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Effect of Citric Acid on Carcass Characteristics and Physico Chemical Attributes of Broiler Chickens

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ABSTRACT

With the removal of antibiotics, the poultry industry is challenged with identifying a valid alternative to antibiotics with similar capabilities. Organic acids like citric acid are agents with the capability to reduce pathogenic bacteria and increase nutrient digestibility through their effect on the pH in the gastrointestinal tract. Citric acid improves animal welfare and economic concerns in the poultry industry by reducing body weight loss and improving meat quality attributes. Citric acid supplementation in feeds diminishes microorganisms within the gastrointestinal tract and consequently enhances feed intake and digestion, with positive effects on growth rate and carcass characteristics of broiler chickens. A review was conducted using PubMed/MEDLINE (published articles) to determine the effect of citric acid supplementation on carcass characteristics, physico chemical attributes and sensory attributes of broiler chickens. Findings indicated that organic acids such as citric acid may improve animal welfare and economic problems in the chicken business by lowering body weight loss and enhancing meat quality qualities. At the same time, citric acid supplementation had an antibacterial effect on the growth of microorganisms. This shows that citric acid can be used in broiler chickens to improve performance and meat quality. The current review evaluates the effect of various citric acid level supplementation on carcass characteristics, physico chemical attributes and sensory attributes of broiler chickens.

Key words: Chickens, Citric acid, Carcass characteristics, Physico-chemical attributes, Sensory analysis.

According to Robinson *et al*. (2015), by 2050, 70% of the world's population will be living in cities, resulting in a 70% rise in demand for animal-derived food, necessitating high levels of efficient production to meet these demands. Global meat production has increased significantly, with much of the increase focusing on poultry and pork production, particularly in developing countries (Thornton, 2010). Since 1946, antibiotic growth promoters have been utilized as a key efficiency-enhancing agent in animal production around the world (Hassan *et al*., 2010). Antibiotics have been shown to decrease sub-clinical and clinical infections by reducing the number of bacteria in the gastrointestinal tract (GIT), which reduces food competition, stimulates the immune system, thins the intestinal wall and increases nutrient digestibility (Economou and Gousia, 2015). Antibiotic resistance, on the other hand, has become a persistent matter of concern for both researchers and buyers (Hamid, 1992). Antibiotics' introduction and widespread use have had a significant effect on animal health and well-being (Goforth and Goforth, 2000). Antibiotic usage in livestock and poultry has been questioned since long-term use can result in side effects such as antibiotic residues in meat and the development of microbial resistance (Muaz *et al*., 2018).

With the withdrawal of antibiotics from some poultry sectors and the introduction of antibiotic-free birds (ABF), the industry is facing with the task of developing a viable alternative to antibiotics that has similar capabilities (Cheng *et al*., 2014). Organic acids such as citric acid, acetic acid, propionic acid and formic acid are potential growth promoters for poultry (Islam, 2012). Organic acids, such as citric acid, have been shown to improve animal welfare and economic concerns in the poultry sector by decreasing body weight loss and enhancing meat quality attributes, according to Menconi *et al*. (2013). Citric acid supplementation in feeds eliminates microorganisms in the gastrointestinal tract, which improves feed intake and digestion and, as a result, improves broiler chicken growth rate and carcass attributes (Dittoe *et al*., 2018).

The new trend of poultry meat consumption emphasizes the importance of meat quality management in the broiler industry (Marić *et al*., 2021). Chickens' meat is also commonly sold as retail pieces or processed meat (Le Bihan-Duval *et al*., 2008). Breast and thigh muscles are the most prevalent chicken carcass sections (Yu *et al*., 2005). Broiler chickens' development rate and carcass quality may be improved by using an acidifier (Mellor, 2000). Considering the above statements, this study is designed to determine the effect of citric acid supplementation on carcass characteristics, physico chemical attributes and sensory properties of broiler chicken.

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Production of citric acid (CA)

Citric acid can be produced by either solid-state fermentation or submerged fermentation (Adham, 2002). Commercial production of citric acid occurs *via* a microbiological technique that typically involves submerged fermentation with *Aspergillus niger* (Prasad *et al*., 2013). Citric acid is a bioengineered and biochemical substance that has yearly productivity of 1.6 million tonnes (Nadeem *et al*., 2010). Citric acid is produced by a variety of microbial species, such as bacteria, fungus and yeast. Nevertheless, most of them are unable to provide commercially viable yields. The fungus *A. niger* is used to produce most of the citric acid nowadays (Ali *et al*., 2002). The reason behind selecting *A. niger* above all other possible future citric acid manufacturing microorganisms include its increased citric acid productive capacity at low pH without the release of harmful compounds, easiness of handling (Nadeem *et al*., 2010) and the possibility to metabolize a variety of cheaper products which include brewers spent seed, orange peels (Torrado *et al*., 2011), cotton waste, cane molasses, bagasse, wheat bran, coffee husk and pumpkin (Pawar and Pawar, 2014).

Effect of citric acid on carcass characteristics of broiler chickens

Dietary supplementation of various levels of citric acid in broilers exhibited a significant increase in dressing percentage (without skin) and analysis of variance revealed that dressing percentage was significantly improved whereas, relative breast and thigh meat, were not affected by dietary citric acid supplementation (Ahsan-ul-Haq *et al*., 2014). These results are in line with those found by Chowdhury *et al*. (2009) and Hassan *et al*. (2010) who reported a significant increase in dressing percentage using citric acid in the feed. The results agree with Alcicek *et al*. (2004) who reported an increase in dressing percentage as compared to control by the use of an organic acid mixture containing citric acid. Acidification might have increased cell proliferation and in this manner increased muscle size. Contrary to the above findings, Denli *et al*. (2003) reported a non-significant effect of organic acid supplementation on dressing percentage. The inconsistency in these results may be caused by different duration of period of feed withdrawals before slaughtering. The results are in line with Islam *et al.* (2008); Abdel-Fattah *et al*. (2008) and Adil *et al*. (2010) who supplemented citric acid to broilers and concluded a non-significant effect on the dressing percentage of broilers. Supplementation of different levels of citric acid showed a non-significant effect on relative breast meat of broilers of different treatment groups (Ahsan-ul-Haq *et al*., 2014). Whereas Hudha *et al*. (2010) reported a significant effect of dietary acidification on thigh meat while a non-significant effect on breast meat.

Ahsan-ul-Haq *et al*. (2014) observed that supplementation of citric acid at the rate of 0.5, 1.0 and 1.5 percent significantly improved the dressing percentage and the relative breast meat, thigh meat and giblet weight of broilers. Aksu *et al*. (2007) reported significant improvement in the carcass weight and some carcass parameters like thigh, breast and neck with citric acid supplementation at 4 g/kg feed. Similarly, Fascina *et al*. (2012) reported that dietary supplementation of citric acids resulted in better carcass characteristics. The results agree with Saki *et al*. (2012) who is of the view that the addition of citric acid increased the carcass weight and breast weight, at 21 days of age. Similarly, Odetola and Adetola, (2022) obtained significant differences in drumsticks and wings in their study. Jha *et al*. (2019) reported that the inclusion of OAs (formic + propionic acid, formic + citric acid, formic + sorbic and formic+ lactic acid) enhanced the meat thigh weight (29.03%), back weight (53.4%), wings weight (31.27%) and breast weight (34.57%) compared to the control group. Other researchers indicated numerical improvements in carcass yield in broilers fed 3% CA but not at 6% level (Nourmohammadi *et al*., 2010). Nevertheless, inconsistent results were obtained by Islam *et al*. (2008) who found that carcass characteristics were not affected by dietary treatments with citric acid supplementation. The unmatched results at the above, could be due to different supplemented diets containing different percentage of nutrients. These results are in line with Kopecky *et al*. (2012) who reported that there were no significant effects of citric acid supplementation on carcass traits. Brzóska *et al*. (2013) reported that the supplementation of OAs to a broiler diet resulted in no significant influence on breast muscle content and leg muscle weight. Odetola and Adetola, (2022) reported the highest value for drumstick on 2% CA (11.17) followed by control (10.65) while the least values were obtained in 4% CA (9.54), respectively. This could be attributed to the level of inclusion or probably the type of organic acid used.

Effect of inclusion of citric acid on meat quality

Consumers define meat quality as the characteristics they perceive as valuable, such as visual, sensory and health characteristics, as well as more invisible qualities such as the environmental impact of meat production and welfare status of the production system (Madruga *et al*., 2008). A carcass with different better proportions of fat or muscle determines the quality of the product (Madruga *et al*., 2008). The first critical point of the judgement of the quality of meat occurs when the consumers buy the product. Thus, they are part of the definition characterizing meat quality (Joo *et al*., 2013). Consumers are interested in meat that can contribute to their personal satisfaction.

In the study of Al-Harthi and Atti (2016) it was clear that different concentrations of CA had no significant effects on the meat's physical traits. Peña *et al*. (2008) found no statistical differences among the analysed treatments for carcass and cut yields of 33-day-old broiler chickens supplemented with citric acid. Upadhya *et al.* (2014) reported that supplementation of an OAs blend (consisting of fumaric, citric, malic and MCFA) did not have adverse effects or improvements in the meat color, pH and water holding capacity (WHC). Similarly, Cho *et al*. (2014) reported that the administration of a microencapsulated OAs combination, including citric and sorbic acids, did not significantly affect the meat color and pH of broiler chickens. Nevertheless, inconsistent results were obtained by Fascina *et al*. (2012), who reported enhanced meat quality characteristics in broilers fed a diet supplemented with OAs, including 30% lactic, 25.5% benzoic, 7% formic, 8% citric and 6.5% acetic acid. The discrepancies in these results may be due to different type and levels of acid inclusion in diet. Also, Popov-raljić *et al*. (2002) found that the color and texture of raw and thermally treated meat of chicken breasts are slightly affected by citric acid addition (1.0% and 2.0%). Chicken legs treated with citric acid by directly adding (2% w/v) (Del *et al*., 2007) or dipping (0.052 to 0.156M solution (Gonz'alez-Fandos *et al*., 2009) were found to improve the color acceptability during a shelf-life study when compared with the control group. Yang and Chen (1993) showed increased lightness values and decreased redness values in raw breast fillets marinated in citric acid.

Effect of citric acid on meat color

The effects of citric acid on the lightness (L*) color value of cooked chicken breast meat samples after citric acid marination were statistically significant (Unal *et al*., 2022). While the lowest lightness (L*) was observed in the CA group (73.30), the control group (76.37) had the highest values. In terms of redness (a*) values, there was a decrease in chicken breast meat marinated with citric acid compared to the control group. While the CA sample (-0.48) had the lowest redness (a*) value, the highest yellowness (a*) value was determined in the control group (1.18), In comparison, the effect of chicken breast meat marinated with CA on yellowness (b*) values was statistically significant whereby it had the highest value (14.68) compared to control groups. The lowest yellowness (b*) value was observed in the control group. Similarly, the CA treatment had the highest Chroma, the lowest value was for the CA treatment for the hue parameter. The total color difference (ΔE) was measured between the treated and the control samples (Patras *et al*., 2011). The CA marinades were significantly different from the control group. According to the color difference classification of the National Bureau of Standards (NBS), the difference in ΔE among samples can be divided into six levels as 0-0.5 (trace), 0.5-1.5 (slight), 1.5-3.0 (noticeable), 3.0-6.0 (appreciable), 6.0-12.0 (high), 12.0 or more (very high) (Jeong *et al*., 2018). There was a high difference between the control group and the samples marinated with citric acid according to the NBS classification. This, in turn, visibly changed the colors of the marinated samples, resulting in a different product for the consumer. Similar results were reported by Jeong *et al*. (2018) and Mutegi and Patimakorn (2020).

Effect of citric acid on meat pH

An increase in citric acid concentration causes a decline in the pH of chicken meat, which reduces microbial load (Meltem *et al*., 2017). Yang and Chen (1993) conducted a trial evaluating the effects of refrigerated storage, pH adjustment and marinade on the color of raw and microwave cooked chicken meat and reported a decreased pH, because of marination in citric acid. Del Rio *et al*. (2007) reported that chicken legs dipped in citric acid significantly reduced pH immediately after treatment. Del Rio *et al*. (2007) stated that immersion of chicken meat in citric acid significantly decreased the pH after marination. The low pH value of meat products is known to influence several factors during storage, such as loss of redness, prolongation of storage, stability of water-binding capacity and texture (Sammel and Claus, 2003). Low pH (pH<5.8), in broiler meat exhibit a pale, soft and exudative (PSE) condition, which is considered a degraded meat quality parameter compared to meat exposed to higher pH levels (pH>5.8) (Mckee *et al*., 1998). Meltem *et al*. (2007) stated that with increasing citric acid concentration, there was a clear decrease in muscle pH. Also agrees with Ji-Han *et al*. (2015) who stated that immersion of chicken meat in citric acid significantly decreased the pH. A similar result was obtained by Yusop *et al*. (2010) who found that acidic marinade solutions decrease pH.

Effect of citric acid on shear force

A reliable approach for evaluating meat tenderness is through shear force determination and the extent of myofibrillar protein proteolysis depends on it (Marcinkowaska-Lesiak *et al*., 2016). Shear force is a measure of softness, with higher values indicating tougher meat or less tender meat (Yang *et al*., 2010). According to Fanatico *et al*. (2009) broilers that grew slowly resulted in breast meat that is more tender than broilers that grew quickly. This was attributed to bodyweight variations in each genotype causing varying rates of post-mortem stiffness.

The shear forces of the citric acid groups were significantly lower than that of control during storage (Ji-Han *et al*., 2015). All groups showed a decline in the shear force during storage. Lipid oxidation affects the decrease in the tenderness of meat products, which can be related to the interaction of lipid oxidation and cross-linking of proteins (Lund *et al*., 2007). The decrease in the shear force of the meat products with increasing citric acid concentration was due to the reduction of pH, which influences the water-binding capacity (Burke and Monahan, 2003). Water-holding capacity of muscle and the tenderness of muscle increases when the pH is below the isoelectric point of the major myofibrillar proteins (Rao *et al*., 1989). The increased water-holding capacity of the muscle at lower pH values may be due to the increase in the net positive charges on the protein molecules and the osmotic pressure exerted by the presence of large amounts of organic acids to decrease pH.

Okeudo and Moss (2005) demonstrated that shear force has a negative correlation with cooking yield and moisture content. Especially, the shear force of 5CIT was significantly lower than that of the other groups. The denaturation of muscle protein due to treatment in acidic solutions is known to induce tissue breakdown and decrease the tenderness of meat (Aktus and Kaya 2001; Ke *et al*., 2009). Therefore, denaturation of protein and moisture content could influence the reduction of shear force due to samples treated with citric acid.

Effect of citric acid on cooking loss

Cooking losses refer to the total losses incurred during meat cooking, including losses due to dripping or evaporation (Obuz and Dikeman, 2003). The pH of meat determines how much moisture is released during cooking. Meat with a high pH will have a lower cooking loss compared to meat with a low pHu (Lawrie and Ledward, 2006) and the resulting meat products will be perceived as being dry (Warriss, 2010). Chicken muscles exposed to high levels of stress prior to sacrifice have lower pH and increased meat loss during cooking (Fletcher, 2002; Lawrie and Ledwar, 2006). Meat juiciness is decreased by increasing cooking losses, but this is undesirable for consumers (Lawrie and Ledward, 2006).

Marination using citric acid contributed to a significant increase in cooking loss values of all the samples compared to the control group except for only in 4% CA. The lowest cooking loss value (15.85%) was determined in the breast sample served 4% CA. The highest value (28.42%) was measured in the thigh sample also served 4% CA. Sammel and Claus (2003) obtained an increase in cooking loss percentages increased with increasing citric acid as a result of increased acidity (lower pH), which decreased the ability of meat to bind water. These findings disagree with Hosseini and Esfahani Mehr (2015) who reported that the lowest cooking loss was observed in samples marinated with the highest concentration of citric acid. The decrease in loss due to cooking acid treatments could be explained by the swelling effect on muscle proteins that could hold more water. Similarly, Serdaroglu *et al*. (2007) reported that samples treated with 0.1M citric acid had the highest cooking loss values. In samples marinated with acidic solutions, the fibers swell and some muscle proteins can hold more water decreasing the cooking loss from the samples (Klinho *et al*., 2011). In contrast, Önenç *et al*. (2004) reported that marinated meat samples had lower cooking losses than the control group. This was probably due to the pH values reducing protein isoelectric point, generating excess water (Kahraman *et al*., 2012). Yusop *et al*. (2010) has indicated that there is no difference in the cooking loss of chicken breast marinated in solutions with various pH containing citric acid. These results might be due to the lack of change in the core pH of meats. Similarly, Cho *et al*. (2014) reported that the administration of a microencapsulated OAs combination, including citric and sorbic acids, did not significantly affect the cooking loss.

CONCLUSION

The world population is increasing leading to a high demand for animal source food therefore high levels of efficient production are necessary to meet those demands. The only way to attain optimal productivity is to improve nutrition management. It is necessary to conduct research and development on alternatives to antibiotics as feed additives. Citric acid is a possible alternative growth promoter that can replace antibiotics as feed additives whenever antibiotics are not permitted in poultry diets. Citric acid is a weak organic acid that lowers the pH of the gastrointestinal tract, which enhances the absorption of nutrients and results in improved growth rates and carcass quality in chickens. There is a lack of data on the effects of CA supplementation in indigenous chickens. As a result, it's critical to evaluate the impacts of CA supplementation levels as a potential growth promoter in indigenous chickens, as well as to find optimal supplementation levels.

Conflict of interest: None.

REFERENCES

Adbdel-Fattah, S.A., El-Sanhoury, M.H., El-Mednay, N.M. and Abdel-Azeem, F. (2008). Thyroid activity, some blood constituents, organs morphology and performance of broiler chicks fed supplemental organic acids. International Journal of Poultry Science. 7: 215-222.

Adham, N.Z. (2002). Attempts at improving citric acid fermentation by Aspergillus niger in beet-molasses medium. Journal of Biochemistry and Technology. 84: 97-100.

Adil, S.T., Banday, G.A., Bhat, M., Mir, S. and Rehman, M. (2010). Effect of dietary supplementation of organic acids on performance, intestinal histomorphology and serum biochemistry of broiler chicken. Veterinary Medical Intentional. 479485. doi: 10.4061/2010/479485.

Ahsan-ul-Haq, Tabassum, M., Ahmad, F., Shafi, J., Ashraf, M., Javed, M. and Shahid-ur-Rehman. (2014). Effect of dietary acidification with citric acid on carcass characteristics, haemogram and serum metabolite values of broiler chicken. Pakistan Journal of Life and Social Science. 12: 36-41.

Aksu, T., Ates, C.T., Erdogan, Z. and Baytok, E. (2007). The response of broilers to dietary organic acid mixture. The Indian Veterinary Journal. 84: 385-387.

Aktus, N. and Kaya, M. (2001). The influence of marinating with weak organic acids and salts on the intramuscular connective tissue and sensory properties of beef. European Food Research and Technology. 213: 88-94.

Alcicek, A., Bozkurt, M., Cabuk, M. (2004). The effect of a mixture of herbal essential oils, an organic acid or a probiotic on broiler performance. South African Journal of Animal Science. 34: 217-222.

Al-Harthi, M.A. and Attia, Y.A. (2016). Effect of citric acid on the nutritive value of olive cake in broiler diets. European Poultry Science. 80. DOI: 10.1399/eps.2016.153.

Ali, S, Haq, I., Qadeer, M.A., Iqbal, J. (2002). Production of citric acid by Aspergillus niger using cane molasses in a stirred fermenter. Electron Journal of Biotechnology. 5: 258-271.

Brzóska, F., Sliwi ´nski, B. and Michalik-Rutkowska, O. (2013). Effect of Dietary Acidifier on Growth, Mortality, Post-Slaughter Parameters and Meat Composition of Broiler Chickens/Wpływ zakwaszacza diety na mas ˛e ciała, ´smiertelno´s´c, wydajno´s´c rze´zn ˛a i skład mi ˛esa kurcz ˛at rze ´znych. Annals of Animal Science. 13: 85-96.

Burke, R.M. and Monahan, F.J. (2003). The tenderization of shin beef using a citrus juice marinade. Meat Science. 63: 161- 168.

Cheng, G., Hao, H., Xie, S., Wang, X., Dai, M., Huang, L. and Yuan, Z. (2014). Antibiotic alternatives: The substitution of antibiotics in animal husbandry. Frontiers in Microbiology. 5: 217. https://doi.org/10.3389/fmicb.2014.00217.

Cho, J.H. Song, M.H. Kim, I.H. (2014). Effect of microencapsulated blends of organic acids and essential oils supplementation on growth performance and nutrient digestibility in finishing pigs. Revista Colombiana de Ciencias Pecuarias. 27: 264-272.

Chowdhury, R., Islam, K.M.S., Khan, M.J., Karim, M.R., Haque, M.N., Khatun, M. and Pesti, C. M. (2009). Effect of citric acid, avilamycin and their combination on the performance tibia ash and immune status of broilers. Poultry Science. 88: 1616-1622.

Del R´ıo, E., Panizo-Mor´an, M., Prieto, C., Alonso-Calleja, C. and Capita, R. (2007). Effect of various chemical decontamination treatments on natural microflora and sensory characteristics of poultry. International Journal of Food and Microbiology. 115: 268-280.

Denli, M., Okan, F. and Celik, K. (2003). Effect of dietary probiotic, organic acid and antibiotic supplementation to diets on broiler performance and carcass yield. Pakistan Journal of Nutrition. 2: 89-91.

Dittoe, D.K., Ricke, S.C. and Kiess, A.S. (2018). Organic acids and potential for modifying the avian gastrointestinal tract and reducing pathogens and disease. Frontier Veterinary Science. 5: 216. https://doi.org/10.3389/fvets.2018.00216.

Economou V., Gousia, P. (2015). Agriculture and food animals as a source of antimicrobial-resistant bacteria. Infection and Drug Resistant. 8: 49-61.

Fanatico, A.C., Owens, C.M. and Emmert, J.L. (2009). Organic poultry production in the United States: Broilers. Journal of Applied Poultry Research. 18: 355-366.

Fascina, V.B., Sartori, J.R., Gonzales, E., De Carvalho, F.B., De Souza, I.M.G.P., Polycarpo, G.D.V., Stradiotti, A.C. and Pelícia, V.C. (2012). Phytogenic additives and organic acids in broiler chicken diets. Revista Brasieira de Zootecria. 41: 2189-2197.

Fletcher, D.L. (2002). Poultry meat quality. Worlds Poultry Science Journal. 58(2): 131-145.

Goforth, R.L. and Goforth, C.R. (2000). Appropriate regulation of antibiotics in livestock feed. Boston College Environmental Affairs Law Review. 28(39): 575-7646.

Gonz ìalez-Fandos, E., Herrera, B.B., Maya, N. (2009). Efficacy of citric acid against Listeria monocytogenes attached to poultry skin during refrigerated storage. International Journal of Food Science and Technology. 44: 262-268.

Hamid, A. (1992). The developmental cycle of a drug epidemic: The cocaine smoking epidemic of 1981-1991. Journal of Psychoactive Drugs. 24: 337-48.

Hassan, H.M.A., Mohamed, M.A., Youssef, A.W., Hassan, E.R. (2010). Effect of using organic acids to substitute antibiotic growth promoters on performance and intestinal microflora of broilers. Asian-Australasian Journal of Animal Science. 10: 1348-1353.

Hosseini, S.E., Esfahani, M.A. (2015). The effect of meat marinating with lactic and citric acid on some physicochemical and electrophoretic pattern of beef burger. Iran Journal of Veterinary Research. 9: 103-108.

Hudha, M.N., Ali, M.S., Azad, M.A.A. Hossain, M.M., Tanjim, M., Bormon, S.C., Rahman, M.S. Rahman, M.M., Paul, A.K. (2010). Effect of acetic acid on growth and meat yield in broilers. Intenational Journal of Bioresearch. 1: 31-35.

Islam, K.M.S. (2012). Use of citric acid in broiler diets. Worlds Poultry Journal. 68: 104-118.

Islam, M.Z., Khandaker, Z.H., Chowdhury, S.D. and Islam, K.M.S. (2008). Effect of citric acid and acetic acid on the performance of broilers. Bangladesh Agricultural University. 6: 315-320.

Jeong, K.O., Hhyeonbin, S.Y., Shin, Y., Kim, Y.S. (2018). Effects of different marination conditions on quality, microbiological properties and sensory characteristics of pork ham cooked by the sous-vide method. Korean Journal of Food Science and Animal Resource. 38(3): 506-514.

Jha, A.K., Azad, M.D.H., Ali, M.D.S.N., Alam, P., Sheikh, N., Ali, H. and Ansari, K. (2019). Evaluation of growth and carcass 590 characteristics of broiler chickens (Cobb 500) feed on different level of organic acids inclusion in diet at Parwanipur. Nep Veterinary Journal. 36: 137-147.

Ji-Han, K., Go-Eun, H., Ki-Won, L., Woojoon, P., Chi-Ho, L. (2015). Influence of citric acid on the pink color and characteristics of sous vide processed chicken breasts during chill storage. Korean Journal of Food Science. 235: 585-596.

Joo, S.T., Kim, G.D., Hwang, Y.H. and Ryu, Y.C. (2013). Control of fresh meat quality through manipulation of muscle fiber characteristics. Meat Science. 95: 828-836.

Kahraman, T., Bayraktaroglu, A.G., Issa, G., Ertugrul, T., Bingol, E.B. and Ergun, L. (2012). Effects of temperature conditioning and citrus juice marinade on quality and microstructure of aged beef. Journal of Food Agriculture and Environment. 10: 117-122.

Ke, S., Hung, Y., Decker, E.A. and Hultin, H.O. (2009). Impact of citric acid on the tenderness, microstructure and oxidative stability of beef muscle. Meat Science. 82: 113-118.

Klinhom, P., Klinhom, J., Senapa, J. and Methawiwat, S. (2011). Influence of Citric Acid, Lemon and Porcupine Fruit Juice on the Tenderness and Sensory Properties of Bovine Meat. In Proceedings of the 49th Kasetsart University Annual Conference, Kasetsart University, Kasetsart, Thailand.

Kopecky, J., Hrncar, C. and Weis, J. (2012). Effect of organic acids supplement on performance of broiler chickens. Animal Science Biotechnology. 45: 51-54.

Lawrie, R. and Ledward, D.A. (2006). Lawrie's Meat Science. 7th ed, CRC Press: Boca Raton, Florida.

Le Bihan, D.E., Debut, M., Berri, C.M., Sellier, N., Santé L.,V., Jégo, Y., Beaumont, C. (2008). Chicken meat quality: Genetic variability and relationship with growth and muscle characteristics. BMC Genetics. 9(53): doi: 10.1186/1471-2156-9-53.

Lund, M.N., Lametsch, R., Hviid, M.S., Jensen, O.N. and Skibsted, L.H. (2007). High oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. Meat Science. 77: 295-303.

Madruga, M.S., Torres, T.S., Carvalh, F.F., Queiroga, R.C., Narain, N., Garruti, D.M., Souza, N. M.A., Mattos, C.W. and Costa, R.G. (2008). Meat quality of Moxoto and Canide goats as affected by two levels of feeding. Meat Science. 30: 149-154.

Marcinkowska-Lesiak, M., Zdanowska-S¹siadek, Z., Stelmasiak, A., Damaziak, K., Michalczuk, M., Po³awska, E., Wyrwisz, J., Wierzbicka, A. (2016). Effect of packaging method and cold-storage time on chicken meat quality. CyTA-Journal of Food Science. 14: 41- 46.

Marić, M., Stajèić, I., Prodanoviæ, R., Nikolova, N., Lika, E. and Puvaèa, N. (2021). Chili pepper and its influence on productive results and health parameters of broiler chickens. Journal of Agronomy, Technology and Engineering Management. 4: 540-546.

McKee, S.R. and Sams, A.R. (1998). Rigor mortis development at elevated temperatures induces pale exudative turkey meat characteristics. Poultry Science. 77: 169-174.

Mellor, S. (2000). Nutraceuticals-alternatives to antibiotics. World Poultry. 16: 30-33.

Meltem, S., Kyialbek, A. and Alper, O. (2007). The effects of marinating with citric acid solutions and grape fruit juice on cooking and eating quality of Turkey breast. Journal of Muscle Foods. 18: 162-172.

Meltem, S., Kyialbek, A. and Alper, O. (2017). The effects of marinating with citric acid solutions and grapefruit juice on cooking and eating quality of Turkey breast. Journal of Muscle Foods. 18: 162-172.

Menconi, A., Kuttappan, V.A., Hernandez-Velasco, X.., Urbano, T., Matté, F., Layton, S., Kallapura, G., Latorre, J. *et al.* (2013). Evaluation of a commercially available organic acid product on body weight loss, carcass yield and meat quality during preslaughter feed withdrawal in broiler chickens: A poultry welfare and economic perspective. Journal of Poultry Science. 2: 448-455.

Muaz, K., Riaz, M., Akhtar, S., Park, S. and Ismail, A. (2018). Antibiotic residues in chicken meat: Global prevalence, threats and decontamination strategies: a review. Journal of Food Protection. 81: 619-627.

Mutegi, R.T., Patimakorn, P. (2020). Application of probiotic strains to extend shelf-life of marinated beef and pork meats. International Food Research Journal. 27: 1067-1075.

Nadeem, A., Syed, Q., Baig, S. Irfan, M. and Nadeem, M. (2010). Enhanced production of citric acid by Aspergillus niger M-101 using lower alcohols. Turkish Journal Biochemistry. 35: 7-13.

Nourmohammadi, R., Hosseini, S.M., Farhangfar, H. (2010). Effect of Dietary acidification on some blood parameters and weekly performance of broiler chickens. Journal of Animal Veterinary Advances. 9: 3092-3097.

Obuz, E. and Dikeman, M.E. (2003). Effects of cooking beef muscles from frozen of thawed states on cooking traits and palatability. Meat Science. 65: 993-997.

Odetola, O.M. and Adetola, O.O. (2022). Growth response, carcass analysis and sensory evaluation of meat from broiler chicken served acidified water. Nigerian Journal of Animal Production. 49: 284-292.

Okeudo, N.J. and Moss, B.W. (2005). Interrealtionships amongst carcass and meat quality characteristics of sheep. Meat Science. 69: 1-8.

Önenç, A., Serdaroglu, M. and Abdraimov, K. (2004). Effect of various additives to marinating baths on some properties of cattle meat. European Food Research and Technology. 218: 114-117.

Pawar, V.A. and Pawar, P.R. (2014). Effect of various parameters on citric acid production using different substratesIndian. Journal of Science Research. 3: 13-15.

Patras, A., Brunton, N.P., Tiwari, B.K. and Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. Food and Bioprocess Technology. 4: 1245-1252.

Peña, J.E.M., Vieira, S.L., López, J., Reis, R.N., Barros, R., Furtado, F.V.F. and Silva, P.X. (2008). Ascorbic acid and citric flavonoids for broilers under heat stress: Effects on performance and meat quality. Brazilian Journal of Poultry Science. 10: 125-130.

Popov-raljić J., Džinić, N., Kelemen-mašić, Đ., Mandić, A., Pavlović, A. and Sikimić, V. (2002). Colour, texture and sensory characteristics of chicken breasts influenced by citric acid addition to the feed. Romanian Biotechnological. Letters. 4: 803-808.

Prasad, M.P.D., Sridevi, V., Surendra babu, N.V., Reddy, O.V.S. and Harsha, N. (2013). Studies on fermentative production of citric acid by Aspergillus niger isolate using sorghum malt and its optimization. International Journal of Innovative Research in Science, Engineering and Technology. 2: 2961-2968.

Rao, M.V., Gault, N.F. and Kennedy, S. (1989). Variations in water-holding capacity due to changes in the fibre diameter, sarcomere length and connective tissue morphology of some beef muscles underacidic conditions below the ultimate pH. Meat Science. 26: 19-37.

Robinson, T.P., Wint, G.R.W., Conchedda, G., Van Boeckel, T., Mcleod, M., Bett, B. and Grace, D., Gilbert, M. (2015). The global livestock sector: Trends, drivers and implications for society, health and the environment. In proceedings of Science with Impact Annual Conference, University of Chester, Chester, United Kingdom. 4-15 April 2015.

Saki, A.A., Eftekhari, S.M., Zamani, P., Aliarabi, H. and Abbasinezhad, M. (2012). Effects of an organic acid mixture and methionine supplements on intestinal morphology, protein and nucleic acids content, microbial population and performance of broiler chickens. Animal Production Science. 51: 1025-1033.

Sammel, L.M. and Claus, J.R. (2003). Citric acid and sodium citrate effects on reducing pink color defect of cooked intact turkey breast and ground turkey rolls. Journal of Food Science. 68: 874-878.

Serdaroglu, M., Abdraimov, K., Onenc, A. (2007). The effects of marinating with citric acid solutions and grapefruit juice on cooking and eating quality of turkey breast. Journal of Muscle Foods. 18: 162-172.

Thornton, P.K. (2010). Livestock production: Recent trends future prospects. Philosophical Transactions of Royal Society of London Series Biological Sciences. 365: 2853-2867.

Torrado, A.M., Cortes, S., Salgado, J.M., Max, B., Rodriguez, N., Bibbins, B.P., Converti, A., Dominguez, J.M. (2011). Citric acid production from orange peel waste by solid-state fermentation. Brazilian Journal Microbiology. 42: 394-409.

Unal, K., Alagöz, E., Çelik, İ., Sarıçoban, C. (2022). Marination with citric acid, lemon and grapefruit affects the sensory, textural and microstructure characteristics of poultry meat. British Poultry Science. 63(1): 31-38.

Upadhaya, S.D., Lee, K.Y. and Kim, I.H. (2014). Protected organic acid blends as an alternative to antibiotics in finishing pigs. Asian Australasian Journal of Animal Science. 27: 1600-1607.

Warriss, P.D. (2010). Meat Science: An Introductory Text, 2nd ed., CABI Publishing: Wallingford, England.

Yang, C.C. and Chen, T.C. (1993). Effects of refrigerated storage, pH adjustment and marinade on color of raw and microwave cooked chicken meat. Poult Science. 72: 355-362.

Yang, X., Zhang, B., Guo, Y., Jiao, P. and Long, F. (2010). Effects of dietary lipids and clostridium butyricum on fat deposition and meat quality of broiler chickens. Poultry Science. 89: 254-260.

Yu, L.H., Lee, E.S., Jeong, J.Y., Paik, H.D., Choi, J.H. and Kim, C.J. (2005). Effects of thawing temperature on the physicochemical properties of pre rigor frozen chicken breast and leg muscles. Meat Science. 71: 375-382.

Yusop, S.M., Kerry, J.F. and Kerry, J.P. (2010). Effect of marinating time and low pH on marinade performance and sensory acceptability of poultry meat. Meat Science. 85: 657-663.