Impact of egg handling and conditions during extended storage on egg quality

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ABSTRACT The international trade of shell eggs has become more important in recent years in order to feed a growing worldwide population, meet food manufacturing demands, and address supply issues during disease outbreaks or product recalls. The primary barriers for the export and import of shell eggs are: whether to wash eggs and egg storage temperature. The current study was undertaken to compare egg quality factors as influenced by egg washing and storage temperature. Three lots of nest run white shell eggs were collected on consecutive d from a commercial in-line egg production facility. The treatment and storage conditions were selected to encompass the primary egg handling and storage conditions utilized throughout the world: washed; washed, oiled; and unwashed stored at 4°C; and unwashed stored at 22°C. Eggs were assessed weekly from 0 to 15 wk. Percent egg weight loss was greatest for the unwashed 22°C eggs (15.72%) and least for washed, oiled 4°C (0.33%, $P < 0.0001$). Less than 24 h at 22°C had a greater impact on yolk shape measurements decline than 15 wk at 4°C ($P < 0.05$). After 15 wk, average Haugh unit scores for all refrigerated treatments were still Grade A, and unwashed 22°C dropped from Grade AA to almost Grade B in one week. Room temperature storage of eggs rapidly declines egg quality. Egg treatment did not impact egg quality factors when stored at 4°C. Washing and oiling eggs before refrigerated storage did suppress the rate of egg weight loss.

Key words: egg, washing, oiling, storage, quality

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INTRODUCTION

The washing of eggs for human consumption has been a topic of debate for over 50 years. The United States was the first country to require the washing of table eggs destined to consumers. US washing standards require the use of spray washers, warm water, warm sanitizing rinse, and high-velocity air drying. Japan and Australia also have adopted egg-washing practices, while many countries—including the United Kingdom and EU—have resisted the practice. The United States began washing eggs in an effort to reduce egg spoilage (Moats, 1978). Specific requirements such as wash water temperature (32°C or 11°C warmer than warmest egg) and 100 to 200 ppm chlorine sanitizing rinse (USDA, 2008) were put in place to deter the potential movement of organisms on the shell surface from entering through the pores during washing.

Historic concerns associated with the washing of table eggs have focused on the removal of the cuticle. The cuticle serves as the first line of defense on an intact egg to water, gas, and microbial movement through the pores. Washing was regarded as an impediment to cuticle integrity, which would then result in greater external microbial penetration and rapid loss in egg quality. More modern shell and cuticle analysis has resulted in researchers reporting both cuticle damage and no change in cuticle structure due to washing (Kim and Slavik, 1996; Wang and Slavik, 1998; Leleu et al., 2011; Gole et al., 2014a,b; Liu et al., 2016).

Over the past 20 yr, there have been drastic changes in laying hen housing, production, and management throughout the world. Furthermore, food safety concerns have resulted in additional changes in consumer egg-handling practices. The interest in international trade of table eggs and breaking stock for further processed products has increased in recent year, due in part to the impact of highly pathogenic avian influenza and other production-related concerns on egg availability in impacted areas of the world. Differences in egg handling, processing, and storage practices around the world have presented barriers in the international trade of table eggs and breaking stock. The current study was conducted to assess the impact of commonly practiced egg handling and storage conditions on physical egg quality characteristics.

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Table 1. Explanation of egg treatment and storage condition.

Treatment name	Washed	Oiled	Storage temperature
Washed 4°C	Yes	No	4°C
Washed, oiled 4°C	Yes	Yes	4°C
Unwashed 4°C	No	No	4°C
Unwashed 22°C	No	No	22°C

MATERIALS AND METHODS

Egg Collection and Treatment

White shell eggs were collected on 3 consecutive days from a single flock at a commercial in-line shell egg production facility. Each day (replicate), 1,800 nest run eggs were collected and placed in refrigerated storage (<7°C) in accordance with US law (FDA, 2009). On the third day of collection, all eggs were transported to the research location and placed in 4°C overnight before initiating assignment to treatments.

Eggs were assigned to one of 4 treatments: washed, 4°C storage; washed, oiled, 4°C storage; unwashed, 4°C storage; and unwashed, 22°C storage (Table 1). Eggs assigned to washed treatments were washed as described by Jones et al. (2014) according to USDA voluntary requirements (USDA, 2008) with a wash water temperature of approximately 48°C and pH 11. Eggs assigned to the washed and oiled treatment were placed on rollers and lightly misted with a food-grade mineral oil (Lineleer 5; Linder Oil Company, Ossian, IN) after drying. Eggs were assessed by a USDA Agricultural Marketing Service egg grader, and downgrades (cracks, loss, or B grade as defined in USDA, 2000) were removed before storage was initiated.

After treatment, all eggs were placed in appropriately labeled, clean, foam, 12-egg cartons. Cartons were then placed in cardboard cases, each containing 30 dozen eggs from each treatment/replicate combination. An additional 36 eggs (3 cartons) from each treatment/replicate combination were grouped according to storage temperature and placed in cardboard cases for egg weight loss determination.

Egg Quality Determinations

Egg Weight Loss Thirty-six eggs from each treatment/replicate combination were numbered and weighed, and total volume of shell was determined (VSP300, Texture Technologies, Hamilton, MS) according to the methods of Jones et al. (2017). Week 0 measurements were made immediately after treatment. Eggs were then placed in the appropriate storage environment according to treatment assignment. The same eggs were weighed weekly throughout the 15 wk of storage. If an egg became cracked during the course of the study, the data associated with the egg was removed from the data set before analysis. Volume of shell and egg weight was utilized to calculate specific density (g/ml) and percent weight loss.

Physical Egg Quality Each week of storage, up to 24 intact eggs from each treatment/replicate combination were assessed for a variety of physical quality factors. Week 0 assessments were conducted the day after treatments were assigned to ensure eggs equilibrated to storage temperatures, since many egg quality factors are highly influenced by egg temperature (Keener et al., 2006). Egg physical quality assessments were conducted according to the methods of Jones et al. (2017): static compression shell strength and deformation, albumen height, Haugh unit, yolk index, and vitelline membrane strength and deformation.

Briefly, static compression shell strength was measured with a texture analyzer (TA-XTplus, Texture Technologies) equipped with a 10 kg load cell and 7.6 cm diameter aluminum compression disc (TA-30, Texture Technologies). The egg was presented on its side in an egg holder with posts (TA-650, Texture Technologies). A test speed of 2 mm/s and trigger force of 0.001 kg were utilized. Albumen height and Haugh unit (Haugh, 1937) were assessed with a TSS QCD system (Technical Services and Supplies, Dunnington, York, UK).

Yolk index was determined by measuring yolk height with a tripod micrometer (S-6428, B.C. Ames, Inc., Melrose, MA) and yolk width with a digital micrometer (Thermo Fisher Scientific, www.fishersci.com). The yolk was separated from albumen before vitelline membrane strength and deformation were measured with a texture analyzer (TA-XTplus, Texture Technologies) equipped with a 1 kg load cell and 7.6 diameter aluminum compression disc (TA-30, Texture Technologies) according to the procedures of Jones et al. (2010).

Statistical Analysis

Data collected during the study were subjected to an analysis of variance (**ANOVA**) utilizing proc GLM analysis in SAS (SAS Institute, 2002). Treatment, replicate, and wk of storage were the main effects. Up to n = 384 intact eggs were analyzed for each treatment/replicate combination during physical quality assessment. Weight loss was calculated on an individual egg basis and was converted to a percentage change in weight before analysis. Means were separated by the least square method. Egg physical quality measurements were monitored for the unwashed 22°C eggs through 6 wk of storage, ceasing the measurements because egg quality had declined past the point of minimum detection limits. Therefore, egg quality statistical analysis was conducted in two phases: 0 to 6 wk of storage for all treatments and 0 to 15 wk of storage for the refrigerated treatments.

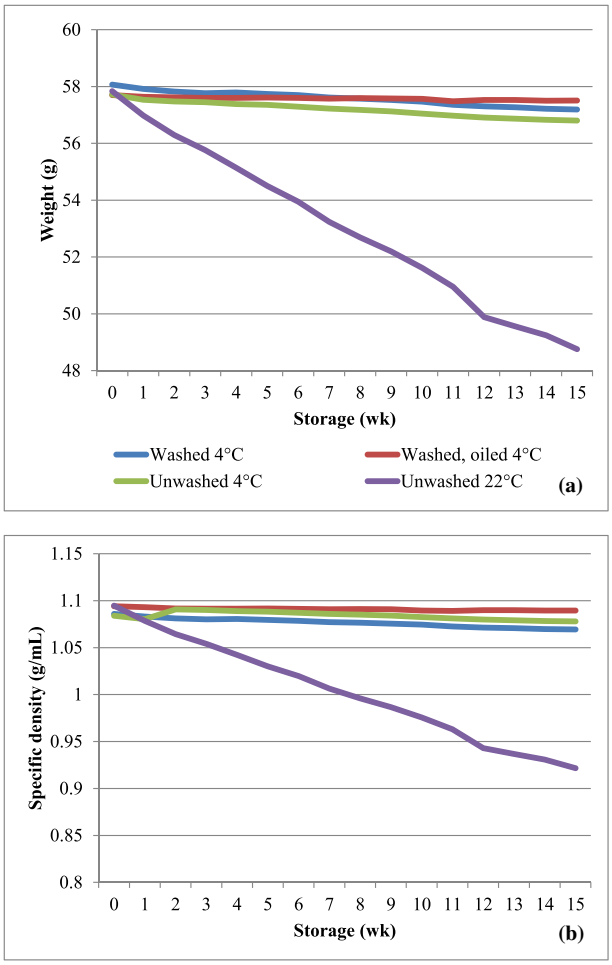

Figure 1. Interaction of treatment and extended storage ($P < 0.0001$) on egg weight (a) and specific density (b).

RESULTS AND DISCUSSION

Egg Weight and Specific Density

The interaction of treatment and week of storage ($P < 0.0001$) on egg weight and specific density is shown in Figure 1. The greatest decline in egg weight and specific density is seen in the unwashed 22°C treatment, with the slightest change seen in the washed, oiled 4°C eggs. The washed and unwashed 4°C eggs were similar in response, with the washed eggs having a slightly heavier egg weight and unwashed eggs having a slightly greater specific density.

The percentages of weight loss during storage for each treatment are presented in Tables 2 to 4. The monthly cumulative percentage of egg weight loss is shown in Table 2. Washed, oiled, refrigerated eggs had the least weight loss each month, while the unwashed room temperature eggs had the greatest ($P < 0.0001$). Washed and unwashed refrigerated eggs experienced similar cumulative weight loss throughout the storage period, with the washed eggs having slightly less cumulative weight loss each month. At the end of the 15-week storage period, cumulative percentage weight losses ($P < 0.0001$) for the treatments were 0.33%, washed, oiled 4°C; 1.51 and 1.59% washed and unwashed 4°C, respectively; and 15.72% unwashed 22°C. Oliveria et al. (2009) and Aygun and Sert (2013) placed unwashed eggs in refrigerated and room temperature storage and found a much higher percent weight loss than the current study. Conversely, the percent weight loss for the washed and unwashed refrigerated eggs in the current study is similar to that reported by Keener et al. (2006) for commercially washed eggs during refrigerated storage.

The rate of egg weight loss among the treatments during each month of storage is shown in Table 3. As with previous discussions of egg weight loss, the washed, oiled, refrigerated eggs experienced very little weight loss each month (greatest change in weight was 0.17%) compared to the other treatments ($P < 0.0001$). The rate of weight loss each month was almost identical for the washed and unwashed refrigerated eggs. The unwashed room temperature eggs experienced 4.5 to 5.5% weight loss each month through 12 wk of storage. This monthly percent weight loss is similar to the findings of Pujols et al. (2014) for unwashed room temperature eggs. Weight loss slowed for all treatments between 12 to 15 wk of storage. While this was only a 3-week storage period, the rates of weight loss seen for all treatments were at least half of the previous 4-week period, indicating a slowing of egg weight loss after 12 wk of storage, regardless of treatment and storage temperature. Differences in weight loss between the replicate sets of eggs occurred in the second and fourth month of storage (Table 4; $P < 0.05$). Each time differences between replicates occurred, replicate 2 had a lower rate of change in egg weight, but the differences were < 0.1%. For a 56 g egg, this would be 56 mg, which is not practical for detection by standard open-top laboratory balances and not perceivable.

Table 2. Percent loss of egg weight during defined lengths of egg storage at refrigerated and non-refrigerated temperatures.

Treatment	0 to 4 wks (% loss)	0 to 8 wks (% loss)	0 to 12 wks (% loss)	0 to 15 wks (% loss)
Washed 4°C	$0.48^{b} \pm 0.04$	$0.86^{b} \pm 0.07$	$1.32^{b} \pm 0.10$	$1.51^{b} \pm 0.11$
Washed, oiled 4°C	$0.17^{c} \pm 0.05$	$0.19^{c} \pm 0.07$	$0.30^{c} \pm 0.10$	$0.33^{c} \pm 0.12$
Unwashed 4°C	$0.58^{b} \pm 0.04$	$0.94^{b} \pm 0.07$	$1.40^{b} \pm 0.10$	$1.59^{b} \pm 0.11$
Unwashed 22°C	$4.67^{a} \pm 0.04$	$8.91^{a} \pm 0.07$	$13.78^{a} \pm 0.10$	$15.72^{a} \pm 0.11$
P-value	0.0001	0.0001	0.0001	0.0001

[a-c]: Means within a column with different letters significantly different; $P < 0.05$.

Table 3. Rate of egg weight loss throughout extended egg storage at refrigerated and non-refrigerated temperatures.

Treatment	0 to 4 wks (% loss)	4 to 8 wks (% loss)	8 to 12 wks (% loss)	12 to 15 wks (% loss)
Washed 4°C	$0.48^{b} \pm 0.04$	$0.37^{b} \pm 0.03$	$0.47^{b} \pm 0.04$	$0.19^{b} \pm 0.02$
Washed, oiled 4°C	$0.17^{c} \pm 0.05$	$0.02^{c} \pm 0.03$	$0.11^{c} \pm 0.04$	$0.03^{c} \pm 0.02$
Unwashed 4°C	$0.58^{b} \pm 0.04$	$0.35^{b} \pm 0.03$	$0.47^{b} \pm 0.04$	$0.19^{b} \pm 0.02$
Unwashed 22°C	$4.67^{a} \pm 0.04$	$4.45^{a} \pm 0.03$	$5.35^{a} \pm 0.04$	$2.25^{a} \pm 0.02$
P-value	0.0001	0.0001	0.0001	0.0001

[a-c]: Means within a column with different letters significantly different; $P < 0.05$.

Table 4. Rate of egg weight loss throughout extended storage as influenced by egg replicate groups.

Treatment	0 to 4 wks (% loss)	4 to 8 wks (% loss)	8 to 12 wks (% loss)	12 to 15 wks (% loss)
Rep 1	1.51 ± 0.03	$1.36^{a} \pm 0.03$	1.65 ± 0.03	$0.69^{a} \pm 0.02$
Rep 2	1.47 ± 0.04	$1.26^{b} \pm 0.03$	1.54 ± 0.04	$0.63^{b} \pm 0.02$
Rep 3	1.45 ± 0.04	$1.28^{b} \pm 0.03$	1.61 ± 0.03	$0.68^{a} \pm 0.02$
P-value	NS	0.05	NS	0.05

[a,b]: Means within a column with different letters significantly different; $P < 0.05$.

Table 5. Treatment and storage condition impacts on egg physical quality factors average values during 6 wk of storage.

Treatment	Haugh unit	Yolk height (mm)	Yolk width (mm)	Yolk index	Shell strength (g force)	Vitelline membrane strength (g force)	Vitelline membrane deformation (mm)
Washed 4°C	82.1	21.4	40.2	0.53	4214.2	155.7	7.8
Washed, oiled 4°C	82.1	21.6	40.2	0.53	4275.0	151.7	7.7
Unwashed 4°C	83.1	21.7	40.1	0.54	4280.4	155.0	7.8
Unwashed 22°C	45.5	14.8	44.6	0.34	4299.8	129.9	4.8
SEM	±0.31 ****	±0.04 *	±0.07 *	±0.001 *	±28.7	±2.25 *	±0.05 *

*: Treatment x week interaction; $P < 0.0001$.
****: Treatment x week x replicate interaction; $P < 0.0001$.

Physical Egg Quality

All Treatments 0 to 6 wk of Storage After 6 wk of storage, egg physical quality characteristics were below detectable limits for the unwashed 22°C treatment. As such, analysis of physical egg quality characteristics comparing all 4 treatments was limited to 0 to 6 wk of storage. The average egg quality values across this storage period by treatment are presented in Table 5. Shell strength was not influenced by treatment or week of storage ($P > 0.05$). There was a difference ($P < 0.05$) in static compression shell strength values between replicate sets of eggs: replicate 1: 4208.4^{b} g force; replicate 2: 4291.8^{ab} g force; and replicate 3: 4301.8^{a} g force; ± 25 g SEM. While the numeric values for shell strength were different, practically the 100 g force range between average replicate values would not be perceivable by consumers or further processed egg products manufacturers.

Both albumen height and Haugh unit were monitored throughout the study. Analysis of this data found the same trends, and thus only Haugh unit values are presented for brevity. The interaction of treatment x week of storage x replicate influenced ($P < 0.0001$) Haugh unit values (Figure 2). The lines delineating egg grades shown in Figure 2 are based on USDA grade standards (USDA, 2000). The refrigerated treatments/replicate combinations (washed,

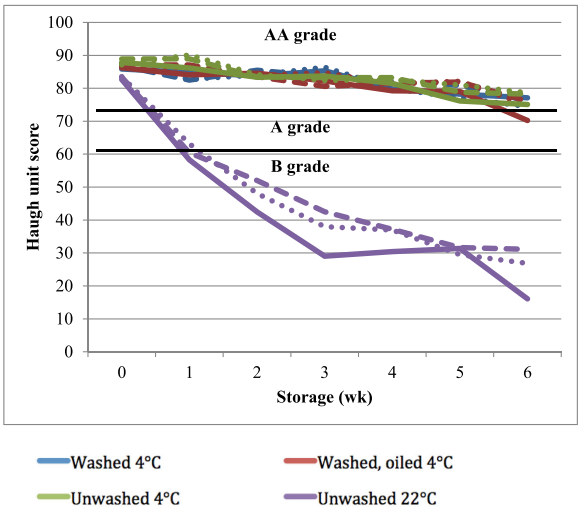

Figure 2. Interaction of treatment x extended storage x replicate ($P < 0.0001$) on Haugh unit scores; 0 to 6 wk of storage (replicates for each treatment in corresponding color line indicated by 1 = solid, 2 = dotted, and 3 = dashed).

washed and oiled, and unwashed) followed a similar trend in Haugh unit scores through the 6-week storage period. In general, at the end of the 6-week period, refrigerated treatments remained AA grade (with washed, oiled replicate 1 eggs having an average Haugh unit score 70.3 = A grade). Unwashed 22°C eggs had a 0 wk Haugh unit score of approximately 83, compared to a value of approximately 87 for the refrigerated treatments. This difference was due to < 24 h storage at 22°C vs. 4°C. After one week of storage, all refrigerated treatments had Haugh scores > 83, whereas room temperature eggs had scores at or below the minimum for A grade classification (72 > A grade ≥ 60; USDA, 2000). Waimaleongora-Ek et al. (2009) stored unwashed eggs at room temperature and found a 30-point drop in Haugh unit scores after one wk, and Pujols et al. (2014) reported a 12-point drop under the same conditions. In the current study, unwashed 22°C eggs had an average 23-point drop in Haugh unit scores at one week. The 3 wk and 5 wk sample times of Pujols et al. (2014) had similar Haugh unit scores for unwashed room temperature eggs as the current study.

Yolk shape measurements were influenced by treatment x week of storage interaction ($P < 0.0001$; Figure 3). As was seen with Haugh unit scores, the < 24 h storage at 22°C vs. 4°C resulted in a 2 mm difference in initial yolk height and yolk width measurements (Figures 3a and 3b). This corresponded to a 0 wk yolk index score of 0.54 for 4°C treatments compared to 0.46 for 22°C treatment. Through the 6 wk of storage, all refrigerated treatments had consistent yolk height, yolk width, and yolk index values. The room temperature eggs experienced a 7 mm reduction in yolk height, 5 mm increase in yolk width, and 0.20 reduction in yolk index (45% reduction). Waimaleongora-Ek et al. (2009) found similar changes in yolk index for unwashed eggs stored at room temperature. During the 6 wk of storage that all treatments were compared, eggs from the 3 refrigerated treatments never experienced yolk height, yolk width, or yolk index values comparable to the 0 wk values of the room temperature treatment. Therefore, yolk shape measurements detected after 24 h at room temperature were of poorer quality than those seen in all 3 refrigerated treatments after 6 wk of storage.

Vitelline membrane force and deformation (elasticity) were impacted by the interaction of treatment x week of storage (Figure 4; $P < 0.0001$). Unlike Haugh unit and yolk shape measurements, vitelline membrane strength for 0 wk was not different among the treatments (Figure 4a). Vitelline membrane strength did decrease for all treatments over the 6 wk of storage, with the 22°C eggs experiencing a larger change (approximately 85 g force) compared to the 3 refrigerated treatments (approximately 18 g force). The average deformation or elasticity of the vitelline membrane decreased less than 1 mm for all the refrigerated treatments over the 6 wk of storage, whereas the room temperature treatment experienced a greater than 3 mm decline in elasticity, indicating a more brittle membrane.

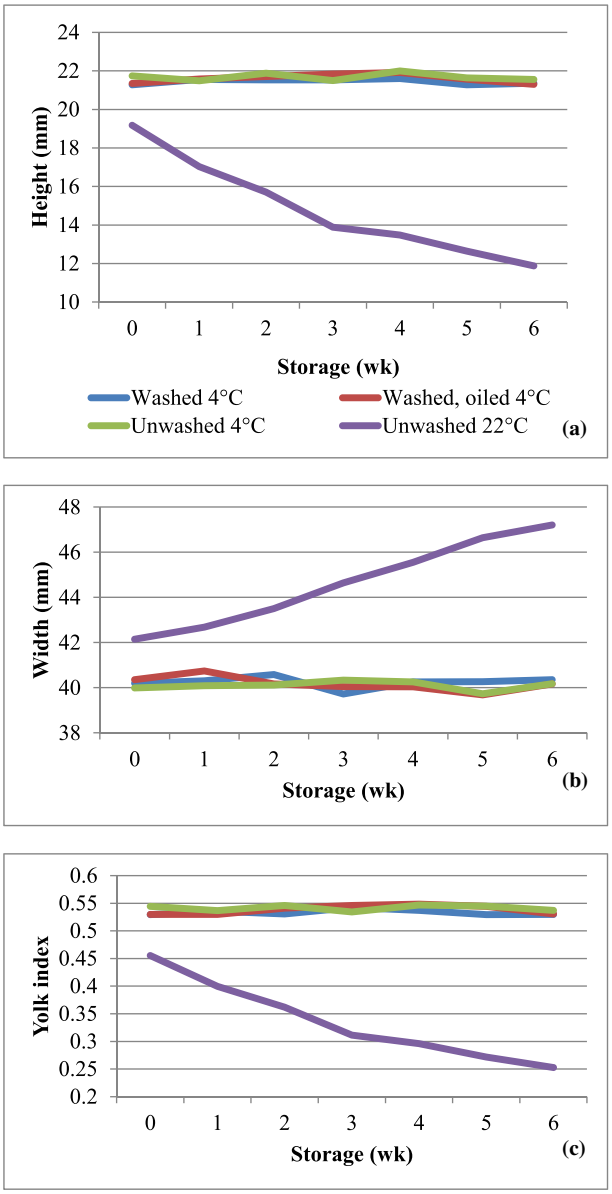

Figure 3. Interaction of treatment and extended storage ($P < 0.0001$) on yolk height (a), yolk width (b), and yolk index (c); 0 to 6 wk of storage.

Refrigerated Treatments 0 to 15 wk Storage The average egg quality values for each of the refrigerated treatments over 15 wk of storage are presented in Table 6. Most egg quality parameters had significant interactions among the main effects. Static compression shell strength was different ($P < 0.05$) between the treatments with the washed, oiled and unwashed eggs having the greatest strength (4331.7 and 4299.4 g force, respectively) compared to the washed (4216.4 g force) eggs. As with the previous comparison among all the treatments over 0 to 6 wk of storage, replicate 1 (4211.1 g force) eggs had lower ($P < 0.05$) static compression shell strengths compared to replicates 2 (4301.1 g force) and 3 (4335.2 g force), which were similar.

Throughout the 15 wk of storage, Haugh unit values had a general downward trend (Figure 5; refrigerated

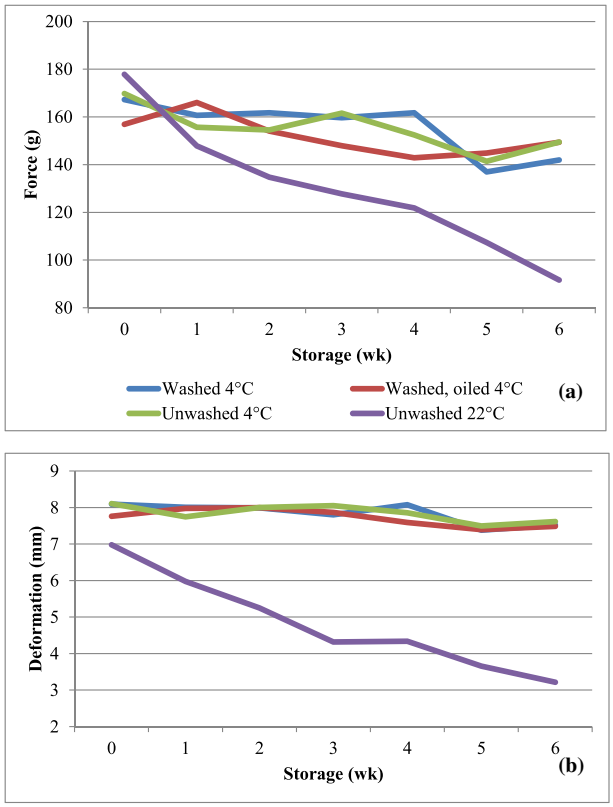

Figure 4. Interaction of treatment and extended storage ($P < 0.0001$) on vitelline membrane strength (a) and deformation (b); 0 to 6 wk of storage.

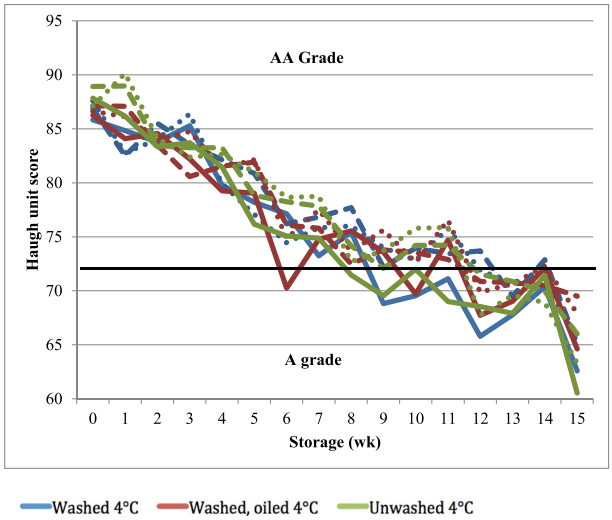

Figure 5. Interaction of refrigerated treatment x extended storage x replicate ($P < 0.05$) on Haugh unit scores; 0 to 15 wk of storage (replicates for each treatment in corresponding color line indicated by 1 = solid, 2 = dotted, and 3 = dashed).

treatment x week of storage x replicate interaction; $P < 0.05$). All treatments were still A grade (USDA, 2000) after 15 wk storage at 4°C. Replicate 1 eggs from each treatment (indicated by solid line of appropriate color for treatment) reached A grade before replicates 2 (dotted line) and 3 (dashed line). On average, refrigerated treatments were grade AA through 8 wk of storage. None of the refrigerated treatments was overall superior compared to the others for maintaining egg quality in regards to Haugh unit scores. Liu et al. (2016) stored washed and unwashed eggs in refrigeration and reported greater Haugh unit scores in unwashed eggs. This was not seen in the current study.

The impact of refrigerated treatments x week of storage interactions on yolk shape measurements is presented in Figure 6 ($P < 0.05$). Over the 15 wk of 4°C storage, a slight decline in yolk height was observed (Figure 6a). The greatest yolk heights were 22 mm at the beginning of the study, and the lowest were 20.8 mm towards the end of the study. Yolk width remained fairly constant with the lowest and highest values (39.5 and 41 mm, respectively) occurring during the middle of the storage period (Figure 6b). Yolk index (Figure 6c) gradually declined from the greatest value of 0.54 to the lowest value of 0.52 over the course of the 15 wk at 4°C. All of the yolk shape characteristics monitored exhibited only minor changes over the course of the 15 wk of storage with no particular treatment having preferable yolk shape characteristics.

Vitelline membrane strength and deformation, as influenced by refrigerated treatment x week of storage interactions ($P < 0.05$), are presented in Figure 7. As 4°C progressed, vitelline membrane force values decreased approximately 50 g (Figure 7a) from a high of 170 g force to a low of 120 g force. Only a slight decrease in vitelline membrane deformation (elasticity) was seen during the 15 wk of storage (8.15 to 7 mm; Figure 7b). As with other egg physical quality measurements

Table 6. Refrigerated treatment and length of storage impacts on egg physical quality factors average values during 15 wk of storage.

Treatment	Haugh unit	Yolk height (mm)	Yolk width (mm)	Yolk index	Shell strength (g force)	Vitelline membrane strength (g force)	Vitelline membrane deformation (mm)
Washed 4°C	76.2	21.3	40.4	0.53	4216.4[b]	142.7	7.5
Washed, oiled 4°C	76.5	21.4	40.3	0.53	4331.7[a]	145.2	7.6
Unwashed 4°C	76.4	21.4	40.3	0.53	4299.4[a]	143.6	7.6
SEM	±0.17	±0.03	±0.04	±0.001	±19.2	±1.28	±0.03
	****	*	*	*		*	*

[a,b]: Means within a column with different letters are significantly different; $P < 0.05$.
*: Treatment x week interaction; $P < 0.05$.
****: Treatment x week x replicate interaction; $P < 0.05$.

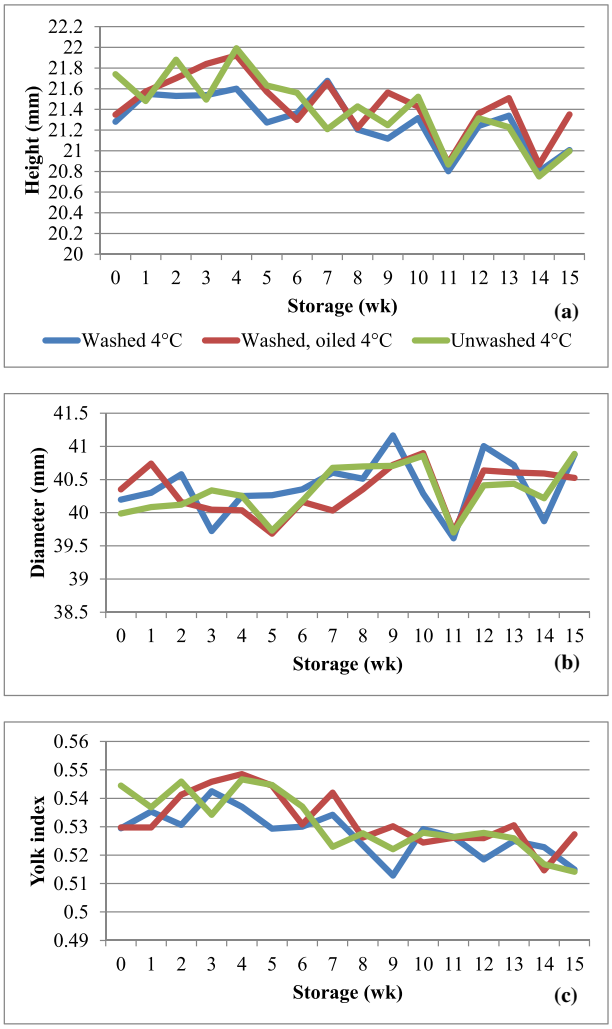

Figure 6. Interaction of refrigerated treatment and extended storage ($P < 0.05$) on yolk height (a), yolk width (b), and yolk index (c); 0 to 15 wk of storage.

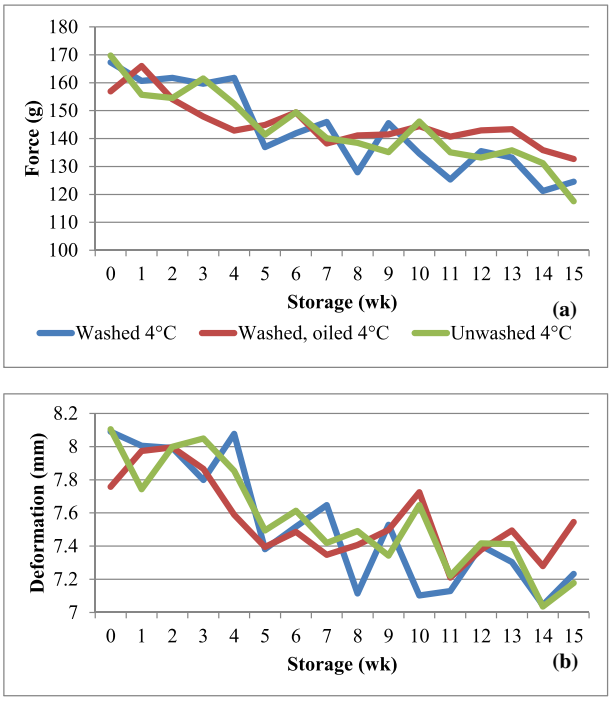

Figure 7. Interaction of refrigerated treatment and extended storage ($P < 0.05$) on vitelline membrane strength (a) and deformation (b); 0 to 15 wk of storage.

compared across the washed; washed, oiled; and unwashed eggs stored for 15 wk at 4°C, no treatment had a more or less favorable outcome on vitelline membrane strength or deformation.

In all quality factors monitored over the course of this storage study, the unwashed 22°C had remarkably lower egg quality after 6 wk of storage compared to 4°C eggs after 15 wk of storage, regardless of treatment. Average Haugh unit scores after 15 wk of 4°C storage were 64.5 (washed), 67.3 (washed, oiled), and 63.3 (unwashed). The unwashed 22°C eggs had an average Haugh unit score of 60.6 after one wk of storage. Average yolk height for all of the 4°C treatments after 15 wk of storage was approximately 21 mm. The unwashed 22°C eggs had an average yolk height of 19.2 mm at 0 wk (< 24 h at 22°C before testing). Yolk diameter and yolk index values followed a similar trend in that the lowest quality measurements for the 4°C treatments occurred at 15 wk of storage, and these values were superior to the 0 wk measurements for the 22°C eggs after less than 24 h at room temperature. Average vitelline membrane force after 15 wk of 4°C storage were 124.5 g force (washed), 132.7 g force (washed, oiled), and 117.5 g force (unwashed). Similar average vitelline membrane force values were found in the unwashed 22°C eggs at 3 and 4 wk of storage (127.8 and 121.9 g force, respectively). Average vitelline membrane deformation for all refrigerated treatments were between 7.2 and 7.5 mm at 15 wk of storage, which was greater than the 0 wk value of 7.0 mm for the unwashed 22°C eggs. Among the refrigerated treatments, the only significantly different quality factor was percent weight loss. The washed and oiled eggs stored at 4°C experienced a cumulative 0.33% weight loss compared to 1.51 and 1.59% for the washed and unwashed 4°C treatments, respectively. The unwashed 22°C had a 15.72% weight loss over the 15 weeks. The washed and oiled 4°C eggs had a significantly lower rate of weight loss at all analyzed intervals of storage compared to all treatments.

Research findings conflict on egg washing and subsequent cuticle integrity (Kim and Slavik, 1996; Wang and Slavik, 1998; Leleu et al., 2011; Gole et al., 2014a,b; Liu et al., 2016). Cuticle damage is thought to lead to greater percent weight loss and quality decline during refrigerated or room temperature storage. Cuticle integrity was not assessed in the current study, but washed and unwashed refrigerated eggs experienced similar rates of egg weight loss throughout 15 wk of storage. Washed, oiled, refrigerated eggs did have a significantly lower rate of egg weight loss. Washing, washing and oiling, or not washing did not impact egg physical quality measurements in the current study when eggs were stored in refrigeration.

Refrigerated storage had the greatest impact on maintaining egg quality factors. Less than 24 h at 22°C had a more profound impact on most yolk quality factors than 15 wk at 4°C. Eggs that were washed and oiled before 4°C storage consistently had the lowest weight loss of the treatments throughout the study, with washed and unwashed eggs stored at 4°C having similar percent weight loss. Storing unwashed eggs at 22°C resulted in rapid percent weight loss and egg quality decline.

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