Influence of milling intensity and storage temperature on the quality of Catahoula rice (*Oryza sativa L.*)

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Abstract

Rice is typically stored in the form of whole kernel (rough rice with husk) to minimize quality changes, although storage of milled rice is more convenient and economically feasible. Expenses associated with low temperature storage of rough rice have prompted the need for alternative processing and storage methods, especially in developing countries. Thus, the effects of temperature (30-60 °C) on quality characteristics of milled Catahoula rice during 31 d of storage were investigated. Additionally, the physicochemical properties and cooking quality of rice milled at different intensities (light, medium, and heavy milling) were analyzed. Storage temperature and milling intensity were found to affect the quality of stored and cooked rice, respectively. Higher levels of rice milling intensity correlated with greater water absorption, easier compression, and faster gelatinization of the cooked kernels. During the storage time, protein contents were consistent, while lipid contents slightly decreased. The milled rice experienced an increase in lightness and decrease in moisture content with increasing storage temperatures. This study revealed that by adjusting rice milling parameters and storage temperature the quality of Catahoula rice can be controlled.

Keywords: Rice, Quality parameters, Storage temperature, Cooking, Milling

1. Introduction

Rice has become a primary staple food for people in many countries in Asia and it serves as a valuable source of grains in the United States and various European countries. Rice distribution and storage are required to ensure its timely delivery to consumers year round. For rough rice, it has been reported that during storage a range of changes in the physicochemical, pasting, and nutritional properties of rice occur, which affects the rice quality (Chrastil, 1990; Chrastil, 1992; Swamy, Sowbhagya, & Bhattacharya, 1978; Villareal, Resurreccion, Suzuki, & Juliano, 1976; Zhou, Robards, Helliwell, & Blanchard, 2002). To minimize these changes, low temperature and controlled atmosphere storage are usually concluded as the recommended methods. However, low temperature storage is considered expensive due to high initial cost of cooling systems and high energy consumption during its operation, while controlled atmosphere storage needs special packaging and storing facilities, which are costly as well. Furthermore, the expenses of facility maintenance are also high, thus the suggested methods cannot be suitably applied in developing countries (Nguyen & Goto, 2009).

Rice storage is typically conducted in the form of whole kernel (rough rice with husk) to minimize quality change (Adhikarinayake, Palipane, & Muller, 2006). On the other hand, it is more convenient and economically feasible to distribute and store milled rice than rough rice, especially in grocery stores and supermarkets in cities. Additionally, milled rice is typically preferred over brown rice and under-milled rice for its superior eating quality (Piggott, Morrison, & Clyne, 1991; Rao, Narayana, & Desikachar, 1967; Roberts, 1979). Because the degree of milling influences cooking and eating qualities it is a critical factor that must be controlled during rice processing (Mohapatra & Bal, 2006). Therefore, the elements influencing quality change in milled rice during storage are important to observe. Through this knowledge, better processing and storage conditions may be facilitated to prolong shelf life of the milled rice.

Milled rice is composed of starch, protein, lipid, and a small quantity of vitamins and minerals. Starch is the major constituent of milled rice at about 90 g/100 g dry matter, while total protein and lipid contents are 6.5 and 1.5-1.7 g/100 g dry matter, respectively (Juliano, 1993). Because protein and lipid are usually parts of the bran layer in the grain, their abundance is likely affected by the milling method. However, in common practices not all parts of this layer are removed by milling, otherwise the yield would drastically decrease. Meanwhile, Zhou et al. (2002) further explain that protein and lipid deteriorate more rapidly than starch, thus the existence of these substances contribute greatly to taste and color changes in milled rice during storage. While there has been prior investigation of the effects of milling and storage conditions on stored and cooked rice quality, there is still a need for more comprehensive research when conditions are varied, especially using Louisiana Catahoula rice, a seldom studied variety. The unique combination of degree of milling, storage temperature and time, and cooking assessment combinations have not been studied for rice. These factors facilitate the understanding of changes in rice protein, lipid and moisture content, color, water absorption, and textural properties, which all play a critical role in consumer acceptance. In addition, the effect of degree of milling on surface morphological characteristics of rice using scanning electron micrographs has not been done or was lacking in previous studies. The objective of this research was to observe the effect of milling conditions and storage temperature on the quality of Catahoula rice.

2. Materials and methods

2.1. Sample preparation

The rough rice used was Catahoula rice (*Oryza sativa L.*), obtained from Louisiana State University Agricultural Center (LSU AgCenter) Rice Research Station, Rayne, Louisiana. Catahoula rice is a conventional long-grain rice that is a high-yielding, blast-resistant, semidwarf cultivar which has good milling quality, lodging resistance, and grain quality parameters (Blanche et al., 2009). Rough rice was dried to 11-13 g/100 g moisture, cleaned, packaged, and stored at room temperature by the Rice Station for 1 month until it was brought to the School of Nutrition and Food Sciences, LSU. The rough rice was hulled and milled using a pilot scale rice milling unit (Satake Corporation, Japan). Three degrees of milling were applied to obtain milled rice with light (4.37%), medium (7.34%), and heavy (10.19%) degrees of milling. The degree of milling is the percentage of rice layer removed by milling and it was obtained from the weight difference between unmilled and milled rice. Higher degree of milling values correspond with greater bran removal (Wadsworth, 1994). Degree of milling was set to minimum, medium, and maximum weight of load for opening the lever of the vertical polisher for light, medium, and heavy milling, respectively.

The milled rice obtained from medium milling was selected for a storage experiment. The samples were stored at three different temperatures: 30, 45, and 60 °C, for a period of 31 d. During the storage period, quality parameters of milled rice such as color and moisture, protein, and lipid content were measured. For determining cooking quality, analyses of water absorption, texture, and rate of gelatinization of cooked brown and milled rice were conducted. In addition, full length brown rice was separated into head rice and broken rice. The head rice yield was based on 75% or more of the total length of the whole brown rice (Yadav & Jindal, 2001). The head rice yield was determined by dividing head rice weight by initial rough rice weight

(Daniels, Marks, Siebenmorgen, McNew, & Meullenet, 1998). Milling yield was based on rough rice and was calculated by dividing brown or milled rice weight by initial rough rice weight.

2.2. Moisture content

Measurement of rice moisture content was conducted using the conventional oven method. Each sample (3-5 g) was placed on an aluminum tray that was weighed before use. The sample was dried at 105 °C for at least 24 h. The dried sample was then weighed again and sample moisture content was determined gravimetrically.

2.3. Color and surface morphology

Rice color was measured using a LabScan XE HunterLab color meter (Hunter Associates Laboratory Inc., Reston, VA). The sample (5-6 g) was placed on a plastic tray and scanned by the color meter which directly displays the values of L^*, a^* and b^* in the Hunter Lab color model. The L^* values assess the degree of lightness to darkness, a^* values correlate with the degree of redness to greenness, and b^* values measure the extent of yellowness to blueness. Scanning electron micrographs of rice were obtained according to the method described by Chotiko and Sathivel (2014).

2.4. Protein and lipid content

Protein analysis of rice was conducted based on the dry combustion method using a Leco TruSpec nitrogen analyzer (Leco Corporation, St. Joseph, MI). A 0.15 g sample was used for analysis and the resulting nitrogen content was multiplied by a correction factor of 5.7 to get g/100 g protein. Lipid content of rice was analyzed using the Soxhlet method (AOCS Official Method Ai 3.75, 1997). Each sample (60 g) was dried at 105 °C for 24 h, and then ground for 20 s to get homogeneous particle size. The ground sample (2 g) was weighed into Whatman filter paper No. 1, folded according to the method, and placed into the Soxhlet system. The sample was extracted for 4 h using petroleum ether as solvent. At the end of the extraction, the weight of the extraction tube was recorded and the difference in weight was used to determine the mass of oil in the sample.

2.5. Water absorption

About 5 g of rice was added to 50 mL of boiling water in a 150 mL beaker. After 5 min of cooking in a 95 °C water bath, the rice was removed from the mixture with a spoon and placed in a strainer for 3-5 s to drain excessive water. Then the sample was placed on a filter paper and kept at room temperature (20 °C) for 10 min, then weighed. This method was repeated for cooking times of 5, 10, 15, 20, and 25 min. Water absorption (%) was determined from the weight difference between uncooked and cooked samples.

2.6. Gelatinization

This method comprises adding 10 kernels of rice to 50 mL of boiling water in a 150 ml glass beaker. After 5 min of cooking in a 95 °C water bath, the kernels were removed from the mixture with a spoon, drained in a strainer, and placed on a filter paper. The sample was kept in room temperature for 10 min and then placed between glass plates (30 x 10 cm) and pressed by hand. Well-cooked kernels are easy to deform into a flat form so their size would become bigger, while the ones that are uncooked would remain the same or slightly larger in size. Analysis was done by visual inspection. The procedure was repeated for cooking times of 5, 10, 15, 20, and 25 min (Billiris, Siebenmorgen, Meullenet, & Mauromoustakos, 2012).

2.7. Textural properties

After cooking at 95 °C, a cooked sample of 10 rice kernels was strained, and then placed on a filter paper. The sample was kept at room temperature for 10 min before transferring the sample to the aluminum plate of an Instron 5544 texture analyzer (Instron Industrial Products, PA, USA). Texture analysis was performed using a 2-kN load cell under a compression test mode, using a 10 cm diameter, 0.60 cm thick aluminum probe, with a speed of 5 mm/s. The kernels were compressed to 0.1 mm, and the force needed to press the kernels was recorded. The maximum compression force (peak force) of the test run was used to quantify cooked rice hardness. This method was repeated for cooking times of 5, 10, 15, 20, and 25 min (Billiris et al., 2012).

2.8. Statistical analysis

Mean values from three separate replications were reported with standard deviations. The statistical significance of differences observed among treatment means was evaluated by Analysis of Variance (ANOVA) (SAS Version 9.4, SAS Institute Inc., Cary, NC), followed by post hoc Tukey's studentized range test. Furthermore, the statistical significance of differences observed among treatment means during storage time was determined by ANOVA, followed by the MIXED procedure to analyze the time * treatment effect.

3. Results and discussion

3.1. Quality characteristics and surface morphology

The effects of milling conditions on quality characteristics of Catahoula rice were summarized in Table 1. Milled rice had higher moisture contents and lower protein contents and milling yields than brown rice. The moisture contents of light (13.33±0.03 g/100 g) and medium (13.31±0.03 g/100 g) milled rice were not significantly different and were lower than that of heavy (13.90±0.02 g/100 g) milled rice, which had the highest moisture. Higher degrees of milling have been shown to produce rice with greater water binding capacity and swelling ratio (Champagne, Marshall, & Goynes, 1990). Milled rice had a slight decrease in lipid content compared to brown rice. More intense milling resulted in less head rice and greater quantities of broken rice and fine broken rice. A significantly lighter color was observed for medium (*L** = 69.36±0.04) and heavy (*L** = 70.92±0.27) milled rice compared to brown (*L** = 61.90±1.74) rice and light (*L** = 66.44±0.66) milled rice. Medium and heavy milled rice also had lower *a** and *b** values, indicating less redness and yellowness, respectively. The SEM (scanning electron microscope) images of the samples were shown in Figure 1. Brown rice had the greatest amount of intact bran, while as intensity of milling conditions increased to light, medium, and heavy, the bran layer was clearly diminished. The data for rice *L** values presented in Table 1 correlates with what was observed in the SEM images, which was that rice with higher lightness values experienced more prominent bran removal. Removal of the bran layer allows for faster cooking due to a higher rate of water diffusion into the rice kernel (Juliano & Bechtel, 1985).

3.2. Moisture content

Figure 2 shows the changes in moisture content of milled rice during storage as influenced by storage temperature. Milled rice stored at higher temperatures tended to lose moisture more rapidly than that stored at lower temperatures. The moisture content also decreased during the duration of storage at all temperatures. Furthermore, the rice stored at 45 and 60 °C experienced drying, thus their moisture contents were significantly lower than those stored at 30 °C. Within a short period (2 d), the rice stored at 60 °C had already lost 10 g/100 g moisture. This was mainly due to the drying effect experienced at higher temperatures. At 31 d of storage, the moisture contents (g/100 g) of rice at 30, 45, and 60 °C were 9.19±0.13, 4.02±0.21, and 1.69±0.16, respectively. Meullenet, Marks, Hankins, Griffin, and Daniels (2000) reported that higher storage temperatures decreased rice stickiness and increased hardness. Similarly, an increase in storage time and temperature may change the structure of the rice to become more organized and resistant to disruption, increasing the amount of time required for gelatinization by slowing moisture penetration into the granule (Zhou, Robards, Helliwell, & Blanchard, 2010).

3.3. Protein content

The protein content of the milled rice stored at their respective temperatures remained relatively stable with little or no significant change during the storage period (Figure 3). This result was expected for the rice protein content when excluding moisture content (dry basis). However, the protein in rice (oryzenin) can undergo denaturation at high storage temperatures. During storage, changes in protein structure such as a decrease in lower molecular weight peptides and an increase in higher molecular weight peptides and free amino acids have been reported (Zhou et al., 2002).

3.4. Lipid content

Rice lipids are relatively stable when the inner constituents of rice are intact. However, when the cell membrane is destroyed, lipid hydrolysis is initiated (Takano, 1989). Lipids become rancid during storage due to various factors. It is important to observe changes in lipids during storage because of the temperature effect, especially at high temperatures. In this study from the initial time to 31 d of storage, there was a slight decrease in lipid content for rice, more so at 45 and 60 °C (Figure 4). The differences in lipid content observed during storage likely results from hydrolysis and oxidation. Hydrolysis of lipids produces free fatty acids and oxidation forms hydroperoxides. It has been determined that non-starch lipids (free lipids) are primarily involved in hydrolysis and oxidation reactions (Yasumatsu & Moritaka, 1964).

3.5. Grain color

The L^* value of milled rice stored at 45 and 60 °C was higher at 31 d of storage than for rice stored at 30 °C (Figure 5). The relatively high temperatures of 45 and 60 °C decreased the moisture of the rice grains making them to appear semi-transparent due to the drying effect (Kim, Jang, Ha, & Bae, 2004). Whiteness has been found to be an important factor affecting the quality of cooked rice and it is used as an index of quality for milled rice (Hosokawa, Ban, Yokosawa, Yanase, & Chikubu, 1995; Kim, 2002), which will help determine the optimum milling duration. Karbassi and Mehdizadeh (2010) reported that rice dried in a fluidized bed dryer at higher temperatures had greater whiteness and lower sensory scores compared to sun dried rice.

3.6. Water absorption

The milling technique (light, medium, and heavy) led to a time-dependent increase in water absorption by the rice during cooking compared to the brown rice (Figure 6). However, the four treatments showed varying water absorption capacities. Heavy milled samples had the highest water absorption capacity with brown rice having the lowest. This was because of the mechanical behavior of the grain during the milling operation, which had implications on the cooked product (Ituen, Mittal, & Adeoti, 1986; Shittu, Olaniyi, Oyekanmi, & Okeleye, 2012). It was proposed by Zhou, Robards, Helliwell, and Blanchard (2007) that the swollen starch granule and starch components after cooking interact with each other to form a homogenous paste where the water held in the cooked rice is mainly involved in the starch hydration. Although there was a significant difference in water absorption capacity among brown rice and milled rice, the differences between light, medium, and heavy milled rice were slight, indicating brown rice would need more time to cook. Increased water uptake produces high quality cooked rice (Choi et al., 2005).

3.7 Gelatinization

During cooking, rice kernels absorb water and heat simultaneously, causing gelatinization of carbohydrates inside the kernel. Rate of gelatinization determines the cooking time and taste of cooked rice. Therefore, for optimizing the cooking process, gelatinization rate is important to observe. The gelatinization characteristics of rice starch may differ with the protein and amylose content, granular size, molecular weight, and structure of the starch (Waters et al., 2006). It is clearly seen that the samples were well cooked after 20 min of cooking under 95 °C, while all samples appear a bit over-cooked (too soft) after 25 min, except for brown rice (Figure 7).

3.8. Textural properties

An important parameter in evaluating cooked rice texture is hardness. Hardness is defined as the amount of force that occurs at any time during the first compression cycle of a material (Park, Kim, Park, & Kim, 2012; Smewing, 1999; Zhou et al., 2007), thus deriving the compressive strength. The strength required to compress the cooked milled rice kernels for all samples showed a decreasing trend with longer cooking times (Figure 8). A rapid decrease in compressive strength occurred during initial cooking up to 10 min cooking. Then the decrease of compressive strength was slower, but still significant. This is in agreement with previous works (Cao, Nishiyama, & Koide, 2004; Kamst, Bonazzi, Vasseur, & Bimbenet, 2002; Kunze & Wratten, 1985), which indicated that maximum compressive strength decreases with increased moisture content. In the present study, longer cooking time was related to high grain water absorption and high moisture content. Moreover, brown rice experienced less decrease in hardness compared to the milled rice. Notwithstanding, light and medium milled rice experienced a smaller decrease compared to heavy milled. Brown rice had the highest value of compressive strength, followed by light, medium, and heavy milled rice.

4. Conclusion

Different milling intensities (light, medium, and heavy) and storage temperatures (30, 45, and 60 °C) significantly influenced the quality characteristics of milled and cooked Catahoula rice. Milling intensity was related to cooked rice texture. As the rice milling intensity increased (from unmilled brown rice to heavy milled rice), cooked kernels absorbed more water, were more easily compressed (softer), and experienced quicker gelatinization. The light, medium, and heavy milled rice had faster gelatinization rates than brown rice and longer cooking times bolstered gelatinization for all rice samples. During 31 d of storage at 30-60 °C the medium milled rice generally showed a slight decrease in lipid content, while the protein content was stable. With increasing storage temperatures the *L** value of the rice increased, however the moisture content was lowered due to the effects of drying, especially at 45 and 60 °C. Storage at 30 °C produced higher quality rice than at 45 and 60 °C. This study showed that milling intensity and storage temperature are essential components in the maintenance of rice quality. This data will provide useful information for processors and farmers alike. Ultimately this would help in efforts to promote the utilization of rice cultivated in Louisiana.

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Figure 1. Scanning electron micrographs of rice subjected to various milling intensities. a = brown rice kernel, b = light milled rice kernel, c = medium milled rice kernel, and d = heavy milled rice kernel.

Figure 2. Moisture content of medium milled rice during storage. —■— = 30 °C, —▲— = 45 °C, and —●— = 60 °C. Moisture content values were reported using a dry weight basis.

Figure 3. Protein content of medium milled rice during storage—■— = 30 °C, —▲— = 45 °C, and —●— = 60 °C. Protein content values were reported using a dry weight basis.

Figure 4. Lipid content of medium milled rice during storage. —■— = 30 °C, —▲—= 45 °C, and —●— = 60 °C. Lipid content values were reported using a dry weight basis.

Figure 5. Lightness of medium milled rice during storage. —■— = 30 °C, —▲— = 45 °C, and —●— = 60 °C.

Figure 6. Water absorption capacity of brown and milled rice during cooking. —■— = heavy milled, —▲— = medium milled, —●— = light milled, and —◆— = brown rice.

Figure 7. Brown and milled rice kernels hand pressed between two glass plates, depicting the degree of gelatinization. Rows, from top to bottom: after 5, 10, 15, 20, and 25 min cooking. Columns, from left to right: brown, light milled, medium milled, and heavy milled rice.

Figure 8. Force required to compress the cooked, brown and milled rice kernels. —■— = heavy milled, —▲— = medium milled, —●— = light milled, and —◆— = brown rice.

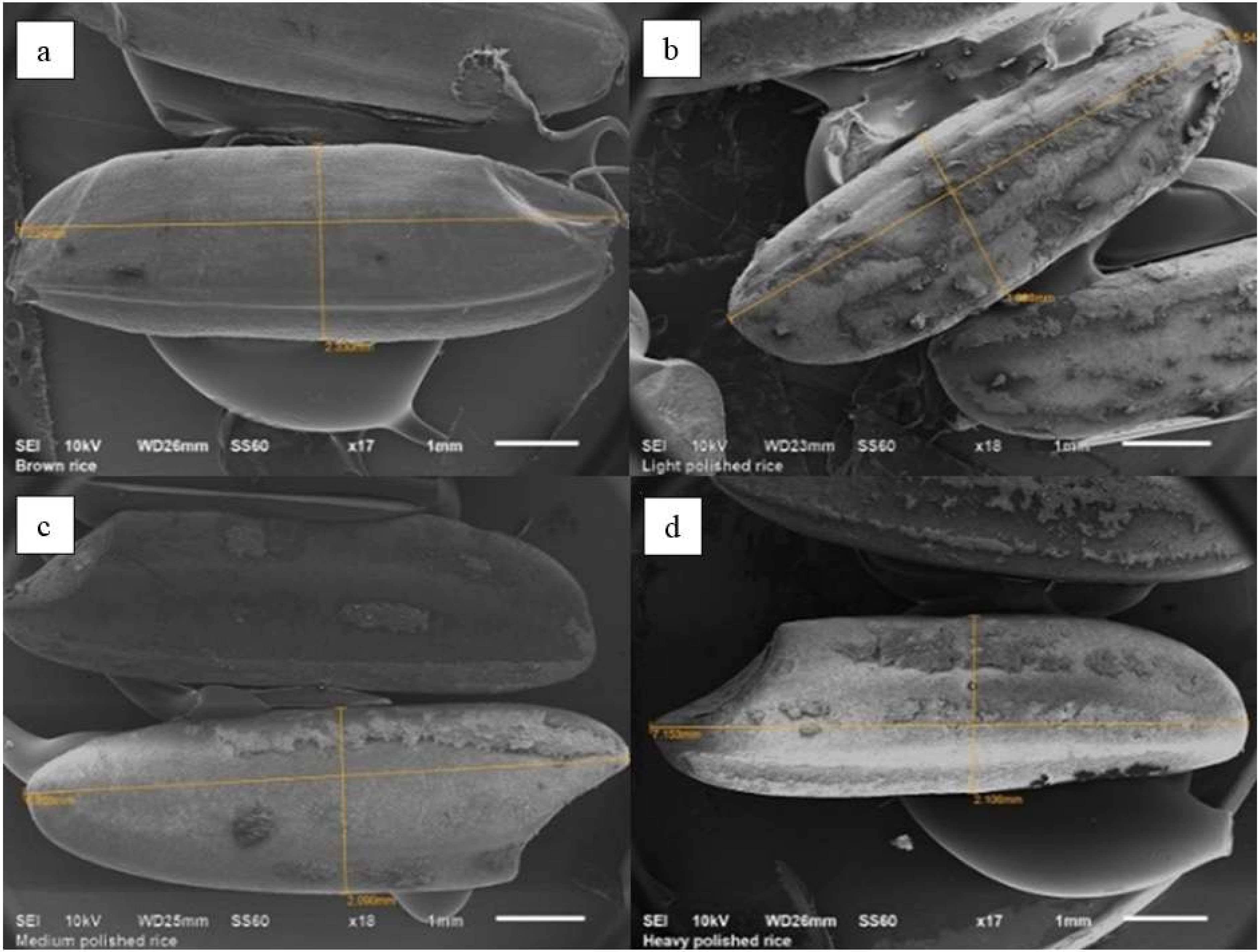
Table

Table 1. Effects of milling intensity on quality characteristics of Catahoula rice.

Quality parameter (g/ 100g)	**Brown rice**	**Light milling**	**Medium milling**	**Heavy milling**
Moisture	12.70±0.07[c]	13.33±0.03[b]	13.31±0.03[b]	13.90±0.02[a]
Protein	9.06±0.23[a]	8.35±0.48[b]	8.41±0.13[ab]	8.41±0.16[ab]
Lipids	2.80±1.02[a]	1.35±0.07[a]	1.37±0.87[a]	1.45±0.61[a]
Milling yield	83.92±0.86[a]	80.25±1.51[b]	77.76±0.69[bc]	75.37±0.93[c]
Yield quality				
Head rice	92.14	89.77	80.90	75.68
Broken rice	4.56	5.69	10.67	11.95
Fine broken rice	3.30	4.54	8.43	12.37
Color				
*L**	61.90±1.74[c]	66.44±0.66[b]	69.36±0.04[a]	70.92±0.27[a]
*a**	4.00±0.29[a]	1.11±0.08[b]	- 0.16±0.04[c]	- 0.48±0.03[c]
*b**	21.59±0.91[a]	16.74±0.29[b]	14.45±0.64[c]	13.42±0.16[c]

[a-c]Means±SD with different letters within a row indicate significant difference ($P \leq 0.05$). L^*, a^*, and b^* are the degree of lightness to darkness, redness to greenness, and yellowness to blueness, respectively. Moisture, protein, and lipid content values were reported using a dry weight basis.

Figure 1


a
b
c
d
SEI 10kV WD26mm SS60 x17 1mm
Brown rice
SEI 10kV WD23mm SS60 x18 1mm
Light polished rice
SEI 10kV WD25mm SS60 x18 1mm
Medium polished rice
SEI 10kV WD26mm SS60 x17 1mm
Heavy polished rice

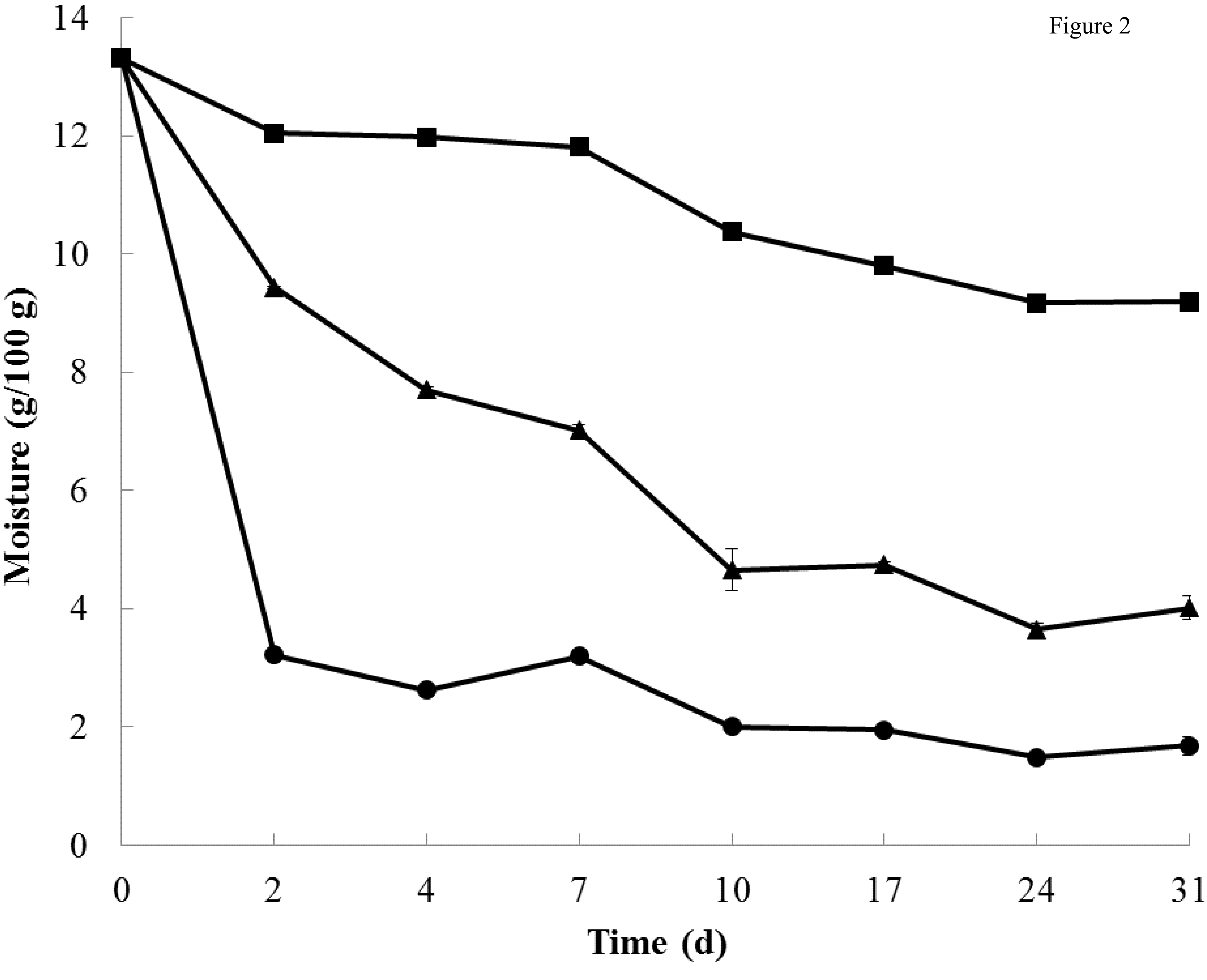


Figure 2
Moisture (g/100 g)
14
12
10
8
6
4
2
0
0
2
4
7
10
17
24
31
Time (d)

Figure 3

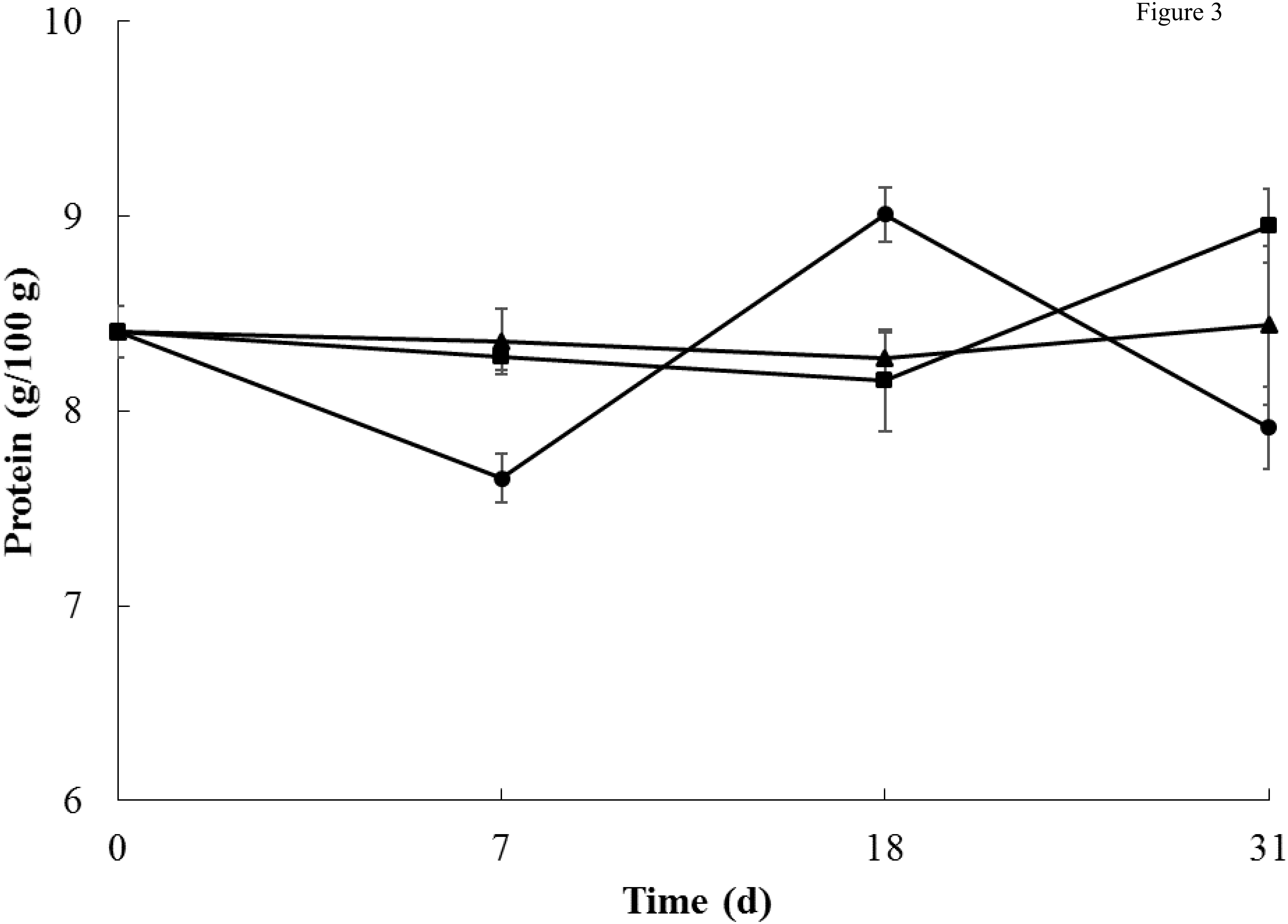


Figure 4

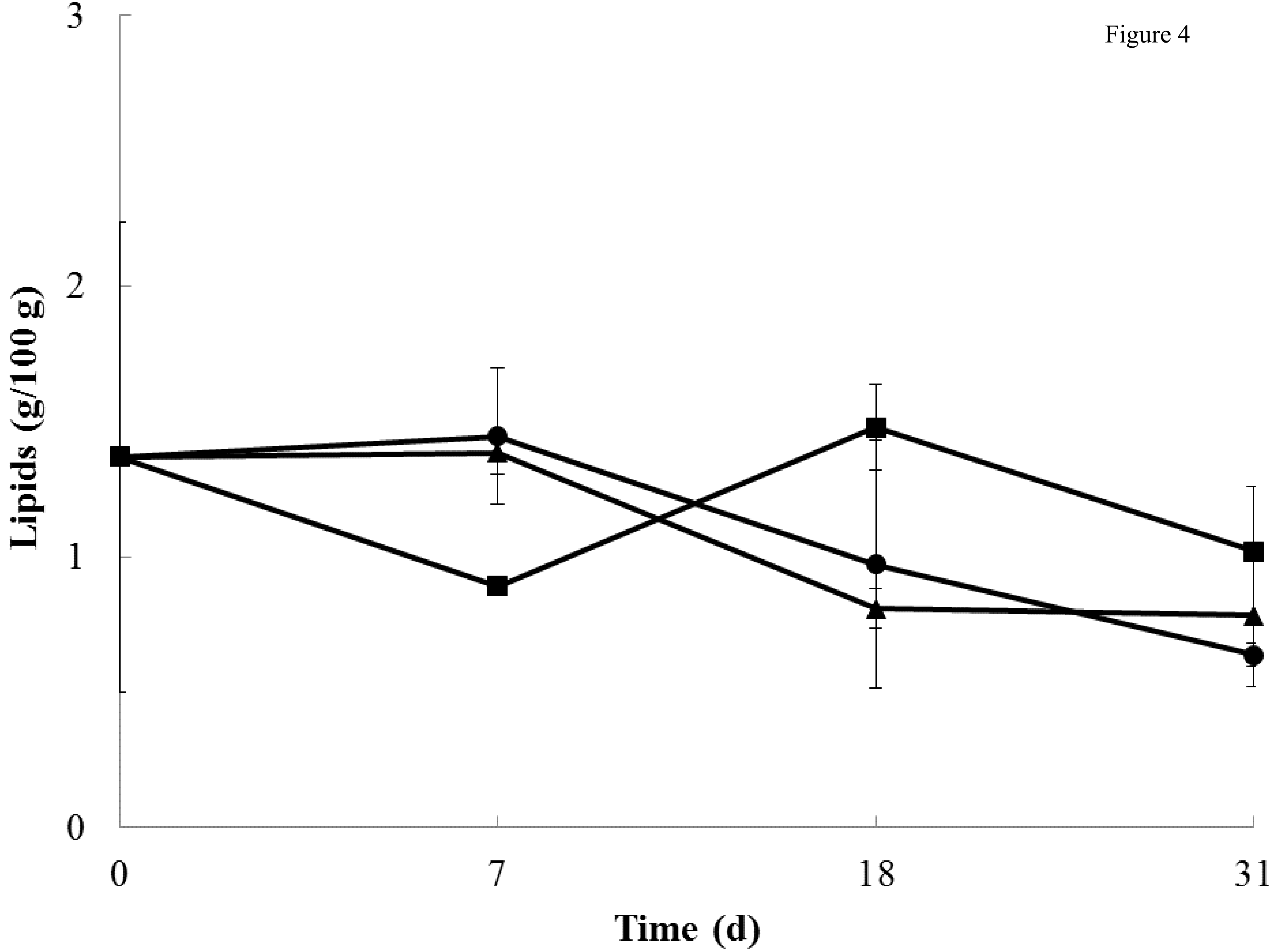
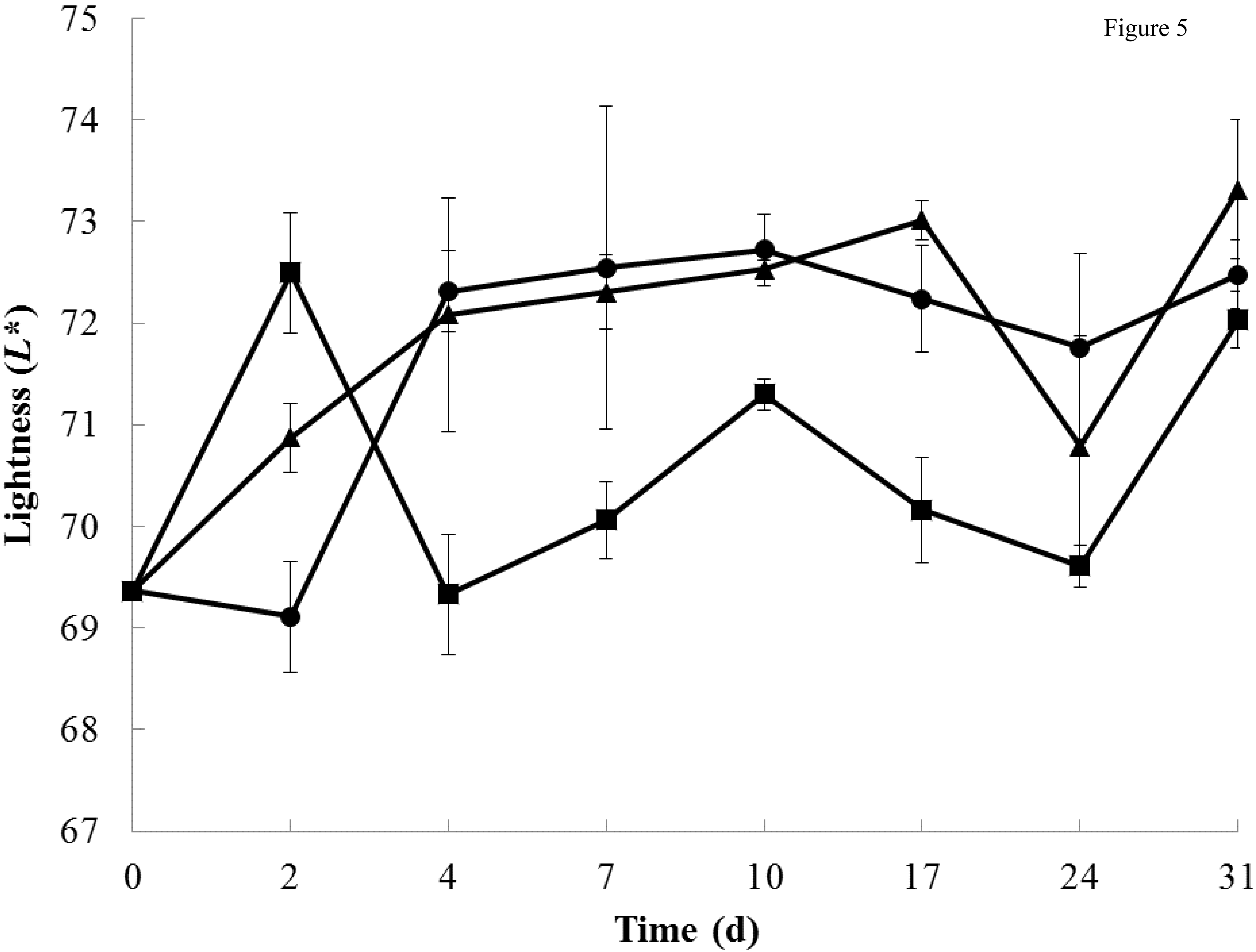


Figure 5



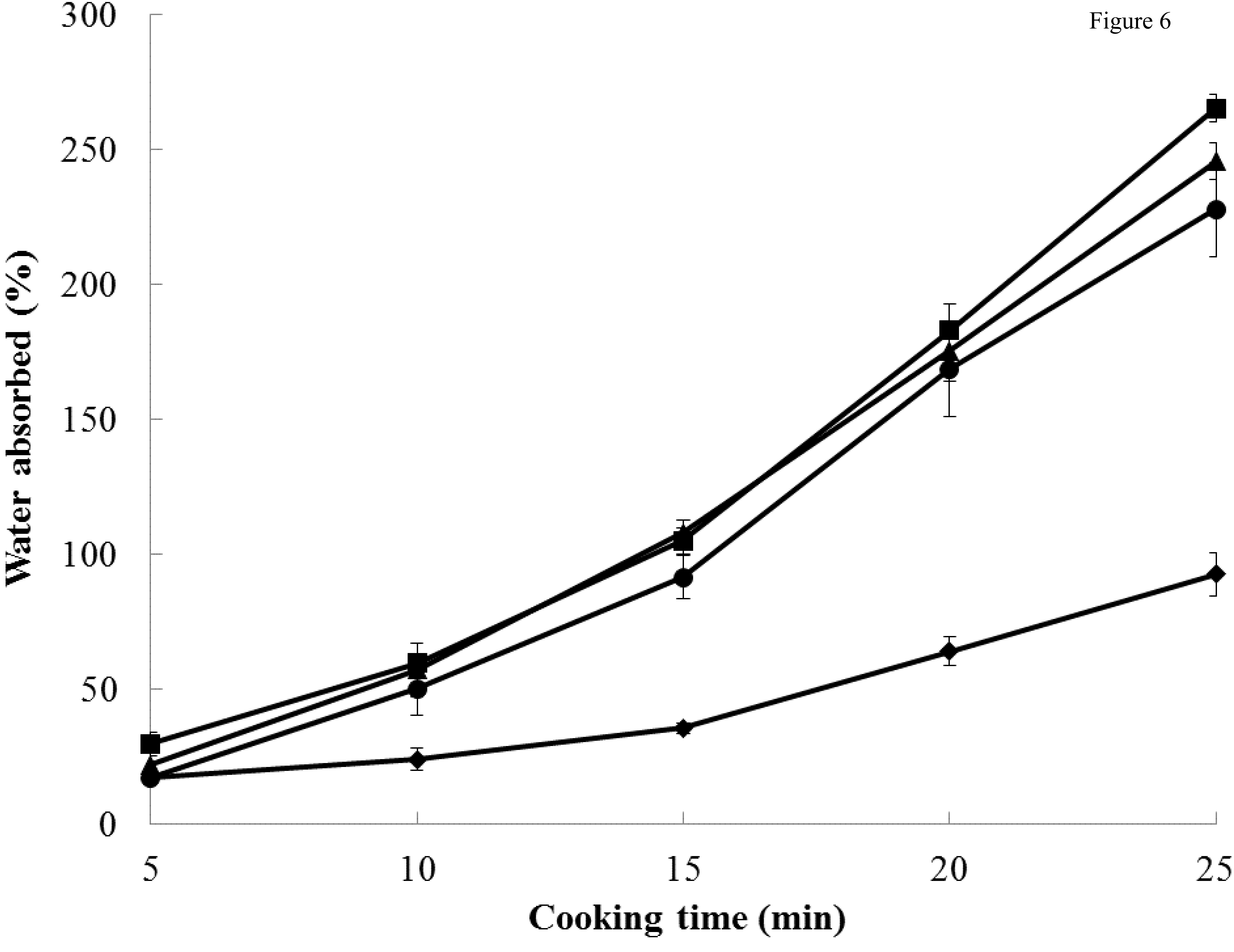
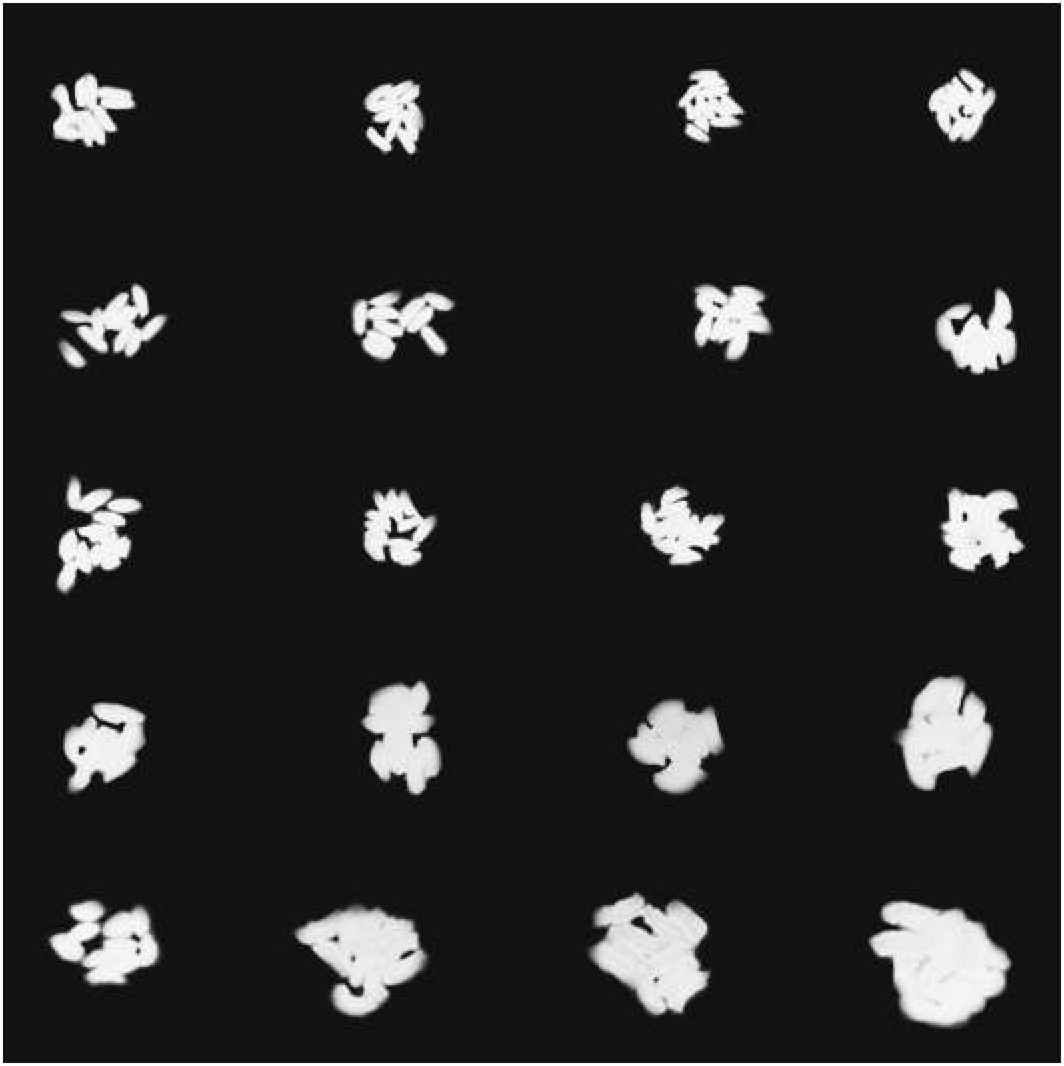


Figure 6
Water absorbed (%)
300
250
200
150
100
50
0
5
10
15
20
25
Cooking time (min)

Figure 7



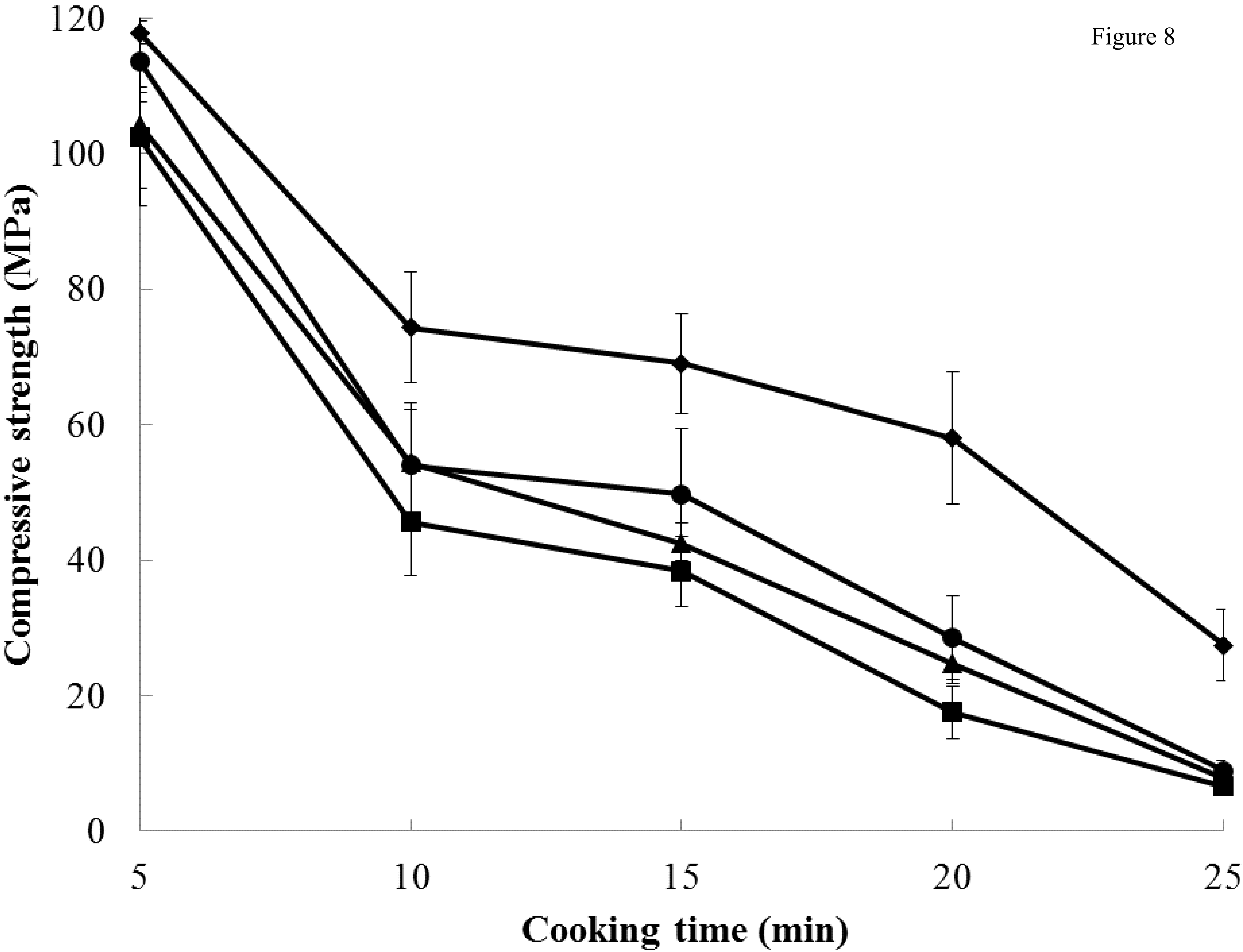


Figure 8
Compressive strength (MPa)
Cooking time (min)
0
20
40
60
80
100
120
5
10
15
20
25