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Effect of Marinade of Fermented Unpasteurised Fruit Vinegars on Poultry Meat Quality

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Abstract: The aim of the study undertaken was to determine the effect of a marinade using unpasteurised fruit vinegars and spirit vinegar, on the quality of raw poultry meat fresh (F) and after thawing (S). The raw material for the study was chicken breast muscle fillets. The meat was divided into two batches (F and S). This study evaluated the potency of unpasteurized quince, apple, grape and cherry fruit vinegars. The effect of the type of fruit vinegar used in the marinating process on the pH value of the meat was shown. Meat (F) marinated in fruit vinegars had a lower pH (4.55–5.04 pH) compared to the control group (5.65 pH). When poultry meat (F, S) was marinated in fruit vinegars, there was a brightening of colour, as evidenced by the higher values of the (L*) component. The use of vinegar in marinating poultry affected the rheological characteristics: hardness, elasticity, chewiness, gumminess, adhesiveness, cohesiveness, stringiness and bumpiness ($p < 0.05$) depending on the type of fruit vinegar used. The type of poultry meat used (F) and (S) in the marinating process had an effect ($p < 0.05$) on hardness, springiness, chewiness adhesiveness, and bumpiness, but not on their ($p > 0.05$) gumminess, cohesiveness, stringiness. Using unpasteurized fruit vinegars to marinate poultry meat can be an attractive alternative to commonly used marinades.

Keywords: marinade; unpasteurised fruit vinegar; poultry meat; texture

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1. Introduction

Marination is a long-established preservation method that entails immersing meat products in liquids infused with spices, flavorings, and functional additives [1,2]. It is the treatment of raw meat with various ingredients, including oil, salt, phosphate, organic acids, sugar, herbs, spices and aromatic ingredients, to tenderise the meat and improve its juiciness and flavour [3,4]. Using a variety of additives, marinating aims to improve the colour, flavour and softness of different types of meat [3,5]. Marinating is also used to improve microbiological quality and ensure meat safety [6,7]. This is very important because meat, due to its nutrient content, high water activity and pH value, creates a suitable environment that favours the growth of microorganisms [8]. The use of antimicrobials is essential for reducing pathogen risk and safeguarding human health [9]. Marination effectively enhances meat tenderness and palatability while also improving consumer appeal. Additionally, it helps prevent microbiological and chemical degradation, increasing food safety by inhibiting the growth of harmful microorganisms [10].

Vinegar is a fermented product that has been considered a functional food since ancient times. It is often used in meals and salads, as well as for the preparation and preservation of marinades, mayonnaise, tomato paste, mustard and other similar foods. The total

phenolic content, as well as the antioxidant and antimicrobial properties of vinegar, depend on the raw materials used and the production techniques applied [11–13]. Vinegar can be derived from various sources, including fruits, vegetables, cereals, and herbs, with its name reflecting the primary ingredient. It retains numerous vitamins and bioactive compounds inherent to its base material [14]. The practice of incorporating fruit vinegar into meat products has a long history [15,16]. Its use has been associated with multiple advantages, such as enhancing sensory characteristics, color, flavor, and tenderness, while also contributing to microbiological safety and extending shelf life [3,17,18].

Texture is a key quality attribute of meat and its products, directly affecting consumer acceptance. It is determined by chemical composition, structural characteristics, and rheological properties [19]

Consumers increasingly expect meat and meat products with natural ingredients that ensure high food quality and also contribute to their health. Biologically active compounds in fruit vinegar enhance the health benefits of meat products [20–22]. Using natural preservatives allows for reducing or replacing synthetic ones, leading to positive effects valued by consumers [23,24].

Fruit juices such as grape [7], mango, pineapple [25], cherry and plum [26] are often used for marinating poultry meat. The use of fruit juices in the marinating process improves the textural properties of meat [27,28]. In addition, the use of fruit juice in marinade can improve the aroma, flavor, juiciness and tenderness of meat [29]. Marinating also affects the ability of meat to retain water, which can increase the juiciness of the final product. However, it is worth noting that the quality of marinated products depends on the marinating method, the type of marinade and the conditions under which it is carried out [28,29]. Adding vinegar to a marinade improves traits indicative of meat quality [15,16]. Numerous benefits of using vinegar have been noted, such as positive effects on meat sensory attributes such as color, palatability, tenderness and microbiological safety, as well as improved product shelf life [3,6,17,18,28].

Our study fills a gap in the scientific literature, as there are few studies on the effects of unpasteurized vinegars on meat quality including rheological properties, so it can be assumed that this is a future research direction.

The aim of this study was to determine the effect of fermented unpasteurised fruit vinegars (quince, apple, grape and cherry vinegars) obtained by natural fermentation, on the physicochemical and rheological properties of raw poultry meat.

2. Materials and Methods

2.1. Materials

The raw material for the study was poultry meat–chicken breast muscle fillets, purchased from a standard retail outlet (Poland). The purchased meat was from a single production batch, in order to eliminate possible differences due to raw material parameters. The purchased meat was divided into two batches (F, S) (Table 1). Batch (F) was fresh meat, batch (S) meat was stored under refrigeration, after 5 days the meat was thawed and analysed. Meat was cut into pieces weighing 15.00 ± 0.50 g in the direction of muscle fibers (each sample).

Table 1. Meat samples tested in the study.

Parameter		pH	Color		
			L	a	b
Meat	F	5.38 ± 0.07	86.10 ± 0.07 ^{x}	−0.50 ± 0.04 ^{x}	0.48 ± 0.02 ^{x}
	S	5.30 ± 0.13	86.31 ± 0.13 ^{y}	−0.43 ± 0.05 ^{y}	0.63 ± 0.11 ^{y}

Explanation: F—fresh meat, S—thawed meat, ^{x,y}—mean values denoted by different letters in the columns are statistically significantly different at $p < 0.05$ for meat (F, S).

Spirit vinegar was purchased at retail (contains 10% acetic acid). For testing, the spirit vinegar was diluted 1:1 to obtain a 5% solution. The fruit vinegars used in the experiment were made from 30 g fruit 4 g sugar and 100 g water. The sugar was dissolved in boiled water, which was poured over the raw material after cooling. The mixture was stored at room temperature in covered, glass vessels with access to air. It was stirred twice a day for 3 weeks. When the acetic fermentation was over, the vinegar was decanted from the lees and used for testing. Fresh fruits (quince, apple, grape, cherry), from farms in Poland, was used to make the vinegars. The fruit was not subjected to any chemical treatment. The resulting vinegar was characterised by appropriate colour and acidity (Table 2). Vinegar samples were prepared at 5% concentration.

Table 2. Vinegar samples tested in the study.

Parameter		pH	Color		
			L	a	b
Vinegar	I	2.54 ± 0.02^{a}	99.99 ± 0.02^{a}	-0.11 ± 0.00^{a}	0.40 ± 0.01^{a}
	II	2.92 ± 0.01^{b}	76.22 ± 0.04^{b}	5.37 ± 0.03^{b}	44.20 ± 0.15^{b}
	III	3.19 ± 0.01^{c}	82.01 ± 1.43^{c}	-1.60 ± 0.27^{c}	14.83 ± 1.34^{c}
	IV	3.44 ± 0.02^{d}	67.74 ± 0.21^{d}	13.18 ± 0.11^{d}	24.12 ± 0.11^{d}
	V	3.46 ± 0.01^{d}	6.46 ± 0.02^{e}	44.88 ± 0.05^{e}	11.13 ± 0.03^{e}

Explanation: I—spirit vinegar, II—quince vinegar, III—apple vinegar, IV—grape vinegar, V—cherry vinegar, $^{a–e}$—mean values marked with different letters in the columns are statistically significantly different at $p < 0.05$ for vinegar (I–V).

2.2. Marination Procedure

Forty-eight meat samples were cut from the batch (F), which were divided into six groups of eight samples each. The meat was cut into pieces measuring a cube of 20 mm side, weight 15.00 ± 0.50 g in the direction of muscle fibers (each sample). The control group (C) consisted of 8 samples not subjected to any treatment. The remaining 40 samples were treated with spirit vinegar (I) and unpasteurised vinegars: quince (II), apple (III), grape (IV) and cherry (V). Samples were marinated in vinegar using the dipping method. Samples were stored at 4 °C for 12 h in sealed plastic containers. The batch of meat (S) was thawed and tested according to the scheme for batch (F).

2.3. Measurement of pH

The pH was measured with a Hanna HI 99163 pH meter, calibrated beforehand using pH 4 and 7 buffer solutions.

2.4. Measurement of Marinade Uptake

Marinade uptake was determined by weighing meat samples before (W1) and after marination (W2). The uptake was then calculated using the following Equation (1):

$$\text{MU marinade uptake [\%]} = [(W2 - W1)/W1] \times 100, \quad (1)$$

2.5. Colour Measurement

The study was carried out using instrumental colour measurement with a Chroma Meter Cr-400, Konica Minolta (Osaka, Japan), using the CIELAB method. The results of the colour measurement are given as trichromatic values in the L*, a*, b(CIE) system, where: L*—denotes metric brightness; a*—colour intensity from red to green; b*—colour intensity from yellow to blue. The saturation (C*) and tone (h°) of the colour were also read from the instrument.

2.6. Textural Analyses

Texture profile analysis, was carried out using the TexVol TVT-300XP/XPH texture analyser, manufactured by Perten Instruments (Täby Sweden). The test samples for the

TPA (Texture Profile Analysis) test were in the shape of a cube with a side of 20 mm, which were cut from the middle of the sample slice. The samples were allowed to equilibrate to room temperature before analysis. The test material was placed on the base of the textometer in such a way that the muscle fibres were aligned longitudinally to the direction of compression. The plunger above the test meat products moved at a constant speed of 2.0 mm/s, consequently contributing to compressing the test sample to 70% of its original height. The TPA recorded the following attributes: hardness, elasticity, chewiness, gumminess, adhesiveness, bumpiness, stringiness. Texture profile analysis for each group was performed for 8 repetitions of the shear force measurement, and texture parameters were determined and calculated from the recorded curve.

2.7. Statistical Analysis

Statistical evaluations were carried out using Statistica 13.3 software [30]. The results in the tables are shown as the mean ± standard deviation (SD) and Standard Error of the Mean (SEM).

The effects of the type of meat used (F, S) and the type of vinegar used on meat quality were verified using ANOVA analysis, the results took into account the data: 2 useful applications of meat (F—fresh meat, S—thawed meat) × 6 groups (control and I—spirit vinegar, II—quince vinegar, III—apple vinegar, IV—grape vinegar, V—cherry vinegar) x 8 repetitions. Significant differences between the mean values of the traits were assessed using Duncan's test. Results were considered statistically significant at $p < 0.05$. A multivariate analysis of variance was conducted to assess the main effects, including the influence of M (type of meat), O (vinegar used for marination), and their interaction (M × O).

3. Results

The marinating process of fresh poultry meat (F) with different types of vinegar had a significant ($p < 0.05$) effect on acidity. The greatest changes were observed in samples marinated in spirit vinegar compared to samples from the control group ($p < 0.05$). The pH value of fresh poultry meat samples marinated in quince, apple and grape vinegar was comparable ($p > 0.05$) and significantly different to samples from the control group and samples marinated in spirit vinegar ($p < 0.05$) (Table 3).

Marinating thawed poultry meat (S) with different types of fruit vinegars had a significant ($p < 0.05$) effect on acidity. Measuring the pH of samples marinated in spirit vinegar showed significantly ($p < 0.05$) lower values compared to meat samples (F) marinated in apple and grape vinegar (Table 3). Overall, the pH values of traditionally produced vinegar were higher than those of industrially produced vinegar (Table 2).

It was observed that the pickle absorption values ranged from 8.68% to 11.25%. However, the effect of marinating in different fruit vinegars on marinade absorption values was not found to be significant ($p > 0.05$).

Marinating fresh poultry meat (F) with different types of vinegar had a significant ($p < 0.05$) effect on colour parameters (L*, a*, b*, C*, h°). The use of apple and grape vinegar increased the brightness (L*) of the meat samples while the use of cherry vinegar decreased the proportion of colour (L*) compared to samples from the control group. A reddening (a*) of the samples treated in sherry vinegar was observed, this was due to the natural colour of the vinegar. The other test samples (F) marinated in vinegar showed a comparable colour (a*)—and this was in the direction of greening. The use of spirit and cherry vinegar in the marinated meat (F) decreased the proportion of yellow colour (b*) compared to the control group samples, while the use of apple and grape vinegar increased the proportion of yellow colour (b*). The surface area of meat samples (F) marinated in apple and grape vinegar had the highest saturation value (C*), while samples marinated in sherry vinegar had the lowest ($p < 0.05$). The surface area of

the meat samples (F) marinated in cherry vinegar had significantly ($p < 0.05$) the lowest colour tone value (h°) compared to the other samples (Table 3).

Table 3. Effect of marinating on the quality of raw breast muscle fresh and after the thawing process.

Parameter		pH	MU	Color				
				L	a	b	C	h°
C	F	5.65 ± 0.05 ^{a}	-	86.21 ± 0.12 ^{a}	−0.42 ± 0.03 ^{a}	0.59 ± 0.02 ^{a}	0.73 ± 0.03 ^{a}	125.26 ± 0.75 ^{ab}
I		3.89 ± 0.26 ^{b}	10.17 ± 0.60	86.52 ± 0.15 ^{ac}	−0.48 ± 0.05 ^{a}	0.44 ± 0.06 ^{b}	0.65 ± 0.03 ^{a}	137.56 ± 6.51 ^{b}
II		4.55 ± 0.23 ^{c}	10.06 ± 2.88	86.66 ± 0.52 ^{ac}	−0.37 ± 0.08 ^{a}	0.64 ± 0.11 ^{ad}	0.74 ± 0.12 ^{a}	120.07 ± 4.81 ^{a}
III		4.64 ± 0.49 ^{cd}	10.20 ± 4.20	87.28 ± 0.06 ^{b}	−0.50 ± 0.05 ^{a}	0.90 ± 0.01 ^{c}	1.03 ± 0.02 ^{b}	119.35 ± 2.62 ^{a}
IV		4.90 ± 0.26 ^{cd}	10.76 ± 0.26	86.76 ± 0.29 ^{c}	−0.35 ± 0.19 ^{a}	0.76 ± 0.13 ^{ad}	0.87 ± 0.06 ^{c}	115.26 ± 15.04 ^{a}
V		5.04 ± 0.22 ^{d}	8.68 ± 0.63	85.35 ± 0.08 ^{d}	0.09 ± 0.04 ^{b}	0.24 ± 0.03 ^{e}	0.26 ± 0.02 ^{d}	72.53 ± 6.06 ^{c}
SEM		0.12	0.54	0.15	0.05	0.05	0.06	5.13
p-value, group F		*	NS	*	*	*	*	*
C	S	4.51 ± 0.46	-	86.35 ± 0.21 ^{x}	−0.08 ± 0.47	0.78 ± 0.06 ^{x}	0.87 ± 0.06 ^{x}	116.34 ± 4.23 ^{x}
I		4.26 ± 0.22 ^{x}	9.41 ± 2.07	86.92 ± 0.59 ^{y}	−0.44 ± 0.01 ^{x}	0.73 ± 0.37 ^{x}	0.87 ± 0.32 ^{x}	124.05 ± 11.47 ^{x}
II		4.44 ± 0.15	11.25 ± 0.25 ^{x}	86.45 ± 0.09 ^{y}	−0.33 ± 0.02 ^{x}	0.67 ± 0.03 ^{x}	0.74 ± 0.03 ^{x}	116.04 ± 1.95 ^{x}
III		4.79 ± 0.46 ^{y}	11.17 ± 0.59 ^{x}	86.57 ± 0.26 ^{y}	−0.34 ± 0.03 ^{x}	0.89 ± 0.06 ^{x}	0.95 ± 0.05 ^{x}	111.05 ± 2.69 ^{x}
IV		4.77 ± 0.20 ^{y}	11.10 ± 0.60	86.61 ± 0.43 ^{y}	−0.23 ± 0.10	0.76 ± 0.13 ^{x}	0.80 ± 0.15 ^{x}	106.70 ± 4.32 ^{x}
V		4.44 ± 0.15	9.18 ± 0.28 ^{y}	85.32 ± 0.05 ^{y}	0.12 ± 0.09 ^{y}	0.19 ± 0.04 ^{y}	0.23 ± 0.03 ^{y}	59.45 ± 23.00 ^{y}
SEM		0.06	1.28	0.14	0.06	0.06	0.06	5.60
p-value, group S		*	NS	*	*	*	*	*
p-value for main effects (group F-group S)								
M		*	NS	NS	*	NS	NS	*
O		*	NS	*	*	*	*	*
M × O		*	NS	NS	NS	NS	NS	NS

Explanation: F—fresh meat, S—frozen meat, MU—Marinade uptake (%). C—control, I—spirit vinegar, II—quince vinegar, III—apple vinegar, IV—grape vinegar, V—cherry vinegar. $^{a–e}$—values with different letters in the columns indicate a statistically significant difference at $p < 0.05$ for group F. ^{x,y}—values with different letters in the columns indicate a statistically significant difference at $p < 0.05$ for group S. * Statistically significant effect ($p < 0.05$); NS—No statistically significant effect ($p > 0.05$).

Marinating thawed poultry meat (S) with different types of vinegar showed clear changes ($p < 0.05$) in the values of colour determinants, i.e., brightness (L*), parameter (a*) and (b*), saturation (C*) and colour tone value (h°). The use of fruit vinegars in the marinating process increased the brightness (L*) of meat samples (S) marinated with spirit, quince, apple and grape vinegar and decreased the brightness (L*) of meat treated with sherry vinegar ($p < 0.05$) compared to the control sample. Reddening (a*) of samples treated in sherry vinegar was observed. The use of sherry vinegar reduced the proportion of yellow colour (b*) in the meat samples (S) compared to the samples in the control group. The area of meat samples (S) marinated in sherry vinegar had the lowest saturation value (C*) ($p < 0.05$). The surface of the meat samples (S) marinated in cherry vinegar had significantly ($p < 0.05$) the lowest colour tone value (h°) compared to the other samples (Table 3).

The type of fruit vinegar used in the marinating process had a significant effect on the pH value of the meat and on the colour parameters, i.e., brightness (L*), colour (a*) and (b*), saturation (C*) and colour tone value (h°). In contrast, the type of meat used (F, S) had an effect on the pH value of the meat and on the colour parameters, i.e., colour (a*) and colour tone value (h°).

The process of marinating fresh poultry meat (F) with different types of fruit vinegar had a significant ($p < 0.05$) effect on texture, i.e., hardness, elasticity, chewiness, gumminess, adhesiveness, cohesiveness, stringiness and bumpiness (Table 4). In the study, a reduction in the hardness of fresh meat (F) was observed in samples marinated in quince, apple and grape vinegar compared to control samples ($p < 0.05$). A decrease in the springiness of fresh meat (F) was observed in samples marinated in quince, apple and grape vinegar compared to control samples ($p < 0.05$). An increase in the chewiness of fresh poultry meat (F) marinated in quince vinegar and a decrease in the chewiness value in samples marinated in grape vinegar were observed compared to control samples ($p < 0.05$). Marinating quince and cherry vinegar marinated poultry meat (F) increased the value of gumminess ($p < 0.05$). Marinating with quince and grape vinegar increased the value of adhesiveness of fresh meat (F) ($p < 0.05$). The

marinating process with quince, apple and cherry vinegar increased cohesiveness compared to samples from the control group ($p < 0.05$). Marinating fresh poultry meat (F) with spirit vinegar, quince vinegar, grape vinegar and cherry vinegar influenced an increase in cohesiveness values compared to samples from the control group ($p < 0.05$). It was shown that marinating with fermented unpasteurized quince, apple, grape and cherry fruit vinegars influenced a decrease in the value of bounce compared to samples from the control group ($p < 0.05$).

Table 4. Effect of marinating with fermented unpasteurized vinegars on the rheological properties of fresh and thawed poultry meat.

Parameter		Hardness	Springiness	Chewiness	Gumminess	Adhesiveness	Cohesiveness	Stringiness	Resilience
C	F	43.60 ± 5.34 ^{a}	0.95 ± 0.01 ^{a}	13.40 ± 0.17 ^{a}	14.13 ± 0.07 ^{a}	2.39 ± 0.83 ^{a}	0.28 ± 0.05 ^{a}	5.56 ± 0.27 ^{a}	0.37 ± 0.07 ^{a}
I		45.27 ± 13.14 ^{a}	0.64 ± 0.09 ^{b}	11.34 ± 5.18 ^{a}	16.22 ± 5.42 $^{a\,b}$	4.01 ± 0.43 ^{b}	0.31 ± 0.02 ^{a}	6.52 ± 0.32 ^{b}	0.21 ± 0.06 ^{b}
II		39.09 ± 2.79 ^{ab}	0.84 ± 0.03 ^{c}	14.73 ± 1.15 ^{ab}	17.58 ± 1.91 ^{b}	1.47 ± 0.18 ^{ac}	0.41 ± 0.02 ^{b}	6.04 ± 0.00 ^{c}	0.15 ± 0.02 ^{c}
III		32.36 ± 1.32 ^{b}	0.90 ± 0.04 ^{ac}	11.35 ± 1.57 ^{ac}	12.55 ± 1.16 ^{ac}	0.94 ± 0.02 ^{c}	0.35 ± 0.02 ^{c}	5.95 ± 0.20 ^{ac}	0.17 ± 0.02 ^{bc}
IV		39.19 ± 1.67 ^{ab}	0.64 ± 0.10 ^{b}	8.00 ± 1.57 ^{d}	12.53 ± 0.50 ^{ac}	5.98 ± 2.23 ^{d}	0.29 ± 0.01 ^{a}	7.56 ± 0.44 ^{d}	0.13 ± 0.01 ^{c}
V		40.67 ± 7.43 ^{a}	0.83 ± 0.12 ^{dc}	13.47 ± 4.77 ^{a}	16.23 ± 4.61 ^{ab}	2.75 ± 1.53 ^{a}	0.36 ± 0.04 ^{c}	6.35 ± 0.81 ^{bc}	0.15 ± 0.02 ^{c}
SEM		1.09	0.02	0.52	0.50	0.29	0.01	0.11	0.01
p-value, group F		*	*	*	*	*	*	*	*
C	S	53.61 ± 21.27 ^{x}	0.50 ± 0.04 ^{x}	9.81 ± 5.04 ^{x}	18.40 ± 8.33 ^{x}	3.96 ± 0.64 ^{x}	0.30 ± 0.02 ^{x}	7.57 ± 0.73 ^{xz}	0.14 ± 0.01 ^{xy}
I		48.07 ± 5.95 ^{xy}	0.80 ± 0.15 ^{y}	13.60 ± 1.83 ^{x}	17.22 ± 2.02 ^{x}	14.11 ± 15.72 ^{y}	0.32 ± 0.02 ^{x}	6.23 ± 2.81 ^{xyz}	0.11 ± 0.02 ^{x}
II		54.09 ± 18.09 ^{x}	0.61 ± 0.15 ^{x}	10.90 ± 4.64 ^{x}	17.53 ± 7.02 ^{x}	7.82 ± 6.66 ^{xy}	0.29 ± 0.01 ^{x}	4.97 ± 3.01 ^{xy}	0.17 ± 0.09 ^{xy}
III		35.27 ± 1.42 ^{y}	0.47 ± 0.06 ^{xz}	5.30 ± 1.51 ^{y}	11.02 ± 1.85 ^{y}	8.56 ± 6.76 ^{xy}	0.28 ± 0.04 ^{x}	4.82 ± 3.47 ^{y}	0.17 ± 0.05 ^{xy}
IV		42.64 ± 5.10 ^{xy}	0.51 ± 0.06 ^{xz}	10.58 ± 5.35 ^{x}	19.04 ± 8.07 ^{x}	9.76 ± 3.49 ^{xy}	0.39 ± 0.13 ^{y}	7.94 ± 0.35 ^{z}	0.17 ± 0.07 ^{y}
V		46.97 ± 4.82 ^{xy}	0.76 ± 0.11 ^{y}	13.00 ± 3.50 ^{x}	16.61 ± 2.28 ^{xy}	1.87 ± 1.42 ^{x}	0.32 ± 0.02 ^{x}	5.24 ± 2.47 ^{xy}	0.14 ± 0.02 ^{xy}
SEM		1.89	0.02	0.67	0.87	1.19	0.01	0.38	0.01
p-value, group S		*	*	*	NS	*	*	*	NS
p-value for main effects (group F–group S)									
M		*	*	*	NS	*	NS	NS	*
O		*	*	*	*	*	*	*	*
M × O		NS	*	*	NS	NS	*	NS	*

Explanation: C—control, I—spirit vinegar, II—quince vinegar, III—apple vinegar, IV—grape vinegar, V—cherry vinegar, F—fresh meat, S—frozen meat. $^{a–d}$—average values marked with different letters in columns are statistically significantly different at $p < 0.05$ for group F. ^{x,y,z}—mean values denoted by different letters in the columns are statistically significantly different at $p < 0.05$ for the S group. * statistically signifcant effect ($p < 0.05$); NS—no statistically signifcant effect ($p > 0.05$).

The process of marinating thawed poultry meat (S) with different types of vinegar had a significant ($p < 0.05$) effect on hardness, chewiness, adhesiveness, cohesiveness, stringiness, but not on their gumminess and bumpiness ($p > 0.05$). Marinating with spirit vinegar increased the hardness value of thawed meat (S) ($p < 0.05$). Marinating with fermented unpasteurized fruit vinegars, i.e., apple, grape and cherry vinegars, was shown to decrease the hardness of thawed meat (S) ($p > 0.05$). An increase in the springiness of frozen poultry meat (S) marinated in spirit and cherry vinegar was observed compared to control samples ($p < 0.05$). A reduction in the chewiness of frozen meat (S) marinated in grape vinegar was observed compared to control samples ($p < 0.05$). Marinating thawed poultry meat (S) with sherry vinegar reduces the adhesiveness value ($p < 0.05$).

The type of poultry meat used—fresh (F) and thawed (S) in the marinating process had an effect ($p < 0.05$) on hardness, springiness, chewiness adhesiveness, and bumpiness, but not on their ($p > 0.05$) gumminess, cohesiveness, and stringiness (Table 4).

It was shown that marinating with fermented unpasteurized fruit vinegars had a significant ($p < 0.05$) effect on the rheological properties of meat.

4. Discussion

The pH value is a key factor influencing food quality. Several factors, such as the marination technique, duration, and the type and pH of the marinade, impact the success of the marinating process. The pH of the marinade plays a significant role in determining properties such as water retention, tenderness, juiciness, and the color of the meat [31–33].

The study carried out demonstrated the effect of marinating on the pH of raw breast meat. The results of meat pH measurements showed that marinating had a significant effect on lowering the pH of raw fresh poultry meat. The decrease in pH during marinating poultry meat in acidic solutions has been reported by many authors [7,10,34–40].

In a study by [10,34,37–39], the absorption of marinade by chicken meat was found to increase as pH decreased, leading to reduced cooking losses. When the meat's pH deviates from its isoelectric point, lower pH enhances its water-binding capacity, which in turn decreases cooking losses. Aktaş et al. [41] further confirmed that shifting the pH away from the isoelectric point enhances water retention within the meat structure. Additionally, variations in the pH of marinated meats may be influenced by the composition of the marinade, as demonstrated by Vişan et al. [42].

Lowering the pH of meat below the isoelectric point can increase the positive charge of myofibrillar proteins, thus causing greater repulsive forces between thick and thin fibers, resulting in the expansion of the protein network [7,43,44].

Also, Sionek et al. [45] studying the pH values of beef hams marinated with apple cider vinegar noted a decrease in pH values compared to the control sample. The authors [45] explain this by the behavior of acetic acid bacteria, once the threshold is exceeded some acetic acid bacteria can further oxidize the acetic acid produced to CO_2 and H_2O. [24]. In Study [45], the number of lactic acid bacteria increased while the pH decreased.

Incorporating fruit juice into marinades can enhance the aroma, flavor, juiciness and tenderness of meat through protein denaturation [29,46].

Acidic marination affects muscle structure by inducing the denaturation of muscle fibrils and connective tissue proteins, promoting the proteolytic degradation of myofibrillar proteins, and increasing collagen solubility during cooking [47]. These changes enhance the water-binding capacity and improve cooking yield. As a result, muscle fibrils become less rigid, leading to improved textural properties and enhanced sensory attributes such as color and aroma [17,48]. Fruit-derived proteolytic enzymes have been shown to facilitate tenderization by selectively breaking down collagen, myofibrillar proteins, and perimysium in muscle cells [49,50]. However, Cao et al. [51] emphasized the necessity of carefully controlling enzyme activity to optimize its diffusion in meat and to prevent excessive enzymatic action, which could negatively affect texture, taste, color, and other quality parameters.

Yusop et al. [52] reported that varying the marination time (30–180 min) and using marinades with different pH levels (pH 3–4.2) had no significant impact on the pH of chicken breast meat.

Color is a key parameter determining the technological quality of meat and its products [53,54]. Our own research showed that marinating affected the colour of raw breast meat both fresh and after thawing.

Myoglobin is the primary pigment responsible for meat coloration. Acidic marinades can enhance the conversion of myoglobin into metmyoglobin, which influences muscle coloration [55–58]. According to Fernandez-Lopez et al. [59] and Hui [60], meat color largely depends on the concentration and chemical state of heme pigments, as well as their ability to absorb and scatter light. Sokołowicz et al. [61] found that marinated meat exhibited a lighter appearance (higher L* values) due to a reduction in pH following marination.

Similarly, Swatland [62] observed a strong correlation between meat brightness and pH, where a lower pH increases light scattering, resulting in elevated L* values.

Research by [56] suggests that significant myoglobin denaturation may be responsible for the reduction in redness (a*) and the increase in yellowness (b*) observed in marinated fillet samples. Serdaroglu et al. [63] reported that turkey breast marinated with citric or grapefruit acid exhibited greater brightness (L* 55.40–63.10) and a lower intensity of red coloration (a* 1.20–2.30) compared to the control group. The authors attributed this effect to the lower pH and ionic strength, which cause muscle proteins to swell and alter light reflection, leading to a lighter meat color [63].

As noted in [56], acidic marinades can lead to myoglobin denaturation, which plays a key role in determining muscle color. Extensive myoglobin denaturation may contribute to reduced redness (a*) and increased yellowness (b*) in marinated tenderloin samples. This relationship was further supported by correlation analyses, which revealed a significant relationship between pH and the color attributes of tenderloins. Karatepe et al. [56] investigated the impact of a hawthorn vinegar-based marinade on beef tenderloin quality and found that marination significantly influenced color attributes (L*, a*, b*) of raw samples. Their study revealed that marinating with 100% vinegar for 24 h resulted in a slight increase in L* values compared to the control. Comparable color modifications in marinated meat have been documented in other studies [18,64].

The composition of the marinade is also a factor shaping the colour of marinated meat [52,65].

Different varieties of vinegar have different effects on meat colour; the extraction of different pigments in vinegar onto the meat surface during marinating is assumed to be related to factors such as pH value, colour and vinegar content [17,58,66]. Sengun et al. [65] reported that meat marinated with blackberry vinegar exhibited the highest redness (a*) values. Similarly, Unal et al. [36] found that samples treated with black chokeberry vinegar had the most intense red coloration (highest a* values) and the lowest b* values. This effect is attributed to the naturally strong red pigmentation of black chokeberry.

Marinating the tested raw material with unpasteurized fruit vinegars significantly affected most of the texture parameters of poultry meat. The marinating treatment of marinated poultry meat (fresh and after thawing) affected the rheological properties of the meat, i.e., hardness, elasticity, chewiness adhesiveness, and bumpiness, but not their gumminess, cohesiveness, stringiness. In the study conducted, fresh meat marinated in fruit occts was characterized by less force required to cut them, indicating better texture. Smaller cutting force, that is, greater tenderness, was characterized by samples of fresh meat vs. after thawing. Greater elasticity was characterized by fresh versus thawed meat. The adhesiveness of poultry raw material increased after the freezing process, after freezer storage. The reason for the change in the value of this parameter may have been a change in the texture of the meat after thawing. It was also observed that in terms of adhesiveness, poultry meat differed statistically significantly according to the type of marinated meat (fresh and after thawing).

Multiple studies [38,53,54,66] indicate that acidic marinades significantly influence the textural properties of meat and meat products.

Research by Sengun et al. [65] examining the effects of organic fruit vinegars (blackberry, pomegranate, rose, and grape) on beef demonstrated that their application in marination significantly reduced meat hardness. Likewise, Sharedeh et al. [65] and Gault [39] reported that immersion in acidic marinades led to a pH drop below 5.0, which correlated with increased meat tenderness compared to the control samples. Furthermore, studies indicate that chicken breast marinated in 100% lemon juice exhibited significantly lower hardness values than non-marinated counterparts [67].

Karatepe et al. [56] observed no significant differences in springiness, cohesiveness, or resilience between marinated and non-marinated samples. Comparable findings were reported by Dilek et al. [37], who noted that chicken breast meat marinated with hawthorn vinegar exhibited similar values for these textural parameters when compared to untreated samples.

Kumar et al. [48] reported that a reduction in pH as a result of acidic marinades positively affects texture by increasing water absorption in poultry meat. Augustinska-Prejsnar et al. [68] found no effect of marinating with lemon juice on firmness as measured by cutting force on turkey meat in both raw and roasted samples.

In a study by Fencioglu et al. [17], the marinating process in different types of vinegar (balsamic, pomegranate, apple and grape) had a significant effect only on the elasticity value of the samples, but not on their firmness, cohesiveness or chewiness.

Differences between studies on rheological properties are thought to be due to differences in animal species (poultry, pork, beef), type of meat, marinating conditions (type of marinade, temperature, size, etc.) and cooking conditions (method, temperature, cooking time, etc.) [17,56].

5. Conclusions

The results of the present study show that the type of vinegar used to marinate poultry meat has an impact on meat quality

In the instrumental evaluation of the color of marinated poultry meat both fresh and after thawing in fruit vinegars, there was a brightening of the color, as evidenced by higher values of the (L*) component.

The study showed a favorable effect of marinating on the quality characteristics of raw meat both fresh and after thawing. The type of poultry meat used (fresh and after thawing) subjected to marinating influences the texture properties of the meat, i.e., hardness, elasticity, chewiness adhesiveness, and bumpiness, but not their gumminess, cohesiveness, stringiness. Lower cutting force, i.e., higher tenderness was characterized by fresh meat samples vs. after thawing. The best tenderness (lowest cutting force of 32.36–39.19 N) was characterized by fresh meat marinated in quince vinegar, apple vinegar and grape vinegar, while the highest (45.27 N) was for meat marinated in spirit vinegar. There was more elasticity in fresh a meat than in thawed meat.

The results obtained may be relevant for optimizing the selection of ingredients stoted for meat marinades. However, further research is needed to fully evaluate the effect of marinades made from fermented unpasteurized fruit vinegars on the quality of poultry meat including testing sensory properties and extending the study to other meats. The results of this research could pave the way for the commercial use of unpasteurized fruit vinegars in the meat industry, positioning them as a valuable asset in the vinegar market. The use of unpasteurized fruit vinegars as meat marinades presents a promising alternative to traditional methods. Future research may investigate the effects of marinating with less commonly used natural ingredients, as well as the incorporation of post-production by-products, such as fruit pomace, into marinade formulations. This strategy could contribute to food waste reduction, align with the 'no waste' movement, and potentially lower production costs.

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