Packaging Effects on Shell Egg Breakage Rates During Simulated Transportation[1]

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ABSTRACT Shell eggs were packaged in either expanded polystyrene (EPS) foam or molded paper pulp (MPP) one dozen cartons, then were bulk packaged in either polypropylene crates or corrugated boxes. The packages were then subjected to a well-defined computer-simulated vibration test on an electrohydraulic test machine. The percentage and the location on the egg (side, top, bottom) of breakage was determined in the secondary (corrugated box or polypropylene crate) and primary (EPS or MPP carton) package after 15, 75, and 180 min. For each of three trials, 60 dozen Grade A large eggs were randomly assigned to each primary package and cross-stacked in a secondary container that contained three cartons in a row and a total of five layers.

When cartons were packed in 15-dozen corrugated boxes, no significant difference was found in total eggshell damage rates between the MPP carton and the EPS carton. However, when eggs were packed in 15-dozen plastic crates, the MPP cartons caused significantly less eggshell damage than the EPS cartons. The EPS cartons packed in corrugated boxes had the lowest breakage (4.63%), whereas the EPS foam cartons packed in plastic crates had the highest breakage (12.59%). When the effect of secondary packaging and vibration time were not considered, no significant difference was found between MPP and EPS cartons. In addition, when the effect of primary packaging was not taken into account, the corrugated boxes had significantly lower breakage rates than the plastic crates. Nearly 55% of the breakage occurred in the bottom section of the eggshell as compared to the side and top. When the test periods were compared, the EPS cartons packed in plastic crates had the highest breakage (16.28%) at 180 min.

(*Key words*: shell egg, packaging, breakage, simulated transportation)

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INTRODUCTION

Throughout distribution, the major function of the egg packaging is the protection of the egg by prevention of eggshell breakage. The egg package may also provide protection to the interior quality of the egg by restricting gas exchange through the shell and shell membrane. From laying to the final destination, more eggs are broken during transportation than in any other step during processing and distribution; therefore, profit or losses due to breakage are greatest during transportation (Thompson and Hamilton, 1986).

Mellor and Gardner (1970) studied the effect of foam, chipboard, and molded pulp cartons in a corrugated box on eggshell quality during transport by making three trips from a processing plant to a laboratory (~300 mi) in a station wagon. No differences in breakage were found for eggs packed in any of the cartons used for normal shipment. However, under rough handling conditions, the foam cartons offered more protection against breakage than the chipboard cartons, but less protection than the molded pulp cartons. Nethercote *et al.* (1974) also compared the molded pulp and foam cartons in corrugated boxes arranged in either parallel or cross-stacking configurations, and their individual protective properties using laboratory testing procedures. They found that crossed tiers of cartons protected eggs better than cartons all aligned in the same direction. Furthermore, they concluded that the carton design was more important than material in determining the relative protective ability.

Denton *et al.* (1981) studied the effect of six egg carton types and three case types on eggshell breakage using a vertical drop test. Two types of molded pulp cartons offered the greatest protection, whereas two foam cartons provided the least protection. In addition, better protection was observed with the corrugated boxes than with the 15-dozen wire or 24-dozen wire cases. Lederer

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Abbreviation Key: EPS = expanded polystyrene; MPP = molded paper pulp.

(1983) evaluated the protective ability of foam and pulp egg cartons when packed and shipped in 15-dozen wire or plastic baskets and 30-dozen cardboard boxes in seven states. It was found that the level of damage was greater among foam cartons than among pulp cartons. When the effect of the secondary container was excluded, two types of foam and two types of molded pulp cartons had less eggshell damage and did not significantly differ from each other.

Roland (1988) estimated that the percentages of the cracked eggs in Grade A cartons at final destination (retail store) ranged from 5 to 7%. This result is not only due to poor eggshell quality but also to the protective quality of egg packages. In 1996, the U.S. annual egg market value was $6.68 billion, comprised of 76.1 billion eggs, of which 64.6 billion were table eggs (Anonymous, 1997). The total breakage loss was estimated to be $250 million. These estimates do not include losses incurred by producers for reimbursement to store owners for cracked eggs that occurred during transportation from the store to the consumer's home.

During distribution, not all packages within a shipment are handled identically, nor are conditions for one shipment the same as those of subsequent shipments. The factors influencing shipment include: truck suspension systems, traffic density, road conditions, location of the package on the truck, and atmospheric conditions (Nethercote *et al.*, 1974). However, test procedures can be used to simulate transportation such that each package is subjected to a set of precise, controlled, and reproducible conditions making comparisons between package effects on breakage more consistent. Therefore, the objectives of this study were to determine the relative protective ability of two commonly used carton types using two types of secondary container under simulated test conditions.

MATERIALS AND METHODS

The packages used in this study included molded paper pulp (MPP) and foam expanded polystyrene (EPS) cartons as the primary packages, and corrugated boxes and polypropylene crates as the secondary packages. All packaging materials were obtained from a local commercial egg packaging facility. The MPP cartons had a continuous horizontal top post in the center and five bottom posts, whereas the EPS cartons had a single short vertical top post with six horizontal and five vertical cell dividers. The 15-dozen Type C flute (3.6 mm thick) closed-top corrugated boxes and the 15-dozen open-top polypropylene crates were used as the secondary packaging.

For each of three trials, 60 dozen Grade A Large white eggs were used, and the primary packages were cross-stacked in a secondary container that contained three cartons in a layer and a total of five layers (Figure 1). The eggs were obtained from a commercial egg packer after washing, inspection, and packaging. After receiving, the eggs were candled and those with cracks were discarded. The remaining eggs were randomly assigned to each primary package.

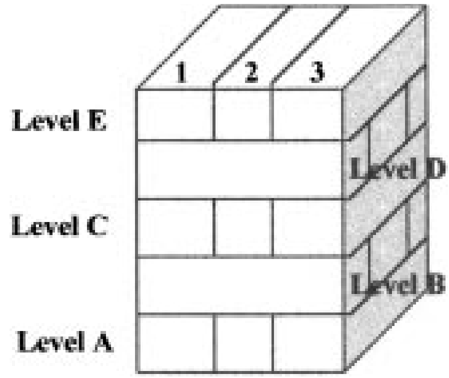

FIGURE 1. The arrangement of primary packages in secondary package during simulated truck vibration testing.

After stacking the primary packages, the secondary packages were then subjected to a Level I Truck Assurance Test (ASTM, 1994) using a computerized electrohydraulic vibration test system.[3] The Level I test utilizes a 1 to 200 Hz frequency range and performance sequence. The vibration test (Level I Truck Assurance) is based on the frequency of vibration, the gravitational (g) forces delivered during each vibration, and is depicted in a Power Spectral Density table (ASTM, 1994). The vibration frequency and g force are varied to simulate the variations found during transportation. For the truck simulation, the frequency range and the overall g force are standardized depending on the frequency and assurance level.

At 15, 75, and 180 min of vibration, cracked and leaker eggs were recorded as to location in the secondary and primary package and for location (top one-third side, middle third, bottom third) on the egg. In the rare instance that a crack crossed into two egg location sites, the location with the greatest part of the crack was designated. All eggshells that showed visual cracks under candling were categorized as a break and were removed from the package.

The experiment used a $2 \times 2 \times 3$ factorial design with carton types, case types, and time effects as the factors. The experiment had three separate replications with main effects of replication, primary package (MPP and EPS), secondary package type (corrugated box and plastic crate), and their interaction used in the model, and residual effects applied to the error term. A General Linear Models procedure of SAS® (SAS Institute, 1996) was used and means were separated using the PDIFF command of SAS® at a significance level of $P < 0.05$. Additionally, primary package layer and eggshell location effects were tested with chi-square analysis for comparison (FREQ and CATMOD).

[3]Lansmont Corp., Monterey, CA 93940.

TABLE 1. The effect of package type on eggshell damage

Carton type[1]	Breakage Corrugated box	Plastic crate	Average for MPP and EPS
	(%)		
MPP	7.78 ± 1.47	6.85 ± 1.40[y]	7.31 ± 1.38
EPS	4.63 ± 1.15[b]	12.59 ± 3.70[a,x]	8.61 ± 5.00[ab]
Average	6.20 ± 2.09[b]	9.72 ± 4.02[a,xy]	

[a,b]Means in rows with no common superscript differ significantly ($P < 0.05$) ($n = 180$).

[x,y]Means in columns with no common superscript differ significantly ($P < 0.05$) ($n = 180$).

[1]MPP = Molded Paper Pulp; EPS = Expanded Polystyrene.

TABLE 2. The effect of primary and secondary package on the location of broken for the total broken eggs

Package type[1]	Breakage location on the eggshell Top	Bottom	Side
	(%)		
Corrugated box			
MPP	6.98[b]	16.86[a]	0.58[c]
EPS Foam	2.91[b]	9.88[a]	1.74[b]
Plastic crate			
MPP	9.88[a]	11.05[a]	0.58[b]
EPS Foam	19.19[a]	17.44[a]	2.91[b]
Total	38.95[b]	55.23[a]	5.81[c]

[a–c]Means within rows with no common superscript differ significantly ($P < 0.05$) ($n = 172$); SEM = 1.62.

[1]MPP = molded paper pulp; EPS = expanded polystyrene.

RESULTS AND DISCUSSION

A significant interaction ($P < 0.05$) between primary and secondary packaging on breakage rate was found. That is, MPP cartons did not differ in breakage due to the secondary package type whereas the EPS cartons had a higher breakage rate in plastic crates than in corrugated boxes (Table 1). Also, when cartons were packed in the 15-dozen corrugated boxes, no significant difference was found in total eggshell damage rates between the MPP cartons and the EPS cartons ($P < 0.05$). However, when eggs were packed in 15-dozen plastic crates, packaging in the MPP cartons resulted in significantly less eggshell damage than the EPS cartons. The MPP cartons in either of the secondary package types and the EPS cartons in corrugated boxes did not differ in breakage rate. Mellor and Gardner (1970) found that MPP cartons offered more protection from breakage than foam cartons packaged in corrugated boxes, whereas no difference was found in these package types in the present study. Variation in testing methodologies may contribute to differences in these results. When the effect of secondary package was not considered, no significant difference was found between MPP and EPS cartons. In addition, when the effect of primary package was not taken into account, the corrugated boxes had a significantly lower breakage rate compared to plastic crates (Table 1). Corrugated boxes possessed an upper closure that prevented the cartons from bouncing and possibly preventing an appreciable amount of impact energy during simulated transportation. Plastic crates tended to be more rigid with very little cushioning effect observed during the test, which resulted in more breakage (Table 1). These results were in agreement with Lederer (1983), in which actual shipping conditions were used. The results contrasted with those of Denton *et al.* (1981), in which the drop-test was used to evaluate the protection against the eggshell breakage, possibly because the drop test does not duplicate the breakage forces encountered during shipping.

Over 55.00% of the breakage occurred on the bottom of the eggs as compared to the side and top (Table 2). Furthermore, the lack of cushioning of cartons packaged in plastic crates resulted in most of the cracks being located on either the top or bottom of the shell. The only published data of the location of the shell damage during transport (Denton *et al.*, 1981) indicated that 56.28% of the broken eggs had damage on the bottom of

TABLE 3. The effect of carton layer on shell egg breakage rate

Package type[1]	Breakage rate due to carton layer[2] A	B	C	D	E
Corrugated box					
MPP	1.16[b]	0.58[b]	2.33[b]	9.30[a]	11.05[a]
EPS Foam	0.58[b]	2.33[a]	3.49[a]	4.65[a]	3.49[a]
Subtotal	1.74[b]	2.91[b]	5.82[b]	13.95[a]	14.54[a]
Plastic crate					
MPP	2.91[b]	1.74[b]	4.65[a]	5.81[a]	6.40[a]
EPS Foam	16.28[a]	0.00[d]	5.23[c]	11.05[b]	6.98[c]
Subtotal	19.19[a]	1.74[c]	9.88[b]	16.86[a]	13.38[a,b]
Total	20.93[b]	4.65[c]	15.70[b]	30.81[a]	27.91[a]

[a–c]Means in a row with no common superscript differ significantly ($P < 0.05$) ($n = 172$), SEM = 1.28.

[1]MPP = molded paper pulp; EPS = expanded polystyrene.

[2]Carton layers are from the bottom (A) to top (E).

TABLE 4. The effect of package type on shell breakage rates during test periods

Package type[1]	Time of exposure to simulated transportation total percentage broken 15 min	75 min	180 min
	(%)		
Corrugated box			
MPP	6.40	9.30	8.72
EPS Foam	2.33	4.07	8.14
Plastic crate			
MPP	2.91	8.72	9.88
EPS Foam	4.65[c]	18.60[a]	16.28[b]
Total	16.28[b]	40.70[a]	43.02[a]

[a–c]Means within rows with no common superscript differ significantly ($P < 0.05$) n = 172, SEM = 1.27.

[1]MPP = molded paper pulp; EPS = expanded polystyrene.

the egg verifying the results of the present study. Whereas numerically, the bottom layer had the greatest percentage of breakage, it was not significantly different from the top two layers (Table 3). When taken together, the top and bottom layers were the sites of the greatest breakage. Furthermore, the total and subtotal means mask the different responses observed between MPP and EPS cartons. When the comparison of carton layer within the secondary package type was made, the cushioning effect of the secondary package types was apparent (Table 4). The majority of the shell breakage in the plastic crates was detected in the bottom layer, which exhibited 19.19% of the total breakage. The higher percentage of breakage in the bottom layer was only apparent in EPS cartons, accounting for 16.28% of the total breakage. In addition, the breakage rate in the bottom layer of the plastic crates was significantly higher than the breakage in the corrugated boxes. The top two layers showed a significantly higher total breakage than other layers. The damage in the top layer is related to a lack of the restriction to movement of the top layers compared to the lower layers.

During the simulated test period, the greatest breakage was found after 75 and 180 min, with 40.70 and 43.02%, respectively (Table 4). There was no significant difference found for breakage rates of eggshells packed in corrugated boxes due to time of exposure, whereas the EPS cartons packed in plastic crates had less breakage at 15 min than after 75 and 180 min.

Cartons were examined for damage after 180 min of exposure to the vibration test. Many of the cartons packed on the bottom layer of plastic crates sustained some structural damage, displaying tiny cracks and dents. This simulation test represents a severe transportation treatment; thus, some package failures would be expected.

An egg processor from the southeastern U.S. provided the total cost for the packaging materials used in this study (Table 5). According to Lappin (D. Lappin, 1997. Personal communication. G&B Enterprises, Ltd. Liberty, SC), the average life of a returnable plastic crate is 10 cycles. Therefore, using $0.38 as an average plastic crate cost per cycle, the average packaging cost of one 15-dozen plastic crate is $1.26 and $1.16 for the MPP and EPS cartons, respectively. The cost for EPS cartons packaged corrugated boxes was $1.08, and the MPP carton cost was $1.17 per 15-dozen box. It was not possible to evaluate all carton cell designs or test all the varieties of carton types available. Conclusions as to the best packaging material for shell eggs must be limited to the package types tested. Only the truck-simulation vibration test was performed and, as other stresses are present during shipping and transportation, these other factors should be considered to determine the optimal package systems used to minimize shell egg breakage. The results do indicate that the primary and secondary packaging combinations are important considerations when attempting to minimize eggshell damage.

TABLE 5. Primary and secondary package costs[1]

Package type[2]	Current cost
EPS carton	$52/1,000 packs
MPP carton	$58/1,000 packs
Corrugated box (15-dozen)	29.5 ¢ apiece
Plastic crates (PP) (15-dozen)	$3.80 apiece (Returnable)

[1]D. Lappin, 1997 personal communication, G & B Enterprises, Liberty, SC 29657.

[2]MPP = molded paper pulp; EPS = expanded polystyrene.

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