Mechanical properties of ten-egg boxes made of different materials

Ante Galic¹ · Stjepan Pliestic¹ · Dubravko Filipovic¹ · Igor Kovacev¹ · Kresimir Copec¹ · Zlatko Janjecic¹ · Dalibor Bedekovic¹

Revised: 2 January 2018 / Accepted: 15 January 2018 / Published online: 3 February 2018
© Association of Food Scientists & Technologists (India) 2018

Abstract This study was conducted to evaluate mechanical properties of ten-egg boxes, which are the most commonly used egg boxes in many countries of Central and South-Eastern Europe. Six ten-egg boxes were tested, two made of cardboard, two made of expanded polystyrene and two made of general purpose solid polystyrene, each from a different producer. There were no significant differences in basic dimensions between tested boxes of various materials, while the significant differences were occurred in weight and box wall thickness. Test included measuring of vertical forces required for deforming complete box and at particular place for each egg in a box till contact with eggs. According to the obtained results, cardboard boxes can provide the best mechanical protection for eggs. The average force required for deforming complete cardboard box was 83.6% higher than for solid polystyrene box, and even 289.5% higher than for expanded polystyrene box. The average force required for deforming cardboard box at particular place for each egg in a box was 60.8% higher than for polystyrene box, and 74.0% higher than for expanded polystyrene box. The disadvantage of cardboard boxes is that they are not resistant to the impact of moisture as polystyrene boxes and in the case of an increase in box moisture due to storage in inappropriate conditions their mechanical resistance decreases.

Keywords Egg box · Cardboard · Expanded polystyrene · Solid polystyrene · Forces · Moisture influence

Introduction

Packaging is an important component in handling, storage and transportation eggs from poultry farms to consumers. The major function of the egg packaging is the protection of the egg by prevention of eggshell breakage (Seydim and Dawson 1999). According to Thompson and Hamilton (1986), more eggs are broken during transportation than in any other step during processing and distribution. Broken eggs cause economic damage in two ways: they cannot be sold as first-quality eggs, and the occurrence of hair cracks raises the risk for bacterial contamination of the broken egg and of other eggs when leaking, creating problems with internal and external quality and food safety (Mertens et al. 2006). For the poultry breeder, farmers, food, egg sorting, and marketing companies, the main priorities are to deliver a safe product which is accepted by the consumers (Nys 2009). Breakage or cracking of eggshells in market channels is a serious concern and egg producers have to be aware of that because the economic consequences of shell failures are significant (Hunton 2005). Study of Bell et al. (2001) showed that almost one-half of the cartons sampled in national supermarkets in several USA states had one or more cracked eggs, and 17% had two or more. An egg carton is a carton designed for carrying and transporting whole eggs. These cartons have a dimpled form in which each dimple accommodates an individual egg and isolates that egg from eggs in adjacent dimples. This structure helps protect eggs against stresses exerted during transportation and storage by absorbing a lot of shock and limiting the incidents of fracture to the fragile egg shells (Quintero 2010).

The problem of packaging eggs so that they may be shipped, handled in grocery stores, and conveyed to the home of the user without breakage, has existed for a long

✉ Dubravko Filipovic
dfilipovic@agr.hr

¹ Faculty of Agriculture, University of Zagreb, Svetosimunska 25, Zagreb, Croatia

time. So far extensive tests are carried out to determine the effectiveness of egg boxes which will prevent breakage. Some researches performed studies to determine the strength requirements for different types of egg boxes before many years (Mellor and Gardner 1970; Nethercote et al. 1974; Denton et al. 1981; Roland 1988), but since that time there have been many changes in design and used materials. Today egg boxes are made of various materials, such as recycled paper, cardboard, moulded pulp, different polymers and others (Marsh and Bugusu 2007; Wani et al. 2014). The two most popular materials for egg boxes (cartons) are polystyrene and pulped paper (Kudzal et al. 2014). Eggs come on market in boxes of different shapes and sizes and that can be designed for different egg number. The objective of this study was to investigate some mechanical properties of ten-egg boxes, the most commonly used egg boxes in many countries of Central and South-Eastern Europe.

Materials and methods

A study was conducted to evaluate the mechanical properties of six commonly used ten-egg boxes on the Croatian market, each from a different producer. Two of them were made of cardboard with different form (CB-1 and CB-2), two of expanded polystyrene (EPS-1 in yellow colour and EPS-2 in white colour) and two of general purpose solid polystyrene (PS-1 in white colour and PS-2 transparent), shown in Fig. 1. A sample of thirty boxes of each type was used in this study, and additional twenty boxes made of cardboard were used to measure influence of moisture on boxes mechanical properties, so a total sample was 200 boxes. Before testing the mechanical properties were measured dimensions and weight of the tested boxes. Dimensions of boxes were measured using an electronic digital calliper with accuracy of 0.01 mm. To evaluate the weight, egg boxes were separately weighed on a precision electronic balance (Sartorius BP 3100S, Göttingen, Germany) reading to 0.01 g. During the test boxes are filled with eggs from ISA Brown strain hens keeping in free range system provided by the local producer.

To measure the forces required to deform the boxes, a testing machine designed by University of Zagreb Faculty of Agriculture, Agricultural Engineering Department, Croatia, was used to compress the box. In the first part of measuring box samples with eggs were placed on the fixed plate and pressed with a moving plate with dynamometer at the compression speed of 1 mm s^{-1} till contact with egg. Eggs were not broken in order to avoid the impact of eggshell strength on results. The forces were measured by the data acquisition system, which included dynamometer HBM (Hottinger Baldwin Messtechnik, Darmstadt,

Fig. 1 Ten-egg boxes tested in this study

Germany) with a capacity of 1000 N, amplifier HBM DMC 9012 A and personal computer (Fig. 2). This measurement was replicated by taking fifteen samples of each type of ten-eggs boxes.

Within this part of the study was also conducted testing of mechanical properties of egg boxes exposed to excessive moisture. It is well known that general purpose solid polystyrene is total water resistance, while water absorption of expanded polystyrene is the minimum, but only after long-term exposure (Gnip et al. 2006). So, mechanical properties of egg boxes exposed to excessive moisture was conducted only at cardboard boxes. This measurement was replicated by taking ten samples of two types of cardboard ten-egg boxes with different moisture. Moisture of boxes was increased by wetting with water sprayer and determined by the difference in weight of wet and dry boxes. The testing procedure for measuring the forces required to deform the boxes was the same as with dry egg boxes.

In the second part of measuring box samples with eggs were placed on the fixed plate and pressed with a cylindrical probe with dynamometer at the compression speed of 1 mm s^{-1} in the center of each egg place till contact with egg. Contact surface of cylindrical probe was 1 cm^2 (Fig. 2). This measurement was replicated by taking ten samples of each egg place of ten-egg boxes.

The obtained data were analysed applying the analysis of variance and the LSD test was used to compare the mean

Fig. 2 Schematic presentation of universal testing machine used to compress complete ten-egg boxes with a moving plate (up) and to compress individual egg places of ten-egg boxes with a cylindrical probe (down)

results. The differences had been considered as significant if $P < 0.05$.

Results and discussion

Dimensions and weight of tested ten-egg boxes are presented in Table 1. There were no significant differences in basic dimensions between tested boxes of various materials. The significant differences were occurred in weight and box wall thickness. The greatest weight had cardboard

Table 1 Dimensions and weight of tested ten-egg boxes

Egg box	Length (mm)	Width (mm)	Height (mm)	Thickness (mm)	Weight (g)
CB-1	246.99 ^a	105.03 ^a	69.03 ^a	1.07 ^a	46.70 ^a
	(0.26)	(0.47)	(0.25)	(0.06)	(0.80)
CB-2	246.87 ^a	104.99 ^a	68.96 ^a	0.93 ^a	43.98 ^a
	(0.28)	(0.20)	(0.30)	(0.04)	(0.46)
EPS-1	246.98 ^a	104.91 ^a	69.02 ^a	2.56 ^b	12.66 ^b
	(0.17)	(0.19)	(0.25)	(0.06)	(0.29)
EPS-2	246.93 ^a	104.88 ^a	69.04 ^a	2.52 ^b	12.43 ^b
	(0.23)	(0.33)	(0.29)	(0.05)	(0.24)
PS-1	250.32 ^a	105.58 ^a	68.87 ^a	0.22 ^c	24.44 ^c
	(0.21)	(0.29)	(0.28)	(0.02)	(0.70)
PS-2	250.25 ^a	105.43 ^a	68.81 ^a	0.21 ^c	20.25 ^d
	(0.16)	(0.21)	(0.25)	(0.02)	(0.44)

Mean values followed by the identical letter are not significantly different ($P < 0.05$). The values in brackets present standard deviation

boxes, whose average weight was twice greater than polystyrene boxes and even 3.6 times more than expanded polystyrene boxes. Only in the case of polystyrene boxes was determined a significant difference in the weight of the boxes of two different producers. The greatest wall thickness had expanded polystyrene boxes, then cardboard boxes, and the lowest had polystyrene boxes.

The measurement of forces required for deforming complete ten-egg boxes till the contact with eggs have shown that the best mechanical protection for eggs are cardboard boxes (Table 2). The average force required for deforming the cardboard box was 83.6% higher than force required for deforming polystyrene box, and even 289.5% higher than force required for deforming expanded polystyrene box. At this, for deforming the CB-1 boxes was necessary 14.2% greater force than for CB-2 boxes, while between the boxes of polystyrene and expanded polystyrene from different producers there were no significant differences.

Cardboard boxes had the highest resistance to deformation in comparison to polystyrene and expanded polystyrene boxes, but in the case of an increase in box moisture due to exposure to precipitation or storage in inappropriate conditions their mechanical resistance decreases. Dry cardboard boxes in standard storage conditions have moisture content below 5%. By increasing the moisture of the boxes on 15%, the force necessary for the deformation of the box till contact with eggs is decreased by 16.1 and 17.7% for CB-1 and CB-2 boxes, respectively. Increasing the moisture content on 30% results that force necessary for deformation of cardboard boxes decreased 3.6 and 4.6 times for CB-1 and CB-2 boxes, respectively (Fig. 3). With further increase of moisture cardboard boxes become unsuitable for eggs storage and transport.

The measurement of forces required for deforming boxes at a particular place for each egg in box also shows that the best mechanical protection is cardboard boxes (Fig. 4). The average measured force at all ten egg places

Fig. 3 Forces required to deforming cardboard ten-egg boxes with different moisture

was 44.45 N for the CB-1 and 41.56 N for CB-2 boxes. In both types of cardboard boxes greatest force required for deformation of the box till the contact with egg has been measured at the top middle egg places. For deformations egg places at the box edges is needed significantly less power, which means that in these boxes eggs on the ends more likely to be harmed than those in the middle. It was also required more force to deform back egg places of the box in comparison to front places.

Comparing forces for deformation at a particular place for each egg in a box of expanded polystyrene and polystyrene boxes, as well as deformation of the complete boxes, proved to be more resistant polystyrene boxes, but are individually shown considerably smaller differences. The average measured force at all ten egg places was 27.06 and 26.43 N for polystyrene boxes PS-1 and PS-2, while 25.32 and 24.09 N for expanded polystyrene boxes EPS-1 and EPS-2, respectively. So, the average force required for deforming the cardboard box at a particular place for each egg in a box was 60.8% higher than force required for deforming the polystyrene box, and 74.0% higher than force required for deforming the expanded polystyrene box. In all types of polystyrene boxes greatest forces required for deformation of the box till the contact with egg has been measured at egg places at the box edges. Contrary to cardboard boxes, for deformations egg places at the box middle is needed the lowest power, which means that in these boxes eggs in the middle more likely to be harmed than those at the edges. At all polystyrene boxes it was also required more force to deform back egg places of the box in comparison to front places. Knowledge of the egg box resistance to the vertical load can help at stacking boxes in transport. Seydim and Dawson (1999) studied influence of location of egg cartons in container (side, top and bottom) and conclude that higher percentage of egg breakage in the bottom layer was only apparent in expanded polystyrene cartons.

Table 2 Forces required to deforming complete ten-egg boxes with a moving plate (N)

Egg box	Mean	Max.	Min.	S_d
CB-1	489.71 ^a	563.17	404.34	67.24
CB-2	428.89 ^b	526.39	344.22	70.01
EPS-1	160.88 ^c	192.46	135.59	22.95
EPS-2	156.37 ^c	184.63	129.46	24.38
PS-1	251.87 ^d	300.71	219.07	33.28
PS-2	248.33 ^d	291.83	214.22	30.87

Mean values followed by the identical letter are not significantly different ($P < 0.05$)

Fig. 4 Average forces required to deforming ten-egg boxes on particular egg place (N)

Results showed that both types of cardboard boxes need to apply more force to deform the box till contact with eggs than the polystyrene boxes. Beside to material properties, reason for this is a construction of cardboard boxes which allows that vertical forces acting on the box are transmitted through its internal structure. Denton et al. (1981) also found that the better protection offered by the cardboard boxes probably was due to the cushioning effects of both the case itself and the cartons inside. Cartons that exhibited greater degrees of protection possessed a relatively strong row of center support posts between the cell rows. In addition, the hinge and closure sides of these carton types were more rigid when subjected to downward stress. The cartons offering less protection did not possess these characteristics. Mellor and Gardner (1970) reported no differences in breakage protection for six carton types tested when eggs were evaluated after normal shipment trials, while differences were detected when the egg cases were subjected to rough handling evaluations. According to Nethercote et al. (1974), besides packing material several factors influence transportation damage: truck suspension, traffic density, road conditions, location of the egg package on the truck, and atmospheric conditions. Lack of cardboard boxes is that are not resistant to moisture as polystyrene boxes. Result obtained in this study showed that

excessive moisture of cardboard boxes significantly reduce the force required to box deformation and thus the protection of eggs in the boxes.

Conclusion

Protection of the eggs during handling, storage and transport is a major function of egg boxes. Most important in this protection is the prevention of egg breakage. Based on the results obtained by testing of ten-eggs boxes made of different materials can be concluded that the cardboard boxes can provide better mechanical protection for eggs than solid polystyrene and expanded polystyrene boxes. Cardboard boxes had the highest resistance to deformation and much higher forces were required for deforming complete cardboard boxes and also at particular place for each egg in a box in comparison to polystyrene boxes. Cardboard mechanical resistance can be reduced in case of an increase in box moisture due to storage in inappropriate conditions.

References

- Bell DD, Patterson PH, Koelkebeck KW, Anderson KE, Darre MJ, Carey JB, Kuney DR, Zeidler G (2001) Egg marketing in national supermarkets: egg quality—part 1. *Poult Sci* 80:383–389
- Denton JH, Mellor DB, Gardner FA (1981) The effect of egg carton and case type on egg shell damage. *Poult Sci* 60:145–150
- Gnip IY, Kersulis V, Vejelis S, Vaitkus S (2006) Water absorption of expanded polystyrene boards. *Polym Test* 25:635–641
- Hunton P (2005) Research on eggshell structure and quality: an historical overview. *Rev Bras Cienc Avic* 7:67–71
- Kudzal A, Zhang Z, Lagassey J (2014) Axiomatic design of an improved egg carton manufacturing process. In: Goncalves-Coelho AM, Cavique M, Mourao A (eds) *Proceedings of the 8th international conference on axiomatic design*. Campus de Caparica, Portugal, pp 187–194
- Marsh K, Bugusu B (2007) Food packaging—roles, materials, and environmental issues. *J Food Sci* 72:39–55
- Mellor DB, Gardner FA (1970) The effect of egg cartons on interior quality and breakage of shell eggs. *Poult Sci* 49:793–798
- Mertens K, Bamelis F, Kemps B, Kamers B, Verhoelst E, De Ketelaere B, Bain M, Decuyper E, De Baerdemaeker J (2006) Monitoring of eggshell breakage and eggshell strength in different production chains of consumption eggs. *Poult Sci* 85:1670–1677
- Nethercote CH, Boisvenu CN, Fletcher DA (1974) Egg carton tests. *Poult Sci* 53:311–325
- Nys Y (2009) Factors contributing to improvement in egg quality. *Volumul de Lucrări Științifice Seria Zootehnie* 52:247–253
- Quintero RA (2010) Measurement of the sound-absorption coefficient on egg cartons using the Tone Burst Method. In: Munteanu V, Raducanu R, Dutica G, Croitoru A, Balas VE (eds) *Proceedings of the 11th WSEAS international conference on acoustics and music: theory and applications*, Iasi, Romania, pp 24–29
- Roland DA (1988) Egg shell problems: estimates of incidence and economic impact. *Poult Sci* 67:1801–1803
- Seydim AC, Dawson PL (1999) Packaging effects on shell egg breakage rates during simulated transportation. *Poult Sci* 78:148–151
- Thompson BK, Hamilton RMG (1986) Relationship between laboratory measures of eggshell strength and breakage of eggs collected at a commercial grading station. *Poult Sci* 65:1877–1885
- Wani AA, Singh P, Langowski HC (2014) Food technologies: packaging. In: Motarjemi Y (ed) *Encyclopedia of food safety*, vol 3. Academic Press, Waltham, pp 211–218