-rice and the control are within those ranges. In the case of the storage time effect (Table 5), the pH values of the fried rice samples decreased significantly ($P < 0.0001$) after 6 weeks of storage. The decrease in the pH of the rice samples could be associated with the increase in the APC mainly for the MAPS-rice ($6.5{\star}10^6$ UFC/g). The pH values of the fried rice samples were close to neutral (pH = 7.0). A pH close to 7.0 in a processed food product makes it more susceptible to microbial spoilage.

The moisture, fat, and salt content of the MAPS-rice and the control are shown in Table 6. The three parameters presented little change over the 6-week period of the study. The moisture content of both samples of fried rice was approximately 60%. Similar values were reported by Ali et al. (2008) in a comparative study of parboiled cooked rice and frozen rice; this study found moisture contents of approximately 66% and 64.38%, respectively. In another study conducted by Yu et al. (2010), the authors reported a moisture content for Japonica cooked rice of 62.98%.

The fat content for the rice samples was less than 10%; it ranged from 7.05 ± 0.35% to 6.50 ± 0.14% for the MAPS-rice after 6 weeks of storage and it was 6.50% for the control. The salt content for the MAPS-rice and the control was approximately 0.50% and did not change considerably after 6 weeks of storage.

3.3.4 Analysis of volatile compounds. To evaluate the impact of the fat content on the rice shelf life, the volatile compounds profile of both types of rice was analyzed with GC-MS. The nonanal concentration, a compound commonly associated with lipid oxidation (Ross & Smith, 2006), of the fried rice samples during storage is presented in Table 4 and 5.

Rice treatment did not impact the concentration of nonanal present in the samples. The mean nonanal concentration of the control did not significantly differ to the one of the MAPS-rice ($P = 0.130$). Meanwhile, the nonanal concentration significantly ($P = 0.020$) decreased due to the influence of storage time after 6 weeks of storage. Based on the results from the sensory evaluation, the panelists did not detect a significant difference in the aroma and flavor of the MAPS-rice that could be related to lipid oxidation. Therefore, the presence of nonanal in the MAPS-rice can likely be attributed to the natural existence of this compound in the rice.

In addition, little is known about how the flavor of cooked RTE rice changes under various storage conditions. Because flavor is a decisive quality parameter for consumers, its potential changes and deterioration in RTE rice after storage should be understood (Yu et al., 2017).

This was a unique, exploratory study where rice processed with MAPS and stored at 7 °C was characterized with sensory, instrumental, and microbial analyses. Some limitations included the use of nonirradiated spices and green onions, ingredients that could have increased the initial microbial load of the rice. Fried rice is a complex matrix to work with an MAPS-processed RTE because of its lower rate of heat transfer as compared to that of food products with a higher moisture content. Therefore, more research on the optimization of processing conditions is suggested. Some possible improvements may be to include more time intervals, conduct additional measurements, and track potential changes in nutritional characteristics, such as protein, starch aging, or vitamin loss to ensure the nutritional quality of the rice. In addition, a larger consumer study would contribute to the value of these results. Due to the limited production capacity of the MAPS system, it was not possible to conduct a consumer study at the time of the study to complement the results obtained with the semitrained panel evaluation.

4. CONCLUSIONS

MAPS-rice reached a shelf life of 42 days while stored at 7.3 ± 2 °C. Compared to the control, it presented a very similar profile for most of the tested variables (i.e., the majority of sensory attributes and pH). Hardness was significantly higher in the control; this finding reveals one of the disadvantages of freezing and how rice texture is affected after the freezing-thawing process. Freezing is also considered an energy intensive preservation method. During the 6 weeks of the study, the MAPS-rice did not present negative changes to its sensory and physicochemical profile: The perception of some texture-related attributes of the green onion did not change from 4 to 6 weeks of storage. The factor that defined the shelf life of the MAPS-rice was microbial spoilage.

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AUTHOR CONTRIBUTIONS

The author's responsibilities were as follows: M. Montero designed the research, collected the data, analyzed the data, interpreted the results, and drafted the initial manuscript. S. Sablani and J. Tang designed the research. C. Ross designed the research and edited the manuscript. All authors approved the final manuscript.

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