

Modified pressure imaging for egg crack detection and resulting egg quality

D. R. Jones,^{*1} K. C. Lawrence,[†] S. C. Yoon,[†] and G. W. Heitschmidt[†]

^{*}Egg Safety and Quality Research Unit, and [†]Quality and Safety Assessment Research Unit, Russell Research Center, USDA, Agricultural Research Service, Athens, GA 30605

ABSTRACT Cracks in the shell surface compromise the primary barrier for external microbial contamination of the egg. Microcracks are very small cracks in the shell surface that are difficult to detect by human graders. New technology has been developed that uses modified pressure and imaging to detect microcracks in eggs. Research has shown the system to have an accuracy of 99.6% in detecting both cracked and intact eggs. A study was undertaken to determine if quality differences existed between modified pressure imaged and control eggs during extended cold storage. Three replicates were conducted with eggs stored at 4°C for 5 wk with weekly quality testing. The physical quality factors monitored were Haugh units, albumen height, egg weight, shell strength, vitelline membrane strength and elasticity, and whole egg total solids. All measure-

ments were conducted on individual eggs (12/treatments per replicate) each week with the exception of whole egg solids, which were determined from 3 pools (4 eggs each)/treatment per replicate each week. Percentage of whole egg total solids was the only significant difference ($P < 0.05$) between treatments (23.65% modified pressure imaged and 23.47% control). There was a significant difference ($P < 0.05$) for egg weight between replicates (60.82, 58.02, and 60.58 g for replicates 1, 2, and 3, respectively). Therefore, imaging eggs in the modified pressure system for microcrack detection did not alter egg quality during extended cold storage. Utilizing the modified pressure crack detection technology would result in fewer cracked eggs reaching the consumer, consequently enhancing food safety without affecting product quality.

Key words: shell egg, crack, detection, imaging, quality

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INTRODUCTION

The shell is one of the first lines of defense of an egg from external bacterial contamination. Eggs with cracks in the shell surface pose greater food safety risks for consumers than intact eggs (Todd, 1996). Furthermore, researchers have found a wide variety of bacteria in the contents of eggs with cracks in their shells (Ibeh and Izuagbe, 1986; Widdicombe et al., 2009). Challenge studies have determined that *Salmonella Enteritidis*, as well as *Campylobacter jejuni*, can penetrate, sustain, or grow in the contents of eggs with cracked shells (Chaudhary et al., 1989; Ernst et al., 1998; Hara-Kudo et al., 2001).

Large cracks in the shell can easily be seen with the human eye or enhanced with illumination in hand candling. Microcracks in the shell, as defined by Bain et al. (2006), are much more difficult to detect. Microcracks are minute cracks in the shell surface (external or

internal) that reduce the protective barrier properties of the shell. Studies confirming (via scanning electron microscopy) the presence of microcracks in the shell surface have also found greater bacterial penetration in eggs with a higher number of microcracks (Fajardo et al., 1993, 1995). Microcracks are not easily seen by the human eye.

All shell eggs marketed in the United States may have a maximum allowable percentage of checked eggs (shell impaired with no egg contents voiding) ranging from 5 to 10% in a grading lot of 100 eggs (USDA, 2000). The actual percentage of checked eggs allowed is variable for the stage of commerce and US egg grade. Traditionally, hand candling with various forms of illumination is used by professional graders to ascertain if cracks are present in the egg shell, which limits the ability to see very small microcracks. Professional egg graders are able to quickly assess a 100-egg lot, but the subjective nature of the process leads to variability between graders.

Researchers have worked to develop objective methods for determining shell soundness, thus increasing the microbial safety of eggs reaching consumers. Staining eggs to visibly detect cracks in the candling booth of processing lines has been tested (Dickens et al.,

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¹Corresponding author: Deana.Jones@ars.usda.gov

1985). Elster and Goodrum (1991) used machine vision to detect sizable eggshell cracks. Dynamic frequency analysis was used for crack detection and sorting by Wang and Jiang (2005). In some instances, developed technologies were assessed for their degree of detection accuracy: global image analysis, 88% (Han and Feng, 1994); machine vision with different light sources, approximately 90% (Worley and Goodrum, 1995); and acoustical resonance frequency, 90% (De Ketelaere et al., 2000). Bain et al. (2006) assessed the microscopic formation of microcracks. They determined that the nature of microcrack formation made it unlikely that online crack detection in shell egg processing equipment would find microcracks because the technology is based on mechanical excitation.

United States consumer eggs are monitored via hand candling to ensure that food safety and quality standards have been met. Human graders experience fatigue from extended hours in darkened rooms with a concentrated light source. The fatigue can impair the grader's ability to consistently assess eggs. During a study examining candling errors in commercial egg processing, 17.3% of pulled eggs were overpull (Bokhari et al., 1995). Of the overpull, 42.5% was due to cage marks on the shell. As a crack in the shell ages, water migrates to the crack causing it to glow during candling much like cage or toenail marks. Fresh microcracks are almost impossible to detect visually. If the eggs are placed in refrigerated storage overnight, the microcracks become more visible due to physical changes such as water migration and entrapment between the shell and shell membranes or enlargement due to thermal stress on the shell during cooling. With the current industry standard of high-throughput machines and inline complexes, it is not plausible to regrade lots of eggs 24 h after processing. A novel system for crack detection utilizing modified pressure and imaging has been developed (Lawrence et al., 2008). The system conditions allow for large and microcracks alike to be seen by subjecting the eggs to a quick, small negative pressure while digital images are collected. The system is designed to be operated by a professional grader, thus allowing for crack detection and quality attribute assessment to occur simultaneously. The modified pressure imaging system had an overall accuracy of 99.6%, compared with 94.2% for trained professional graders in a study comparing 1,000 eggs (Lawrence et al., 2009). The current study was undertaken to determine if exposure to the modified pressure imaging system produced egg quality changes during extended cold storage.

MATERIALS AND METHODS

Egg Sampling

Three 30-dozen cases of grade A large white eggs were removed from the processing line after packaging at a local inline egg processor. The eggs were processed

under the voluntary shell egg grading program with continuous USDA Agricultural Marketing Service inspection (USDA, 2008). Each 30-dozen case (360 eggs minus cracked eggs) was considered a replicate with 15 dozen imaged and 15 dozen controls. All eggs were stored at 25°C overnight and hand candled to remove visible cracks before initiating the experiment.

Imaging of the Eggs

Approximately 15 dozen eggs from each case (replicate) were exposed to the modified pressure crack detection system. The basis of the crack detection system is described by Lawrence et al. (2008). The system used in the current study is a modified version of the Lawrence et al. (2009) system. The primary difference between the 2 systems is the 20-egg capacity in the current study (Figure 1). All imaged eggs were exposed to 4 pressure modifications consisting of an approximately 0.5-s exposure to an ~200-mm mercury-negative pressure, as described by Lawrence et al. (2008). Any cracked eggs discovered during imaging were removed from the experiment. The untreated control eggs were moved to the imaging room to maintain consistent temperature conditions between the treatments. After imaging, treated and control eggs were placed in clean foam cartons (Dolco Packaging Corp., Lawrenceville, GA) and eggs from a single replicate were stored in the same cardboard case (Dahlonega Packaging Inc., Dahlonega, GA). All eggs were stored at 4°C for the remainder of the study.

Egg Quality Determination

Egg quality testing was conducted weekly from 0 to 5 wk of cold storage. Week 0 testing was conducted the morning after imaging was concluded. Eggs remained under refrigeration until testing and were hand candled to remove cracked eggs. A 12-egg sample for each treat-

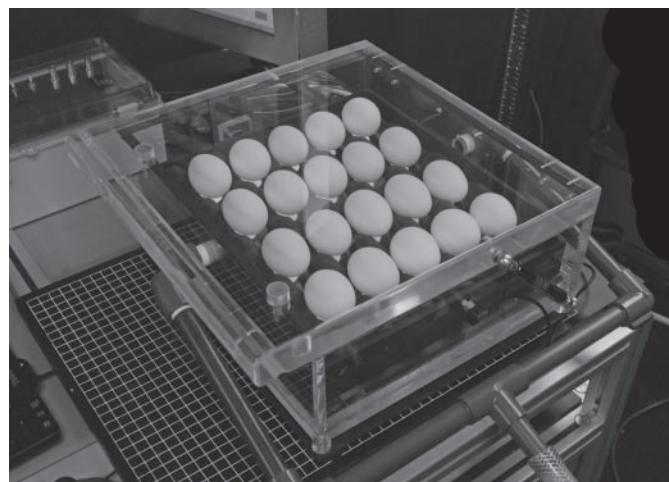


Figure 1. Twenty eggs in the modified pressure imaging chamber.

Table 1. Egg weight, albumen height, Haugh unit values, and whole egg total solids as affected by modified pressure imaging for crack detection

Treatment	Egg weight (g)	Albumen height (mm)	Haugh unit	Whole egg total solids (%)
Imaged	59.95 (n = 216)	6.2 (n = 209)	77.63 (n = 209)	23.65 ^a (n = 162)
Control	59.66 (n = 216)	6.2 (n = 212)	77.10 (n = 212)	23.49 ^b (n = 162)
SE	0.23	0.1	0.55	0.05

^{a,b}Means within a column with different superscripts are significantly different ($P < 0.05$).

ment and replicate combination was tested each week. Tests were conducted in an order that allowed for all analyses to be run on each individual egg with the exception of total solids determination. The egg quality parameters monitored (in order of occurrence) were egg weight, shell strength, Haugh unit, albumen height, vitelline membrane strength and elasticity, and whole egg total solids.

Haugh unit measurements were conducted according to the methods of Jones and Musgrove (2005a) with the aid of an automated Haugh unit system (TSS QCD Instrument, Technical Services and Supplies, York, UK). Static compression shell strength was determined according to the method of Jones and Musgrove (2005a) utilizing a texture analyzer (TA.XT Plus Texture Analyzer, Texture Technologies Corp., Scarsdale, NY) equipped with a 5-kg load cell and a 75-mm aluminum compression plate (TA-30, Texture Technologies Corp.). Vitelline membrane strength and elasticity were monitored with a texture analyzer (TA.XT Plus Texture Analyzer, Texture Technologies Corp.) equipped with a 750-g load cell and a 75-mm aluminum compression plate. The albumen was separated and the yolk placed in a disposable 15 × 100 mm Petri dish. The unit was set with a 1 mm/s test speed, 5-g trigger force, and 2-mm trigger distance.

The albumen and yolk from 4 eggs were combined in laboratory sample bags to create 3 separate pools of whole egg from each treatment and replicate combination each week. The pools were combined for 1 min at 230 rpm in a laboratory mixer (Stomacher 400 circulator, Seward Limited, London, UK) then allowed to rest overnight at 4°C. The following morning, pools were equilibrated to 23°C in a recirculating water bath before repeating the mixing to break down any remaining thick albumen. Immediately after mixing, triplicate samples were prepared from each of the 3 treatment pools (n = 9) per replicate for moisture analysis according to AOAC 950.46, Moisture in Meat (AOAC, 1990).

Statistical Analysis

Data collected during the study were subjected to the GLM analysis in SAS (SAS Institute, 2002). Treatment and week of storage were the main effects. Data were subsequently sorted by week to examine treatment difference at each week of storage. Means were separated by the least squares means method.

RESULTS

Overall egg weight, albumen height, and Haugh unit were not different between the modified pressure imaged and control eggs (Table 1). The overall percentage of whole egg total solids was significantly different ($P < 0.05$) for the modified pressure imaged and control eggs (23.65 and 23.49%, respectively). The significant difference was 0.16%, which is not practically important for egg functionality and most likely was the result of great precision in testing, resulting in a low SEM for the n = 162 samples for each treatment. Egg weight was the only parameter monitored that exhibited significant differences ($P < 0.05$) between replicates and during the weeks of storage. Replicate 2 had the lightest eggs (58.02 g) compared with replicates 1 and 3 (60.82 and 60.58 g, respectively). Egg weight decreased during storage, with the greatest overall weight found after the first week of storage (60.56 g) compared with the lowest weight occurring at wk 4 (59.08 g).

Overall static compression shell strength, vitelline membrane strength, and vitelline membrane elasticity results between the treatments are found in Table 2. No significant differences were recorded. The modified pressure imaged eggs had the highest vitelline membrane strength and elasticity, indicating that the yolk membrane was strong and pliable.

The data for each of the parameters monitored were sorted by week of storage and analyzed to determine if significant differences existed between the modified

Table 2. Shell strength, vitelline membrane strength, and vitelline membrane elasticity as affected by modified pressure imaging for crack detection

Treatment	Shell strength, g (force, N)	Vitelline membrane strength, g (force, N)	Vitelline membrane elasticity, mm
Imaged	3,672.78 (36.03) (n = 216)	162.44 (1.59) (n = 194)	7.47 (n = 194)
Control	3,762.48 (36.91) (n = 216)	153.56 (1.51) (n = 193)	7.23 (n = 193)
SE	48.38 (0.47)	3.80 (0.04)	0.08

Table 3. Changes in egg weight, albumen height, Haugh unit values, and whole egg total solids due to modified pressure imaging for crack detection and extended cold storage

Week	Egg weight (g)			Albumen height (mm)			Haugh unit			Whole egg total solids (%)		
	Imaged	Control	SEM	Imaged	Control	SEM	Imaged	Control	SEM	Imaged	Control	SEM
0	60.40	59.89	0.61	6.6	7.1	0.2	79.88	83.51 ^b	1.44	74.94	75.39	0.22
1	60.54	60.57	0.56	6.8 ^a	6.0 ^b	0.2	81.40 ^a	75.43 ^b	1.59	76.65	76.77	0.08
2	60.63	59.98	0.55	6.2	6.2	0.2	77.50	77.27	1.41	76.63	76.72	0.08
3	59.33	58.92	0.55	5.9	6.1	0.2	75.84	77.25	1.26	76.91	77.02	0.08
4	59.14	59.03	0.53	6.0	5.6	0.2	75.79	72.83	1.36	76.66	76.74	0.07
5	59.67	59.58	0.61	5.9	6.0	0.1	75.37	76.31	0.96	76.31	76.45	0.08

^{a,b}Means having different superscripts in the same row within a measurement are significantly different ($P < 0.05$).

pressure imaged and control eggs at each monitoring point (Tables 3 and 4). Albumen height, Haugh unit, and vitelline membrane strength and elasticity were all significantly greater ($P < 0.05$) for the modified pressure imaged compared with control eggs at wk 1 of storage. Static compression shell strength was significantly greater ($P < 0.05$) for the control eggs at wk 2 of storage (3,951.26 vs. 3,482.72 g for modified pressure imaged eggs). An additional significant difference ($P < 0.05$) in vitelline membrane strength and elasticity was found at 3 wk of storage, with the modified pressure imaged eggs once again having greater values.

DISCUSSION

Aside from the slight difference in whole egg total solids, there were no differences between the modified pressure imaged and control eggs for the overall quality parameters monitored. Although previous research (Jones et al., 2002; Jones and Musgrove, 2005a) has noted significant reductions in albumen height or Haugh unit scores, or both, during extended cold storage, there was not a pronounced occurrence of the phenomenon in this study. Stadelman (1995) discussed the effects of time and temperature on the decrease of egg quality. The quicker an egg is brought near the freezing point, the greater the egg quality is maintained. In the current

study, eggs were left at room temperature overnight to achieve equitable temperatures during modified pressure imaging. The exposure to warmer temperatures may have affected the degree of subsequent quality loss during cold storage.

In this study, shell strength was measured via static compression testing. Jones and Musgrove (2005b) reported variable shell strength among samples when conducted in this manner. There were no indications of changes in shell strength during cold storage in this study. This concurs with the results of Jones and Musgrove (2005a), who monitored shell strength during 10 wk of extended cold storage. Anderson et al. (2004) found differences in static compression shell strength among different strains of laying hens. In the current study, eggs were collected after packaging from an inline processing facility without knowledge of the age or strains of the hens supplying the eggs.

Vitelline membrane strength was lower at the end of this study, but degradation was not in as linear a fashion as previously reported (Fromm and Matrone, 1962; Jones et al., 2002; Jones and Musgrove, 2005a). Fromm and Matrone (1962) reported that vitelline membrane elasticity increased with egg age; however, Jones and Musgrove (2005a) found an inverse relationship. In the current study, there was no clear trend for vitelline membrane elasticity during storage. Comparing these

Table 4. Changes in shell strength and vitelline membrane strength and elasticity due to modified pressure imaging for crack detection and extended cold storage

Week	Shell strength, g (force, N)			Vitelline membrane strength, g (force, N)			Vitelline membrane elasticity, mm		
	Imaged	Control	SEM	Imaged	Control	SEM	Imaged	Control	SEM
0	3,751.37 (36.70)	3,674.35 (36.05)	111.34 (1.09)	171.50 (1.68)	170.10 (1.67)	10.45 (0.10)	7.40	7.34	0.19
1	3,686.74 (36.17)	3,874.81 (38.01)	113.33 (1.11)	167.44 ^a (1.66)	141.64 ^b (1.39)	9.94 (0.10)	7.83 ^a	7.09 ^b	0.23
2	3,482.72 ^b (34.17)	3,951.26 ^a (38.76)	109.64 (1.08)	158.14 (1.55)	169.15 (1.66)	9.83 (0.10)	7.41	7.63	0.20
3	3,691.04 (36.21)	3,582.59 (35.15)	125.88 (1.23)	163.65 ^a (1.61)	137.44 ^b (1.35)	7.50 (0.07)	7.48 ^a	7.00 ^b	0.16
4	3,634.78 (35.66)	3,656.70 (35.87)	115.16 (1.13)	160.55 (1.57)	145.83 (1.43)	9.94 (0.10)	7.30	7.02	0.20
5	3,790.03 (37.18)	3,835.14 (37.62)	133.73 (1.31)	151.36 (1.48)	157.22 (1.54)	8.86 (0.09)	7.38	7.31	0.18

^{a,b}Means having different superscripts on the same row within a measurement are significantly different ($P < 0.05$).

studies requires broad inferences of the trends in the data because each manuscript used different testing methodologies. Jones et al. (2002) and Jones and Musgrove (2005a) used a similar static compression device as the current study but with a much smaller 1-mm probe exposed to the membrane compared with the 75-mm disc used here.

Overall, of the egg quality parameters tested in this study, only whole egg solids were different between imaged and control eggs (0.16% difference). The use of the modified atmosphere imaging system for crack detection did not adversely affect egg quality through 5 wk of cold storage. Use of the modified pressure imaging system by graders in egg processing facilities will increase the safety of shell eggs reaching consumers by reducing the number of cracked eggs entering retail without having a negative effect on egg quality.

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