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SOYBEAN GRAIN STORAGE ADVERSELY AFFECTS GRAIN TESTA COLOR, TEXTURE AND COOKING QUALITY

ADEL M. YOUSIF[1]

School of Exercise and Nutrition Sciences, Deakin University, 221 Burwood Highway, Burwood, Vic 3125, Australia

[1]Corresponding author.
TEL: +61-3-9251-7261;
FAX: +61-3-9244-6017;
EMAIL: adel.yousif@deakin.edu.au

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ABSTRACT

This article determines the effect of postharvest storage time and conditions on soybean rehydration, cooking (texture) quality and testa color. Soybean (*Glycine max* L.) samples were stored for 12 months (0, 3, 6, 9 and 12 months) at three moisture contents (MC) (9, 11 and 13%) and at three temperatures (10, 20 and 30C). Soybeans were measured for rehydration, cooked bean texture and testa color. Soybeans stored at increasing MC and temperature, especially at MC 13%, 30C, exhibited increased hydration after 6 h of soaking, increased cooked bean texture strength, reduced L^*, increased a^*, reduced b^* color values and increased ΔE^*ab color difference. This effect increased with increased storage time. Soybean storage at high MC and temperature for extended periods resulted in reduced cooked bean cooking quality and darkening of the soybean testa. This is expected to have a negative effect on soybean processing quality, sensory acceptability and economic value.

PRACTICAL APPLICATIONS

This work elucidates the effect of soybean storage for extended periods of time under varying temperatures and MC. Such storage may lead to detrimental changes in the soybean technological and physical properties; the major changes being testa darkening, reduced hydration and loss of cooking quality. Unfavorable soybean storage and related loss of quality will result in lower commercial value and reduced acceptability of soybeans by food processors and consumers. As a consequence, this work will provide information relevant to the formulation of appropriate soybean storage conditions for maintaining good soybean processing quality.

INTRODUCTION

Soybeans (*Glycine max* L.) are one of the most important grain legumes in the world. Projected global soybean production for 2011/2012 is 87.23 million tons (United States Department of Agriculture 2012); Australian soybean production for 2012 was around 174,800 tons (Australian Oilseeds Federation 2012). Soybeans are utilized in many traditional foods, such as soy milk, miso, tem peh and soy sauce (Golbitz 1995). In addition, soybeans are increasingly used in mainstream western food products in the form of textured soy protein. When color, flavor and seasoning are added, this fabricated product can be processed into a limitless number of manufactured food products that resemble beef, bacon, ham, fish and chicken (Liu 2005).

Further, an increased demand for thermo-extruded soy snack products has resulted in significant amounts of soybeans being used in seasoned, expanded food snacks (Faller *et al.* 1999). As a result, Australia's domestic consumption of edible soybeans, as well as its export of soybeans to countries such as Japan, Taiwan, Singapore and Indonesia, is increasing (Australian Oilseeds Federation 2010).

Soybean is a broad acre, mass-produced grain that is harvested in a short period at a particular time of the year in the northern and southern hemispheres (Liu 1997). In Australia, the soybean is mostly grown in the eastern states of Queensland and New South Wales (Australian Oilseeds Federation 2011) and is harvested in April and May (Grains Research and Development Corporation 2010). Once harvested, soybeans undergo a period of extended postharvest storage, where the grain is held below 14% moisture content (MC) until it is processed and utilized in food products (Liu 1997). As a result, soybean storage time may vary between 6 months (on farms) and as long as 3 years (during storage and handling) depending on the soybean MC (Barger 1981).

Stored grains are living, breathing entities that are biologically active. As a result, stored soybeans may experience deterioration during storage, especially when stored in improper conditions, such as high MC and high temperature, for an extended period (Liu 1997). Stored soybeans "grain" deterioration manifests in reduced physical and processing quality (Liu 1997). A loss of physical quality, such as changes to the grain hydration ability, cooked grain texture and grain testa color, affect the grain processing quality, the sensory acceptability of the processed soybean and ultimately the economic value of the stored grain (Hou and Chang 2004). Therefore, it is of interest to study the effect of postharvest storage conditions on the physical and processing quality of stored soybeans.

MATERIALS AND METHODS

The soybeans used were a culinary line, 98050-46, obtained from the CSIRO Plant Industry Canberra Black Mountain Laboratories (Canberra, ACT, Australia). Postharvest, soybeans were conditioned to higher MC 11% (as a % of total weight) and 13%. Soybeans were placed in large trays in a cold room (4C, 80% relative humidity), and periodically mixed to give an even uptake of moisture from the air. Soybeans were conditioned to a lower MC of 9% under ambient laboratory conditions.

Soybean MC was determined by the modified solids (total) and moisture in flour-air oven method AOAC, 925.10, (Association of Official Analytical Chemists International; AOAC 2012). Upon reaching the required MC (9, 11 and 13%), all soybean treatments were placed separately in sealed food grade nylon/polyethylene bags, and allowed to equilibrate for a week before checking the final MC.

Storage Conditions

Following moisture conditioning to the correct MC, separate 4.2 kg lots of soybeans were stored at three temperatures 10, 20 and 30C in resealable food grade nylon/polyethylene bags (350 × 270 mm), placed in 5 L polypropylene, food grade plastic buckets with sealable lids for the following storage times; 0, 3, 6, 9 and 12 months. The storage trial time and conditions were replicated twice.

Analytical Methods

Bean Mass. Triplicate 100 soybean grains were chosen at random, counted and weighed. Bean size was expressed in grams per 100 beans (Yousif *et al.* 2002).

Water Hydration Trial. Duplicate soybean (10 g) samples were placed in 50 mL sealed plastic containers and soaked in 45 mL of deionized Milli-Q water (Millipore Australia Pty Ltd, Kilsyth, Australia). The beans were weighed at 0 h and then incubated at 25C for 6 h (Yousif *et al.* 2002). The beans were then drained, blotted dry and weighed. Bean hydration was expressed as weight increase in grams.

Cooking of Soy Beans. Soybeans' volume of 20 mL (average weight 13.5 g) were placed in a 250 mL Pyrex glass beaker and soaked in 100 mL of deionized water at 25C for 18 h (Jackson and Varriano-Marston 1981). Following the soaking, beakers ($n = 6$) were placed on a perforated steel plate (heat distributor) inside a cooking pot (inside diameter 243 mm × 145 mm) with 1,800 mL of water at 100C. Then, in the beaker, 100 mL deionized water temperature was measured with a Centre 309 data logger thermometer (Centre Technology Crop, 238 Shu-lin, Taipei, Taiwan). Once the in beaker temperature reached 95C, the beans were cooked (>95C) for 30 min (Jackson and Varriano-Marston 1981). Following the cooking stage, the cooked soybeans were immediately cooled in ice water. All cooked bean samples were placed in a sealed container in a refrigerator at 4C until texture analysis. Four hours prior to texture analysis, the cooked soybean samples were taken out of the refrigerator and permitted to acclimatize to room temperature (20C).

Texture Measurements. Individual cooked beans had the testa removed and the cotyledons separated. The two cotyledons were placed with the flat side facing the Texture Analyzer platform. A Stable Micro Systems Model TA-XT Plus Texture Analyzer (Godalming, Surrey, U.K.) with a probe (Stable Micro Systems P/36R) was used to measure cotyledon texture (firmness). The result was reported as grams-force.

Texture analyzer settings were as follows: (Test mode, compression); (Pre-test speed, 2 mm/s); (Test speed, 1 mm/s); (Post-test speed, 1 mm/s); (Target mode, Distance); (Distance, 3 mm); (Trigger type, Auto) and (Trigger force, 5g). The texture of each sample was estimated as an average of the compression of 10 soybeans in the manner described above.

Soybean Color Measurement. L^*, a^* and b^* color values were measured using a Konica Minolta CR series Chroma Meter CR-400 (Konica Minolta Sensing Americas

Inc., Ramsey, NJ). Beans were placed in a glass light projection tube CR-A33e. Each soybean sample was measured 60 times and reported as an average. Between measurements, soybeans were removed from the glass light projection tube, placed in a bowl and mixed.

Color measurement derivatives were also calculated via the color difference index (ΔE^*ab), calculated as $\Delta E^*ab = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$ (Konica Minolta 2007).

According to the handbook of color science (Yamauchi 1989), the ΔE^*ab difference is an index for visual color differences. The color difference index *(ΔE^*ab)* is described in terms of related visual color difference as follows: (0–0.5, trace difference); (0.5–1.5, slightly discernible; hard to detect with the human eye); (1.5–3.0, noticeable; detectable by trained people); (3.0–6.0, Appreciable; detectable by ordinary people); (6.0–12.0, Large; large difference in the same color group) and (Larger than 12, extreme; another color group).

Statistical Analysis

Descriptive analyses were calculated and presented as mean ± the standard error of the mean. A three-way mixed analysis of variance with MC (9, 11 and 13%) and storage temperature (10, 20 and 30C) as among cohort factors plus storage time (0, 3, 6, 9 and 12 months) as a repeat measure. If the analysis of variance revealed a significant interaction then multiple comparisons (with Bonferroni adjustments where appropriate) were used to locate specific differences between storage conditions and/or time. The level of significance in this work is $P < 0.05$ unless otherwise stated. Statistical analysis was carried out via Statistical Package for Social Sciences version 17.0 for Windows (patch 14.0.2; IBM Corporation, NY).

RESULTS AND DISCUSSION

Bean Mass

The average soybean mass was found to be 24.75 ± 0.70 g/100 beans. Andrade and Ferreiro (1996) reported an average soybean mass to be between 19 and 20.6 g/100 beans. The difference in the reported soybean mass may be attributed to different growing conditions and soybean variety.

Water Hydration

Soybean storage MC (9, 11 and 13%) and temperature (10, 20 and 30C) had a significant effect on the soybean samples' ability to hydrate (6 h hydration). The largest significant effect on soybean hydration was found to be storage MC (9, 11 and 13%), which individually caused the greatest increase in the stored soybeans' ability to hydrate (Fig. 1).

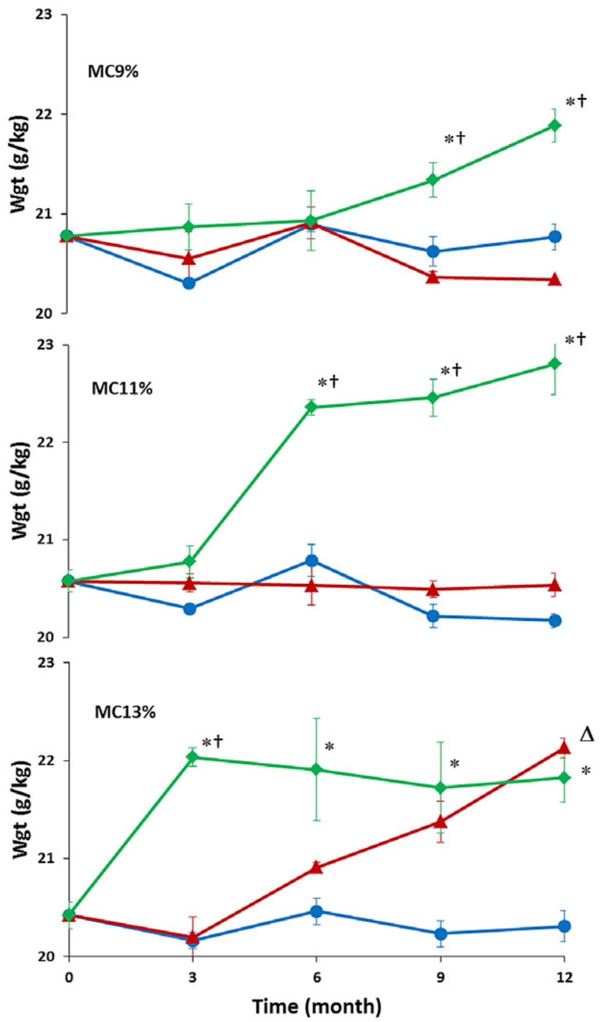

FIG. 1. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) WEIGHT (WGT) AFTER 6-H HYDRATION (AVERAGED OVER REP.). (●) 10C (▲) 20C (◆) 30C
Bars indicate standard error of the mean ($n = 2$ per point).
* indicates a significant difference between 10 and 30C storage; Δ indicates a significant difference between 10 and 20C storage; † indicates a significant difference between 20 and 30C storage.

Soybean storage MC (9, 11 and 13%) and temperature (20 and 30C) interacted significantly, resulting in increased soybean hydration ability. Further, hydration ability increased significantly with storage time (3, 6, 9 and 12 months). A comparison of the effect of storage MC% on soybean hydration ability indicated that storage time had a significant effect on soybeans stored at MC9, 11 and 13% (Fig. 1).

Effect of Soybean Storage MC and Temperature on Hydration. A comparison of the interaction of soybean MC% and storage temperature indicated no difference between beans stored at MC9%, 10C versus MC9%, 20C for the duration of the storage trial 12 months (Fig. 1). This suggests that soybean hydration ability remained relatively stable for these storage treatments. At 9 and 12 months of storage, a significant increase in soybean hydration ability was observed between soybeans stored at MC9%, 10C versus MC9%, 30C and MC9%, 20C versus MC9%, 30C (an increase of 5.3 and 7.9%, respectively) (Fig. 1). Soybeans with an MC of 11% behaved in a similar manner to MC9% at 10C and 20C storage temperatures, which exhibited an almost flat line (Fig. 1) in relation to hydration weight between 0 and 12 months storage.

At 6, 9 and 12 months of storage, a significant increase in soybean hydration was observed between soybeans stored at MC11%, 10C versus MC11%, 30C (an increase of 7.7, 11.4 and 12.9%, respectively) and MC11%, 20C versus MC11%, 30C (an increase of 9.3, 9.8 and 11.2%, respectively) (Fig. 1).

Soybeans stored at MC13% for 3 months exhibited a significant increase in soybean hydration between soybeans stored at MC13%, 10C versus MC13%, 30C and MC13%, 20C versus MC13%, 30C (an increase of 8.9 and 8.9%, respectively) (Fig. 1). Further, storage at 6, 9 and 12 months exhibited a significant increase in soybean hydration between soybeans stored at MC13%, 10C versus MC13%, 30C (an increase of 6.8, 7.4 and 7.4%, respectively). At 12 months storage, a significant increase in soybean hydration was also observed between soybeans stored at MC13%, 10C versus MC13%, 20C (an increase of 8.9%) (Fig. 1).

An increase in soybean water absorption when stored under different MCs, temperatures and time periods is dependent on the soybean grain testa and cotyledon water permeability. The initial rate (1–6 h) of grain water imbibition is controlled by the grain testa (Sefa-Dedeh and Stanley 1979). This effect is described as the hard shell phenomena. In contrast to other grains that have a hard testa (Yoshida *et al.* 1995; Yousif *et al.* 2002), soybeans have a thinner softer testa and hydrate in a short time, requiring 30–60 min (Redden 1994). This indicates that the soybean testa has higher permeability and a higher capacity for hydration. Therefore, in contradiction to the findings of other researchers (Moscoso *et al.* 1984; Yousif *et al.* 2002; Nasar-Abbas *et al.* 2008), this work has shown that stored soybeans' ability to hydrate increased with increased storage MC and temperature. The reason for this increase is possibly due to the collection of free water between the seed coat and cotyledons and in the fissure between the two cotyledons (Plhak *et al.* 1989; Pietrzak *et al.* 2002).

Further, previous research has shown that initial grain MC has a positive correlation with the rate of hydration (Moscoso *et al.* 1984). This may be why stored soybeans with higher MC (13%) exhibited a higher capacity of hydration compared with soybeans with lower MC (9%).

Texture Analysis

Preparation of soybeans for eating requires hydration and cooking. The cooking time, defined by Jones and Boulter (1983), is the time required to cook 50% of the beans. The beans are considered cooked when a degree of tenderness is achieved that is acceptable to the consumer (Moscoso *et al.* 1984).

Soybean cooking quality measured in cooked bean textural strength followed the same trends as the soybean water hydration, with significant effects of MC (9, 11 and 13%) and temperature (10, 20 and 30C). Soybean storage MC individually exhibited the largest significant effect on the increase in soybean cooked bean texture (Fig. 2). Soybean storage MC (9, 11 and 13%) and temperature (10, 20 and 30C) interacted significantly in increasing the cooked bean textural strength. This effect was enhanced significantly with storage time (0, 3, 6, 9 and 12 months) (Fig. 2).

Ability of grain to soften during cooking is related to the ability of the bean to hydrate during soaking and cooking. Coelho *et al.* (2007) observed that common beans (*Phaseolus vulgaris* L.) stored for 135 days at 29C exhibited a reduced capacity for water absorption, which resulted in reduced bean cooking ability. In this work, an increase in the cooked soybean textural strength is observed; however, in contradiction to the above, soybeans absorbed higher amounts of water with storage at higher MC and temperature conditions for extended periods of time (Fig. 1).

Effect of Soybean Storage MC and Temperature on Texture. A comparison of the effect of storage MC% on the soybean cooked bean texture indicated that storage time exhibited a significant effect in increasing the textural strength of soybeans stored at MC9, 11 and 13%. Further, at MC9%, storage time interacted significantly with storage temperature. A comparison of soybeans MC% interaction with storage temperature indicated no difference between soybeans stored at MC9%, 10C versus MC9%, 20C for the duration of the storage trial 12 months (Fig. 2). At 9 months storage, a significant difference (increase) was observed between soybeans stored at MC9%, 20C versus MC9%, 30C (an increase of 10.8%) (Fig. 2).

The cooking quality behavior of soybeans stored at MC11% (Fig. 2) followed the same trends as the MC11% hydration rate (Fig. 1), indicating a significant increase in cooked soybean textural strength over time. Soybeans stored at MC11%, 10C texture remained relatively unchanged for the duration of the storage trial 0–12 months. At 3 months of storage, a significant increase in cooked bean strength was exhibited between soybeans stored at MC11%, 20C versus MC11%, 30C (an increase of 16.5%). At 9 months storage, a significant increase in textural strength was exhibited between soybeans stored at MC11%, 10C versus

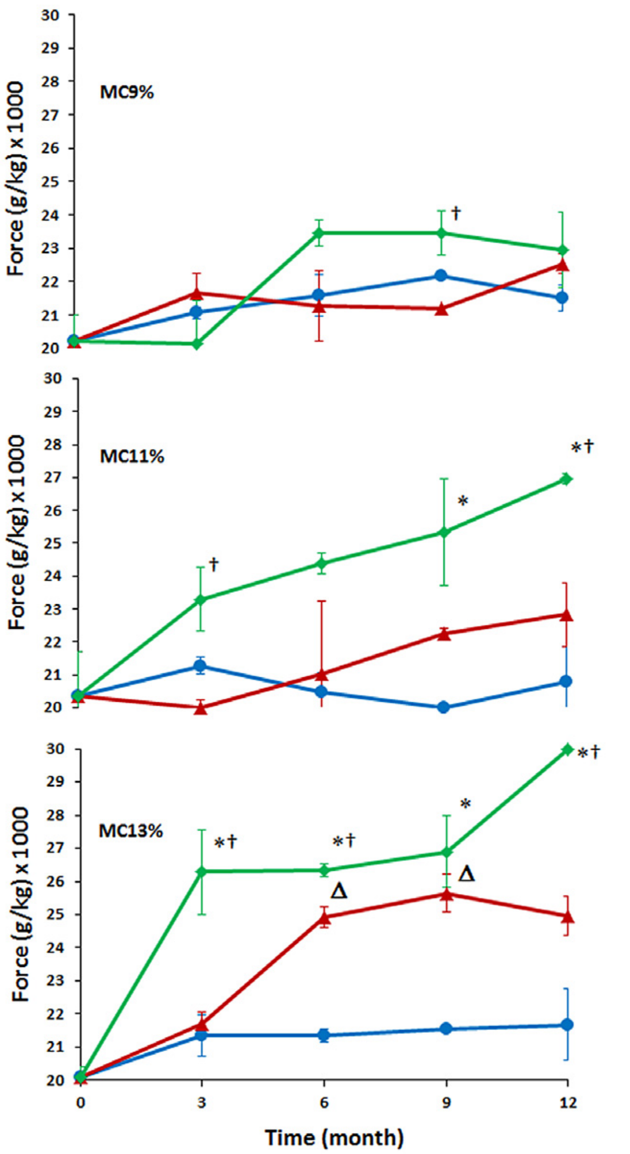

FIG. 2. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) COOKED TEXTURE (AVERAGED OVER REP.). (●) 10C (▲) 20C (◆) 30C
Bars indicate standard error of the mean (*n* = 10 per point).
* indicates a significant difference between 10 and 30C storage; Δ indicates a significant difference between 10 and 20C storage; † indicates a significant difference between 20 and 30C storage.

MC11%, 30C (an increase of 26.6%) (Fig. 2). Further, at 12 months of storage, a significant increase in cooked bean strength was exhibited between MC11%, 10C versus MC11%, 30C (an increase of 29.7%) and MC11%, 20C versus MC11%, 30C (an increase of 18.1%) (Fig. 2). This indicated that increased soybean MC resulted in increased cooked bean textural strength.

Soybeans stored at MC13%, 30C exhibited the largest significant increase (49.2%) in cooked bean textural strength at 12 months storage compared with 0 month storage. At 3, 6, 9 and 12 months storage, a significant increase in cooked bean strength was exhibited between soybeans stored at MC13%, 10C versus MC13%, 30C (an increase of 23.2, 23.4, 24.9 and 38.4% respectively) (Fig. 2). At 6 and 9 months storage, a significant increase in cooked bean strength was exhibited between soybeans stored at MC13%, 10C versus MC13%, 20C (an increase of 16.7 and 19.1%, respectively). Finally, at 3, 6 and 12 months storage, a significant increase in cooked bean strength was exhibited between soybeans stored at MC13%, 20C versus MC13%, 30C (an increase of 21.1, 5.7 and 20.1%, respectively) (Fig. 2).

A loss of stored soybeans' cooking quality is related to postharvest storage time and conditions. Soybeans stored at high MC and high temperature for extended periods hydrate and cook unevenly, resulting in uneven softening and the presence of hard beans, which require longer cooking times. The presence of hard beans has a detrimental effect on processing and results in cooked beans with poor nutritional value and sensory (textural) quality (Moscoso *et al.* 1984; Stanley 1992; Garcia and Lajolo 1994).

The reason for the increase in cooked soybean textural strength (reduced softening) in relation to storage, especially under high MC (13%) and high temperature (30C), is described as the hard-to-cook phenomena (HTC). HTC in soybeans is a consequence of the following storage-related biochemical process: lignification/protein depolymerization and phytic acid hydrolysis.

The process of lignification (and the formation of lignin) usually occurs within a carbohydrate matrix (Terashima *et al.* 1996). The presence of lignin where carbohydrates such as pectin and hemicelluloses are present reduces water penetration and hydration of the aforementioned carbohydrates; as a result, it is expected to reduce grain cotyledon hydration (Hincks and Stanley 1986; Terashima *et al.* 1996).

Further, soybean proteins may experience storage-related depolymerization into aromatic amino acids that, through the action of peroxidases, cross-link with polyphenols, migrate to the cell wall middle lamella, where they are precipitated as part of the stored grain lignification process (Hohlberg and Stanley 1987). This results in reduced water penetration into the cotyledon tissue and a related reduction in cotyledon cell separation during cooking, which ultimately results in an increase in cooked bean texture (Coelho *et al.* 2007).

Further, as a consequence of soybean storage at high MC and high temperature for extended periods, increased phytase activity may occur in the cotyledon tissue. Phytic acid is a chelating agent for divalent cations such as Ca, Mg, K and Zn (Kim *et al.* 2002). Phytic acid hydrolyses reduce chelating ability and results in the release of the divalent cations, which in turn migrate to the cotyledon cell middle lamella, creating cross-links with the galacturonic acid (Sievwright and Shipe 1986), which is the main building block for pectin. Ultimately, this process impairs pectin dissolution during cooking, resulting in reduced cotyledon cell separation and related soybean hydration and textural softness. Thus, HTC results in increased cooked beans texture, which creates difficulties in processing for home and commercial use.

Soybean Color Analysis

Soybean testa colors vary according to the soybean variety; colors include yellow, green, brown and black (Snyder and Kwon 1987). All varieties of soybeans are green in the early stages of maturity because of the presence of chlorophyll. As the bean matures further, the chlorophyll is lost and flavonoid pigments predominate (Snyder and Kwon 1987), providing individual coloration for each soybean variety.

Soybean testa color is an important indicator of soybean quality and economic value. In relation to this, the US grading standards discriminate against green, brown and black soybeans (Snyder and Kwon 1987). Further, soybean testa color has been observed to be a factor in the indication of the soybean storage stability in relation to cooking quality, marketing and consumer acceptability (Wszelaki *et al.* 2005). Legume grain storage time and conditions have been found to affect the grain seed coat color (Nasar-Abbas *et al.* 2009) which has been found to have a strong correlation with grain textural strength and cooking quality (Yousif *et al.* 2003).

Effect of Soybean Storage MC and Temperature on *L and *a** Color Value.** Soybean storage resulted in a general reduction of the testa *L** and increase in the *a**color value resulting in darkening of the soybean testa (Figs. 3 and 4). Soybean MC (9, 11 and 13%) and storage temperature (10, 20 and 30C) each exhibited a significant effect and interacted significantly in the reduction of the *L** and increase of the *a** color value. The above effects were enhanced significantly with increased storage time (3, 6, 9 and 12 months).

The above data have been corroborated by other researchers, who found that grain storage at high MC and/or high relative humidity, as well as high temperatures, resulted in reduction of the *L** color value and increase in the *a** color value (Reyes-Moreno *et al.* 2000; Yousif *et al.* 2003).

Effect of Soybean Storage MC and Temperature on *b Color Value.** In general, the *b** color value exhibited a gradual reduction with increased soybean MC (9 and 13%). The storage temperature also exhibited a significant but inverse effect on *b** color value. Soybean MC 13% and storage temperature (10, 20 and 30C) interacted significantly with the higher MC (13%) and higher temperature

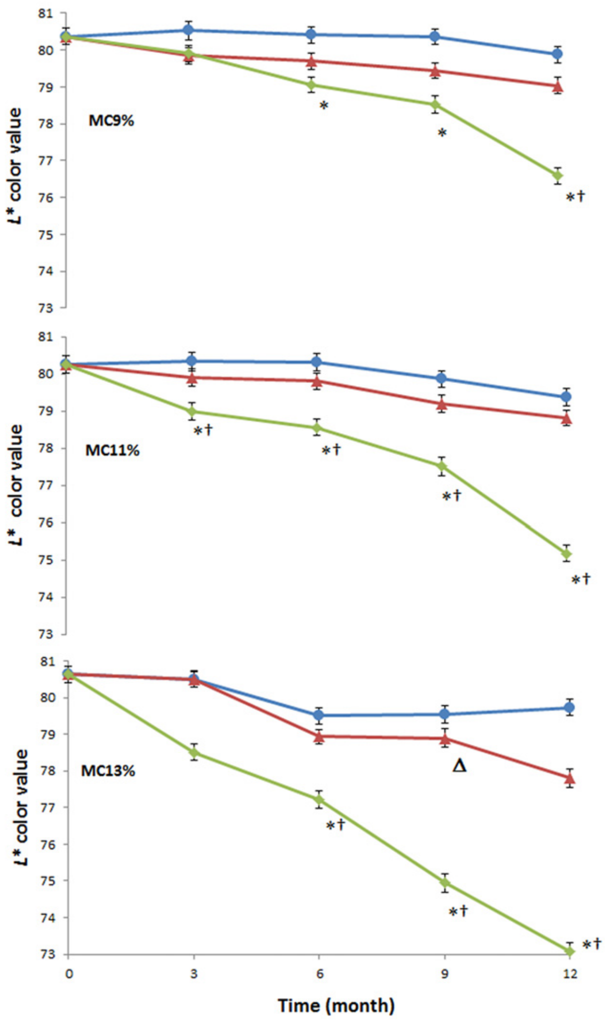

FIG. 3. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) *L** COLOR MEASUREMENT (AVERAGED OVER REP.). (●) 10C (▲) 20C (◆) 30C
Bars indicate standard error of the mean (*n* = 60 per point).
* indicates a significant difference between 10 and 30C storage; Δ indicates a significant difference between 10 and 20C storage; † indicates a significant difference between 20 and 30C storage.

(30C), resulting in the largest significant reduction in *b** color value. This effect was enhanced significantly with increased storage time (3, 6, 9 and 12 months) (Fig. 5).

A possible reason for the reduction in the soybean *b** color value is that one of the effects of soybean storage at high MC and temperature is the hydrolysis of β-Carotenes. Žilić *et al.* (2006) reported that soybeans that underwent an accelerated storage trial at 41C, at high relative humidity (>95%), for 3 days (72 h) resulted in a 42.8% decrease of β-Carotenes compared with the control sample. β-Carotenes are known to impart a yellow/orange color (Coultate 2009); therefore, the loss of β-Carotenes in

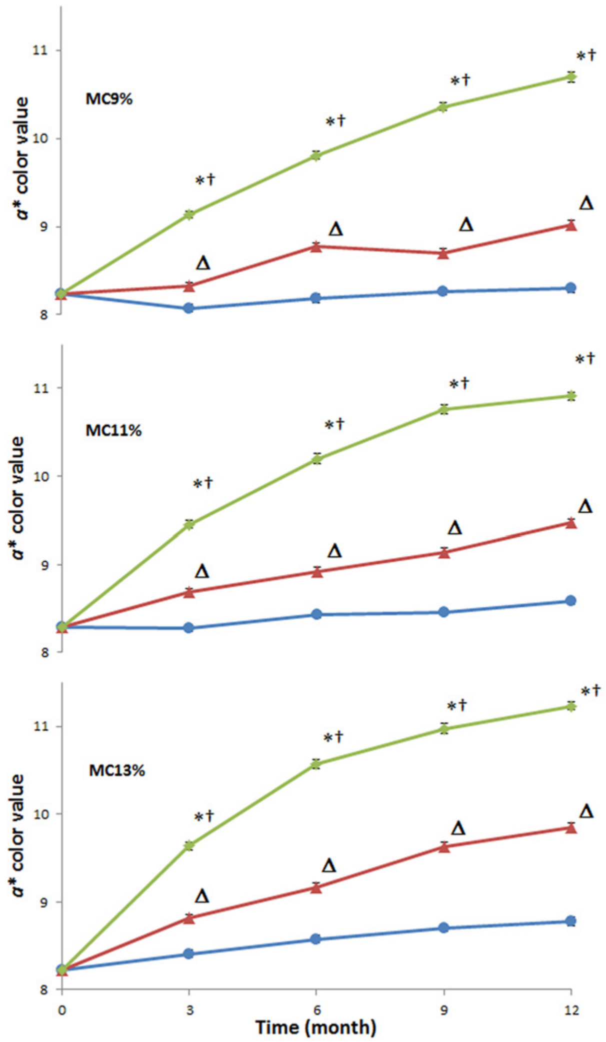

FIG. 4. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) *A** COLOR MEASUREMENT (AVERAGED OVER REP.). (●) 10C (▲) 20C (◆) 30C
Bars indicate standard error of the mean ($n = 60$ per point).
* indicates a significant difference between 10 and 30C storage; Δ indicates a significant difference between 10 and 20C storage; † indicates a significant difference between 20 and 30C storage.

relation of improper storage conditions is related to the reduction of the b^* color value.

ΔE^*ab Color Difference

Soybean seed testa color changes during on-farm silo storage and at grain-trading companies affect the economic value of this commodity. This is a serious concern to farmers, grain traders and processors (Snyder and Kwon 1987; Wszelaki *et al.* 2005).

The L^*, a^*, b^* color measurement system is a standardized and approved method used to compare grain color quality (Kato *et al.* 2000; Velu *et al.* 2006; Nasar-Abbas *et al.* 2009). However, the L^*, a^*, b^* system is a complicated three-dimensional method for the expression of color difference. As a result, it is imperative to have a simple method for grain testa color comparison that is easy to use for commercial application.

The simplest and most direct system for sample color comparison is the ΔE^*ab color difference. This is a one-dimensional color comparison method utilized by a number of researchers (Kato and Meguro 1998; Yousif *et al.* 2003; Nasar-Abbas *et al.* 2009) to compare the testa color of edible grain samples.

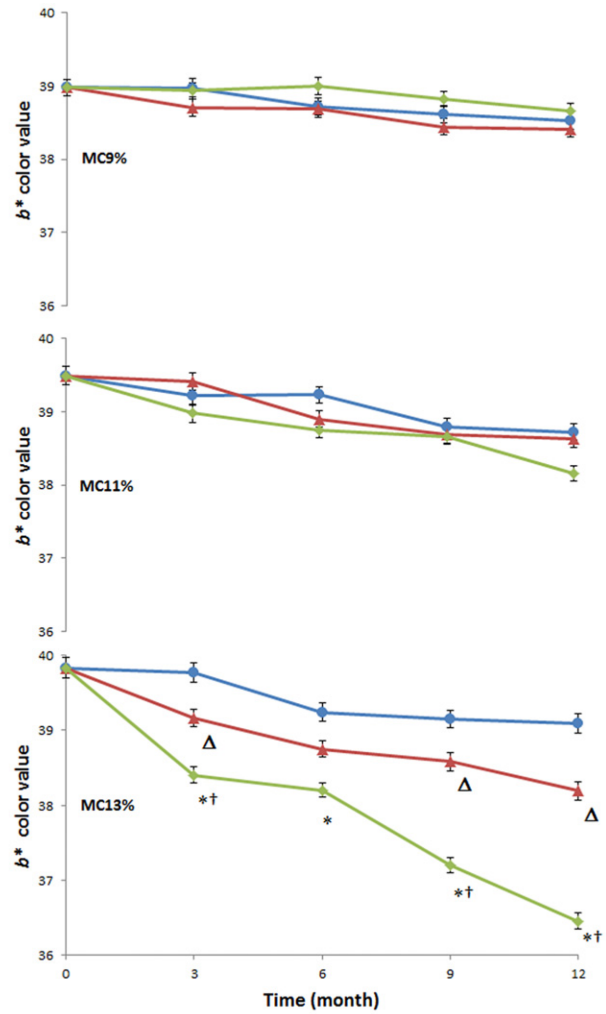

FIG. 5. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) *B** COLOR MEASUREMENT (AVERAGED OVER REP.). (●) 10C (▲) 20C (◆) 30C
Bars indicate standard error of the mean ($n = 60$ per point).
* indicates a significant difference between 10 and 30C storage; Δ indicates a significant difference between 10 and 20C storage; † indicates a significant difference between 20 and 30C storage.

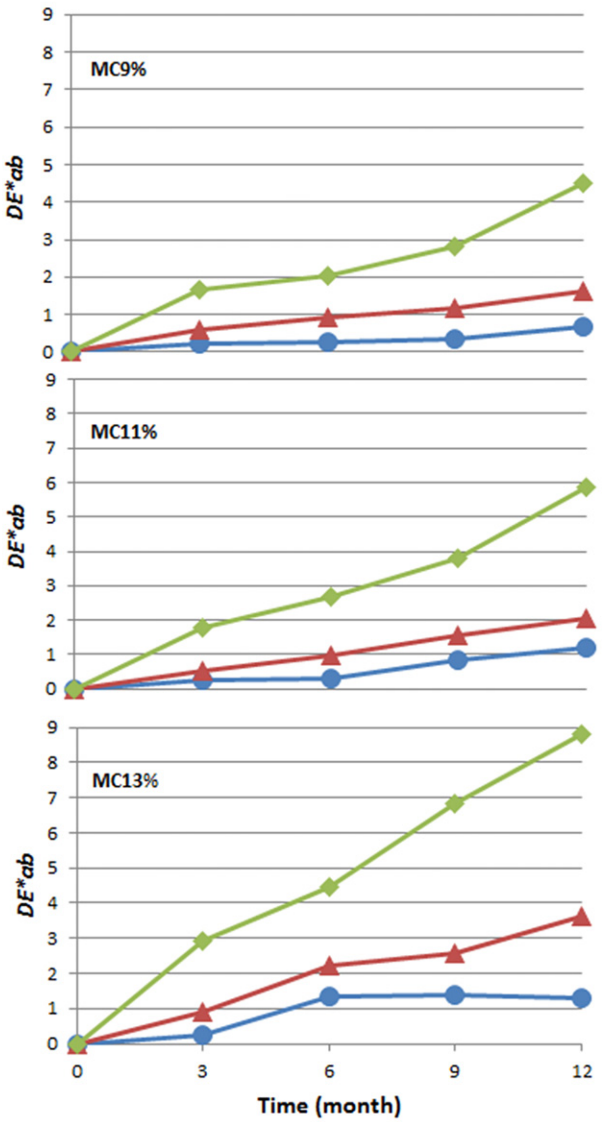

FIG. 6. EFFECT OF STORAGE TIME AND CONDITIONS ON SOYBEAN MOISTURE CONTENTS (MC; 9, 11 AND 13%) Δ*E*AB* COLOR MEASUREMENT (AVERAGED OVER REP.) (●) 10C (▲) 20C (◆) 30C

Individually, the storage MC (9, 11 and 13%), temperature (10, 20 and 30C) and time (0, 3, 6, 9 and 12 months) had a large effect on the soybean testa Δ*E*ab* color difference. Further, storage MC, temperature and time interacted, results in increased Δ*E*ab* color differences with high MC, temperature and increased storage time (Fig. 6).

Effect of Soybean Storage MC and Temperature on Δ*E*ab* Color Difference. Compared with 0 month, soybeans stored at MC9% and a temperature of 10C exhibited a Δ*E*ab* trace color difference of 0.2 in testa color up to 9 months of storage. Soybean 12 months storage at MC9%, 10C exhibited a Δ*E*ab* value of 0.7, which is a slightly discernible difference resulting in a slightly darker testa color compared with soybeans MC9% stored at 0 month. This color change is difficult to detect with the human eye (Fig. 6) (Yamauchi 1989).

Soybeans stored at MC9%, 20C at 3 months storage exhibited Δ*E*ab* value of 0.6, which is also a slightly discernible difference in testa color. With increased storage time, the MC9%, 20C testa color gradually became darker; however, despite the fact that soybean testa color difference doubled to 1.2 at 9 months of storage, it remained within the slightly discernible category. At 12 months, the MC9%, 20C stored soybeans exhibited a Δ*E*ab* value of 1.6, which equates to a noticeable darker testa difference in color compared with soybeans MC9%, 20C at 0 month (Fig. 6). This color difference is detectable by trained people only and would not be discerned by the conventional consumer (Yamauchi 1989).

Soybeans stored at MC9%, 30C exhibited a noticeably darker (1.7) difference in testa color after 3 months of storage; with 6 and 9 months of storage, the MC9%, 30C soybean testa color darkened further (2.0 and 2.8, respectively); however, both storage times remained within the noticeable change category. The MC9%, 30C soybeans stored for 12 months exhibited an appreciable darkening in testa color (4.5) (Fig. 6). This color difference can be discerned by the conventional consumer (Yamauchi 1989).

According to the Δ*E*ab* color difference method, soybeans stored at MC11%, 10C exhibited a trace difference of 0.3 in testa color compared with soybeans stored at 0 month for up to 6 months of storage. At 9 months, the MC11% exhibited a slightly discernible difference (0.8, darkening) in testa color; with 12 months storage at MC11%, 10C, the Δ*E*ab* color difference increased slightly to 1.2; however, it remained within the slightly discernible color difference category (Fig. 6).

Soybeans stored for 3 months at MC11%, 20C exhibited Δ*E*ab* color difference of 0.5, which is a slightly discernible difference (darkening) in color compared with the 0 month storage. After 6 months of storage, the color Δ*E*ab* difference (1.0, darkening) remained within the slightly discernible category and increased to noticeable (1.6) at 9 months of storage (Fig. 6). At 12 months of storage, the Δ*E*ab* color difference was 2.1, which indicated that the testa color difference was still within the noticeable category.

Storage of MC11% soybeans at 30C resulted in a noticeable difference (1.8) in the darkening of the soybean testa after 3 months of storage. With 6 months of storage, the Δ*E*ab* increased to 2.7 (darkening); however, the testa color difference remained within the noticeable color change category.

Following 9 months of storage, the MC11%, 30C exhibited an appreciable testa color difference (darkening), and at 12 months, the Δ*E*ab* color difference increased to 5.9; however, the difference in color (darkening) remained in the appreciable category (Fig. 6).

Soybeans stored for 3 months at MC13%, 10C exhibited a trace color difference of 0.2 in relation to soybeans MC13%, 10C at 0 months. With 6 months storage at MC13%, 10C, the soybeans exhibited a Δ*E*ab* color difference of 1.3, which is a slightly discernible testa color change (darkening). The Δ*E*ab* color difference for the MC13%, 10C soybeans remained constant until the end of the storage trial at 12 months (Fig. 6).

The stored MC13%, 20C soybeans exhibited a Δ*E*ab* value of 0.9, which is a slightly discernible color difference (darkening) after 3 months of storage. After 6 months of storage, the color difference of 2.2 increased to noticeable (darkening) and despite an increase in the color difference to 2.6 at 9 months storage, the color difference remained in the same category of noticeable (Fig. 6). The color difference of soybeans stored for 12 months at MC13%, 20C exhibited a Δ*E*ab* of 3.6, which is an appreciable testa color difference (darkening) compared with soybeans stored at MC13%, 0 month.

Soybeans stored at MC13%, 30C exhibited a noticeable Δ*E*ab* of 2.9, testa color difference (darkening) at 3 months of storage (Fig. 6). At 6 months, the stored MC13%, 30C soybeans exhibited an appreciable color difference (4.5), with the Δ*E*ab* increasing to 6.8 at 9 months of storage, thereby remaining within the appreciable difference in stored soybean testa color. At 12 months storage, the MC13%, 30C soybean testa exhibited the largest increase in Δ*E*ab*, (8.8) color difference (darkening) for all soybean storage treatments (Fig. 6). This color difference is described as large, which is easily perceived by the consumer as a large difference in the soybean testa color within the same color group (Yamauchi 1989).

The darkening of the stored soybeans, especially at the higher MC (13%) and temperature (30C), is due to the polymerization of phenolic compounds into polyphenols (Rozo 1982). In support of the polymerization hypothesis, Nasar-Abbas *et al.* (2009) observed a substantial reduction (75%) of phenolic compounds in tandem with the postharvest storage testa color darkening of faba beans (*Vicia Faba*) stored for extended periods (12 months) at high temperatures (50C). The grain testa storage-related darkening is also linked to the HTC phenomena (Yousif *et al.* 2003), whereby the stored grain does not soften adequately when cooked and in turn needs extended cooking time. This leads to increased energy usage, reduced textural quality and consumer acceptability (Garcia and Lajolo 1994).

These results indicate that the color change (darkening) increased with increased soybean MC (9, 11 and 13%) and increased storage temperature (10, 20 and 30C). Further, soybean MC, storage temperatures and time worked in tandem to increase the soybean testa color change (darkening). Soybean storage for extended periods (12 months) at the higher MC of 13% and higher storage temperature of 30C resulted in the largest color difference and darkening of the soybean testa. In contrast, the storage of soybeans at the lower MC9% and lower temperature of 10C resulted in the least testa color change (darkening). This outcome has a large bearing on the soybean testa color quality, which is expected to affect the consumer acceptability and marked value of soybeans and soy products.

CONCLUSIONS

Storage of soybeans at high MC (13%) and temperature (30C) for extended periods resulted in reduced cooked beans cooking quality and a darkening of the soybean testa. This outcome indicated that soybean storage under improper conditions of high MC and temperature for extended periods created a loss of soybean storage and processing quality. This loss of quality may result in reduced consumer acceptability and loss of economic value. To maintain the economic value of soybeans and low storage costs, it is advised that soybeans be stored at MC9%, 20C.

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