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Effect of vacuum tumbling with natural vinegar based marinades on the quality attributes of broiler chicken legs

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Abstract
This study investigated the impact of vacuum tumbling with plant-derived vinegar-based marinades on the physico-chemical properties, organoleptic characteristics and chemical composition of broiler chicken legs. Five treatments were compared: immersion in 3.5% salt solution (C1), vacuum tumbling with 3.5% salt solution (C2), and vacuum tumbling with 3.5% salt and 3% coconut vinegar (T_1), 3% apple cider vinegar (T_2) and3% black plum vinegar (T_3) solutions. Vinegar-based treatments exhibited significantly lower pH, higher marinade absorption, improved water holding capacity, increased collagen solubility, and reduced cooking loss and shear force compared to controls. Black plum vinegar based marinade showed the highest antioxidant activity. Sensory analysis revealed no adverse effects on colour, tenderness or aftertaste, with treatments scoring higher in overall acceptability than controls. Chemical composition analysis indicated increased moisture and ash contents and reduced protein levels in treated samples. The findings demonstrated that vacuum tumbling with natural fruit vinegar marinades effectively enhanced the quality of broiler chicken legs.

Keywords: Marination, natural vinegar, vacuum tumbling, broiler chicken legs

Introduction

Marination is a long-established method involving the treatment of raw meat with various ingredients, including oil, salt, phosphates, organic acids, sugar, herbs, spices and aromatic ingredients, to tenderize the meat and improve its juiciness and flavour (Dykiel *et al.*, 2025) [7]. The functional properties of marinating liquids vary depending on the ingredients used in the marinade the muscle structure and promotes proteolysis. Therefore, incorporating vinegar into marinade formulations is beneficial due to its naturally low pH (Unal *et al.*, 2023) [23]. Natural fruit vinegars are considered superior to synthetic vinegar, as they are rich in organic acids, phenolic compounds, vitamins and minerals and exhibit strong antioxidant activity (Ousaaid *et al.*, 2021) [13] and antimicrobial activity (Sengun *et al.*, 2021) [18].

To improve marination efficiency, several techniques have been developed, including ultrasound-assisted marination, blade tenderization, tumbling, and vacuum tumbling. Among these, vacuum tumbling has become a widely adopted method in chicken meat processing (Ge *et al.*, 2022) [9]. Tumbling is a common physical-mechanical method that disrupts muscle cell membranes, allowing marinades to penetrate more easily and reducing marination time (Conde *et al.*, 2012) [6]. The use of a vacuum tumbler enhances this process by creating pressure differences that expand muscle fibres and remove trapped gases, thereby improving marinade absorption (Zhu *et al.*, 2019) [27]. Hence a study was envisaged to evaluate and compare the impacts of vacuum tumbler marination using different plant derived vinegar based marinades on the physico-chemical properties, organoleptic characteristics and chemical composition of broiler chicken legs.

Materials and Methods

Five-week-old broiler chickens were sourced from the local market and brought to the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Pookode, Wayanad, Kerala. They were slaughtered and dressed under hygienic conditions, leg cuts harvested, washed and drained. The chicken legs were divided into five equal batches.

Unpasteurised and unfiltered cocoanut vinegar, apple cider vinegar and black plum vinegar were purchased locally. Concentrations of salt and different vinegars in the marinades were determined based on sensory evaluation of preliminary trials. Control 1, C1 consisted of chicken legs immersed in a 3.5 percent salt marinade at 1:1 (meat: marinade) ratio for 2 h under chiller conditions (4 ± 1 °C). Control 2 (C2) consisted of chicken legs that were vacuum tumbled with a 3.5% salt solution in a 1:1 ratio of meat to marinade. Treatments T_1, T_2 and T_3 consisted of chicken legs vacuum tumbled with 3 percent coconut vinegar and 3.5 percent salt solution, 3 percent apple cider vinegar and 3.5 percent salt solution and 3 percent black plum vinegar and 3.5 percent salt solution, respectively. Vacuum tumbling was done twice, each for 15 minutes with an interval of five minutes in between, for C2, T_1, T_2 and T_3. Analyses of physico-chemical properties, chemical composition, and organoleptic characteristics were conducted on both control and treated samples, as detailed below.

Marinade absorption

Marinade absorption was calculated as per Yusop *et al.* (2010) [24] based on the weight difference of the meat after and before marination.

Marinade absorption (%) = [(Weight after marination-Initial weight) ÷ Initial weight] × 100

Cooking loss

Cooking loss was determined following the method of Boccard *et al.* (1981). An 80-gram meat sample was placed inside a HDPE pouch, with the air removed between the meat and pouch walls, then sealed using aerobic packaging. The pouch was cooked in a water bath at 75 °C for 50 minutes, followed by cooling under running tap water for 40 minutes. After cooking, the meat was removed, blotted dry, and weighed. The percentage of cooking loss was then calculated as follows:

Cooking loss (%) = [(Initial weight-final weight) ÷ Initial weight] × 100

pH

The pH of the samples was determined using a digital pH meter following the AOAC (2016) [1] method. Ten grams of the sample was blended with 50 mL of distilled water for one minute using a tissue homogenizer (Kinematica, Switzerland) at 4000 rpm. The pH of the resulting homogenate was then measured by immersing the combined glass electrode of a digital pH meter (EUTECH Instruments pH 510, Singapore).

Water holding capacity

Water holding capacity was assessed following the method described by Wardlaw *et al.* (1973) [23]. A 10-gram portion of the chopped sample was mixed with 16 mL of 0.6 M sodium chloride solution. The mixture was then incubated at 4 ± 1 °C for 30 minutes, followed by centrifugation at 7000 rpm for 15 minutes. The volume of the supernatant was recorded, and the water holding capacity was expressed in milliliters (mL).

Tyrosine value

Tyrosine content was determined using the method described by Pearson (1968) [15]. Accurately weighed 2 g sample was mixed with 40 mL of 5% trichloroacetic acid (TCA) solution. The mixture was homogenized for 2 minutes using a tissue homogeniser (Kinematica, Switzerland) at 4000 rpm, then filtered. The resulting TCA extract was used for tyrosine estimation. For the assay, 2.5 mL of the TCA extract was transferred to a test tube, mixed with an equal volume of distilled water and 10 mL of 0.5 N sodium hydroxide, and shaken thoroughly. Next, 3 mL of diluted Folin-Ciocalteu's phenol (FC) reagent (prepared by mixing 1 mL of concentrated FC reagent with 2 mL of distilled water) was added. The mixture was allowed to stand at room temperature for 5 minutes. Absorbance was then measured at 660 nm using a double beam spectrophotometer (UV/VIS Lambda 25, Perkin Elmer, Singapore). A blank containing 2.5 mL of 5% TCA, an equal volume of distilled water, 10 mL of 0.5 N sodium hydroxide, and 3 mL of diluted FC reagent was used as a reference. Tyrosine values were calculated from a standard curve and expressed as milligrams of tyrosine per 100 grams of sample.

L*, a* and b* colour values

Colour values of the samples were measured objectively following the method described by Page *et al.* (2001) [14] using a Hunter Lab MiniScan XE Plus Spectrophotometer (Hunter Lab, Virginia, USA) with diffuse illumination. The device was configured to record CIE L*, a*, and b* values using a 45/0 geometry and a 10º standard observer, with an aperture size of 2.54 cm. Prior to measurement, the instrument was calibrated using standard black and white tiles. In this system, the L* value ranges from 0 (black) to 100 (white), a* values indicate redness (positive) or greenness (negative), and b* values indicate yellowness (positive) or blueness (negative). Each sample was measured three times, and the average values of L* (lightness), a* (redness), and b* (yellowness) were recorded.

Shear force

Shear force was determined following the procedure described by Sams (1990) [17]. Each deboned muscle sample was packed in high-density polyethylene (HDPE) pouches and cooked for 50 minutes until an internal temperature of 80 °C was reached, monitored using a probe thermometer. The samples were cut intopieces of size 1.5cm x 1.5cm x 0.5cm and sheared by a wedge-shaped blade shear jig (500 N, cross head speed of 200 mm/min) in a texture analyser (Model EZ-SX, Shimadzu Corporation, Japan) and the values were expressed in Newton (N).

Collagen solubility

Collagen solubility in the muscle was assessed using the method described by Hill (1966) [10]. Collagen solubility was calculated from the hydroxyproline content of the sample.

1,1-diphenyl-2-picryl hydrazyl (DPPH)assay of marinades

The antioxidant activity of the marinade solution was evaluated using the 1,1-diphenyl-2-picryl hydrazyl (DPPH) assay, as described by Zare *et al.* (2019) [26]. For the DPPH free radical scavenging assay, a methanolic solution of DPPH was prepared by dissolving four milligrams of DPPH (Sisco Research Laboratories Pvt. Ltd, Mumbai, India) in 100 mL of methanol. Then, 5 mL of the marinade solutions were added to 5 mL DPPH solution and the absorbance at 517 nm was measured after keeping it in the dark for six hours. The control used in this assay comprised the solution without the marinade. The antioxidant activity of the marinades was calculated using the following equation,

Antioxidant activity (%) = ((Absorbance of control − Absorbance of sample)/Absorbance of control) × 100

Sensory evaluation

Sensory evaluation of chicken legs was performed by a panel of semi-trained individuals from the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Pookode. The panelists were given a brief overview of the experiment without revealing the identity of the samples. Deboned samples were cooked until reaching an internal temperature of 80 °C and held at that temperature for 20 minutes. After cooking, the samples were cut into uniform pieces and served warm (around 50 °C) to the panelists, who received coded samples. Filtered water was provided to the panelists to cleanse their palates between tasting each sample. Panelists evaluated samples for colour, flavour, juiciness, sourness, tenderness and overall acceptability and the scores were averaged for statistical analysis.

Chemical composition

Moisture, protein, fat, and ash content were determined following the procedures outlined by AOAC (2016) [1].

Results and Discussion

pH

The treatments (T_1, T_2 and T_3) exhibited significantly lower pH values compared to the controls (C1 and C2), which This could be due to the acidic components present in the marinades (Dykiel *et al.*, 2025) [7].

Marinade absorption

A significant difference (p<0.001) was noted in marinade absorption among all groups, with treatments (T_1, T_2 and T_3) showing markedly higher absorption than controls (C1 and C2). Samples T_3 and T_2 recorded the highest absorption, followed by T_1, whereas among controls, C2 exhibited greater uptake than C1, which showed the lowest absorption overall. These results are in agreement with those of Unal *et al.* (2020) [21], who reported that decreased pH enhanced marinade absorption, as acidic marinades cause protein swelling and structural changes that create spaces for water retention within muscle fibres. Additionally, Singh *et al.* (2020) [19] observed that vacuum tumbling significantly improved marinade uptake by physically loosening the meat structure.

Cooking loss

C1 exhibited significantly (p<0.001) higher cooking loss compared to C2 and the vinegar-based treatments. Similar findings were reported by Unal *et al.* (2022) [21], who showed that citric acid, lemon and grapefruit juice marinades improved chicken meat quality by enhancing water retention, lowering the pH and reducing cooking loss. Similarly, Chouljenko (2017) [5] confirmed that vacuum tumbling enhanced water-holding capacity and decreased cooking loss.

Water holding capacity

Water holding capacity differed significantly (p<0.001) between samples on all days of storage, with C1 and C2 showing lower capacity to retain water compared to the treatments. Among the controls, C1 exhibited significantly (p<0.001) lower water holding capacity than C2. This observation is supported by Singh *et al.* (2020) [19], who reported that vacuum tumbling significantly improved water holding capacity compared to non-tumbled samples. The enhanced water holding capacity in treatments could be attributed to the action of vinegar-based marinades and vacuum tumbling, which promoted protein extraction and swelling, thereby improving the water-binding properties of meat.

Tyrosine value

C1 and C2 exhibited significantly lower tyrosine values (p<0.001) than the treatments, with C1 having the lowest and T_3 having the highest value. This higher release of tyrosine in vinegar-based treatments could be attributed to vinegar-induced muscle swelling and enhanced proteolysis (Fencioglu *et al.*, 2022) [8].

Shear force and collagen solubility

The treatment groups exhibited significantly lower shear force values compared to the controls (p<0.001), indicating increased tenderness, with C1 showing the highest toughness. This result aligns with the findings of Ünal *et al.* (2023) [20], who reported that grape vinegar marinades significantly reduced shear force in beef, and with Ge *et al.* (2022) [9], who observed that vacuum tumbling enhanced tenderness more effectively than immersion method.

All treatments (T_1, T_2, and T_3) exhibited significantly higher collagen solubility compared to the controls (C1 and C2). Kim *et al.* (2014) [11] reported comparable results, noted that acidic marinades enhanced collagen solubility in tumbled chicken breast, leading to improved tenderness compared to sodium chloride treatment alone.

L*, a* and b* Colour values

Treatments had significantly higher lightness (L*) values than control samples. Augustyńska-Prejsnar *et al.* (2019) [2] reported that marination of broiler chicken breast meat with acid marinade increased the lightness (L*) due to higher marinade uptake and protein denaturation changing surface reflectance compared to the non-marinated muscles. The a* (redness) values and b* (yellowness) values showed no significant differences between samples.

1,1-diphenyl-2-picryl hydrazyl (DPPH) assay of marinades

Among three marinades, black plum vinegar based marinade exhibited the highest antioxidant activity (71.80 percent), followed by apple cider vinegar based marinade (68.90 percent) and coconut vinegar based marinade (55.90 percent). The elevated activity ofblack plum vinegar based marinade indicates a stronger antioxidant potential, likely due to the free radical-scavenging effects of its specific ingredients (Rauf *et al.*, 2021) [16]

Sensory evaluation

Colour, sourness, tenderness and aftertaste scores did not differ significantly between samples (p = 1.000), which suggested the absence of any undesirable colour, sourness and aftertaste in the natural vinegar-marinated samples. However, C1 scored significantly lower in juiciness compared to all other samples (p<0.05), which might be attributed to the effect of tumbling, as it enhanced meat juiciness by increasing water retention during marination (Ge *et al.*, 2022) [9]. In terms of overall acceptability, T_1, T_2, and T_3 received significantly higher scores than the control samples (p<0.05) showing the positive effect of natural vinegars on the sensory attributes of meat.

Chemical composition

Protein levels were significantly higher in C1 and lowest in T_3 (p<0.001). Control, C1 also exhibited a significantly lower moisture percentage compared to the other samples (p<0.05). This aligns with findings by Motycka and Bechtel (1983), who reported that extended tumbling increased moisture while reducing protein concentration in hams. Fat content did not show any significant variation across samples. Ash content, however, was significantly lower in the control group compared to the treated samples (p<0.001). This increase in ash content in the treatments might be attributed to greater mineral and salt uptake from the vinegar-based marinades. Additionally, natural fruit vinegars are known to be rich sources of essential minerals (Ousaaid *et al.*, 2021) [13].

Table 1: Marinade absorption (%), cooking loss (%), pH, water holding capacity (mL), tyrosine value (mg/100g), shear force (N) and collagen solubility (%) of control and treatment chicken legs

Parameter	C1	C2	T_1	T_2	T_3
pH	$5.98^a \pm 0.04$	$6.03^a \pm 0.03$	$5.88^b \pm 0.01$	$5.85^b \pm 0.02$	$5.83^b \pm 0.01$
Marinade absorption (%)	$2.59^d \pm 0.15$	$6.98^c \pm 0.09$	$7.82^b \pm 0.11$	$8.31^a \pm 0.04$	$8.58^a \pm 0.05$
Cooking loss (%)	$24.25^a \pm 0.18$	$23.88^b \pm 0.05$	$22.28^c \pm 0.20$	$22.50^c \pm 0.30$	$23.26^b \pm 0.28$
Water holding capacity (mL)	$15.04^a \pm 0.004$	$14.56^b \pm 0.005$	$14.38^c \pm 0.003$	$14.39^c \pm 0.011$	$14.4^c \pm 0.012$
Tyrosine value (mg/100g)	$9.16^d \pm 0.28$	$11.23^c \pm 0.5$	$13.14^b \pm 0.05$	$13.42^b \pm 0.12$	$14.30^a \pm 0.16$
Shear force (N)	$58.01^a \pm 0.74$	$51.84^b \pm 0.73$	$40.24^c \pm 0.74$	$40.89^c \pm 0.45$	$41.69^c \pm 0.69$
Collagen solubility (%)	$30.28^c \pm 0.096$	$32.05^b \pm 0.311$	$34.63^a \pm 0.357$	$34.92^a \pm 0.296$	$35.36^a \pm 0.245$

Table 2: L*,a* and b* colour values of control and treatment chicken legs

	C1	C2	T_1	T_2	T_3
L* value	$52.07^b \pm 0.08$	$52.33^b \pm 0.07$	$53.26^a \pm 0.09$	$53.27^a \pm 0.15$	$53.31^a \pm 0.08$
a* value	9.32 ± 0.13	9.28 ± 0.10	9.29 ± 0.04	9.37 ± 0.07	9.34 ± 0.08
b* value	18.56 ± 0.44	18.59 ± 0.39	18.63 ± 0.31	18.66 ± 0.38	18.64 ± 0.34

Table 3: Sensory scores of control and treatment chicken legs

	C1	C2	T_1	T_2	T_3
Colour score	8 ± 0	8 ± 0	8 ± 0	8 ± 0	8 ± 0
Flavour score	7.89 ± 0.02	7.89 ± 0.07	7.89 ± 0.06	7.89 ± 0.07	7.89 ± 0.06
Sourness score	8 ± 0	8 ± 0	8 ± 0	8 ± 0	8 ± 0
Juiciness score	$7.81^b \pm 0.02$	$7.96^a \pm 0.02$	$7.96^a \pm 0.04$	$7.96^a \pm 0.04$	$7.96^a \pm 0.02$
Tenderness score	7.72 ± 0.02	7.8 ± 0.05	7.88 ± 0.05	7.89 ± 0.04	7.94 ± 0.02
Aftertaste score	8 ± 0	8 ± 0	8 ± 0	8 ± 0	8 ± 0
Overall acceptability score	$7.85^b \pm 0.02$	$7.86^b \pm 0.02$	$7.96^a \pm 0.02$	$7.96^a \pm 0.02$	$7.96^a \pm 0.02$

Table 4: Chemical composition-Moisture (%), Ash (%) and protein (%) of control and treatment chicken legs

	C1	C2	T_1	T_2	T_3
Moisture (%)	$74.64^d \pm 0.04$	$74.95^c \pm 0.05$	$75.05^{bc} \pm 0.03$	$75.15^{ab} \pm 0.02$	$75.22^a \pm 0.03$
Ash (%)	$0.945^d \pm 0.015$	$1.004^{cd} \pm 0.029$	$1.089^{bc} \pm 0.053$	$1.153^{ab} \pm 0.041$	$1.215^a \pm 0.031$
Protein (%)	$17.72^a \pm 0.03$	$17.47^b \pm 0.03$	$17.38^b \pm 0.02$	$17.13^c \pm 0.05$	$17.01^d \pm 0.04$
Fat (%)	6.54 ± 0.10	6.39 ± 0.04	6.40 ± 0.18	6.38 ± 0.09	6.37 ± 0.03

Conclusion

The study demonstrated that vacuum tumbling with plant-derived vinegar-based marinades significantly improved the physico-chemical properties of broiler chicken legs. Treatment groups marinated with coconut, apple cider, and black plum vinegar exhibited higher marinade absorption, water holding capacity, lightness (L*) values, collagen solubility, and antioxidant activity, while showing reduced pH, shear force, and cooking loss compared to controls. Among the treatments, black plum vinegar based marinade showed the most pronounced effects on tyrosine release and antioxidant potential, indicating enhanced proteolysis and bioactivity. These findings suggest that incorporating natural fruit vinegars in vacuum-tumbler marination can be an effective strategy to enhance meat quality, tenderness, and functional properties.

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