THE IMPACT OF SHELL EGG PROCESSING ON FOOD SAFETY

D.R. JONES and M. T. MUSGROVE

Summary

The microbial quality of shell eggs is affected by many factors such as: hen health, production environment, nutrition, storage conditions, processing conditions, processing facilities, etc. Most of the regulations and guidelines utilised for the processing of shell eggs in the U.S. are based on research conducted before the early 1970s. This research focused on egg quality more than food safety. There has been an absence of current research examining the role of processing technologies, procedures and equipment on product safety and quality. For this reason, our laboratories began to examine individual aspects of shell egg processing to determine what, if any, changes should be made in order to enhance shell egg food safety in the U.S. We started with a regional survey of the effectiveness of sanitation practices utilised by shell egg processors in the southeastern U.S. We then progressed to examining the changes in microbial quality of shell eggs during prolonged refrigerated storage. Most recently, we have monitored the changes in microbial quality of the shell egg as it progressed through the processing line. The results of the studies have shown that there is room for improvement, but the microbial quality of the eggs produced is high.

I. INTRODUCTION

The microbial quality of shell eggs is affected by many factors such as: hen health, production environment, nutrition, storage conditions, processing conditions, processing facilities, etc. In the United States, the washing of shell eggs for retail sale is a requirement for all product marketed under the United States Department of Agriculture (USDA) grade shield (USDA, 2005). These guidelines state that wash water temperature must be at least 32°C or 110°F warmer than the warmest egg. Wash water pH must be maintained at pH 10 or greater. Furthermore, a post-wash sanitising rinse of 100-200 ppm chlorine or its equivalent must be applied. All shell eggs packaged in containers ultimately destined for consumers are required to be maintained (during storage and shipping) at 7°C (USDA, 1999). Most of the previously mentioned regulations and guidelines are based on research conducted before the early 1970s and this research focused on egg quality more than food safety.

Currently, two federal agencies in the U.S. are drafting and publishing proposed rules focused on ensuring the microbial safety of shell eggs and egg products. There has been an absence of current research examining the role of processing technologies, procedures and equipment on product safety and quality. For this reason, our laboratories began to examine individual aspects of shell egg processing to determine what, if any, changes should be made in order to enhance shell egg food safety in the U.S. We started with a regional survey of the effectiveness of sanitation practices utilised by shell egg processors in the southeastern U.S. We then progressed to examining the changes in microbial quality of shell eggs during prolonged refrigerated storage. Most recently, we have monitored the changes in microbial quality of the shell egg as it progressed through the processing line. An overview of each of these studies will be presented in this talk.

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II. SHELL EGG PROCESSING FACILITY SANITATION

The cleanliness of a processing facility has often been associated with the cleanliness of the final product. Moats (1981) stated that bacterial counts on the surface of washed eggs correlated with counts on equipment surfaces and in wash water. In addition, the major source of contamination for the wash water was found to be the eggs, not the equipment. Bartlett et al. (1993) found that merely maintaining wash water at the recommended temperatures and pH was not enough to keep bacterial levels on the equipment <10⁵ CFU/ml. Unfortunately, many processors feel that if they meet the minimum wash water guidelines during processing, the need for thorough post-processing cleaning is negated.

The principle contamination sources in a processing facility have been identified as: direct and indirect contact surfaces, water, air and personnel (Slade, 2002). Drains, solid waste handling, transportation equipment within a plant, and maintenance personnel and equipment have also been identified as possible sources of contamination (Shapton and Shapton, 1991; Evancho et al., 2001; Kornacki and Johnson, 2001; Carsberg, 2003; Davies and Breslin, 2003) Cleaning processes may not be as effective due to lack of employee knowledge. Plant personnel frequently do not read the labels of the detergents utilised during cleaning (Powitz, 2002). This can contribute to ineffective cleaning. Furthermore, employees may not be aware what effect their actions can have on product quality or plant sanitation.

In 2002, our laboratory coordinated, in conjunction with research personnel from Auburn University, the University of Georgia and North Carolina State University, a survey to determine the effectiveness of sanitation practices in nine shell egg processing plants throughout the southeastern U.S. A summary of the results are presented in Tables 1 and 2. Plants were sampled immediately after processing ended (POST) and again just before the start of the following processing day (PRE). Table 1 shows the results from the direct contact surface portion of the study (Jones et al., 2003). Non-contact surface results are presented in Table 2 (Musgrove et al., 2004). No significant differences were found between POST and PRE operational sampling of the same locations. While conducting this study, investigators did not inquire about sanitation practices utilised in each facility so as not to influence the normal procedures utilised each day.

These results not only indicate the need for more effective plant sanitation practices, but several locations in the process have been identified as areas of important concern. The high levels of aerobic bacteria and Enterobacteriaceae found at the check detector are of particular concern, since all washed eggs must come in contact with the check detector. Currently, this portion of most processing lines is not able to be completely cleaned due to design limitations of the equipment. The same situation exists for the packer head brushes. All eggs must come into contact with a packer head brush before being placed into a carton. With new HACCP-based (Hazard Analysis and Critical Control Points) regulations impending from USDA Food Safety Inspection Service, sanitation issues need to be addressed for effective prerequisite programs to be in place. There is a great need for more focused work in this area to aid both regulatory groups and industry to make a successful transition to HACCP-based processing.
Table 1. Effect of sanitation practices on aerobic plate and Enterobacteriaceae counts for direct contact surfaces.

<table>
<thead>
<tr>
<th>Sample Site</th>
<th>Post APC (log CFU/ml)</th>
<th>Pre APC (log CFU/ml)</th>
<th>Post VRBG (log CFU/ml)</th>
<th>Pre VRBG (log CFU/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Belt (n=5)</td>
<td>5.55 ± 0.45</td>
<td>5.02 ± 0.56</td>
<td>0.77 ± 0.44</td>
<td>0.72 ± 0.45</td>
</tr>
<tr>
<td>Guide bar for farm belt (n=5)</td>
<td>5.48 ± 0.79</td>
<td>4.42 ± 1.02</td>
<td>1.10 ± 0.51</td>
<td>0.75 ± 0.55</td>
</tr>
<tr>
<td>Vacuum loaders (n=7)</td>
<td>6.16 ± 0.59</td>
<td>4.79 ± 0.93</td>
<td>1.97 ± 0.55</td>
<td>1.05 ± 0.58</td>
</tr>
<tr>
<td>1st Washer brushes (n=9)</td>
<td>3.71 ± 0.75</td>
<td>3.11 ± 0.73</td>
<td>0.39 ± 0.25</td>
<td>0.43 ± 0.30</td>
</tr>
<tr>
<td>2nd Washer brushes (n=6)</td>
<td>2.98 ± 0.99</td>
<td>3.34 ± 0.76</td>
<td>0.37 ± 0.37</td>
<td>0.18 ± 0.18</td>
</tr>
<tr>
<td>Oiler flaps (n=2)</td>
<td>4.04 ± 0.65</td>
<td>4.64 ± 0.79</td>
<td>ND</td>
<td>0.60 ± 0.42</td>
</tr>
<tr>
<td>Spools (n=9)</td>
<td>2.96 ± 0.31</td>
<td>3.52 ± 0.41</td>
<td>0.29 ± 0.18</td>
<td>0.31 ± 0.19</td>
</tr>
<tr>
<td>Check detector (n=9)</td>
<td>4.03 ± 0.58</td>
<td>3.87 ± 0.39</td>
<td>1.48 ± 0.64</td>
<td>0.68 ± 0.27</td>
</tr>
<tr>
<td>Re-wash belt (n=9)</td>
<td>6.23 ± 0.57</td>
<td>5.84 ± 0.50</td>
<td>1.41 ± 0.75</td>
<td>1.66 ± 1.02</td>
</tr>
<tr>
<td>Guide bar for re-wash belt (n=3)</td>
<td>4.83 ± 0.69</td>
<td>5.64 ± 0.78</td>
<td>0.66 ± 0.37</td>
<td>1.57 ± 0.33</td>
</tr>
<tr>
<td>Packer head brush (n=9)</td>
<td>2.65 ± 0.34</td>
<td>3.33 ± 0.65</td>
<td>ND</td>
<td>0.58 ± 0.37</td>
</tr>
<tr>
<td>Packer head belt (n=9)</td>
<td>3.13 ± 0.66</td>
<td>3.56 ± 0.59</td>
<td>0.46 ± 0.30</td>
<td>0.41 ± 0.41</td>
</tr>
</tbody>
</table>

P<0.05 In table 1. VRBG = violet red bile glucose agar; utilised for the determination of Enterobacteriaceae
ND = none detected

Table 2. Effect of sanitation practices on aerobic plate and Enterobacteriaceae counts for non-contact surfaces.

<table>
<thead>
<tr>
<th>Sample Site</th>
<th>Post APC (log CFU/ml)</th>
<th>Pre APC (log CFU/ml)</th>
<th>Post VRBG (log CFU/ml)</th>
<th>Pre VRBG (log CFU/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor under farm belt</td>
<td>6.5 ± 0.6</td>
<td>6.2 ± 0.5</td>
<td>2.7 ± 0.6</td>
<td>1.8 ± 0.8</td>
</tr>
<tr>
<td>Floor under nest-run loader</td>
<td>5.9 ± 0.3</td>
<td>5.7 ± 0.6</td>
<td>2.7 ± 0.7</td>
<td>1.6 ± 0.5</td>
</tr>
<tr>
<td>Floor under washers</td>
<td>5.7 ± 0.9</td>
<td>4.8 ± 0.6</td>
<td>2.3 ± 0.5</td>
<td>1.2 ± 0.5</td>
</tr>
<tr>
<td>Floor under packer heads</td>
<td>5.2 ± 0.4</td>
<td>5.2 ± 0.8</td>
<td>2.7 ± 0.6</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td>Drain near washers</td>
<td>5.7 ± 0.9</td>
<td>5.2 ± 0.8</td>
<td>2.7 ± 0.6</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td>Wall near washers</td>
<td>3.8 ± 0.7</td>
<td>3.8 ± 0.7</td>
<td>0.4 ± 0.3</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>Outside of inedible bin</td>
<td>4.8 ± 0.3</td>
<td>4.7 ± 0.2</td>
<td>1.3 ± 0.3</td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>Post-processing cooler floor</td>
<td>2.4 ± 0.2</td>
<td>2.7 ± 0.4</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Nest-run cooler wall</td>
<td>4.0 ± 0.3</td>
<td>4.0 ± 0.6</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Nest-run egg cart shelf</td>
<td>6.7 ± 0.3</td>
<td>6.7 ± 0.2</td>
<td>2.9 ± 0.6</td>
<td>2.4 ± 0.2</td>
</tr>
<tr>
<td>Nest-run cart wheel</td>
<td>6.1 ± 0.1</td>
<td>5.7 ± 0.2</td>
<td>2.1 ± 0.3</td>
<td>1.4 ± 0.4</td>
</tr>
<tr>
<td>Loading dock floor</td>
<td>4.9 ± 0.3</td>
<td>4.8 ± 0.3</td>
<td>1.0 ± 0.3</td>
<td>0.8 ± 0.3</td>
</tr>
<tr>
<td>Store delivery crate</td>
<td>2.7 ± 0.4</td>
<td>2.6 ± 0.6</td>
<td>0.2 ± 0.2</td>
<td>0.1 ± 0.1</td>
</tr>
</tbody>
</table>

P>0.05 ND = none detected

III. SHELL EGG MICROBIAL QUALITY DURING EXTENDED STORAGE

Shell eggs are a unique agricultural commodity because when they reach the consumer, they are still in the original packaging as when they left the hen. In historical egg research, it has been determined that many of the natural defences present in the egg degrade over time. Board (1966) summarised a collection of previous research and determined there was a 20 day lag between shell penetration and the contamination of the egg contents. Furthermore, it has been found that stored or aged eggs are more easily infected when inoculated (Elliott, 1954). In another study, the infection rate during inoculation was greater
for eggs with a moderate weight loss, which is common during egg storage (Kraft et al., 1958).

The washing of shell eggs for retail sale has not always been a common industry practice in the U.S. Currently, all eggs are washed before retail sale in the U.S., Canada, Japan, Sweden and a significant proportion are also washed in Australia. A previous report has stated that visibly clean eggs usually have fewer microorganisms on the surface than dirty (Board et al., 1964). Garibaldi and Bayne (1960) described a trend towards washing eggs because it took less time to wash them than sort clean from dirty. This study was undertaken to determine what effect current U.S. shell egg processing technologies had on the microbial quality of eggs during prolonged storage.

While the work of Jones and colleagues (2003) found a lack of efficacy in current egg processing facility sanitation practices on reducing the number of microorganisms present on direct egg contact surfaces. A recent study illustrated that the washed eggs were contaminated with microorganisms at lower frequency and with fewer cells than were found in unwashed eggs. Furthermore, no differences were found in aerobic bacteria, Enterobacteriaceae and pseudomonads cultured in the pooled contents of unwashed or washed eggs (Jones et al., 2004).

Eggs are a difficult product to accurately sample for microbial contamination, especially when attempting to evaluate the growth of organisms in specific segments of the egg (Mayes and Takeball, 1983). Due to the nature of the egg, completely separating the components without crossover contamination is almost impossible. Furthermore, research (Mayes and Takeball, 1983) has shown the multiplication of organisms in the contents can be slowed by the viscosity of the egg white, pH, lysozyme and conalbumin. Characteristics of the shell have also been implicated in limiting the ability of organisms to enter the egg contents. Garibaldi and Stokes (1958) reported a complete cessation of bacterial penetration in vitro when the shell and both membranes were present. Others have found a linear response between shell porosity and microbial infection of the contents (Kraft et al., 1958). Orel (1959) demonstrated a greater resistance to microbial penetration and egg spoilage at room temperature when shell specific gravity was greater than 1.080. Some researchers have considered changes during the storage of eggs and found eggs of three different shell permeabilities had similar spoilage levels until 15 days of storage when the most permeable began to spoil at a greater rate (Fromm and Monroe, 1960).

In a recent study conducted in our laboratory (Jones et al., 2004), we avoided some of these issues by utilising eggs from an in-line processing facility. Under these circumstances, eggs were always less than 24 hours old when processed. The birds from which the eggs were derived were in a multi-aged facility including young, old and past-moult flocks. Therefore, the eggs sampled represented the spectrum of physical and microbial characteristics the consumer would be exposed to in the retail market.

Additional researchers have found the shell membrane to lose its effectiveness as a microbial barrier as a challenge increased (Hartung and Stadelman, 1962). The yeast and mould results for the shell surface and egg contents at week eight of storage further support this finding. Miller and Crawford (1953) reported spoilage organisms to be virtually 100% absent from the contents of fresh eggs. In the current study, fewer than 10 CFU/ml of pseudomonads in pooled egg contents were detected in samples and only after three weeks of storage. Fluorescence, from Pseudomonas fluorescens, in the past had been utilised to determine when an egg had spoiled. Visible fluorescence in the egg is not detected until 5.0 log CFU/ml (Imai, 1976). Board and colleagues (1964) had difficulty finding fluorescent pseudomonads in shell eggs. In the current study, a single pool of eggs reached 4.2 log CFU/ml at nine weeks of storage.
Recent research has indicated that commercial sanitation operations did not significantly reduce aerobes and *Enterobacteriaceae* on the direct contact surfaces in shell egg processing facilities (Jones *et al.*, 2003). However, the present study demonstrates that bacterial populations were greatly diminished by current processing techniques. This reduction in shell contamination is further continued throughout storage and in the contents of the eggs. The storage time in the current study was much greater than the 30 day sell by date and 19 days post-processing when most eggs are purchased (Bell *et al.*, 2001; Patterson *et al.*, 2001). Therefore, current federal guidelines for the production and processing of shell eggs appear to have a beneficial effect on the microbial quality of the eggs being produced, even during long-term storage.

IV. CHANGES IN MICROBIAL POPULATIONS DURING SHELL EGG PROCESSING

A further study (Musgrove *et al.*, 2005) was conducted to determine microbial populations on the surface of shell eggs as they progress through the processing line. Samples were collected from three in-line egg processing facilities. Each plant was visited three times. A typical schematic of a U.S. shell egg processing facility is shown in Figure 1. The sampling sites are labeled on the figure.

Rinses from shells of eggs collected at the accumulator indicate that populations of yeasts and moulds were not significantly different for any of the three plants. For all other populations analysed from eggs collected at the accumulator, eggs from the second plant were the least contaminated. For aerobic microorganisms and *E. coli*, eggs from the first and third plants were equivalent while eggs from the second plant were contaminated to a significantly lower level of *Enterobacteriaceae*. All the populations surveyed decreased throughout processing in every plant.

For aerobic microorganisms, yeasts and moulds, *Enterobacteriaceae*, and *E. coli*, greatest numbers of organisms were recovered from shell rinses of eggs collected at the accumulator or the re-wash belt. Pre-wash counts were higher than those obtained from eggs at most other sample collection sites (in-process and post-process). Stages of processing were grouped as pre-processing (accumulator, pre-wash, re-wash belts), in-processing (washers, sanitizer rinse, dryer, oiler), or post-processing (scales, packer lanes). From the pre-processing to post-processing stages, average prevalence of aerobic mesophilic
microorganisms, yeasts and moulds, Enterobacteriaceae, and E. coli decreased from 100 to 80.6%, 80 to 62%, 60 to 10% and 35 to 2%, respectively.

There were some differences in microbial levels recovered from egg shells collected at different plants on different visits (replications). Each plant was visited within two weeks of each other in sequential fashion to prevent a seasonal bias. Prior to processing, aerobic microorganisms, E. coli, and yeasts and moulds were determined to be less than a log CFU/ml rinse different among the plants. Despite differences in plant age, processing capacity, and water quality, all three plants were contaminated at similar levels for yeasts and moulds, Enterobacteriaceae and E. coli at the end of processing.

Despite plant differences, the way shell eggs were washed, graded, and sorted was similar. Regardless of plant or microbial population, highest bacterial and fungal counts were observed at the accumulator or the re-wash belts. Eggs at these points along the processing chain are visibly dirty or unwashed eggs. In fact, wash water at one plant was harsh enough that all populations were decreased by greater than a log CFU/ml at the pre-wash rinse. The second plant achieved the same result for all populations except for aerobic microorganisms, which were reduced in washer 1. The third plant achieved a log reduction in washer 1 for the four directly plated populations only after eggs reached the first washer.

Data for each population were averaged for the three plants and separated by sample site. Aerobes reached the lowest levels by the dryer while Enterobacteriaceae and E. coli were reduced to the lowest levels by washer 1. Yeasts and moulds were reduced at pre-wash rinse but increased again at oiling. Oilng follows drying, accomplished by forcing warm air over the eggs as they emerge from the sanitiser rinse. A survey of air quality in shell egg processing plants indicated poorest yeast/mould air quality near the dryers and washers (Northcutt et al., 2004). De Reu et al. (2003) compared aerobic shell populations on eggs collected from production through retail from cage and organic production systems. Their results indicated that air quality affected shell counts regardless of production system. However, by the end of the processing chain, all microbial populations determined in our study were significantly reduced compared to pre-processing levels.

Sanitising rinse application is just one of the hurdles designed to diminish microbial egg shell contaminants. In a 1979 study, Moats (1979) visited commercial facilities in Maryland and Pennsylvania that used different combinations of washing compounds and sanitising or water rinses. Microbial populations on shell eggs in plants using sanitiser rinses were very low (<50 cells or CFU’s /shell), and significantly lower than one plant using an unsupplemented water rinse. However, when sanitiser rinse was temporarily cut off in plants that employed this type of rinse, populations on the shell did not change. Moats (1979) concluded that a lack of significant change in egg shell bacterial numbers indicated that sanitiser rinse was of most an indirect effect. In a separate study, Moats (1980) obtained population data from equipment surfaces, wash water, and eggs. Based on correlations, he concluded that the sanitiser rinse was of no use. Our data offers no sound argument against his conclusion. United States Department of Agriculture (2005), Agricultural Marketing Service American Microbiological Society guidelines specify that sanitiser rinses must be compatible with detergents and of a strength equivalent to 100-200 ppm chlorine. Chlorine compounds perform optimally between pH 6.5-7.5 (Curtis and Johnston, 1998), much lower than that measured for wash water in this study. Other compounds have been analysed to replace chlorine but none has been as effective (Kuo et al., 1997).

Prevalence data for individual plants and an average of the three plants were organised by stage of processing. Once eggs were introduced into the washer, microbial populations were reduced and biologically relevant increases were not observed through the remainder of the processing chain. Sanitation affects microbial populations during shell egg processing (Moats, 1981). Certain sections of the equipment are not water proof (scales), are
difficult to reach (re-wash belt), or are difficult to remove and clean regularly (packer head brushes). However, contact with these surfaces did not result in significant increases in counts.

These data indicate that commercial egg processing significantly reduced levels of aerobic, yeasts and molds, *Enterobacteriaceae* and *E. coli* populations recovered by shell egg rinses. Populations decrease once eggs reach the first washer and remained low through packaging. Therefore, while current sanitation practices utilised by shell egg processors in the U.S. could be more effective, the product has a high microbial quality post-processing which remains during extended storage.

REFERENCES


