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Evaluation of water holding capacity in broiler breast meat by electrical conductivity

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Abstract

The objective of this study was to evaluate water holding capacity by electrical conductivity (EC) of broiler breast meat (*Pectoralis major* muscle) both in marinated and stored meat conditions. Broiler breast meat marinated with various ionic strength salt solutions (phosphate and NaCl at I = 0.17-0.85) had different decreasing in drip loss and cooking loss. However, significant increase in EC of broiler breast meat with ionic strength of marinade was observed in meat marinated with NaCl solution ($p<0.05$). The relationship between EC and drip loss of marinated broiler breast meat was obtained as negative correlation (r = -0.78). Inversely, non-marinated broiler breast meat had increasing in drip loss, cooking loss and EC during chilled storage at 4°C for 10 days. Increase in drip loss of broiler breast meat had high correlation with the change in EC during storage (r = 0.66). The data obtained showed that broiler breast meat had EC lower than 1.30 mS/cm when drip loss was lower than 3.0% for 85.29% of total samples determination. The result suggested that EC could be applied as control parameter for determining drip loss of broiler breast meat during marinating process or storage. However, standard EC should be performed specific with marinade solution and amount of drip loss for each process control.

Introduction

In last decades, the production of poultry and poultry products has a gradual increasing trend. Broiler meat is still being the most significant poultry type compared to duck and quail. Chicken meat industries try to maintain or improve meat quality and yield during production. Therefore, any aspects regarding to quality and yield determination of chicken meat during production are very interesting. As regard to its quality, water holding capacity, the ability of meat to retain moisture one of important meat properties should be concerned. It is because the level of this property will determine the yield and other quality of meat during production and storage. Therefore, water holding capacity is a significant parameter examined and controlled by meat industry. Changes in water holding capacity are very sensitive indicator for changes in the charges and structure of myofibrillar protein. Numerous factors can affect to water holding capacity in broiler breast meat both the internal factors (net charge effect, rate of pH decline and breed) and the external factors (animal husbandry, transportation and pre-rigor condition).

Evaluation of water holding capacity (WHC) is the most important because WHC could effect to quality of raw meat and cooked products. Economically, the production yield will be determined by the level of weight loss as associated to its water holding capacity. For example, the weight loss during the production process are estimated 2-4 millions of dollars/year (Gorsuch and Alvarao, 2010). Chicken meat processing industry had been set the standard of the average yield at 18.10% for chicken breasts (Narasri and Wangwerawong, 2013). Thus, the higher yield compared to such report will provide higher income for meat producer.

In general, traditional analysis such as drip loss and cooking loss are frequently used to view the level of water holding capacity of meat and poultry meat. However, sample destruction could not be denied when those analyses were applied. Besides, time consuming and more area to set up instrument could limit the application of those analyses in industrial scale. Therefore, some researchers have tried to find other possible non-destruction, short and real time analyses. For example, electrical conductivity in meat was explored. However, a very limited report on later analyze was studied related to chicken meat quality evaluation.

Conductivity itself was electrical characteristic in meat. The electrical conductivity (EC) is determined by measuring the concentration and mobility of ion (Shi *et al*., 2014). The SI unit for conductivity

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is the siemen (S). Conductivity measurement is an indicator of membrane completeness. Therefore, enhanced conductivity is an indirect measurement of drip loss which is fluids leak from membrane structures to move between the intracellular and extracellular space. Therefore, water held in the spaces between thick and thin filaments, any changes in the content and distribution of water within meat originating from changes in this spacing will surely have an influence on muscle electrical properties (Byrne *et al*., 2000). Electrical properties represent an alternative approach for the estimation of quality attributes in meat and meat products. Perre *et al.* (2010) used electrical conductivity to measure quality of pork in winter and summer. This technique is alternative to traditional methods, being quickly and easy to perform. Research on electrical conductivity to predict the water holding capacity of pork had been reported by Lee *et al.* (2000). They found that PSE meat had higher electrical conductivity than normal and DFD (dark firm dry) meat, respectively. The higher of electrical conductivity in PSE meat due to PSE meat has low water holding capacity it causes to fluid leak and dissolve mineral from the muscle protein. Thus, this phenomenon surely affects high electrical conductivity in PSE meat. In meat industry, the storage time is important factor could affect to WHC in meat. Suwattitanun and Wattanachant (2014) evaluated the WHC changes of broiler breast meat during storage, which indicated that longer storage time at 0-4ºC for 4 days induced greater drip loss from 2.66% to 3.92% in broiler breast meat. Therefore, "food additive" is commonly used to improve WHC of meat in production of processed meat. Sodium chloride and phosphates are additives that enhance water holing capacity of meat. The objective of this research was to evaluate the relationship between water holding capacity and electrical conductivity (EC) of broiler breast meat. The research was investigated both in fresh breast meat during storage and marinated breast meat with different ionic strength marinade solutions to obtain various WHC breast meat. The data obtain would be provided the information how to apply EC technique to evaluate WHC and quality of broiler breast meat.

Materials and Methods

Preparation of broiler breast meat with different water holding capacity

The material used in this study was broilers aged 38-42 days. Broilers with live weight ranged from 2.16-2.56 kg were purchased from commercial deboning production plant (4 h postmortem) at Phatthalung Province, Thailand. They were slaughtered and processed as carcass handling and cutting breast meat conventionally at commercial production plant. Subsequently other purchased, the breast meat (*Pectoralis major* muscle) obtained were placed in a cold room (4°C) for 24 hour at meat laboratory before study. Any obvious fat and connective tissue were removed from breast meat. Breast meat samples were prepared in two parts study to obtain various range of WHC. Part 1, broiler breast meat for 216 fillets (18 fillets for each treatment) were marinated with water and different ionic strength salt solutions (sodium tripolyphosphate and sodium chloride solutions) at 0.1750, 0.3500, 0.4893, 0.7014 and 0.8547 ionic strength with a ratio of 1:2 (muscle: brine solution) before subjected to store at 4°C for 10 hour. After treated, the marinated broiler breast meat was determined the effect of those various ionic strengths of solution on its water holding capacity and electrical conductivity. Part 2, broiler breast meat for 132 fillets were packed in polyethylene plastic bag (12 fillets for each bag) and stored at 4°C. Non-marinated broiler breast meats for each bag were determined the effect of storage times on its water holding capacity and electrical properties. Samples were stored for 10 days and the sampling every day for analyses.

Preparation of marinade solutions

A total of 11 solution treatments, were prepared for several effects of ionic conditions (Low, medium and high level of ionic strength). The ionic strength conditions were obtained from addition of sodium chloride and sodium triphosphate according to the following equation (Bertram *et al*., 2004)

$$I = ½(\Sigma\, C_i Z_i^2)$$

Where, C_i = concentration; Z_i = ion charge

pH measurement

Approximately 5 gram of sample was grinded by a blender (Panasonic, Malaysia). The minced sample was homogenized with 50 ml of distilled water for 1 minute. The pH of sample was determined using a pH meter (Mettler Toledo, SevenGo SG2-FK2, Switzerland). Calibration procedure was applied to probe of pH meter with standard buffer at 4.00 and 7.00.

Color

Color was measured on the surface area of broiler breast meat fillets (six filets for each treatment) for three replicates of upper, middle and lower areas in each fillet. Instrumental color measurements by using colorimeter (Color Flex, Hunterlab colorimeter, U.S.A.), was conducted with D65 illuminant and reported in the CIE color system (L^*, a^*, b^*). Standard Minolta calibration plate (Black and white calibration plate serial no 7097) were used to calibrate the instrument.

Drip loss

The drip loss was determined as described by Honikel (1998). Broiler breast meat were weighed and placed into a sealed polyethylene bag. The samples were stored for 24 h at chill temperatures (1-5°C) and reweighed. Drip loss was reported as a percentage and calculated as follows:

% Drip loss = [(raw weight - after 24 h. weight) / (raw weight)] ×100

Cooking loss

Cooking loss was determined as described by Honikel (1998). Broiler breast meat were weighed and placed into a sealed polyethylene bag before heating in water bath at 80°C. Samples were cooked until define internal temperature 75°C. The breast fillets were cooled in an ice and cooled down to room temperature, reweight and cooking loss was reported as a percentage and calculated as follows:

% Cooking loss = [(raw weight - cooked weight) / (raw weight)] ×100

Electrical conductivity measurement

Electrical conductivity was determined as modified method from Yao *et al.* (2011). Approximately 5 gram of sample was grinded by blender (Panasonic, Malaysia). The minced sample was homogenized with 50 ml of distilled water for 1 minute. The electrical conductivity of sample was determined using a conductivity meter (Mettler Toledo, Seven Go SG3, Switzerland). Calibration procedure was applied to probe of electrical conductivity meter with potassium chloride standard buffer at 1413 µS/cm and 12.88 mS/cm.

Statistical analysis

The correlation between water holding capacity and the physical properties were calculated by Pearson's correlation coefficients. The difference between quality broiler breast meat data were analyzed by one-way analysis of variance (ANOVA) and significant treatments were analyzed by Duncan's multiple range tests using the Statistical Package for Social Science (SPSS for windows. SPSS Inc., Chicago, IL, USA).

Results and Discussion

Effect of ionic strength of solutions on water holding capacity and electrical properties of broiler breast meat

Table 1 shows the drip loss, cooking loss and electrical conductivity value of breast meat which marinated with sodium tripolyphosphate and sodium chloride at different ionic strength conditions (0.1750, 0.3500, 0.4893, 0.7014 and 0.8547). With increasing level of ionic strength, samples marinated with sodium tripolyphosphate showed non-significant differences in electrical conductivity ($p \geq 0.05$). This was probably due to the ionic strength range of sodium tripolyphosphate solution used did not effect on WHC of breast meat. It was elucidated by the less decrease in drip loss and cooking loss. The significant result in decreasing drip loss and cooking loss was observed in breast meat marinated with sodium chloride solution ($p < 0.05$). The different change in WHC of breast meat after marinated resulted to significant electrical conductivity was obtained. The effect of ionic strength on water holding capacity and electrical conductivity of breast meat obtained from two brine solutions was significantly different. This might be due to at the same ionic strength, sodium chloride had higher concentration than sodium tripolyphosphate. Sodium tripolyphosphate had long chain structure. Thus, in the meat matrix, the different size of chloride ion (Cl^-) and tripolyphosphate ion ($[P_3O_{10}]^{5-}$) had influence on efficiency to penetrate into meat fillet. Benjakul (2006) reported that the smaller size of phosphate could increase protein solubility and capability to penetrate in muscle than the bigger size. Therefore, the smaller size of chloride ion had higher efficiency to penetrate into the breast meat more than phosphate ion and influence on electrical properties of muscle (Markus *et al.*, 2009).

The Pearson's correlation coefficient between drip loss cooking loss and physical properties in marinated broiler breast meat is shown in Table 2. Electrical conductivity showed the best correlation with drip loss when compared with cooking loss. Moreover, electrical conductivity had higher correlation with drip loss than other traits ($r = -0.777$). These data were in agreement with Lee *et al*. (2000) who reported the high correlation between electrical conductivity and drip loss in pork loins ($r = 0.810$).

The electrical conductivity had an inverse correlation type with drip loss in marinated broiler breast meat in with drip loss decreased while electrical conductivity increased (Figure 1). This correlation

Table 1. Effect of ionic strength of solutions on water holding capacity and electrical properties in marinated broiler breast meat

Treatments	Ionic strength (solutions)	Drip loss (%)	Cooking loss (%)	EC (mS/cm)
Water	-	1.70±0.30	25.23±3.42	1.03±0.10
STPP	0.1750	1.55±0.48^{ab}	23.69±4.83^{a}	1.04±0.11^{ns}
	0.3500	1.50±0.33^{ab}	23.99±2.20^{a}	1.02±0.11^{ns}
	0.4893	1.66±0.45^{a}	22.37±2.98^{ab}	1.00±0.16^{ns}
	0.7014	1.63±0.49^{ab}	22.42±1.95^{ab}	1.07±0.05^{ns}
	0.8547	1.34±0.39^{b}	22.77±2.21^{ab}	1.08±0.04^{ns}
NaCl	0.1750	1.22±0.38^{a}	20.43±2.25^{a}	1.44±0.04^{e}
	0.3500	0.90±0.11^{b}	19.38±2.40^{a}	1.76±0.09^{d}
	0.4893	0.77±0.22^{bc}	18.12±1.13^{ab}	2.17±0.31^{c}
	0.7014	0.56±0.09^{c}	17.60±0.33^{ab}	2.65±0.31^{b}
	0.8547	0.62±0.36^{bc}	15.37±2.63^{b}	2.97±0.31^{a}

Results shown as means ± SD (n=216). $^{a-c}$ Means with different letters under the same treatment within a column are significantly different (p<0.05). ^{ns} Means within a column are not significantly different.
STPP: Sodium tripolyphosphate, NaCl: Sodium chloride, EC: Electrical conductivity

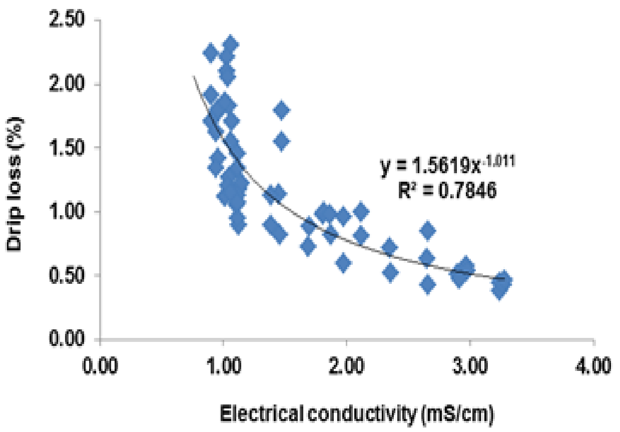

Figure 1. Correlation between drip loss and electrical conductivity of marinated broiler breast meat (n = 60)

was obtained only in sample marinated with sodium chloride. The high coefficient of determination (R^2 = 0.7846) of non-linear correlation between drip loss and electrical conductivity indicated the acceptability of the model for determining drip loss of marinated broiler breast meat by electrical conductivity. The inverse correlation between electrical conductivity and drip loss has been proposed that the concentration of ion within the myofibrillar protein were increased due to the ion of salt penetrated in broiler breast meat (Hong *et al.*, 2012; Shi *et al.*, 2014). These ions were function to unfolding myofibrillar as electrostatic repulsion was increased. Then, the electrostatic repulsion will increase the space between the thin and thick filaments and thus increase the amount of

Table 2. Pearson's correlation coefficient (r) between physical properties and water holding capacity (drip loss and cooking loss) in marinated and non-marinated broiler breast meat

Treatments	Physical properties	Pearson Correlation coefficients (r)	
		Drip loss	Cooking loss
Marinated	pH	0.26*	0.37**
	EC	-0.78**	-0.74**
	L*	0.51**	0.66**
	a*	-0.49**	-0.38**
	b*	0.34**	0.46**
Non-marinated	pH	0.20	-0.15
	EC	0.66**	-0.09
	L*	-0.12	0.19
	a*	-0.06	0.06
	b*	-0.14	0.18

*Correlations are significantly different at 0.05 levels (two-tail)
**Correlations are significantly different at 0.01 levels (two-tail)
EC : Electrical conductivity

water could be retained by muscle protein. For this reason, the marinated broiler breast meat had an inverse correlation between drip loss and electrical conductivity.

Effect of storage times on water holding capacity and electrical properties in broiler breast meat

Drip loss and electrical conductivity were increased with storage times (p<0.05) as shown in Table 3. Broiler breast meat before storage (Day 0), had electrical conductivity in the range of 1.23-1.25 mS/cm and increased up to 1.40 mS/cm within 10 days storage. The increasing of drip loss during storage of breast meat was due to degradation of muscle proteins and structural damage of membranes as proteolysis happened (Suwattitanun and Wattanachant, 2014). This might lead more fluids come out. Then, these fluids could increase the electrical conductivity (Yao *et al.*, 2011; Shen *et al.*, 2014). The result of drip loss and electrical conductivity during storage found in this study was similar to the report of Shen *et al.* (2015). Although drip loss was increased during storage, the tendency of cooking loss had increased significantly during 6 days of storage and decreased after that. At the same time, the pH was increased significantly on the days 10 of storage. The accumulation of ammonia in fresh meat during storage could contribute to increase the pH. This might be due to microbial development to attack free amino acid and then produced ammonia resulting in pH change (Suwattitanun and Wattanachant, 2014).

Table 3. Effect of storage times on water holding capacity and physical properties in non-marinated broiler breast meat during storage at 4°C

Storage times (Day)	Drip loss (%)	Cooking loss (%)	pH	EC (mS/cm)	L*	a*	b*
0	1.24±0.54^{e}	18.80±3.75^{bc}	6.08±0.18^{b}	1.24±0.01^{e}	54.04±2.82^{a}	0.47±0.36^{ns}	11.34±2.11^{ns}
1	1.47±0.17^{e}	18.65±2.76^{bc}	6.03±0.22^{b}	1.26±0.03^{de}	54.58±3.22^{a}	0.47±0.35^{ns}	10.66±2.08^{ns}
2	2.28±0.24^{d}	19.54±2.22^{bc}	5.92±0.13^{b}	1.28±0.03^{cd}	54.72±3.92^{a}	0.45±0.35^{ns}	11.63±1.75^{ns}
3	2.44±0.42^{d}	19.11±1.49^{bc}	5.95±0.10^{b}	1.29±0.03^{cd}	54.94±2.04^{a}	0.48±0.45^{ns}	11.74±1.89^{ns}
4	2.17±0.30^{d}	20.41±3.89^{bc}	6.00±0.09^{b}	1.31±0.03^{bc}	54.35±3.16^{a}	0.49±0.36^{ns}	11.38±1.55^{ns}
5	2.12±0.28^{d}	21.38±3.16^{ab}	6.06±0.10^{b}	1.30±0.03^{bc}	54.17±1.81^{a}	0.51±0.20^{ns}	11.66±1.86^{ns}
6	2.17±0.21^{d}	24.52±2.78^{a}	6.08±0.18^{b}	1.31±0.03^{bc}	54.50±2.54^{a}	0.50±0.19^{ns}	11.31±2.02^{ns}
7	3.75±0.28^{bc}	21.91±2.88^{ab}	6.04±0.12^{b}	1.31±0.03^{bc}	54.51±1.76^{a}	0.49±0.40^{ns}	11.87±1.62^{ns}
8	3.48±0.57^{c}	21.31±3.22^{abc}	6.00±0.16^{b}	1.31±0.03^{bc}	54.39±2.44^{a}	0.51±0.28^{ns}	11.79±1.95^{ns}
9	3.98±0.24^{b}	19.72±2.14^{bc}	6.10±0.19^{b}	1.33±0.02^{b}	52.46±2.94^{b}	0.43±0.23^{ns}	11.34±1.06^{ns}
10	4.57±0.65^{a}	17.35±2.56^{c}	6.27±0.12^{a}	1.40±0.02^{a}	52.74±2.70^{b}	0.42±0.51^{ns}	11.49±2.62^{ns}

Results shown as means ± SD (n=132). $^{a\text{-}c}$ Means with different letters within a column are significantly different ($p<0.05$). ^{ns} Mean values within a column are not significantly different. EC : Electrical conductivity

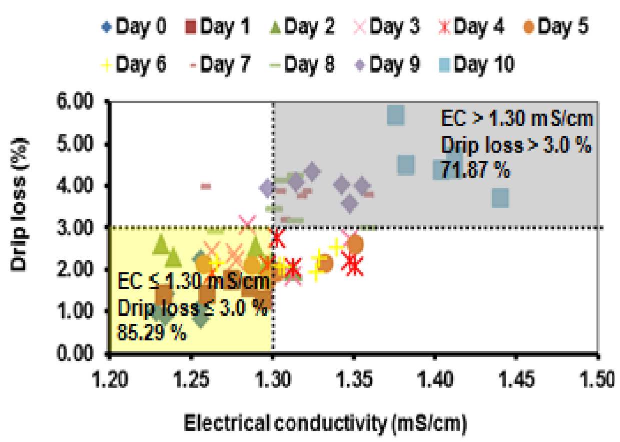

Figure 2. Correlation between drip loss and electrical conductivity of non-marinated broiler breast meat during storage at 4°C (n = 66)

During storage, broiler breast meat showed significant result in decreasing L* value in samples stored over 9 days ($p<0.05$).The decreasing of L* value might be due to the increasing of pH value. It caused change in structure of broiler breast meat and loss of water during storage resulting in more compact muscle fiber leading to decrease reflecting light. However, non-significant differences in a* and b* values was observed during storage ($p\geq0.05$).

The Pearson's correlation coefficients between water holding capacity and physical properties in non-marinated broiler breast meat are shown in Table 2. Electrical conductivity showed the best correlation with drip loss when compared to the cooking loss. Moreover, electrical conductivity had higher correlation with drip loss than other traits ($r = 0.656$). This result was similar to that of marinated broiler breast meat as mentioned previously. On the other hand, the relationship obtained in non-marinated broiler breast meat showed the positive correlation between electrical conductivity and drip loss (Figure 2). In non-marinated stored breast meat, the higher electrical conductivity, the higher drip loss would be obtained.

The relationship between electrical conductivity and drip loss are presented in Figure 2. The result demonstrated that electrical conductivity and drip loss had positive correlation in non-marinated broiler breast meat, in which drip loss increased while electrical conductivity increased during chilled storage. The positive correlation between drip loss and electrical conductivity during storage might be due to the degradation of muscle proteins contributed in proteolysis. This might be to leading the fluid flow out from intramyofibrillar spaces and thus made drip production. Consequently, these fluids can increase the electrical conductivity of the samples (Shen *et al.*, 2015). Although, electrical conductivity had high correlation with drip loss in non-marinated broiler breast meat, specific range of drip loss could be evaluated by electrical conductivity with high percent accuracy. As observed in Figure 2, electrical conductivity was obtained lower than at 1.30 mS/cm when drip loss of breast meat was lower than 3.0% at 85.29 percent accuracy. Breast meat with high drip loss greater than 3.0% could be revealed by high electrical conductivity more than 1.30 mS/cm with 71.87 percent accuracy. The data obtained in this study suggested that electrical conductivity could be used as guideline parameter for determining standard control drip loss of breast meat during production or storage.

Conclusion

Fresh broiler breast meat without storage and marination had electrical conductivity in the range of 1.00-1.20 mS/cm. Broiler breast that treated with salt solution exhibited decreasing level in drip loss with increasing level of electrical conductivity. Electrical conductivity of marinated samples was increased when the level of ionic strength of marinade solution increased. Consequently, electrical conductivity had negative correlation (r = -0.777) with drip loss in broiler breast meat treated with sodium chloride. During storage, drip loss and electrical conductivity of non-marinated breast meat were increased. Therefore, the relationship between electrical conductivity and drip loss had positive correlation (r = 0.656) in non-marinated breast meat. Non-marinated breast meat in amount of 85.29% accuracy that had electrical conductivity lower or equal to 1.30 mS/cm showed lower trend in drip loss at lower or equal to 3.0%. In addition, samples in amount of 71.87% accuracy had electrical conductivity greater than 1.30 mS/cm when drip loss was greater than 3.0%. The results of this study indicated that electrical conductivity could be used as a possible parameter in evaluation of water holding capacity of breast meat. Determination electrical conductivity of meat using conductivity meter is an economic and a quick method, which could be applied as weight loss indicator in meat industry.

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