The effect of season on dead on arrival rate and meat quality characteristics of broiler chicken transported in commercial slaughter conditions

BULENT TEKE[1], PEMBE DILARA AKIN[2], FILIZ AKDAG[1], MUSTAFA UGURLU[1], BULENT EKIZ[2]

[1] Department of Animal Breeding and Husbandry, Ondokuz Mayis University, Veterinary Faculty, 55200 Atakum, Samsun, Turkey
[2] Department of Animal Breeding and Husbandry, Istanbul University-Cerrahpaşa, Veterinary Faculty, 34320 Avcilar, Istanbul, Turkey

SUMMARY

The aim of the study was to determine the effect of season on dead on arrival rate and meat quality characteristics of broiler chicken in commercial transport and slaughter conditions. The study was performed on the broiler chickens reared under similar commercial conditions from 12 different flocks (4 seasons × 3 replicates). Transportation distance was approximately 80 km and duration was 2 h per transport. Meat samples were taken on April, July, October, and December for spring, summer, autumn and winter seasons, respectively during 2018. Broilers in trucks were waited in holding barn for 1 h and the numbers of dead on arrival (DOA) were recorded per transport.

Meat colour, pH_{4h}, drip loss, cooking loss and Warner Bratzler shear force (WBSF) were determined. The effect of season on DOA rate ($P < 0.05$) and all investigated meat quality characteristics ($P < 0.001$) was significant. DOA rate was highest in the winter while the rate was lower in spring and autumn. In winter, pH_{4h}, a^*_{24h} and b^*_{24h} were higher than other seasons, while L^*_{24h}, drip loss and WBSF were lower than other seasons. The incidence of PSE meat was the highest in summer (31.12%), while the incidence of DFD meat was the highest in winter (55.55%). The lowest incidence of normal breast meat was in winter season.

In conclusion, transportation of broiler chickens in winter resulted with highest DOA rate, as well as decreased incidence of normal breast meat. On the other hand, the incidence of PSE meat was the highest in summer. In order to reduce the DOA rate and to improve the meat quality, transportation of broiler chickens within thermal comfort zone ranges is recommended.

KEY WORDS

Broiler chicken, DOA, meat quality, PSE meat, transportation.

INTRODUCTION

Transportation is a fundamental component of the poultry production, because poultry are constantly transported for several reasons such as breeding or slaughter. Broiler chickens may expose to several stressors during transport from the farms to the slaughterhouses, even under optimal conditions. The stressors consist of thermal stress, acceleration, vibration, movement, withdrawal of water or feed, social disruption and noise[1]. Among those factors, thermal stress is an important threat for poultry industry, especially during the end of the farming period or pre-slaughter stages. Heat or cold stress creates detrimental effects on meat quality and increases mortality rate. Thereby, the thermal stressors can cause great economic losses[1,2].

Mortality of the birds between catching in the farm and unloading from their crates at the slaughterhouse are defined as "dead on arrival" (DOA). DOA is an important determinant for assessment of animal health and welfare[3]. Furthermore, DOA rate also reflects economic loss due to condemned and inappropriate meat for human consumption[4]. Ambient temperature and humidity are main reasons for mortality, since 40% of the DOA is related with heat or cold stress[5,6]. The effect of ambient temperature and relative humidity on broiler chickens may alter according to seasons, stocking density in crates, ventilation in trailer and holding barn conditions[7]. The DOA rate has been reported by several authors between 0.15 - 0.68%[3,5,8,9].

Thermal stress can also cause unsuitable changes in meat quality parameters such as pale, soft and exudative (PSE) or dark, firm and dry (DFD) meat[10]. Most of consumers don't prefer these products because of noticeable colour differences and low meat quality[11]. Recently, several researchers have studied the relationships between raw breast meat colour and defective meat problems[12,13]. They reported that lightness (L*) values can be used as an indicator of the PSE or DFD meat as well as for the estimation of the incidence of meat defects[14,15,16,17,18].

Season of transportation may also have an influence on meat quality characteristics. When chickens exposed to the cold, water holding capacity, WBSF and meat colour might be influenced adversely[19,20,21], while higher drip loss, cooking loss and WBSF values with paler meat colour were reported for chickens transported in hot weathers[10,13,18,22]. On the other hand, no significant season effect on meat quality was also reported in some studies[23,24,25].

Corresponding Author:
Bulent Teke (bulentteke@gmail.com).

The objective of the present study was to determine the effect of season on DOA rate and meat quality characteristics of broiler chickens in commercial transport and slaughter conditions.

MATERIALS AND METHODS

Animals, study design and slaughter processes

The study was carried out on Ross-308 broilers from 12 different flocks (4 seasons × 3 replicates). Broiler chickens were reared under similar commercial conditions in Samsun city, Turkey. The flocks were maintained on 23 h light and 1 h dark lighting regime, and feed and water were supplied *ad libitum*. The feed in the rearing farm were withdrawn 8 hours before loading in all flocks. The dimensions of the plastic crates were 80 cm length × 45 cm width × 30 cm height. The type of trailers was similar and there were 320 crates in each vehicle. The space between crates was about 10 cm, and space among crate stacks and roof was about 20 cm. In addition, no lateral curtains of truck were available during the winter season for protection to exposure of cold temperatures. The minimum area for each broiler chicken was obtained by using the formula of the Farm Animal Welfare Council[26]. The formula, $A = 0.021W^{0.67}$, is based on mean slaughter weight, where A is the area in square metres and W is the mean slaughter weight of animal in kg. Stocking densities in crates for all transports were within the range of values suggested by the FAWC[26] (Table 1). Transport distance was approximately 80 km and duration was 2 h per transport. Average speed of the vehicle was 40 km/h and transportation was completed without any stops, sudden accelerations or decelerations in all transports. The data logger (Testo 174H) was placed outside of the slaughterhouse to record temperature and humidity values throughout the study (Table 1). The slaughtering processes were carried out between 11:30 p.m. and 8:00 a.m. according to workload of the slaughterhouse. Study was conducted on April, July, October and December for spring, summer, autumn and winter seasons, respectively during 2018. Numbers of broilers transported in each season were, 8983 in spring, 8976 in summer, 8992 in autumn and 9003 in winter. Broilers in trucks were waited in a holding barn for 1 h, afterwards, the crates were manually unloaded from the vehicles and broiler chickens were hanged upside down in the shackle line. At this stage, the number of DOA was recorded and the mortality rate was calculated for each transport. Chickens were electrically stunned before slaughter. Broilers were manually cut for bleeding and then scalded at 60°C. Afterwards, defeathered and eviscerated automatically and then air chilled for 2 h, according to the routine procedures of the slaughterhouse. Thirty broilers from each flock, totally 360 broilers, were randomly chosen to investigate meat quality parameters.

Meat quality analysis

M. *pectoralis major* was removed from the 30 carcasses for each replicate. Muscle pH at 4 h after slaughter (pH_4) was determined by inserting a portable pH meter (Testo 205) probe into the cranial section of each left breast sample.

Meat colour was determined by a Minolta chromometer (Model CR 400). The CIE[27] criterions were used and D65 was selected as the light source. Calibration of the chromometer was carried out with a standard white plate (Y=93.8, x=0.316, y=0.3323). Lightness (L*), redness (a*), and yellowness (b*) was measured on medial surface (bone side and near the median line) of the left M. *pectoralis major*, in an area free of obvious defects. Meat samples were stored at 4°C and under constant white light (750 lx) for 24 h, and then second measurements were performed.

The method described by Honikel[28] was used to determine the drip loss. Briefly, approximately 20 g meat samples were taken from M. *pectoralis major*. After a 24 h storage period at 4°C in the refrigerator, the samples were reweighed. Drip loss (%) was calculated by the percentage of weight loss to initial sample weight.

In order to determine cooking loss, the samples were firstly weighed and then packed under vacuum and cooked for 20 min in an 80°C water bath[28]. After a 24 h storage period at 4°C in the refrigerator, the samples were softly dried with paper towels to remove excess moisture and reweighed. Cooking loss (%) was calculated by the percentage of weight loss to initial sample weight.

The method described by Pekel et al.[29] was used to determine WBSF value. In this analysis, cooked meat samples from cooking loss analysis were used. Three sub-samples from each cooked meat samples were cut parallel to the muscle fibres with a cross section of 1×1 cm and 2.5-3 cm length. An Instron Universal Testing Machine (Model 3343) was used to measure WBSF value at a crosshead speed of 200 mm/min.

Sample classification

Breast meat samples were classified as PSE, DFD, or normal meat based on L^*_{24h} value. $L^*_{24h} \geq 49.0$ as PSE, $L^*_{24h} \leq 44.0$ as DFD, and $44.0 < L^*_{24h} < 49.0$ as normal meat[13,15].

Statistical analysis

Kruskal-Wallis and Mann-Whitney U tests were used in comparison of different seasons regarding DOA rates. Chi-

Table 1 - Certain transportation and slaughtering characteristics by season.

Item	Spring n=90	Summer n=90	Autumn n=90	Winter n=90
Stocking density (m^2/bird)	0.039±0.001	0.045±0.001	0.042±0.001	0.043±0.001
A value (m^2/bird)	0.035±0.001	0.036±0.001	0.036±0.001	0.035±0.001
Slaughter weight (kg)	2.17±0.30	2.21±0.36	2.19±0.34	2.18±0.33
Slaughter age (d)	42.00±0.56	41.86±0.77	41.68±0.65	41.78±0.75
Temperature (°C)	8.52±0.53	18.69±0.18	7.66±0.09	-1.32±0.24
Humidity (%)	72.11±2.06	89.76±0.46	96.04±0.53	92.76±0.35

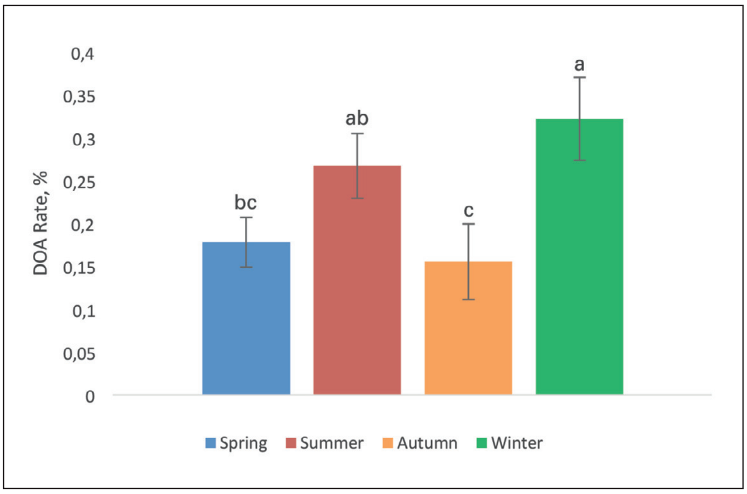

Figure 1 - DOA rates by season.
a, b, c: DOA rates in different column with different letters differ significantly (P < 0.05).

square test was used to compare seasons regarding incidence of DFD, normal and PSE meat. In order to determine the effect of season on meat quality characteristics, one-way ANOVA was performed. If the effect of season were determined to be significant, Tukey's multiple range test option was used to evaluate the significance of the difference. The Pearson correlation test was also carried out to determine possible relationships between meat quality characteristics.

RESULTS

The effect of season on DOA rate was significant (*P* < 0.05) and DOA rate was the highest in winter season (Figure 1). Meat quality characteristics by season are shown in Table 2. The effect of season on all investigated meat quality characteristics was significant (P <0.001). In winter season, pH_{4h}, and b^*_{24h} were higher and L^*_{24h} and WBSF were lower than other seasons. The incidence of DFD, normal and PSE meat by season are shown in Table 3. The incidence of PSE meat was the highest in summer (31.12%), while the incidence of DFD meat was the highest in winter (55.55%). In addition, the lowest incidence of normal breast meat was obtained in winter. DFD and PSE incidences in all dataset were 28.61 and 11.39%, respectively, while there were no meat defects in 60% of the chickens.

DISCUSSION

Poultry and pigs are susceptible to stress, especially heat stress. Therefore, poultry and pig meat are vulnerable to meat quality defect[30]. Many researchers found that pre-slaughter stress factors such as pre-slaughter handling, ambient temperature and humidity, holding area conditions might affect both DOA rate and meat quality in broiler chickens[1,21,30,31].

Table 2 - Mean (± SEM) values for meat quality characteristics by season.

Meat quality characteristics	Spring n=90	Summer n=90	Autumn n=90	Winter n=90	Sig.
pH_{4h}	6.05^c±0.02	6.05^c±0.01	6.12^b±0.01	6.28^a±0.02	***
L^*_0	47.20^a±0.24	46.36^b±0.23	46.06^b±0.24	44.49^c±0.18	***
L^*_{24h}	46.63^a±0.26	46.40^a±0.28	44.71^b±0.20	43.77^c±0.18	***
a^*_0	2.76^a±0.08	2.58^a±0.09	2.21^b±0.07	2.69^a±0.09	***
a^*_{24h}	2.69^a±0.09	1.97^b±0.08	2.25^b±0.09	2.76^a±0.09	***
b^*_0	5.38^b±0.17	4.60^c±0.13	6.20^a±0.12	5.44^b±0.17	***
b^*_{24h}	4.48^c±0.13	5.53^b±0.17	5.63^b±0.13	6.18^a±0.16	***
Drip Loss (%)	2.70^a±0.05	2.79^a±0.13	2.20^b±0.04	1.86^b±0.05	***
Cooking Loss (%)	19.06^{ab}±0.24	19.27^a±0.32	16.02^c±0.27	18.09^b±0.27	***
WBSF (kg)	2.10^b±0.07	2.48^a±0.08	1.88^b±0.04	1.57^c±0.05	***

a, b, c: Mean values in the same row with different letters differ significantly (P≤0.05).
Sig.: Significance, *** (*P* < 0.001).

Table 3 - The incidences of DFD, normal and PSE meat by season.

Traits	Spring (n=90)		Summer (n=90)		Autumn (n=90)		Winter (n=90)		Sig.
	n	%	n	%	n	%	n	%	
DFD	15	16.67^c	7	7.77^c	31	34.44^b	50	55.55^a	***
Normal	64	71.11^a	55	61.11^a	57	63.33^a	40	44.44^b	**
PSE	11	12.12^b	28	31.12^a	2	2.23^c	0	0.00^c	***

a, b, c: Incidence values in the same row with different letters differ significantly (P≤0.05).
Sig.: Significance, ** (*P* < 0.01); *** (*P* < 0.001).

The effect of season on DOA rate

Broilers transported in cool ambient temperatures (-5°C to 5°C) might be subjected to the high level of stress and their plasma corticosterone levels might be higher compared to other seasons[32]. Vecerek et al.[33] and Caffrey et al.[34] found that DOA rate was higher in both summer and winter than that in other seasons. Vecerek et al.[35] also found the significant relationship of DOA rate with environmental temperatures. The researchers observed that the DOA rate was the highest (about 0.80%) at the ambient temperatures between -6°C and -3.1°C. In present study, DOA rate was the highest in winter (0.322%) and the rate was below recommended maximum level by EU (0.5%)[36]. In addition, the lowest DOA rate was observed in autumn (0.155%). In the present study, one possible explanation for higher DOA rate in winter might be that challenging environmental conditions were only associated with the winter season, while temperature/humidity levels found in the remaining seasons were overall mild. It was determined that transport under conditions of low ambient temperatures in winter represents a more stressful event than transport during other seasons. Therefore, transportation in the winter season might be considered the most stressful environmental challenge for broiler chickens[1]. These results are in accordance with results reported by previous researchers[32,33,34]. Nijdam et al.[3] found that when the ambient temperature was between 5°C and 15°C (within thermal comfort zone), DOA rate decreased. If the ambient temperature is very hot or cold, broiler chickens cannot sustain thermoregulation and may die from hyperthermia or hypothermia[37,38].

The effect of season on meat quality characteristics

Pre-slaughter heat stress accelerates the rate of rigor mortis development and contributes protein denaturation. If there is a rapid decline in pH at early post-mortem stages when carcass temperatures are high, this event results in undesirable alterations such as the pale, soft and exudative (PSE) meat[22,39,40]. The majority of researches point out that a decrease in pH and redness with an increase in drip loss, cooking loss and lightness of the breast meat were observed in hot ambient conditions compared with optimum or cold weather conditions[13,18]. In addition, some researchers found that exposure of broiler chickens to heat stress before slaughter results in higher shear force (tougher meat)[22,41,42]. However, some studies[23,24,25] that found no significant influence of heat stress on meat quality parameters of broiler breast were also available. Chickens transported in summer had paler (+2.63 L* unit), less red (-0.79 a* unit) and less yellow (-0.65 b* unit) breast meat after 24 h blooming with higher drip loss and WBSF values than those transported in winter. These results are in accordance with those reports by Warriss and Brown[39], Petracci et al.[18,41] and Bianchi et al.[13]. In this study, although average environmental temperature was 18°C in summer, the temperature was probably high in crates. Heat exposure probably resulted in PSE meat. In the current study, the WBSF value could be expected to be lower in the summer group, which had also higher PSE meat incidence. However, incidence of PSE meat in summer group was only 31.12%. On the other hand, a higher meat ultimate pH may also result in lower shear force value[19]. Barbut et al.[19] found a lower shear force value for DFD meat compared to PSE meat. Therefore, in the current study, the fact that DFD meat incidence was very high in the winter season (55.55% vs 7.77%) may be one of the possible reasons for the higher WBSF value in the summer group compared to the winter group. On the other hand, cold ambient temperatures before slaughter process may cause stress to broiler chicken and might affect meat quality characteristics. Several researchers found that breast meat from cold-stressed birds had lower drip loss, lower shear force (more tender) and darker colour due to higher pH compared with those from optimum weather conditions[19,20]. Similar results were also found in the current study. Seasonal cold exposure during transportation leads to glycogen depletion in the muscle of broiler chicken in order to maintain body temperature. As a result, these broiler chickens have less muscle glycogen stores during slaughter to transform it to lactic acid, which might result in high meat pH.

Incidence of DFD, normal and PSE meat

It is pretty difficult to compare the incidence of PSE or DFD with other studies because of differences in limit values of L* for PSE meat. In the previous studies, incidence of PSE meat in chicken breast was reported as 37-47% for USA[43] (who classified breast meat as PSE-like if L*>54), 20% for England[15] (pH< 5.7 and L*>53.0) and 10% for Europe[44]. The overall incidence of PSE meat was 11.39% in the current study, which is in accordance with previous studies. Petracci et al.[18] reported that the incidence of PSE meat (L*>56.0) was higher in summer (26.7%) than winter (5.9%). A similar pattern of increase in PSE meat was reported by Van Laack et al.[45] (L*>55.0) and Bianchi et al.[13] (L*>53.0). Supporting these reports, the highest incidence of PSE meat was observed in summer (31.12%) while no PSE meat was occurred in winter (0%) in present study.

The overall incidence of DFD meat was 28.61% in the current study. Chickens transported in winter had the highest incidence of DFD meat (55.55%), while summer transportations resulted in the lowest incidence (7.77%). Dadgar et al.[20] reported the DFD meat incidence as 8% in the chickens transported between -8°C to 0°C. Lower DFD meat incidence in Dadgar et al.[20] might be a result of DFD defining criterions in their study (pH>6.1 and L*<46) was different from the current study.

CONCLUSIONS

In the conditions of the current study, season affected both DOA rate and meat quality characteristics. The results may indicate that transportation in winter might be resulted with increased DOA rate and decreased normal breast meat incidence. However, the incidence of PSE meat was the highest in summer. Therefore, transportations of broiler chickens within thermal comfort zone ranges are recommended to reduce the DOA rate and to improve the meat quality. On the other hand, it should be considered that results found in the current study are valid for environmental conditions in the Northern Region of Turkey. Therefore, these results cannot be generalized for either other Regions of Turkey or other European/Asiatic Regions.

ACKNOWLEDGEMENTS

The authors are thankful to the Scientific Research Fund of Ondokuz Mayis University (PYO.VET.1901.17.022) for financial support of this study.

References

1. Mitchell MA, Kettlewell PJ (1998) Physiological stress and welfare of broiler chickens in transit: solutions not problem! Poult. Sci 77: 1803-1814.
2. Lara LJ, Rostagno MH (2013) Impact of Heat Stress on Poultry Production. Animals 3: 356-369.
3. Nijdam E, Arens P, Lambooij E, Decuypere E, Stegeman JA (2004) Factors influencing bruises and mortality of broilers during catching, transport, and lairage. Poult Sci 83: 1610-1615.
4. Jacobs L, Delezie E, Duchateau L, Goethals K, Tuyttens FAM (2017) Broiler chickens dead on arrival: associated risk factors and welfare indicators. Poult Sci 96: 259-265.
5. Ritz CW, Webster AB, Czarick M (2005) Evaluation of hot weather thermal environment and incidence of mortality associated with broiler live haul. J Appl Poult Res 14: 594-602.
6. Schwartzkopf-Genswein KS, Faucitano L, Dadgar S, Shand P, González LA, Crowe TG (2012) Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: A review. Meat Sci 92: 227-243.
7. Tao X., Xin H. (2003). Acute Synergistic Effects of Air Temperature, Humidity, and Velocity on Homeostasis of Market-Size Broilers. Agricultural and Biosystems Engineering Publications and Papers. http://lib.dr.iastate.edu/abe_eng_pubs/142 Paper 142.
8. Mitchell MA (2006) Influence of pre-slaughter stress on animal welfare and processing efficiency. Worlds Poult Sci J 62: 254.
9. Petracci M, Bianchi M, Cavani C, Gaspari P, Lavazza A (2006) Preslaughter mortality in broiler chickens, turkeys, and spent hens under commercial slaughtering. Poult Sci 85: 1660-1664.
10. Langer ROS, Simões GS, Soares AL, Oba A, Rossa A, Shimokomaki M, Ida EI (2009) Broiler transportation conditions in a Brazilian commercial line and the occurrence of breast PSE (Pale, Soft, Exudative) meat and DFD-like (Dark, Firm, Dry) meat. Braz Arch Biol Technol 53(5): 1161-1167.
11. Fletcher DL (1999) Color variation in commercial packaged broiler breast fillets. J Appl Poult Res 8: 67-69.
12. Qiao M, Fletcher DL, Smith DP, Northcutt JK (2001) The effect of broiler breast meat color on pH, moisture, water holding capacity, and emulsification capacity. Poult Sci 80: 676-680.
13. Bianchi M, Fletcher DL, Smith DP (2005) Physical and functional properties of intact and ground pale broiler breast meat. Poult Sci 84: 803-808.
14. Barbut S (1997) Problem of pale exudative meat in broiler chickens. Br Poult Sci 38: 355-358.
15. Wilkins LJ, Brown SN, Phillips AJ, Warriss PD (2000) Variation in the colour of broiler breast fillets in the UK. Br Poult Sci 41: 308-312.
16. Soares AL, Lara JAF, Ida AI, Guarnieri PD, Olivo R, Shimokomaki M (2002) Variation in the colour of Brazilian broiler breast fillet. International Congress of Meat Science and Technology 48, 540- 541.
17. Galobart J, Moran Jr. ET (2004) Refrigeration and freezethaw effects on broiler fillets having extreme L* values. Poult. Sci 83:1433-1439.
18. Petracci M, Bianchi M, Betti M, Cavani C (2004) Color variation and characterization of broiler breast meat during processing in Italy Poult Sci 83: 2086-2092.
19. Barbut S, Zhang L, Marcone M (2005) Effects of pale, normal, and dark chicken breast meat on microstructure, extractable proteins, and cooking of marinated fillets. Poult Sci 84: 797-802.
20. Dadgar S, Lee ES, Leer TL, Burlinguette N, Classen HL, Crowe TG, Shand PJ (2010) Effect of microclimate temperature during transportation of broiler chickens on quality of the pectoralis major muscle. Poult Sci 89: 1033-1041.
21. Dadgar S, Lee ES, Leer TLV, Classen HL, Crowe TG, Shand PJ (2011) Effect of acute cold exposure, age, sex, and lairage on broiler breast meat quality. Poult Sci, 90: 444-457.
22. McKee SR, Sams AR (1997) The effect of seasonal heat stress on rigor development and the incidence of pale, soft and exudative turkey meat. Poult Sci 76: 1616-1620.
23. Holm CGP, Fletcher DL (1997) Antemortem holding temperatures and broiler breast meat quality. J Appl Poult Res 6: 180-184.
24. Sandercock DA, Hunter RR, Nute GR, Mitchell MA, Hocking PM (2001) Acute heat stress-induced alterations in blood acid-base status and skeletal muscle membrane integrity in broiler chickens at two ages: Implications for meat quality. Poult Sci 80: 418-425.
25. Debut M, Berri CE, Baeza N, Sellier C, Arnould D, Guemene N, Hehl B, Boutten Y, Jego C, Beaumont Le Bihan- Duval E (2003) Variation of chicken technological meat quality in relation to genotype and preslaughter stress conditions. Poult Sci 82: 1829-1838.
26. FAWC (1991) Report on the European Commission Proposals on the Transport of Animals. London: MAFF Publications.
27. Centre Internationale de L'Eclairage (CIE) (1976) 'Definition dun space de coleur por deux coordonees de cromaticite et la luminosite. Supplement 2 to CIE publication no 15 (E-1-3-1) 1971/ (TC-1-3).' (Cente Internationale de L'Eclairage: Paris).
28. Honikel KO (1998) Reference methods for the assessment of physical characteristics of meat. Meat Sci 49: 447-457.
29. Pekel AY, Demirel G, Midilli M, Yalcintan H, Ekiz B, Alp M0 (2012) Comparison of broiler meat quality when fed diets supplemented with neutralized sunflower soapstock or soybean oil. Poult Sci 91: 2361-2369.
30. Adzitey F (2011) Effect of pre-slaughter animal handling on carcass and meat quality. Int Food Res J 18: 485-491.
31. Kannan G, Heath JL, Wabeck CJ, Souza MCP, Howe JC, Mench JA (1997) Effects of crating and transport on stress and meat quality characteristics in broilers. Poult. Sci., 76: 523-529.
32. Vosmerova P, Chloupek J, Bedanova I, Chloupek P, Kruzikova K, Blahova J, Vecerek V (2010) Changes in selected biochemical indices related to transport of broilers to slaughterhouse under different ambient temperatures. Poult Sci 89: 2719-2725.
33. Vecerek V, Grbalova S, Voslarova E, Janackova B, Malena M (2006) Effects of travel distance and the season of the year on death rates of broilers transported to poultry processing plants. Poult Sci 85: 1881-1884.
34. Caffrey NP, Dohoo IR, Cockram MS (2017) Factors affecting mortality risk during transportation of broiler chickens for slaughter in Atlantic Canada. Prev Vet Med 147: 199-208.
35. Vecerek V, Voslarova E, Conte F, Vecerkova L, Bedanova I (2016) Negative trends in transport-related mortality rates in broiler chickens. Asian Australas. J Anim Sci 29 (12): 1796-1804.
36. Anonymous (2005) European Commission Health and Consumer Protection Directorate General. The welfare of chickens kept for meat production (Broilers) [monograph on the Internet]. Report of the Scientific Committee on Animal Health and Welfare SANCO.B.3/AH/R15/2000 Adopted 21 March 2000, 149 pp. Available from https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out39_en.pdf
37. Hunter RR, Mitchell MA, Carlisle AJ (1999) Wetting of broilers during cold weather transport: a major source of physiological stress Br Poult Sci 40: S48-S49.
38. Warriss PD, Pagazaurtundua A, Brown SN (2005) Relationship between maximum daily temperature and mortality of broiler chickens during transport and lairage. Br Poult Sci 46: 647-651.
39. Warriss PD, Brown SN (1987) The relationships between initial pH, reflectance and exudation on pig muscle. Meat Sci 20: 65-74.
40. Sams AR (1999) Meat quality during processing. Poult Sci 78: 798-803.
41. Petracci M, Fletcher DL, Northcutt JK (2001) The effect of holding temperature on live shrink, processing yield, and breast meat quality of broiler chickens. Poult Sci 80: 670-675.
42. Bianchi M, Petracci M, Sirri F, Folegatti E, Franchini A, Meluzzi A (2007) The Influence of the season and market class of broiler chickens on breast meat quality traits. Poult Sci 86: 959-963.
43. Woelfel RL, Owens CM, Hirschler EM, Martinez-Dawson R, Sams, AR (2002) The characterization and incidence of pale, soft, and exudative broiler meat in a commercial processing plant. Poult Sci 81: 579-584.
44. Petracci M, Bianchi M, Cavani C (2009) The European on pale, soft, exudative condition in poultry. Poult Sci 88: 1518-1523.
45. Van Laack RLJM, Liu CH, Smith MO, Loveday HD (2000) Characteristics of pale, soft, exudative broiler breast meat. Poult Sci 79: 1057-1061.