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EFFECT OF A*lpinia galanga* EXTRACT TREATMENT ON PHYSICOCHEMICAL PROPERTIES AND ANTIMICROBIAL ACTIVITIES OF COLD STORED FRESH CUT CHICKEN BREAST MEAT

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Abstract

The long-term health detrimental effects of chemical additives used in food products cause worries among consumers. Hence, the use of phytochemical compounds as alternatives are being explored by many researchers. This study aimed to evaluate the effect of *Alpinia galanga* extract on the physicochemical properties and antimicrobial activities of chicken breast meat. The samples were immersed in galangal aqueous extract (0.5, 1.0 and 2.0%), stored at chill temperature (5±1 ºC) and monitored for 8 days. The result showed that the pH of the sample was significantly ($p<0.05$) increased with the increased concentration of galangal extract used. For colour values, the sample immersed with galangal had lighter colour (L*) compared to the control. During storage, redness (a*) of the control sample was reduced to a greenish hue but no changes were observed for yellowness (b*). Samples with galangal showed a gradual increase in a* and b* until day 4 followed by a gradual decline until the end of storage. No changes in the textural property observed through the penetration force of the control sample were observed. However, the penetration force of only 2% (v/w) galangal immersed sample was found to decrease after day 4. An increase in microbial growth was observed for all samples similar to control with the increase of storage time indicating no microbial inhibition effects. This study points out that the galangal extract used was able to maintain the pH, colour and textural properties of chicken meat. However, a higher concentration of more than 2% galangal extract is required to exhibit the antimicrobial properties needed to prolong the shelf-life of fresh-cut chicken meat.

Keywords: poultry, *Alpinia galanga*, galangal, antimicrobial, meat quality, chill storage

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Introduction

Poultry meat is categorised as one of the perishable food due to its high susceptibility to microbial spoilage. The nutrient-dense poultry meat's notably moisture and protein content make it suitable for microorganisms to thrive (Ghollasi-mood *et al*., 2017). Changes in textural and sensorial properties brought about by microbial activities significantly reduce the shelf life of poultry meat. On the other hand, contamination of pathogenic bacteria on food products is a crucial food safety issue globally. In Malaysia, food poisoning is a public health issue associated with the presence of pathogenic bacteria. Ministry of Health (MOH) Malaysia has reported an increase in the incidence rate of 47.2 to 50.9 per 100,000 populations in 2016 and 2019 respectively (MOH 2017; MOH 2020). The commonly known microorganisms associated with the spoilage of meat and meat products are *Escherichia coli, Campylobacter jejuni, Salmonella spp., and Listeria monocytogenes (*Jayasena & Jo*,* 2013). In the United States, *Salmonella* and *Campylobacter* are responsible for about 18 and 64% of poultry-related foodborne illnesses respectively (IFSAC, 2018). To reduce the chances of cross-contamination during processing and handling by foodborne pathogens, poultry processors have implemented several

antimicrobial interventions at various locations throughout the processing line. For example, the addition of antimicrobial agents namely chlorine, acetyl-pyridinium chloride and peracetic or peroxyacetic acid (Kataria *et al*., 2020) is conducted during broiler washing and carcass rinsing. Similarly, antimicrobial treatment in the post-cut up parts of chicken carcasses is also being practised in some poultry processing plants (Zhang *et al*., 2018).

The deterioration of chicken meat by microorganisms will start to occur within a short period after slaughtering. Fresh poultry meat can last only within a week when stored at chill temperature before texture softness, slimy appearance, off-flavour and off-odour are detected. About 10% of the microbial presence on meat after the slaughtering process can grow under refrigerated temperature thus causing the spoilage of meat (Luong *et al*., 2020). The soluble compounds content in muscle tissue such as glucose and amino acid in meat promote microbial growth. The off-odour of spoiled chicken arise from the degradation of amino acid by microorganism thus producing a large amount of ammonia, organic sulphides and amines (Kamenik, 2013).

The short shelf life of fresh chicken meat means that the meat must be cooked and consumed within a limited time. To prolong its shelf life, poultry meat can be kept at frozen temperature however this will affect the taste, aroma and texture associated with the freshness quality of the meat. Preservation of fresh food and processed food products using chemical substances are highly rejected by most consumers. Therefore, studies are being conducted in finding suitable natural preservatives, especially from the herbs plant sources. These plants either their fruit, leaves or rhizomes are used in cooking and traditional medicines practices contain various bioactive compounds such as carotenoids, phenolic acids, flavonoids, coumarins, alkaloids, polyacetylenes, saponins and terpenoids, among others (Chandrasekara & Shahidi, 2018). It has been reported that phenolic compounds cause the disruption of the membrane of bacteria by damaging its cell wall, changing fatty acids and phospholipids constituents, influencing the synthesis of DNA and RNA and destroying protein translocation of the pathogen microorganism (Radha Krishnan *et al*., 2014).

Alpinia galanga from the ginger family of Zingiberaceae is a commonly use herb that is widely added in certain dishes to increase palatability, flavouring and as an aromatic stimulant. It is commonly known as galangal, Siamese ginger or 'lengkuas' in the Malay language. The herb is also extensively used in traditional medicine to treat stomachache, diarrhoea, abdominal discomfort, increase the digestion, treat skin disease, dyspepsia, flu, malaria, rheumatoid arthritis, stomach cancer and throat cancer (Chudiwal *et al*. 2010; Nguyen and Nguyen, 2016). The bioactive compounds present in *A. galanga*, are found to exhibit antioxidant, antifungal and antibacterial properties (Manse *et al*., 2016).

The most used part of the galangal plant is its rhizome which has an internal light-yellow and reddish-brown outer colour. For cooking purposes, the 3 months old rhizome is used, and the rhizome will start to become hard and fibrous if harvested after more than 4 months. However, for essential oil extraction, the best harvesting time is when the plant reaches 7 months old (Ravindran *et al*., 2012). The essential oils in galangal rhizome are composed of several bioactive compound groups which are terpenes (sesquiterpenes, diterpenes and oxygenated monoterpenes) and flavonoids (kaempferide, galangin, kaemperol and alpinin) (Chudiwal *et al*., 2010). The major component in galangal extract was 1,8-cineole, β-bisaboline and β-selinene; minor components are α-selinene, fernesene, 1,2-benzeneicarboxylix acid and pentadecane while, the pungent compound is 1'-acetoxychavicol acetate (Chudiwal *et al*., 2010). A study by Rana *et al.* (2010) showed that galangal rhizome from Malaysia is rich in β-farnesese and β-bisabolene, whereas major components from Indonesia are monoterpenoids with pinene and 1,8 cinole.

The objective of this study was to determine the physicochemical properties and antimicrobial activities of *A. galanga* extract on fresh-cut chicken breast meat stored at chilled storage. To date, there is still lack of studies on the utilisation of *A. galanga* extract as a natural antimicrobial agent for fresh-cut poultry meat.

Methods

Sample preparation

The six months old galangal rhizomes were purchased from the planting area at Sabak Bernam, Selangor. The rhizomes were washed with tap water to remove any adhered soil, sliced (2 mm thickness) and then dried in a cabinet drier at 50 °C for 12 hours. The dried galangal was then ground using a dry blender (Panasonic, Japan) into a smaller size. The galangal immersion solution was prepared by dissolving the ground galangal of the desired concentrations (0.5, 1.0 and 2.0 % w/v) in 100 mL distilled water. The galangal extract was obtained using ultrasonic-assisted extraction (Thermo-6D, Chemolab Supplies Sdn. Bhd.) at 30 °C for 30 minutes to ensure bioactive compounds release into the extraction medium. After that, the mixture was filtered using filter paper Whatman No.1 to remove any fibrous matter before the meat immersion process.

The freshly slaughtered chicken meat was purchased from a slaughterhouse at Meru, Klang Selangor, packed in ice in a cooler box and was immediately brought to the laboratory. The whole breast (without skin) of the chicken was cut into 4 parts, standardised to 100±5 g in weight cleaned, rinsed, and then immersed in galangal extract. The control sample was prepared by immersing the sample in distilled water without the addition of galangal. After exactly 5 minutes of immersion, the meat samples were removed from the immersing solution, placed on a wire rack for 2 minutes to let the remaining solution to drip off. After that, the samples were packed in a polyethene terephthalate tray and seal using polyvinyl chloride cling film. The samples were kept in a chiller (5±1 °C) for 8 days with 2 days interval of sampling time.

Physical and microbial analysis

The pH value was measured using a pH meter (HI 2211 pH/ORP meter, Hanna Instrument Incorporation, USA) after calibration using a buffer at pH 4.00 and 7.00. 10 grams of the chicken meat was homogenised in 100 mL distilled water, filtered and the pH of the filtrate was measured (Zhang *et al*., 2016). The colour values (L*, a* and b*) were determined with chromameter (CR-400, Konica Minolta, Japan) using the CIELab colour system. The instrument was calibrated with the standard white tile provided by the manufacturer.

For texture analysis, the samples were boiled for 3 minutes and left to cool at room temperature prior to analysis. The textural parameters were evaluated using a texture analyser (TA-XT2plus, Stable Micro Systems, UK) using a 2 mm diameter needle probe (P/2N) and 5 kg load cell. Penetration test was conducted by placing the sample on the heavy-duty platform, the arm of the instrument moved down (2 mm/s) to fully penetrate the meat before returning to its initial position.

The total plate count method was conducted to determine microbial growth on the sample during storage. The chicken meat samples were homogenates in peptone water (1: 1 w/v ratio) using stomacher. Serial dilutions were prepared in peptone water and 0.1 mL of each sample was spread on the prepared plate count agar then incubated at 37 ºC for 24 hours. The number of colony-forming units (CFU) was calculated as $\log_{10}$ CFU/g.

Statistical Analysis

The experimental data were statistically analysed using SPSS 23.0 software. Statistical significance of differences in means was calculated using Analysis of Variance (ANOVA) Duncan's multiple range tests at $p<0.05$.

Results and Discussion

Effect of galangal extract on pH

One of the most commonly used parameters in determining the quality of meat is pH as it plays a significant role in eating quality and preferable appearance of raw meat products. The limit of pH value for acceptable poultry suggested by Ristic & Damme (2010) is pH 5.9 to 6.2. When the pH of poultry meat is below 5.8, the undesirable characteristics of pale, soft and exudative are obtained while pH equal to or above 6.3, a low meat quality of dark, firm and dry are produced. Table 1 shows the effect

of galangal extract concentrations on the pH of fresh cut chicken breast meat at chill storage.

Table 1. Changes in pH of the chicken meat samples during storage

Storage day	Concentration of galangal extract (w/v)			
	Control (0 %)	0.5 %	1.0 %	2.0 %
0	5.94 ± 0.06^{Ad}	5.91 ± 0.06^{Ad}	5.97 ± 0.02^{Ae}	5.89 ± 0.01^{Ae}
2	6.17 ± 0.01^{Ac}	6.09 ± 0.01^{Bc}	6.07 ± 0.02^{Bd}	6.06 ± 0.01^{Bd}
4	6.21 ± 0.01^{Ac}	6.16 ± 0.02^{Bb}	6.15 ± 0.01^{Bc}	6.11 ± 0.01^{Cc}
6	6.28 ± 0.02^{Ab}	6.22 ± 0.01^{Ba}	6.18 ± 0.01^{Cb}	6.17 ± 0.02^{Cb}
8	6.34 ± 0.01^{Aa}	6.27 ± 0.02^{Ba}	6.24 ± 0.01^{BCa}	6.22 ± 0.02^{Ca}

Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples.
Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

The initial pH values of control and galangal immersed samples are found to be in the acceptable pH limit of above pH 5.8 indicating a good meat quality. At day 0 which was measured before further storage is conducted showed no significant difference in pH among all samples. This shows that the concentration of galangal used does not affect the pH of meat. During storage, a similar increase in pH values was observed with the increased days of storage for all samples. On day 8, the highest increase in pH was shown by control and the lowest increase was by 2.0% galangal immersed meat. No significant difference between 0.5% and 1.0% galangal immersed samples were observed at the end of day 8 of storage. The only sample with pH above the limit for acceptable poultry meat quality (pH ≥ 6.3) is the control sample at day 8 of storage. Therefore, pre-treatment by galangal immersion is capable of hindering pH increment that will lead to poor quality of poultry meat upon prolong storage. According to Zhang *et al*. (2016), the increment of pH during storage is due to the growth of microorganisms that metabolise protein and amino acids after glucose was depleted. The degradation of amino acids and the development of ammonia led to an increase in pH and off-odour smell.

Effect of galangal extract on colour

Colour is an important indication of freshness used by the consumer at the point of purchase. Any obvious changes in colour than usual will be perceived as poor in quality and product rejection. The colour of fresh meat and poultry is related to the concentration of myoglobin that is responsible for the red colour. The brown colour of meat does not necessarily indicate that spoilage has occurred since it is due to the oxidation reaction of myoglobin into metmyoglobin. Many factors such as poultry species, nutrients present in feed meal, age of poultry play a significant role and contribute to the colour of meat. For consumers, using the naked eye to gauge the freshness of meat, especially white meat is difficult since the colour changes are not obvious. For poultry, changes in colour either fading pale or darkening coupled with off-odour, sticky and slimy appearance are an extreme indicator of spoilage. In a study by Tomasevic *et al.* (2019), the colour values for fresh chicken breast measured indicated an L* value of 58.09±1.35. a* of 2.23±0.92 and b* of 10.31±2.32 using a chromameter. Tables 2, 3 and 4 show the L*, a* and b* values respectively of control and galangal treated chicken breast meat during storage.

Table 2. Changes in lightness (L*) of chicken meat samples during storage

Storage day	Concentration of galangal extract (w/v)			
	Control (0 %)	0.5 %	1.0 %	2.0 %
0	56.59 ± 0.29^{Aa}	55.60 ± 0.32^{Bd}	54.37 ± 0.30^{Ce}	55.65 ± 0.65^{Be}
2	55.14 ± 0.34^{Cb}	56.27 ± 0.20^{Bc}	56.63 ± 0.34^{Bd}	58.85 ± 0.17^{Ad}
4	54.79 ± 0.14^{Cb}	57.80 ± 0.31^{Bb}	57.70 ± 0.22^{Bc}	59.34 ± 0.09^{Ac}
6	54.72 ± 0.12^{Db}	57.53 ± 0.05^{Cb}	58.28 ± 0.04^{Bb}	59.71 ± 0.23^{Ab}
8	53.72 ± 0.09^{Cc}	59.25 ± 0.33^{Ba}	60.18 ± 0.12^{Aa}	60.29 ± 0.11^{Aa}

Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples.
Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

A significant decrease in L* value was observed between control and samples immersed in galangal extract after the pretreatment process (day 0). This shows that the natural pigments of the galangal extract were absorbed into the meat. The natural pale-yellow colour of galangal extract was contributed

by the presence of the flavonoid compound such as kaemperol, kaempferide and galangin and alpinin phytoconstituents (Chudiwal *et al*., 2010).

No significant difference was observed among the different concentrations used on L* value of treated meat. During storage, L* value of the control sample decreases indicating the meat flesh colour turning darker. In contrast to the galangal treated meat, the L* value increases indicating the flesh becoming lighter in colour during storage and much whiter than the initial fresh meat colour of the control.

Table 3. Changes in redness (a*) of chicken meat samples during storage

Storage day	Concentration of galangal extract (w/v)			
	Control (0%)	0.5 %	1.0 %	2.0 %
0	1.54 ± 0.04^{Aa}	0.14 ± 0.025^{Cb}	0.18 ± 0.13^{Cc}	0.84 ± 0.05^{Bc}
2	1.42 ± 0.16^{ABa}	1.17 ± 0.21^{BCa}	1.51 ± 0.21^{Aa}	1.03 ± 0.06^{Cb}
4	1.39 ± 0.19^{Ca}	1.21 ± 0.015^{Ca}	1.62 ± 0.13^{Ba}	2.09 ± 0.07^{Aa}
6	0.91 ± 0.02^{BCb}	1.17 ± 0.05^{Aa}	0.93 ± 0.04^{Bb}	0.80 ± 0.11^{Cc}
8	-0.85 ± 0.07^{Cc}	0.05 ± 0.01^{Cb}	0.51 ± 0.32^{Bc}	0.87 ± 0.04^{Ac}

Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples.
Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

For redness a* hue, a significantly higher value was observed for control compared to all galangal treated samples at day 0. The a* value of control decreases with the increase of day of storage until day 8 where the colour changes drastically from redness (+a* value) to greenness (-a* value). For galangal treated samples, an increase was observed between days 0 to 2 followed by a gradual decrease towards the end of storage day 8. However, the a* hue for 0.5% treated sample was stable at day 2 up to day 6. This behaviour may be related to either the increase or decrease in the myoglobin oxidation process or the activities of microorganisms. Radha Krishnan *et al.* (2014), explained the reduction in the redness colour of meat is due to pigment oxidation in which iron atom or myoglobin molecules were oxidised by free radicals produced during oxidation thus changing the colour of meat.

Table 4. Changes in yellowness (b*) of the chicken meat samples during storage

Storage day	Concentration of galangal extract (w/v)			
	Control (0%)	0.5 %	1.0 %	2.0 %
0	6.47 ± 0.10^{Aa}	5.83 ± 0.18^{Bd}	5.54 ± 0.13^{Bd}	6.70 ± 1.12^{Ad}
2	6.29 ± 0.10^{Ca}	7.95 ± 0.06^{Ba}	6.54 ± 1.20^{Cc}	9.25 ± 0.19^{Aa}
4	6.29 ± 0.10^{Da}	6.97 ± 0.03^{Cb}	8.39 ± 0.09^{Aa}	8.17 ± 0.07^{Bb}
6	6.25 ± 0.27^{Ca}	6.74 ± 0.04^{Bc}	8.12 ± 0.19^{Ab}	8.12 ± 0.19^{Ab}
8	6.24 ± 0.14^{Ba}	6.24 ± 0.01^{Be}	6.48 ± 0.02^{Bc}	7.72 ± 1.85^{Ac}

Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples.
Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

For the yellowness b* value (Table 4), no significant difference between the control and 2.0% galangal treated sample was observed at day 0. This indicates that at 2% concentration the pale-yellow pigments present in galangal extract contributed to the yellow hue similar to the redness of control. No changes in the b* value of control were observed from day 0 to day 8 of storage. However, a drastic increase in b* was observed for all treated samples at day 2 followed by a gradual increase until day 8. Comparison between samples at day 8 showed no significant difference between control, 0.5% and 1.0% treated samples except for 2.0% galangal treated sample which shows higher in b* value.

According to Voravuthikunchai (2007), phenolics and flavonoids compounds in galangal can interrupt the lipid oxidation process and therefore may have contributed to the yellow colour changes of the meat. In this study, the presence of polyphenolic compounds in the galangal extracts contributes to the increase in b* value observed in 1.0% extract immersed sample at day 4 and 6 while for 2.0% extract immersed sample the effect was observed from day 2 until day 8 of storage.

Effect of galangal extract on texture

Meat texture is related to the size of muscle fibre, fat content and the amount of connective tissue present. Meat with a high amount of fat marbling creates a juiciness sensation when eating but meat with a large number of muscle bundles will result in coarse and undesirable texture (Joo *et al*., 2013). For consumers, the quality of cooked meat is related to flavour, tenderness and juiciness experienced when eating. In this study, penetration force was used to assess the tenderness of boiled control and galangal treated meat samples as shown in Table 5.

Table 5. Penetration force (kg) of boiled chicken meat samples

Storage day	Concentration of galangal extract (w/v)			
	Control (0 %)	0.5 %	1.0 %	2.0 %
0	0.093 ± 0.002^{Aa}	0.095 ± 0.001^{Aa}	0.096 ± 0.003^{Aa}	0.095 ± 0.001^{Aa}
2	0.095 ± 0.001^{Aa}	0.095 ± 0.003^{Aa}	0.093 ± 0.004^{Aa}	0.094 ± 0.002^{Aa}
4	0.096 ± 0.001^{Aa}	0.095 ± 0.002^{ABa}	0.093 ± 0.002^{BCa}	0.091 ± 0.001^{Cb}
6	0.096 ± 0.002^{Aa}	0.094 ± 0.003^{ABa}	0.093 ± 0.003^{Ba}	0.091 ± 0.001^{Cb}
8	0.097 ± 0.004^{Aa}	0.094 ± 0.003^{ABa}	0.092 ± 0.001^{ABa}	0.091 ± 0.001^{Bb}

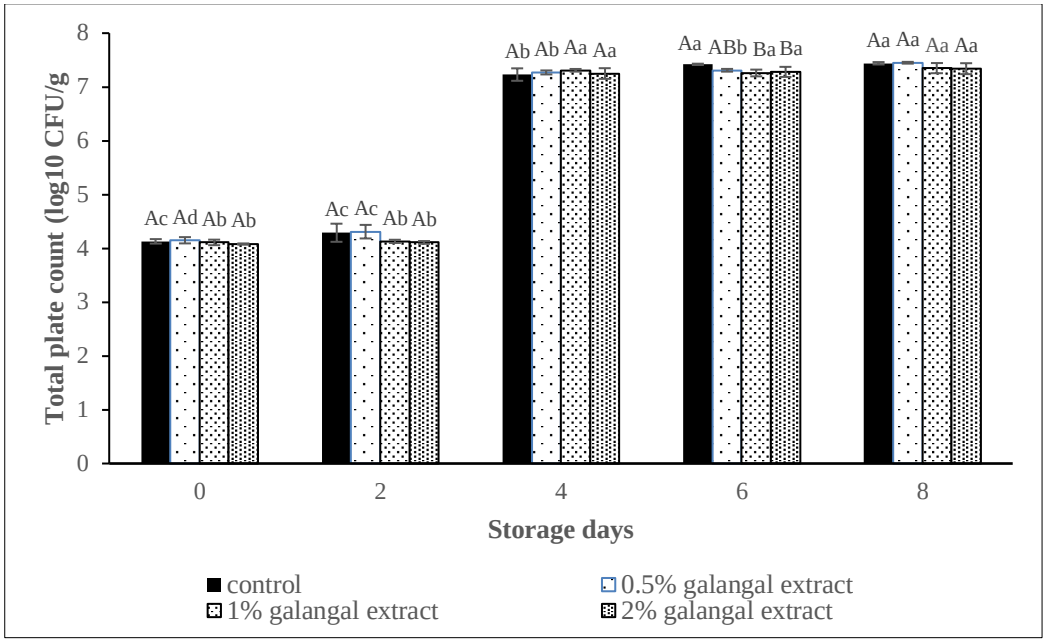
Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples. Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

No significant difference was observed between control and treated samples at day 0 which indicates that the immersion of meat in galangal extract for 5 minutes during sample preparation does not cause degradation effects on meat texture. During storage, no changes in penetration force were observed for control, 0.5% and 1.0% galangal treated meat samples. However, a decrease in penetration force was observed for 2.0% galangal treated meat from day 4 and remained constant until the end of storage. Comparison between samples at day 8 of storage showed no significant difference between control, 0.5% and 1.0% galangal treated samples, however, the penetration force was significantly decreased for the 2.0% sample. This indicates that for tenderising effect, galangal extract at 2.0% or higher concentration is required.

During storage of fresh meat, a complex interaction related to proteolytic enzymes that weaken the cross-linkage bonds between actin and myosin, liberation of actin from myofibrillar protein, myofibril fragmentation, and the dissociation of actomyosin affect the tenderness of meat (Barido & Lee, 2021). Proteolytic enzymes from plant sources such as papain from papaya, bromelain from pineapple and protease from ginger are well-known meat tenderisers. These enzymes can degrade muscle proteins and dissolve collagen, which helps in meat tenderisation (Zahir *et al*., 2019). Although, galangal has been used as one of the marinating ingredients for meat prior to grilling however the usage of galangal by itself as meat tenderiser is unknown. Further study is required to determine whether galangal contains proteolytic enzymes that aid in the meat tenderising process.

Effect of galangal extract on microbial growth

Many studies have proven the antibacterial and antifungal properties of the essential oil extracted from galangal rhizomes (Manse *et al.,* 2016). However, the efficacy of galangal aqueous extract as an antimicrobial has not been studied. Figure 1 shows the growth of microorganisms during storage for the control and galangal treated samples.



Capital alphabet (A-D) indicates significant difference ($p<0.05$) of the same day of storage of different samples. Small alphabet (a-e) indicates significant difference ($p<0.05$) of the same sample at different storage days.

Figure 1. Microbial growth of chicken meat samples during storage

A similar trend in microbial growth was observed among samples during storage with no significant difference between samples on the same day of storage. From day 0 to day 2, no increase in microbial growth was observed, however at day 4, a drastic jump doubles in the number of microorganisms were observed for all samples and remained constant until the end of storage day 8. It is obvious from the result obtained that the galangal aqueous extract of the concentration studied was not able to inhibit microbial growth.

The major chemical compounds found in galangal essential oil are 1,8-cineole, 4-allylphenyl acetate and methyl eugenol and these compounds were reported to have strong antibacterial and antifungal activities (Bakkali *et al*., 2008; Packiavathy *et al*., 2012; Kahkeshani *et al.*, 2018). Although the results in this study showed otherwise but Sripor & Jinda (2014) confirmed the antimicrobial activity of galangal against *Escherichia coli, Staphylococcus aureus*, and *Salmonella typhimurium* at 45% (v/w) concentration. The antimicrobial activities of the galangal compounds are also reduced in the food system due to the interference with food substances such as lipids, proteins and proteases (Juneja *et al*., 2012). Therefore, even though the galangal essential oil was proven as a natural antibacterial and antifungal agent but the high effective concentration required and the interference effects may hinder its usage. Furthermore, the high amount of galangal used will contribute to the undesirable organoleptic effect that is unacceptable by the consumers.

Conclusion

The study showed that the immersion in galangal aqueous solution as a post-cut up treatment for poultry was able to retain the meat pH and colour within the acceptable value during chilled storage. The result of texture obtained indicated that a minimum of 2% (v/w) concentration is needed to soften the meat texture. Unfortunately in the range of concentration studied, no microbial inhibition activities were observed. Therefore, further study is required to ascertain the optimum concentration of galangal extract to inhibit microbial growth at the desired shelf-life without greatly affecting the taste, appearance and texture of the meat.

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