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Effect of White Pomace Seasoning as a Natural Antioxidant for Chicken Products Packaged in Vacuum or Modified Atmosphere Conditions

Inmaculada Gómez *, Beatriz Melero, Isabel Jaime and Pilar Muñiz

Department of Biotechnology and Food Science, University of Burgos, Plaza Misael Bañuelos s/n, 09001 Burgos, Spain; bmelero@ubu.es (B.M.); ijaime@ubu.es (I.J.); pmuniz@ubu.es (P.M.)
* Correspondence: igbastida@ubu.es

Abstract: Chicken breasts and burgers (88% breast and 12% backfat) were evaluated for physico-chemical characteristics, thiobarbituric acid reactive substances (TBARS), and antioxidant capacity during storage in vacuum or atmosphere conditions for 18 days at 4 °C using the following two formulations: one without incorporating white pomace seasoning (WPS) and another with 3% WPS. The WPS was obtained from white grape skins, a byproduct resulting from the elaboration of white wine. The addition of the WSP decreased the L* values and increased the a* values, resulting in a significant turning toward brown tones in the chicken products. The addition of 3% of WSP led to higher values of ABTS and FRAP, regardless of the type of packaging. Both types of packaging significantly increased the levels of TBARS, although vacuum packaging proved more effective in protecting against lipid oxidation compared to modified atmosphere package (MAP). Additionally, the WSP improved the oxidative stability regarding the TBARS values. In conclusion, the WSP could be a viable alternative to chemical antioxidants and would lead to healthier and innovative chicken products.

Keywords: antioxidant capacity; lipid oxidation; meat products; storage stability; winemaking byproducts

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1. Introduction

Chicken meat has a high consumption rate, and ready-to-cook products constitute a significant portion of chicken products due to their widespread use and high acceptance among many consumers. Burgers are a popular meat product due to their convenience in cooking and ease of consumption. Additionally, there is a growing trend in the consumption of seasoned chicken breasts to meet evolving consumer demands.

As is well-known, the grinding process, which disrupts the muscle structure, renders the food matrix less stable, making it more susceptible to chemical and enzymatic oxidation processes and promoting increased microbial growth [1,2]. The same is true of the addition of salt, due to its prooxidant effect [3,4], and the presence of oxygen during the storage contribute to lipid oxidation. Likewise, the composition and fat content of the meat will also influence the oxidative process of the lipids [5].

In the meat industry, packaging is one of the most commonly employed methods for preservation. Traditional options are air-permeable packaging, vacuum packaging, and modified atmosphere packaging [6]. Moreover, the incorporation of antioxidants can extend the shelf life of meat products by slowing down lipid and protein oxidation. The industry is currently seeking natural antioxidants as an alternative to chemical antioxidants [7]. For instance, the high polyphenol content in plant or fruits has the potential to decrease oxidative reactions. The transformation of grape byproducts into wine pomace products, with a high concentration of bioactive compounds, represents environmentally sustainable and economically feasible methods [8] signifying a new alternative as a source

for functional food ingredients with preservative, antimicrobial, flavoring, and potentially healthy properties [9–11].

In this context, our research group has developed a seasoning from winemaking byproducts that is high in dietary fiber, minerals, and polyphenols, such as proanthocyanidins, flavonoids, phenolic acids, and stilbenes [12,13]. Ortega-Heras et al. [14] studied the effect of red wine pomace as a seasoning in chicken products to improve microbial stability and product quality, which led to a significant change in the color of chicken breasts. For this reason, we hypothesized that white wine pomace, with its high total polyphenol content [15], could be a good alternative that would not change the color of the product so radically. To date, studying the valorization and application of white grape seasoning in meat is novel, as it has barely been investigated compared to the studies conducted on the effect of red grape seasoning in meat products. In this context, this research aim was to evaluate the effect of the addition of 3% of white pomace seasoning (WPS) during refrigerated storage on chicken products (breasts and burgers) packaged in vacuum or atmosphere conditions, focusing on quality parameters (aw, pH, color), lipid oxidation, and antioxidant capacity.

2. Materials and Methods

2.1. Raw Materials

The chicken breasts, pork backfat, and salt were bought in a local supermarket. The seasoning used was obtained from white grape skins, a byproduct resulting from the alcoholic fermentation and maceration process of the skins of the *Verdejo* grape varieties. The process of obtaining the bioactive seasoning is patented under CCP:ES2524870 [8]. The seasoning was milled (particle size < 250 µm mesh) and kept in the dark until use, for no more than 6 months. The seasoning used is microbiologically stable.

2.2. Experimental Design

The following two different model products were studied: chicken burgers elaborated with minced chicken breast (88%) and pork backfat (12%) and sliced chicken breast. Both products had 2% salt added to them. For each product, the following two formulations were prepared: one control (C) without seasoning and another with 3% white pomace seasoning (S). This concentration was selected based on in vitro studies, as well as considering sensory and technological aspects. In previous in vitro studies [16], three doses of WPS were evaluated (2, 3, and 4%). According to in vitro studies, 4% WPS was effective against 10 strains of *Listeria monocytogenes*, whereas between 2 and 3% WPS were effective against *Campylobacter jejuni*, depending on the strain [16]. The selected concentration of WPS was 3%, which is the minimum effective dose against *C. jejuni*. This bacterium, whose main reservoir is poultry meat, is the most problematic microorganism in chicken products, having a high incidence in them [16]. Moreover, the use of more than 3% WPS in the elaboration of one of the model products studied (sliced chicken breast) generated unacceptable technological and sensory problems. The samples were stored in two types of packaging, vacuum (V) and modified atmosphere (A) (30% CO_2 and 70% N_2), and were refrigerated (4 ± 1 °C) for 18 days. The composition was evaluated on day 0, and the physicochemical parameters, aw, pH, color, antioxidant capacity (ABTS y FRAP), and lipid oxidation, were evaluated on days 0, 7, 14, and 18. Two experiments were carried out on different days for the two different products. Chicken breasts and pork backfat were purchased twice, once for each experiment. For each experiment and product (breast and burger), according to the formulation (C or S) and packaging (V or A) used, 4 treatments were studied (C-V, S-V, C-A, and S-A). In addition to this, two samples per treatment were elaborated. The following sections indicate the repetitions for each analysis.

2.3. Elaboration

The chicken breast slices were cut horizontally along the thickest side in order to obtain slices of 0.5 ± 0.25 cm thickness and then coated with 2% salt and, optionally, with

WPS (0 or 3%). Salt and WPS were evenly distributed over the surface of both sides using a kitchen brush for each one. Regarding the burgers, the ground chicken breast (88%), pork backfat (12%), salt (2%), and optionally, WPS (0 or 3%) were then blended together under vacuum in a Cato mixer (Sabadell, Spain) for 60 s. The mix was next weighed out into portions of 100 g and formed into small burgers between sheets of grease-proof paper using a burger press to an average size of 10 cm in diameter by 1.5 ± 0.15 cm in thickness. Half of the samples (breast slices and burgers) were placed in a transparent bag and vacuum-packaged (Tecnotrip, Terrasa, Spain). The other half of the samples were packaged in a modified atmosphere (30% CO_2 and 70% N_2) in a Smart 500 packaging machine (Ulma, Oñate, Spain).

2.4. Proximate Composition

The moisture content was evaluated using the difference in the sample weight before and after drying for 24 h at 103 ± 2 °C [17]. The fat content was evaluated using Soxhlet extraction with petroleum ether in a Buchi B-811 extraction system (Büchi, Flawil, Switzerland) [18] without previous hydrolysis. The dry and defatted residues were used for the analysis of protein. The protein content was determined using the Kjeldahl method [19], with a conversion factor of 6.25 to convert nitrogen into protein values.

2.5. Color

The color was measured using a Minolta CM-2600d spectrophotometer (Konica Minolta Sensing Inc., Osaka, Japan) (Illuminant D65, 10° standard observer). Following the CIELab system, lightness (L*), green–red coordinate (a*), and blue–yellow coordinate (b*) were measured. The analysis was carried out in duplicate, performing five measurements on the surface of each sample.

2.6. Physicochemical Analysis

Water activity (a_w) was evaluated using the equipment AquaLab CX-2, and pH was determined with a pH-meter Micro pH2001 (Crison, Barcelona, Spain). The analysis was carried out in duplicate, performing two measurements of each sample.

2.7. Antioxidant Capacity

The antioxidant activity was evaluated using the ABTS and FRAP methods. The extraction of each sample was performed in duplicate. For the extraction, 3 g of the sample was mixed with a solution of methanol/HCl 1N (9:1) for 24 h in an orbital shaker. Afterward, the mix was centrifuged and filtered.

2.7.1. ABTS Radical Scavenging Activity

The radical scavenging activity of samples was assessed according to the method described by Miller and Rice-Evans [20], adapted to meat samples. The ABTS reagent was prepared by mixing ABTS solution and K2O8S2 in Milli Q water (1:1). Next, 20 µL of the sample extract was mixed with 980 µL of the solution of ABTS reagent and incubated in a dark room for 15 min at 20 °C ± 4 °C, and the absorbance was read at 734 nm using a spectrophotometer (Genesys 10S UV-VIS, Thermo Fisher Scientific, Horsham, UK). Three replicates per extract were performed. Standard calibration was conducted using Trolox and results were expressed as µmol Trolox/g sample.

2.7.2. Ferric Reducing Antioxidant Power (FRAP) Assay

The antioxidant capacity of samples was assessed according to the method described by Benzie and Strain [21], adapted to meat samples. The working FRAP reagent was prepared by reacting 25 mL of 0.3 M sodium acetate buffer (pH 3.6) with 2.5 mL of 10 mM TPTZ, 2.5 mL of aqueous ferric chloride, and 3 mL of miliQ water. The FRAP reagent (30 µL) was mixed with 970 µL of the extract and incubated in a thermostatic bath at 37 °C for 30 min, and after reaching room temperature, the absorbance was measured at 593 nm.

Three replicates per extract were performed. Standard calibration was conducted using a solution of 10 mM $FeSO_4$, and the results were expressed as µmol Fe/g sample.

2.8. Lipid Oxidation

This method is based on the procedure reported by Maraschiello et al. [22]. Ultrapure water (20 mL) was added to 2.5 g of chicken meat. Sample homogenization was carried out using an Ultra-Turrax T-25D (IKA-Labortechnik, Staufen, Germany) at 13,500 rpm for 45 s. Cold 25% trichloroacetic acid (TCA) (5 mL) was then added to the homogenate followed by gentle stirring at 4 °C for 15 min. A supernatant was obtained using centrifugation at 10,000 rpm for 15 min at 4 °C. Supernatant (3.5 mL) was transferred to a test tube, and 1.5 mL of 0.6% aqueous thiobarbituric acid (TBA) was added. The screw-capped test tube was incubated for 30 min in a water bath at 70 °C (Selecta. S.A. Barcelona, España). The tubes were cooled, and the absorbance was recorded at 532 nm using a Thermo spectrophotometer (Genesys 10S UV-VIS, UK) against a blank consisting of 2.5 mL of ultrapure H2O, 1 mL 25% aqueous TCA, and 1.5 mL 0.6% TBA. Calibration curves were prepared using malondialdehyde (MDA) standard working solutions. The thiobarbituric acid reactive substance (TBARS) values are expressed as mg of MDA per kg of meat.

2.9. Data Analysis

The results of physicochemical properties were presented as the average ± standard deviation of the different replicates. An ANOVA test was performed with the purpose of determining whether statistically significant differences existed due to the formulation, packaging, or time at a significance level of $p < 0.05$. Tukey's test was performed with the objective of establishing between which samples there were statistically significant differences. A statistical analysis was carried out using the package SPSS Statistics version 24 (IBM Corp., New York, NY, USA).

3. Results and Discussion

3.1. Proximate Composition of Chicken Breast and Burgers

The main components of WPS, a byproduct of winemaking, and its antioxidant capacity have been published previously [15,23].

The proximate composition of the chicken breasts is set out in Table 1. The moisture content was lower in the samples with WPS than in the control breast (69.49 vs. 70.88%) due to the addition of the WPS, whose moisture (4.92%, [15]) is lower than that of chicken breast. The fat percentage was approximately 0.48%, and the protein percentage was approximately 24.11%, without significant differences between the formulations ($p > 0.05$). These values are similar to those reported by other authors for chicken breasts [24–26].

Table 1. Proximate composition of chicken breast and burger controls (C) and with 3% of white pomace seasoning (S). Values are expressed as mean (n = 4) ± standard deviation.

Product	Parameter (%)	Formulation	
		C	S
Breast	Moisture	70.88 ± 0.58 ^{b}	69.49 ± 0.81 ^{a}
	Fat	0.43 ± 0.11 ^{a}	0.52 ± 0.15 ^{a}
	Protein	24.74 ± 2.72 ^{a}	23.47 ± 0.54 ^{a}
Burger	Moisture	65.91 ± 1.14 ^{b}	63.86 ± 0.54 ^{a}
	Fat	11.17 ± 1.88 ^{a}	10.94 ± 1.01 ^{a}
	Protein	21.39 ± 1.15 ^{a}	20.71 ± 1.10 ^{a}

$^{a, b}$: mean values with different superscripts in the same row are significantly different ($p < 0.05$).

Regarding the model product simulating burgers, in this study, the moisture was higher in the control samples than in the samples with WPS (65.9% vs. 63.9%), similar to the

value reported in other studies of beef burgers [27]. The model burgers of the present study were formulated by adding a noticeable amount of pork backfat because the chicken breast had a very low fat content, and one of the objectives of the present study was to evaluate the antioxidant effect of white grape seasoning in meat products. The fat percentage was approximately 11.06%, and the protein percentage was approximately 21.05%, without significant differences between the formulations ($p > 0.05$).

3.2. Color

Table 2 presents the instrumental color parameters (L*, a*, and b*) for the chicken breasts and burgers with and without WPS during the 18-day refrigeration period.

Table 2. Changes in lightness (L*), redness (a*), and yellowness (b*) in chicken breast and burger controls (C) and those with 3% of white pomace seasoning (S) stored in vacuum (V) or atmosphere (A) conditions for 0, 7, 14, and 18 days. Values are expressed as mean (n = 10) ± standard deviation.

Product	Parameter	Treatment	Time (Days)			
			0	7	14	18
Breast	L*	C-V	44.32 ± 4.14^{1b}	44.81 ± 1.84^{1b}	49.88 ± 2.15^{2c}	49.82 ± 2.74^{2b}
		S-V	21.86 ± 5.93^{1a}	22.32 ± 3.92^{1a}	20.83 ± 5.58^{1a}	20.46 ± 5.23^{1a}
		C-A	46.53 ± 3.74^{1b}	44.22 ± 2.06^{1b}	44.12 ± 2.06^{1b}	46.66 ± 9.52^{1b}
		S-A	23.64 ± 5.13^{1a}	22.35 ± 3.84^{1a}	20.89 ± 2.76^{1a}	22.36 ± 5.760^{1a}
	a*	C-V	1.46 ± 0.79^{3a}	0.39 ± 0.94^{23b}	-0.57 ± 1.69^{12a}	-1.26 ± 0.67^{1a}
		S-V	5.18 ± 2.25^{1b}	5.64 ± 1.74^{1d}	6.02 ± 2.64^{1b}	6.60 ± 1.38^{1b}
		C-A	1.82 ± 0.93^{3a}	-1.04 ± 0.62^{1a}	0.67 ± 0.96^{2a}	-0.60 ± 0.76^{1a}
		S-A	3.05 ± 1.52^{1a}	3.05 ± 0.94^{1c}	5.51 ± 1.07^{2b}	5.75 ± 1.52^{2b}
	b*	C-V	9.24 ± 2.97^{2ab}	8.25 ± 1.70^{2b}	4.96 ± 1.11^{1a}	7.29 ± 1.13^{2a}
		S-V	9.20 ± 4.63^{1ab}	9.98 ± 2.69^{1b}	10.97 ± 2.73^{1b}	12.59 ± 2.49^{1b}
		C-A	12.58 ± 3.99^{2b}	5.45 ± 1.14^{1a}	6.18 ± 0.70^{1a}	6.60 ± 0.83^{1a}
		S-A	6.81 ± 1.74^{1a}	5.30 ± 2.18^{1a}	9.78 ± 1.88^{2b}	11.04 ± 3.15^{2b}
Burger	L*	C-V	53.12 ± 1.40^{b1}	56.03 ± 1.31^{b2}	58.96 ± 1.45^{b3}	58.41 ± 2.15^{b3}
		S-V	29.97 ± 2.58^{a1}	30.22 ± 1.76^{a1}	30.54 ± 2.50^{a1}	31.72 ± 1.74^{a1}
		C-A	54.95 ± 1.67^{b1}	56.39 ± 3.94^{b1}	61.38 ± 1.51^{c2}	60.22 ± 1.52^{b2}
		S-A	31.34 ± 2.10^{a12}	29.92 ± 2.65^{a1}	31.33 ± 2.13^{a12}	33.26 ± 3.37^{a2}
	a*	C-V	0.35 ± 0.49^{a3}	0.20 ± 0.35^{a23}	-0.62 ± 0.36^{a1}	-0.31 ± 0.54^{a12}
		S-V	4.56 ± 0.97^{b1}	5.62 ± 0.85^{b1}	5.93 ± 0.60^{b1}	5.53 ± 0.65^{c1}
		C-A	0.11 ± 0.30^{a2}	0.07 ± 0.46^{a2}	-0.42 ± 0.33^{a1}	-0.33 ± 0.46^{a12}
		S-A	3.89 ± 1.05^{b1}	5.31 ± 0.62^{b23}	5.84 ± 0.42^{b3}	4.66 ± 0.54^{b12}
	b*	C-V	9.43 ± 1.81^{b1}	10.22 ± 1.29^{a1}	9.47 ± 1.20^{a1}	9.39 ± 0.87^{a1}
		S-V	7.31 ± 1.61^{a1}	9.41 ± 2.02^{a2}	10.30 ± 1.26^{a2}	11.17 ± 1.29^{b2}
		C-A	9.58 ± 0.89^{b1}	9.86 ± 0.92^{a12}	9.96 ± 1.22^{a12}	10.97 ± 1.08^{b2}
		S-A	6.45 ± 1.82^{a1}	9.69 ± 1.20^{a2}	10.44 ± 1.03^{a2}	9.42 ± 1.09^{a2}

$^{a, b, c}$: mean values with different superscripts in the same column are significantly different ($p < 0.05$). $^{1, 2, 3}$: mean values with different superscripts in the same row are significantly different ($p < 0.05$).

The L* values of the chicken breasts remained stable throughout the storage period ($p > 0.05$), except for the C-V treatment, which showed an increase in its L* values at 14 and 18 days. In the case of burgers, in the control formulation, both vacuum- and modified atmosphere-packaged, there was an increase in the L* value throughout storage, which remained stable in the burgers with WPS with both types of packaging. Moreover, there were significant differences ($p < 0.05$) in the L* values between the control samples (C-V and S-V) and samples ($p < 0.05$) containing WPS (S-V and S-A), regardless of the packaging and product.

In terms of the a* value as an indicator of the degree of redness or greenness, the control samples (C-V and C-A) exhibited a decreased in the a* values over time in both breast and burger samples, indicating a discoloration. The a* values of the seasoned breasts and burgers packaged in vacuum conditions were stable over time. Moreover, the seasoned chicken breast and burger treatments (S-A) that were vacuum-packaged showed an increase in a* values by the end of the storage. Therefore, these results indicate that the addition of WPS and MAP in the chicken breasts and burgers resulted in color stabilization ($p < 0.05$).

With regard to the value b*, the effect of the storage was dependent on the type of product (breast or burger). The control chicken breast samples (C-V and C-A) showed a decrease in the b* values across the time, indicating a discoloration. However, in the case of the burgers, the C-V treatment retained its yellowness, whereas the C-A treatment showed an increase throughout the refrigerated storage. The storage effect on seasoned chicken breast and burger had a significant ($p < 0.05$) impact on the b*values, resulting in higher values compared to those at the initial time.

According to our results, the addition of WPS to chicken products resulted in a reduction in lightness and a significant increase in redness in the samples without storage. This change in color implies a transition from pale pink to brown when the WPS is added (Figures A1 and A2). This color effect on the L* and a* parameters is consistent, regardless of how the WPS is incorporated, whether on the surface, as in the chicken breast, or mixed with the meat, as in the burger. This significant change in color in chicken products could potentially influence the consumer's response, as reported by Ortega-Heras et al. [14] in their study on marinated chicken breasts with red pomace added. Similar results were observed by García-Lomillo and González-SanJosé [28] in the use of products from wine pomace in different foodstuffs. In this regard, González-SanJosé et al. [29] performed a preliminary sensory study using the check-all-that-apply (CATA) and rate-all-that-apply (RATA) methodologies and reported that despite the darkening of the product, this did not adversely affect product evaluation. Similar findings have been reported in the case of chicken burgers with the addition of 2% red grape pomace, resulting in a similar color change (lower L* and b* values, higher a* values) without affecting the product acceptability [30]. In a study by our research group [31], nuggets seasoned with red wine pomace were evaluated by consumers, half of whom were in blindfolded conditions and the other half of whom were under normal visual conditions; according to the results obtained, the color was not a parameter that affected the overall liking, which depended on the integration of all sensory properties. These results support the theory of other authors [32–37], who reported that food perception depends on the integration of multisensory cues. Therefore, the WPS studied could be a good alternative to other preservatives traditionally used, offering the advantage of being a natural product free of allergens. Further studies would be necessary to evaluate adequately the consumer's response.

3.3. Physicochemical Analysis of Chicken Products Seasoned Stored under Vacuum and Atmosphere Conditions

The pH in meat plays a crucial role in determining its physical and chemical stability. The chicken breast and burger pH values were around 6.7 (Table 3), which are similar values to those reported for marinated chicken breasts [14]. The addition of WPS resulted in lower pH values after elaboration (day 0). It should be noted that microbial growth is significantly promoted at pH > 7, which would increase the risk of deterioration and shorten the shelf life [38], so the addition of WPS could contribute to the preservation of these products. This decrease could be attributed to the compounds present in the wine pomace seasoning, among which are phenolic acids, including tartaric acid, which cause acidification of the environment [39,40]. The package conditions, vacuum and atmosphere, did not result in an increase in pH in the seasoned breast and burger during storage, and microorganism growth was not improved by the WPS added.

Table 3. Changes in pH, and aw values in control (C) chicken breasts and burgers and those with 3% white pomace seasoning (S) stored in vacuum (V) or atmosphere (A) conditions for 0, 7, 14, and 18 days. Values are expressed as mean (n = 4) ± standard deviation.

Product	Parameter	Treatment	Time (Days)			
			0	7	14	18
Breast	pH	C-V	6.69 ± 0.02^{2c}	6.60 ± 0.01^{1a}	6.72 ± 0.01^{2b}	6.70 ± 0.02^{2b}
		S-V	6.62 ± 0.04^{1b}	6.63 ± 0.04^{1a}	6.64 ± 0.01^{1a}	6.62 ± 0.04^{1ab}
		C-A	6.55 ± 0.01^{1a}	6.60 ± 0.04^{1a}	6.78 ± 0.01^{2c}	6.60 ± 0.06^{1a}
		S-A	6.59 ± 0.04^{12ab}	6.62 ± 0.01^{23a}	6.64 ± 0.01^{3a}	6.55 ± 0.01^{1a}
	a_w	C-V	0.980 ± 0.006^{12ab}	0.977 ± 0.004^{1a}	0.991 ± 0.008^{2b}	0.972 ± 0.001^{1a}
		S-V	0.976 ± 0.004^{12ab}	0.971 ± 0.005^{1a}	0.982 ± 0.003^{2ab}	0.976 ± 0.004^{12a}
		C-A	0.987 ± 0.007^{2b}	0.978 ± 0.003^{1a}	0.979 ± 0.002^{12a}	0.973 ± 0.000^{1a}
		S-A	0.970 ± 0.006^{1a}	0.974 ± 0.006^{1a}	0.977 ± 0.002^{1a}	0.971 ± 0.003^{1a}
Burger	pH	C-V	6.70 ± 0.03^{b3}	6.59 ± 0.03^{a1}	6.74 ± 0.01^{a3}	6.65 ± 0.01^{a2}
		S-V	6.60 ± 0.02^{a1}	6.60 ± 0.04^{a1}	6.74 ± 0.03^{a2}	6.65 ± 0.02^{a1}
		C-A	6.70 ± 0.03^{b1}	6.69 ± 0.03^{b1}	6.78 ± 0.01^{a2}	6.72 ± 0.04^{b12}
		S-A	6.59 ± 0.03^{a1}	6.62 ± 0.04^{ab1}	6.72 ± 0.05^{a2}	6.64 ± 0.03^{a12}
	a_w	C-V	0.973 ± 0.003^{a23}	0.975 ± 0.003^{b3}	0.970 ± 0.001^{a12}	0.969 ± 0.001^{a1}
		S-V	0.972 ± 0.002^{a1}	0.972 ± 0.001^{ab1}	0.966 ± 0.005^{a1}	0.968 ± 0.003^{a1}
		C-A	0.970 ± 0.002^{a1}	0.974 ± 0.002^{b2}	0.970 ± 0.001^{a1}	0.971 ± 0.001^{a1}
		S-A	0.969 ± 0.001^{a1}	0.970 ± 0.002^{a1}	0.967 ± 0.002^{a1}	0.968 ± 0.001^{a1}

$^{a, b, c}$: mean values with different superscripts in the same column are significantly different ($p < 0.05$). $^{1, 2, 3}$: mean values with different superscripts in the same row are significantly different ($p < 0.05$).

The a_w is a critical parameter responsible for the stability of foods that modulates the microbial response and determines the type of microorganisms present in foods [41]. In this study, the a_w values for the chicken products (breast and burger) were approximately 0.985 (Table 3), which is similar to the values reported for marinated chicken breasts [14]. The addition of WPS, in both breasts and burgers, resulted in stable a_w values. However, the control treatments showed a decrease in their a_w values, with the exception of the C-A treatment in the case of burgers.

3.4. Antioxidant Characteristics of Chicken Products Seasoned Stored in Vacuum and Atmosphere Conditions

White wine pomace is a potential source of polyphenols, which are recognized for their substantial antioxidant potential. These compounds efficiently neutralize free radicals or chelate transition metals. This property is vital in preventing rancidity development in food products [30].

The effectiveness of antioxidants cannot be evaluated using only one assay protocol due to the several multifunctional mechanisms that participate in the antioxidant activity [42]. For that reason, the assessment of several antioxidant assays that include different mechanisms is necessary to evaluate the potential antioxidant activity [43]. In general, ABTS and FRAP antioxidant capacity assays show a high and positive correlation among them [44], regardless of the food product considered [45–47]. Therefore, in the present study, in order to evaluate the antioxidant characteristics of chicken products with and without WPS during 18 days of vacuum or atmospheric storage, the ABTS and FRAP analysis were performed and the results are shown in Table 4.

Table 4. Antioxidant capacity (ABTS and FRAP) in control (C) chicken breasts and burgers and those with 3% white pomace seasoning (S) stored in vacuum (V) or atmosphere (A) conditions for 0, 7, 14, and 18 days. Values are expressed as mean (n = 8) ± standard deviation.

Product	Para-Meter	Treatment	Time (Days)			
			0	7	14	18
Breast	ABTS (µmol Trolox/g)	C-V	0.81 ± 0.34^{12a}	0.60 ± 0.28^{1a}	0.92 ± 0.08^{12a}	1.22 ± 0.66^{2b}
		S-V	1.62 ± 0.43^{12b}	1.95 ± 0.37^{2c}	1.471 ± 0.157^{1b}	1.46 ± 0.10^{1b}
		C-A	0.66 ± 0.34^{12a}	0.56 ± 0.22^{1a}	0.85 ± 0.046^{2a}	0.49 ± 0.07^{1a}
		S-A	1.66 ± 0.26^{2b}	1.44 ± 0.15^{12b}	1.61 ± 0.11^{2b}	1.37 ± 0.09^{1b}
	FRAP (µmol Fe/g)	C-V	2.98 ± 0.26^{3a}	3.70 ± 0.16^{4a}	2.66 ± 0.30^{2a}	0.87 ± 0.14^{1a}
		S-V	5.93 ± 0.61^{2b}	8.86 ± 0.62^{3c}	4.33 ± 0.25^{1b}	3.97 ± 0.25^{1}
		C-A	3.17 ± 0.14^{3a}	3.57 ± 0.45^{3a}	2.56 ± 0.60^{2a}	0.87 ± 0.05^{1a}
		S-A	6.69 ± 0.39^{3c}	7.39 ± 0.55^{4}	5.31 ± 0.26^{2c}	4.54 ± 0.44^{1c}
Burger	ABTS (µM Trolox/g)	C-V	0.896 ± 0.236^{a2}	0.695 ± 0.104^{a12}	0.748 ± 0.176^{a12}	0.575 ± 0.104^{a1}
		S-V	1.441 ± 0.219^{b1}	1.716 ± 0.248^{c2}	1.475 ± 0.140^{b12}	1.299 ± 0.154^{b1}
		C-A	0.727 ± 0.202^{a2}	0.500 ± 0.148^{a12}	0.586 ± 0.048^{a12}	0.428 ± 0.231^{a1}
		S-A	1.615 ± 0.143^{b23}	1.435 ± 0.169^{b1}	1.491 ± 0.068^{b12}	1.749 ± 0.089^{c3}
	FRAP (µmol Fe/g)	C-V	2.738 ± 0.599^{a2}	3.315 ± 0.113^{a3}	0.931 ± 0.123^{a1}	0.760 ± 0.061^{a1}
		S-V	5.614 ± 0.341^{b2}	6.865 ± 0.844^{b3}	4.170 ± 0.303^{b1}	4.200 ± 0.271^{b1}
		C-A	2.871 ± 0.271^{a2}	3.507 ± 0.196^{a3}	0.731 ± 0.078^{a1}	0.638 ± 0.055^{a1}
		S-A	6.052 ± 0.387^{b2}	6.750 ± 0.121^{b3}	4.436 ± 0.352^{b1}	4.198 ± 0.295^{b1}

$^{a, b, c}$: mean values with different superscripts in the same column are significantly different ($p < 0.05$). $^{1, 2, 3}$: mean values with different superscripts in the same row are significantly different ($p < 0.05$).

The addition of WPS significantly increased ($p < 0.05$) the antioxidant capacity of chicken products (Table 4), regardless of packaging type. This increase could be provided by the polyphenols present in wine pomace seasoning, which have the ability to donate electrons to free radicals formed during lipid oxidation, subsequently stabilizing their structure through resonance delocalization by an electron within its aromatic ring [30,48]. It is likely that the phenolic acids released by the seasoning are the main contributors to the antioxidant activity [43]. Regarding the effect of time storage, chicken breasts maintained similar values throughout refrigerated storage, with the values always being higher for the samples treated with the WPS. However, the burger control (C-V and C-A) showed decreasing ABTS values during storage, whereas the addition of WPS stabilized the ABTS values. Changes in the antioxidant capacity of the WPS recovered from chicken breast storage under vacuum and atmospheric conditions were evaluated by Gutierrez-Gonzalez et al. [15], who reported a significant increase in the ABTS values. This increase could be attributed to the migration or interaction of antioxidant compounds in the meat with the seasoning [49].

The FRAP values were higher in samples with WPS, for both chicken breasts and burgers, regardless of the packaging type. Additionally, there was a decrease in FRAP values observed during refrigerated storage for all treatments, regardless of the addition of WPS. These results could be explained by the decrease in FRAP activity of WPS, as observed by Gutierrez-Gonzalez et al. [15] over a 15-day storage period.

3.5. Lipid Oxidation Levels in Chicken Breast and Burgers Treated with Seasoning under Vacuum and Atmospheric Storage Conditions

Lipid oxidation in meat products is usually evaluated using the TBARS method, which serves as an indicator of lipid oxidation [50]. The TBARS values for chicken products stored in vacuum and atmospheric conditions and refrigerated for 18 days are presented in Table 5.

Table 5. Lipid oxidation (TBARS) in control (C) chicken breasts and burgers and those with 3% white pomace seasoning (S) stored in vacuum (V) or atmosphere (A) conditions for 0, 7, 14, and 18 days. Values are expressed as mean (n = 4) ± standard deviation.

Product	Parameter	Treatment	Time (Days)			
			0	7	14	18
Breast	TBARS (mg MDA/kg)	C-V	0.13 ± 0.04^{1a}	1.16 ± 0.40^{12a}	1.48 ± 0.23^{123a}	2.99 ± 1.05^{234b}
		S-V	0.50 ± 0.07^{1b}	0.90 ± 0.13^{12a}	1.50 ± 0.71^{12a}	1.59 ± 0.11^{12a}
		C-A	0.13 ± 0.04^{1a}	3.62 ± 1.21^{2b}	2.76 ± 0.80^{2b}	2.24 ± 0.60^{2ab}
		S-A	0.50 ± 0.07^{1b}	1.05 ± 0.11^{1a}	1.33 ± 0.45^{2a}	1.38 ± 0.09^{2a}
Burger	TBARS (mg MDA/kg)	C-V	4.74 ± 0.81^{b1}	6.41 ± 0.41^{b23}	7.36 ± 0.27^{b3}	6.01 ± 0.33^{b2}
		S-V	1.78 ± 0.04^{a1}	1.88 ± 0.13^{a1}	1.95 ± 0.20^{a1}	1.69 ± 0.10^{a1}
		C-A	4.74 ± 0.81^{b1}	9.12 ± 0.24^{c2}	8.37 ± 0.11^{c12}	10.20 ± 0.70^{c2}
		S-A	1.78 ± 0.04^{a1}	1.96 ± 0.05^{a123}	2.04 ± 0.06^{a23}	1.88 ± 0.19^{a12}

$^{a, b, c}$: mean values with different superscripts in the same column are significantly different ($p < 0.05$). $^{1, 2, 3, 4}$: mean values with different superscripts in the same row are significantly different ($p < 0.05$).

The TBARS values of the control treatments (C-V and C-A) of chicken products (breasts and burgers) showed an increase during refrigerated storage, with a more pronounced increment observed when modified atmosphere packaging (MAP) was used. This suggests that vacuum packaging could effectively delay lipid oxidation during refrigerated storage. Similar observations have been reported in the study by Hai et al. [51] in spiced beef samples that were vacuum-packaged compared to samples packaged with three different MAPs, as well as the study by Nauman et al. [52], who observed lower TBARS values in poultry breast fillets in vacuum packaging than those in MAP. According to Hai et al. [51], this was probably because of the rapid propagation of aerobic bacteria, which promoted the aerobic microbial decomposition of fat via oxidation. Furthermore, it should be taken into account that oxygen may accelerate the increase in TBARS values and promote lipid oxidation [53]. In spite of the composition of the modified atmosphere used in the present study (30% CO_2 and 70% N_2), the residual oxygen in the treatments under MAP was approximately 0.24%. Therefore, this residual oxygen could have led to a greater susceptibility of the chicken to lipid oxidation, causing a reduction in lipid stability and greater oxidation in the control treatments packaged in MAP (C-A).

The addition of WPS in the formulation delayed the lipid oxidation of the chicken products (breast and burger) and led to stable TBARS values over the refrigerated storage, regardless of the packaging method (Table 5). These results could be attributed to the high total polyphenol content in the WPS (0.60 g GAE/100 g WPS) and its associated antioxidant properties (Q-ABTS, 0.46 mmol TE/100 g WPS; Q-FRAP, 7.13 mmol FeII E/100 g WPS), results which were previously observed by our research group [15]. The antioxidants in the pomace can inhibit the propagation of lipid oxidation by scavenging free radicals generated during this process, as well as through synergistic reactions involving high levels of extractable polyphenols [13]. Therefore, the addition of 3% WPS could be enough to delay the lipid oxidation in chicken breasts or chicken burgers with 8.3% fat content. Similar findings have been reported by Sáyago-Ayerdi et al. [30] for chicken burgers with 2% red grape pomace that were vacuum-packaged for 13 days. The efficacy of 2% red wine pomace seasonings in delaying lipid oxidation in beef burgers has been shown in previous studies [54].

The higher lipid oxidation in the burgers than in the breasts could be due to their higher fat content (8.36 vs. 2.04%), which is a factor that intensifies lipid oxidation [5]. Furthermore, 2% salt was added to the burgers, which can promote lipid oxidation when added to the meat [4]. This fact could explain the extensive formation of TBARS, not only during storage but also during burger preparation, leading to differences in TBARS values at day 0 between burger formulations with and without WPS (4.74 vs. 1.78 mg MDA/kg).

Moreover, the TBARS value of the backfat used (1.40 mg MDA/kg) should be considered, which could explain the relatively high TBARS values at day 0.

When highlighting the results of FRAP (Table 4) in conjunction with TBARS (Table 5), an inverse relationship can be seen. The FRAP values decreased over the storage period, and the TBARS values in both chicken breasts and burgers increased. This indicates that as the ferric reducing power of antioxidants decreases, lipid oxidation increases [55]. The same tendency was observed by Sáyago-Ayerdi et al. [30] in chicken burgers with red grape pomace added. Consequently, lipid oxidation can be prevented at the outset by free radical scavengers and singlet oxygen quenchers, and the propagation chain reaction can be broken by peroxy-radical scavengers [56]. In addition to free radical scavenging activities, wine pomace flavonoids may also delay lipid oxidation by chelating metals [57].

4. Conclusions

The incorporation of 3% WPS into chicken model products (breast and burgers), regardless of packaging type, led to an improvement in the antioxidant capacity and oxidative stability with regard to the lipid oxidation values of chicken products elaborated with WPS as an additive. The absence of WPS in the chicken product formulations resulted in significant increases in TBARS levels in both packaging methods; however, vacuum packaging was more effective in preventing lipid oxidation compared to modified atmosphere packaging (MAP). It is worth highlighting the significant color change in the products, which turned to brown tones. The technological effectiveness of integrating bioactive components into meat products has been demonstrated and could be used to preserve the quality and improve the antioxidant properties of chicken products. However, the present study also has certain limitations. Further research is necessary to explore the influence of color transformation on consumers' responses. This requires an optimal approach, in which consumers would receive detailed information regarding the reasons behind the color modifications. Moreover, it is crucial to ascertain the positive impact that bioactive compounds derived from WPS can potentially have on human health. Understanding these factors in depth would provide valuable insights into consumer behavior and preferences related to food products enhanced with WPS. In conclusion, these results are novel and could help valorize the application of the WPS, a byproduct of wineries, as a natural seasoning in chicken products, resulting in healthier and innovative chicken products.

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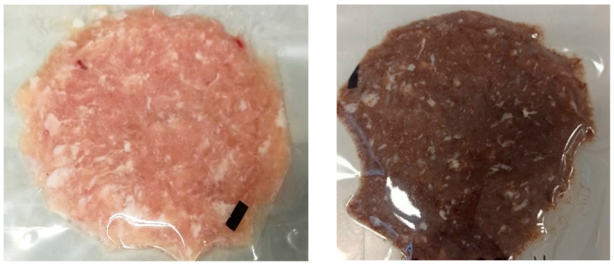
Appendix A

(**a**) (**b**)

Figure A1. Sliced chicken breasts: breast control (**a**); breast with 3% of white pomace seasoning (**b**).



(**a**) (**b**)

Figure A2. Chicken burgers: burger control (**a**); burger with 3% of white pomace seasoning (**b**).

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