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Combined effects of encapsulated raspberry powder and phosphate on the lipid oxidation, microbiological properties and shelf life of modified atmosphere packaged chicken nuggets during chilled storage

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ABSTRACT

1. Further-processed poultry products, such as chicken nuggets, are susceptible to rapid lipid oxidation and microbial spoilage. Natural ingredients from various plants or fruits may contribute to improving the quality and extending the shelf life of meat products. In the present study, the use of encapsulated raspberry powder (ERP; control, 0.5%, 1.0%) in chicken nugget production with and without phosphate (0.0%, 0.3%) and its effects on chemical composition, lipid oxidation, microbial quality and shelf life were examined.
2. Phosphate and ERP had effects on chemical composition and a_w; ($p < 0.01$). During storage, the ratio of O_2 and N_2 increased and the amount of CO_2 decreased ($p < 0.05$), but the increase in samples with 1.0% ERP addition was lower than in the control and 0.5% groups.
3. Both the use of ERP ($p < 0.01$) and phosphate ($p < 0.01$) for nugget production prevented lipid oxidation. The lowest was determined in samples containing phosphate + 1.0% ERP ($p < 0.05$) during storage. However, the TBARS values were within acceptable limits (<1 mg MDA/kg) for all the samples with 0.5% and 1.0% ERP added with phosphate.
4. The counts of total aerobic mesophilic bacteria decreased depending on the level of ERP added to the nugget composition ($p < 0.01$). Counts only exceeded 6 log CFU/g in the control samples on the 120th day of storage. *Salmonella* spp. and *Listeria monocytogenes* were negative in all nugget samples during storage. The counts of *Enterobacteriaceae* were below the detectable limit (<2.0 log CFU/g) during storage.

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KEYWORDS
Nugget; raspberry; phosphate; oxidation; microbial quality

Introduction

Chicken nuggets are among the most-produced poultry products, and their popularity is increasing daily (Aksu and Arslan 2024; Tamsen et al. 2018; Yılmaz and Yılmaz 2018). When the nugget was first produced, it was produced by marinating the chicken breast fillet and then coating the product during processing. Later, instead of being produced from breast fillets, it was produced by using lower-quality shaving waste meat, mechanically recovered meat and skin in combinations, resulting in different shapes (Barbut 2002). A nugget is formed from the prepared meat dough which is shaped and covered with first a liquid coating and then dry materials. After brief frying, it is cooked in a steam oven (Aksu and Arslan 2024; Aktepe 2019). Breast fillets, ground breast and neck meat, mechanically separated poultry meat, shaving waste meat and skin are used as raw materials in poultry meat products. Nuggets are produced using advanced processed or restructured emulsion technologies. Different methods, such as mechanical modification, heating and the combination of pH, salt, phosphates and water, can be used to improve collagen solubility in chicken skin (Kim et al. 2015). In addition, pH is an important factor in nugget production and preservation quality and pH changes with the addition of skin, mechanically deboned meat, shaving waste meat or coating material to the products. For these reasons, phosphates are often added to nuggets and similar products in the polyphosphate structure to ensure stability in terms of end-product properties. Polyphosphates, which are effective mainly through pH, are mostly used in the meat industry due to their various functions. These include improving textural properties by increasing water retention capacity and preventing oxidative and microbial spoilage (Lai et al. 1991; Ünal et al. 2004; Xu et al. 2009).

Since nuggets are considered a risky food group because of their structural features and composition, they should be kept at low storage temperatures. Research on this subject has shown that fresh nugget products have a varying shelf life depending on the composition of the product in a temperature environment of 0–4°C (Aktepe 2019; Öztürk-Kerimoğlu and Serdaroğlu 2020). Within the scope of 'risky food', oxidation and microbial spoilage are important changes that shorten shelf life. Due to the properties of the raw meat material used in nugget production and the fat layer under the skin, oxidation rate of these products is quite high during production and storage. For these reasons, the properties of further processed chicken products can be improved, and their shelf life can be extended by the addition of antioxidant and preservative substances. Additives, such as sodium tripolyphosphate, added to further processed meat products improve the structural properties of the product and delay spoilage and oxidation (Ünal et al. 2004; Xu et al. 2009). Oxidative deterioration can be prevented by using antioxidants such as TBHQ and rosemary extract in addition to sodium tripolyphosphate in reconstituted chicken nuggets (Lai et al. 1991). Poultry and its meat products may contain many foodborne pathogens, including *Salmonella* spp.,

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Campylobacter jejuni, Clostridium perfringens and *Staphylococcus aureus*, which originate from raw materials or processing technologies. Additionally, raw and processed poultry products can often be contaminated with *Listeria monocytogenes* (Weise 1996). All this information reveals that oxidation and microbial spoilage are important problems in poultry meat and their products. Therefore, the use of clean label antimicrobial and antioxidant substances in product formulations is important. Within the scope of the current research, it has been predicted that product quality can increase and shelf life can be extended by adding encapsulated raspberry powder, whose antioxidant and antimicrobial effects have been determined by various studies (Aksu et al. 2021, 2022, 2023; Sadowska et al. 2020).

Encapsulated raspberry powder obtained from fresh raspberry fruits (*Rubus ideaus* L., from the Rosaceae family) is a good source of phytochemicals. The presence of phytochemicals gives raspberries antimicrobial and antioxidant properties (Aksu and Arslan 2024; Aksu et al. 2023). Encapsulated raspberry powder obtained by spray drying has strong antimicrobial effects against both Gram (-) and Gram (+) bacteria and has strong antioxidant and colour-enhancing properties under industrial conditions (Aksu et al. 2023). Lyophilised raspberry extracts also have a similar effect on fresh meat products (Aksu et al. 2021, 2022). In a previous study (Aksu and Arslan 2024), various useful properties of raspberry powder, such as moisture content, pH, antioxidant activity and colour, were observed. This material could be used in chicken nugget production for positive effects on the a* colour value.

The aim of the present research was to determine the combined effect of encapsulated raspberry powder and phosphate on the quality properties such as chemical composition, lipid oxidation, microbial and shelf life of chicken nuggets.

Materials and methods

Ethical statement

The research did not include any human subjects or animal experiments.

Preparation of encapsulated raspberry powder and phosphate

The production of raspberry powders was determined and given according to the procedures of Aksu et al. (2023) and Aksu and Arslan (2024). Fresh raspberry juice samples were encapsulated in maltodextrin (12–16 DE; 40.0%, m/m) with a laboratory-scale spray-dryer (B-290, Buchi, Switzerland). Characteristics of the encapsulated raspberry powders (ERP) used in the study were moisture 4.49%; pH 3.32; ABTS radical scavenging activity 15.51 µg TE/mg; DPPH radical scavenging activity 11.45 µg TE/mg and total amount of phenolics 602.42 mg GAE/100 g (Aksu and Arslan 2024). Sodium di- and polyphosphate with a pH of 9.5–10.5 in a 1% solution was used as a preservative.

Production of chicken nuggets

The nuggets used in the study were produced at the Bilecik/Turkey facilities of C.P. Standard Food Industry and Trade Inc., as described in detail Aksu and Arslan (2024). The present study was carried out with two different phosphate concentrations (0.0% and 0.3%), three different ERP concentrations (0.0%, 0.5% and 1.0%) over eight storage times (0, 15, 30, 60, 75, 90, 105 and 120 d). Six groups of chicken nuggets were produced in two batches, and each production was repeated with different materials. According to the method, the mixing process of nugget raw materials with ERP was carried out at temperatures between 0 and −5°C. In production, the liquid batter temperature was ≤10°C, the polar matter amount of the oil used in frying was ≤25%, the cooking core temperature was 74–82°C and the IQF cooling temperature was 0–4°C.

Packaging and storage of nuggets

The nuggets were packaged in a modified atmosphere packaging (MAP) unit (GEA, Powerpack 420 with Lebeling and X Y Traverse Unit, 2009, 665/624, CFS Germany GmbH) using a gas composition of 40% CO_2 +60% N_2 and stored at 2.0 ± 0.5° C for 120 d. Laminated PVC films made of PVC+PE+EVOH +PEEL with a thickness 500 µm +50 µm EVOHPE; oxygen transmission rate (OTR): ≤ max 1 ml/m^2/day at 23°C, 90% RH were used as packaging materials. These had a water vapour transmission rate (VWTR) ≤max 2 g/m^2/d at 38°C and 90% RH. The other material used was a laminated PVC consisting of a PET+COEX EVOH ANTIFOGL film (thickness 65±%10 µm, oxygen transmission rate (OTR): ≤3 ml/m^2/day/bar; N_2 transmission rate: ≤15 ml/m2/day; water vapour transmission rate (VWTR): ≤2 g/m^2/day).

Nugget analyses

The total protein, total fat, moisture, salt, collagen, water activity, gas composition in the packaging (MAP: nitrogen, carbon dioxide and oxygen ratio), total aerobic mesophilic bacteria, yeast-mould, *Salmonella* spp., *Listeria monocytogenes* and *Enterobacteriaceae* spp. counts were determined at 0, 15, 30, 45, 60, 75, 90, 105 and 120 d of storage. Lipid oxidation in the nugget samples was determined at 0, 30, 60, 90 and 120 d of storage.

Determination of moisture, protein, fat, collagen and salt contents

The moisture, protein, fat, collagen and salt contents of the nugget samples were determined as percentages using the FOSS meat analysis system (Anderson 2007).

Determination of water activity

The water activity (a_w) in the nugget samples was determined using a cooling water activity determination system (Steroglass, Sweden). After calibration, measurements were made at a constant temperature of 20 ± 0.5°C.

Determination of lipid oxidation

Lipid oxidation analysis was performed by determining the thiobarbituric acid reactive substances (TBARS) using the method detailed by Lemon (1975) and Aksu (2009) and modified by Aksu and Turan (2021). The TBARS values of the samples were calculated as mg malondialdehyde per kg of nugget material.

Determination of gas composition in MAP

During the storage of nugget samples in MAP, changes in oxygen (O_2), carbon dioxide (CO_2) and nitrogen (N_2) concentrations in the modified atmosphere package were detected with a gas analyser (Oxybaby® M+, Witt-Gasetechnik GmbH & Co Kg, Germany).

Microbiological analysis

Nugget samples weighing 25 g were aseptically homogenised for 3 min in 225 ml of saline solution (0.85% NaCl) using a stomacher (VWR, Star-Blender LB400, France). For total aerobic mesophilic bacteria (TAMB) counts, plate count of agar was used and incubated under aerobic conditions for 48 h at 30°C. Violet-red bile dextrose agar (VRBD, Merck, USA) was used for *Enterobacteriaceae* counts which were determined after the inoculated plates were incubated anaerobically (Anaerocult A, Merck, USA) for 48 h at 30°C. Dichloran rose Bengal chloramphenicol agar (DRBC, Merck, USA) was used for yeast-mould counting, which was determined after the inoculated plates were kept at 25°C for 4–5 d. The presence of *Listeria monocytogenes* and *Salmonella* spp. in the samples was determined using the 3 M™ Molecular Detection System using ready-made kits (3 M, USA).

Statistical analysis

The study was conducted according to a completely randomised block design, using two replications. Analysis of variance was performed using the general linear model (GLM) of SPSS 25.0 software (IBM SPSS Inc., Chicago, USA). To determine significant differences among phosphate levels, ERP levels and storage time, Duncan's multi-range tests at the 5% significance level ($p < 0.05$) were used. The research model included treatment (phosphate levels 0.0% and 0.3%; ERP 0.0%, 0.5% and 1.0%) and storage period (0, 15, 30, 45, 60, 75, 90, 105 and 120 d) as the main effects and all interactions.

Results and discussion

Proximate analysis

The effects of phosphate level ($p < 0.01$), ERP ($p < 0.01$) and storage time ($p < 0.01$) on the moisture content of the chicken nuggets were highly significant (Table 1). The moisture content was lower for the phosphate treatments ($p < 0.05$) at 52.61 ± 0.37%. Among the ERP treated chicken nuggets, the lowest moisture content was detected in the 0.5% group. Although there was no statistical difference ($p > 0.05$) in terms of the average moisture value of the control and 1.0% ERP groups, the average moisture content in the samples containing 0.5% and 1.0% ERP addition was 0.32% and 0.06% lower than the control samples (Table 1). Since fruit powders are hygroscopic, anti-caking agents are added to stabilise the product and the water retention capacity of the produced powders decreased (Asgar et al. 2016; Wei et al. 2022). Additionally, the moisture content of ERP added to the nugget was 4.49 ± 0.23% (Aksu and Arslan 2024), which was low. Therefore, these decreases may be due to both the low moisture content and water-absorption capacity of ERP. There was a partial increase in moisture content during storage, whereby the value, which was 52.13 ± 0.32% at the beginning of storage, increased to 53.08 ± 0.54% after 120 d of storage. The amount of moisture decreased with the addition of phosphate to the nugget.

Table 1. Effect of ERP treatment and storage period on the moisture, protein, fat, collagen and salt content of nugget samples during chilled storage.

	Moisture (%)	Protein (%)	Fat (%)	Collagen (%)	Salt (%)
Phosphate (P)					
Without phosphate	52.82^{a}	17.98^{b}	10.52^{b}	1.71	2.24
With phosphate	52.61^{b}	18.17^{a}	10.70^{a}	1.72	2.26
SEM	0.023	0.021	0.025	0.007	0.007
p Value	**	**	**	NS	NS
Encapsulated Raspberry Powder Levels (ERPL)					
Control	52.84 ^{a}	18.17^{a}	10.75 ^{a}	1.71	2.22^{c}
0.5%	52.52 ^{b}	17.98^{c}	10.66 ^{b}	1.72	2.24^{b}
1.0%	52.78^{a}	18.07^{b}	10.43^{c}	1.72	2.27^{a}
SEM	0.028	0.026	0.030	0.008	0.008
p Value	**	**	**	NS	**
Storage period (days. SP)					
0	52.13^{f}	17.04^{c}	10.06^{e}	1.63^{c}	2.40^{a}
15	52.73^{cd}	18.52^{a}	10.74^{ab}	1.73^{ab}	2.21^{bcd}
30	52.96^{ab}	18.13^{b}	10.76^{ab}	1.74^{a}	2.19^{d}
45	52.88^{bc}	18.24^{b}	10.55^{cd}	1.74^{a}	2.26^{b}
60	52.83^{bcd}	18.15^{b}	10.70^{bc}	1.74^{a}	2.25^{b}
75	52.38^{e}	18.20^{b}	10.64^{bcd}	1.73^{ab}	2.24^{bc}
90	52.74^{cd}	18.13^{b}	10.52^{d}	1.69^{b}	2.24^{bc}
105	52.71^{d}	18.16^{b}	10.70^{bc}	1.72^{ab}	2.22^{bcd}
120	53.08^{a}	18.10^{b}	10.86^{a}	1.73^{ab}	2.20^{cd}
SEM	0.048	0.044	0.053	0.015	0.014
p Value	**	**	**	**	**
Interactions					
P x ERPL	**	**	**	*	NS
P x SP	**	**	NS	NS	**
ERPL x SP	**	*	**	NS	**
P x ERPL x SP	NS	NS	**	NS	NS

*: $p < 0.05$, **: $p < 0.01$: NS: $p > 0.05$.

a–d: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of the treatments.

a–f: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of the storage periods.

This value was lower in samples where phosphate + ERP has been added than in those without phosphate (Figure 1(a)). During storage, except for on d 0 and 30, lower moisture contents were detected in the phosphate-treated samples compared to the non-phosphate samples (Figure 1(b)). This showed that the addition of phosphate made the nuggets more stable. However, the moisture content determined during storage was generally higher in the control samples than in the samples where ERP was added (Figure 1(c)). The differences in moisture values occurred because the addition of phosphate and ERP to the nugget emulsion at different rates affected the pH of the product. In the present study, the moisture content was between 53.05 ± 0.47% and 52.50 ± 0.34% (Table 1). Similar findings (52%) were found in the research conducted by Chayawat and Rumpagaporn (2020) and Lishianawati et al. (2022). However, in a study conducted by Davarcıoglu and Demirok Soncu (2021), 59.75% and 59.93% were seen in nuggets stored for 180 d. In the research conducted by Yılmaz and Yılmaz (2018), the average moisture content in nugget samples was 55.29% (46.19–60.96%). During production, the amount of moisture is affected by the ingredients used in production, especially the properties of the frying oil (William et al. 2024) and the barrier properties of the coating materials.

The total protein concentration of the nugget samples was affected by the addition of phosphate ($p < 0.01$) or ERP ($p < 0.01$) and by the storage time ($p < 0.01$). The addition of phosphate increased the protein concentration ($p < 0.05$). However, it can be seen from the phosphate x raspberry level interaction graph (Figure 2(a)) that nuggets with ERP plus phosphate had higher protein than those without phosphate. This increase may have been due to the stronger structural formation in the emulsion with the addition of phosphate. The fact that the mean amount of nitrogen in the MAP during storage was lower for the phosphated products than for the non-phosphated products confirmed this situation.

The mean ratio of nitrogen in MAP was lower in the ERP nuggets than in the control (Table 2). Except for after 30 and 120 d of storage, protein in the phosphate-treated nuggets was higher than that of the non-phosphate group.

During storage, the lowest protein values were found at the beginning of storage in both groups (Figure 2(b)). The concentration of protein in chicken nuggets varied depending on the composition and quality of the meat used in

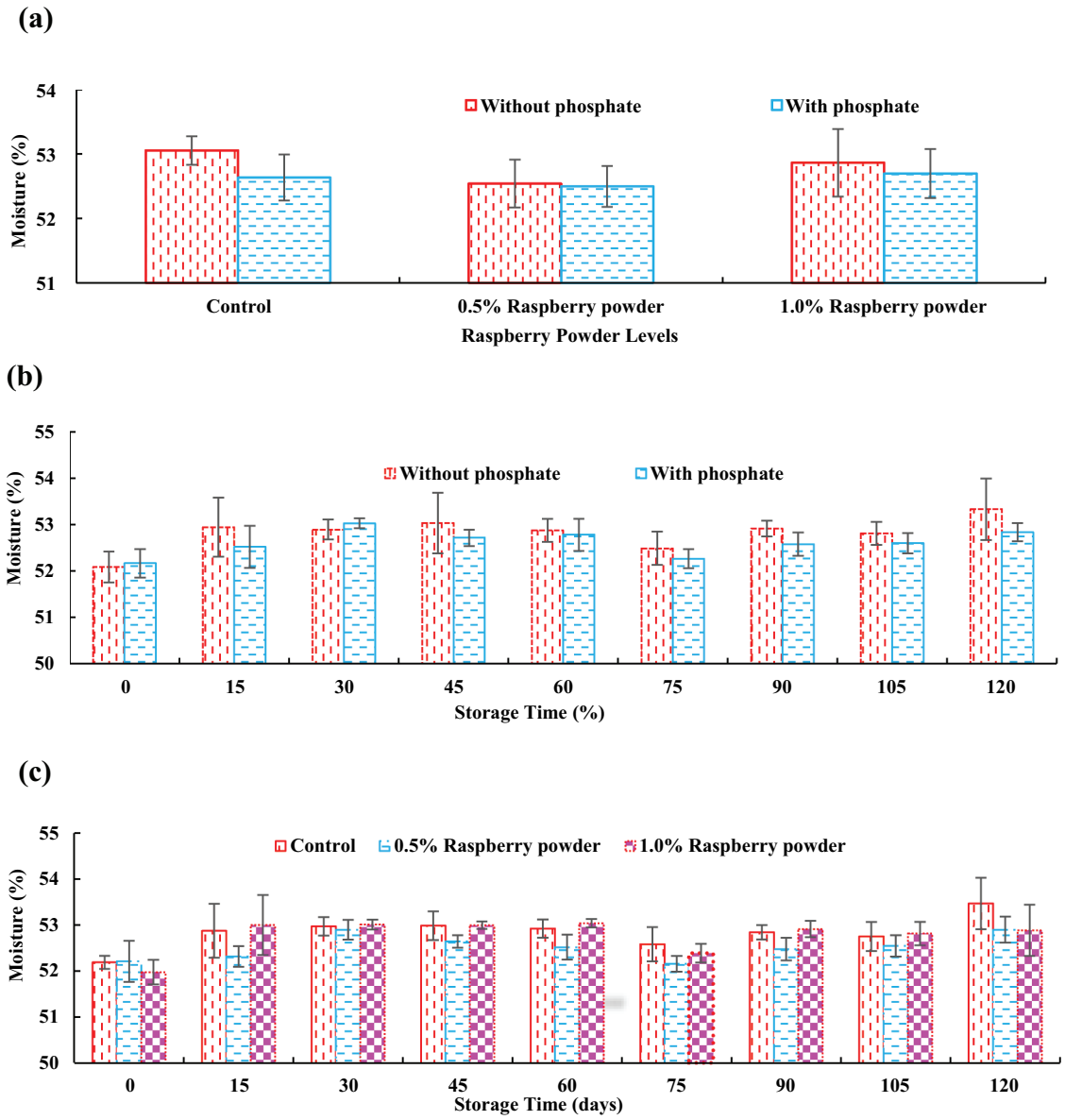

Figure 1. Effect of the phosphate x raspberry powder level (a), phosphate x storage time (b) and raspberry powder level x storage time (c) interaction on the moisture content (%) of nugget samples during storage at 2.0 ± 0.5°C for 120 days.

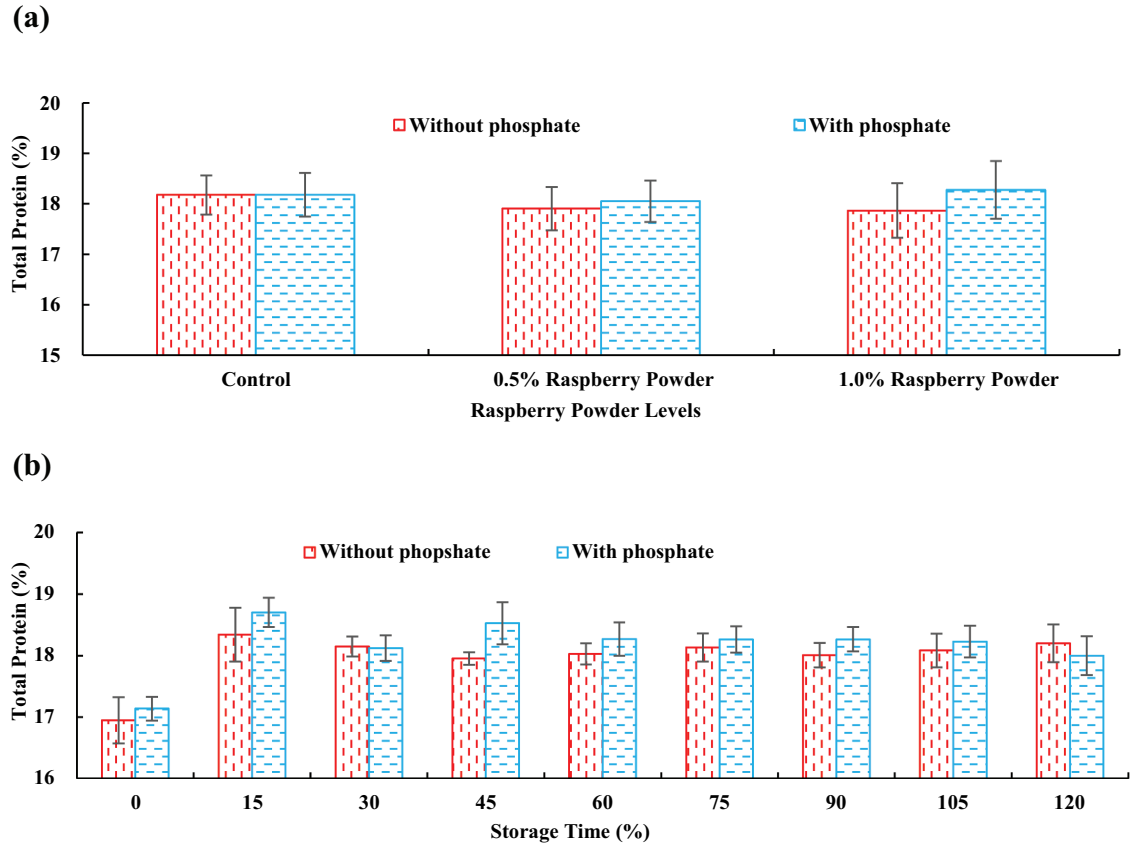

Figure 2. Effect of the phosphate x raspberry powder level (a) and phosphate x storage time (b) interaction on the total protein amount (%) of nugget samples during storage at 2.0 ± 0.5°C for 120 days.

Table 2. Effect of ERP treatment and storage period on the a_w, TBARS and gas composition in the MAP (CO_2, O_2 and N_2) of nugget samples during chilled storage.

			Gas Composition in the MAP (%)		
	a_w	TBARS[1]	O_2	CO_2	N_2
Phosphate (P)					
Without phosphate	0.984^{b}	1.63^{a}	1.06^{a}	27.23^{b}	71.71^{a}
With phosphate	0.985^{a}	1.02^{b}	0.91^{b}	28.33^{a}	70.76^{b}
SEM	0.001	0.012	0.026	0.137	0.136
P	**	**	**	**	**
Encapsulated Raspberry Powder Levels (ERPL)					
Control	0.983^{b}	2.00^{a}	1.05^{a}	27.29^{b}	71.66^{a}
0.5%	0.986^{a}	1.09^{b}	0.97^{ab}	28.15^{a}	70.88^{b}
1.0%	0.985^{a}	0.89^{c}	0.94^{b}	27.89^{a}	71.17^{b}
SEM	0.001	0.015	0.032	0.168	0.167
P	**	**	*	**	**
Storage period (days. SP)					
0	0.987^{a}	0.81^{e}	0.37^{d}	40.45^{a}	59.18^{g}
15	0.979^{d}	–	0.37^{d}	40.61^{a}	59.03^{g}
30	0.985^{a}	1.13^{d}	0.43^{d}	32.76^{b}	66.80^{f}
45	0.985^{b}	–	0.40^{d}	27.05^{c}	72.55^{e}
60	0.984^{c}	1.35^{c}	0.72^{c}	25.06^{d}	74.23^{d}
75	0.987^{bc}	–	0.75^{c}	22.79^{e}	76.46^{c}
90	0.986^{bc}	1.56^{b}	2.00^{a}	21.47^{f}	76.53^{c}
105	0.985^{bc}	–	1.80^{b}	19.43^{h}	78.77^{a}
120	0.984^{bc}	1.77^{a}	2.08^{a}	20.36^{g}	77.57^{b}
SEM	0.001	0.019	0.055	0.291	0.289
P	**	**	**	**	**
Interactions					
P x ERPL	**	**	*	NS	NS
P x SP	**	**	**	**	**
ERPL x SP	NS	**	**	**	**
P x ERPL x SP	NS	**	NS	NS	NS

*: $p < 0.05$, **: $p < 0.01$: NS: $p > 0.05$.

[1]TBARS: Thiobarbituric acid reactive substances (mg malondialdehyde/kg nugget).

a–d: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of treatments.

a–f: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of the storage periods.

production and the coating material. Therefore, the protein concentrations in chicken nuggets varied among studies. Akesowan (2016), Madane et al. (2019) and Aktepe (2019) determined the concentration of protein in control samples as 27.2%, 14.4% and 13.2%, respectively. Madane et al. (2019) reported that the mean protein level in the control nuggets produced from 22% chicken meat, 20% breast trimmed and 10% chicken skin was 14.4%. The authors determined that the concentration increased depending on the level of *Moringa flower*, with 17.9% protein.

The fat content of the nugget samples was 10.7 ± 0.42 in the phosphate-treated samples ($p < 0.01$) and 10.5 ± 0.42 in the non-phosphate samples. The amount of fat decreased depending on the level of ERP added to the nugget. The amount of fat, which was affected by storage period, was lowest at the beginning of storage and highest at d 120 ($p < 0.01$; Table 1). As shown by the phosphate x ERP interaction shown in Figure 3(a), the fat in the control samples treated with phosphate and the 1.0% ERP treated samples was higher than in the non-phosphate control sample ($p < 0.05$). This difference was due to higher fat in the phosphate-containing control samples during storage (Figure 3(c)). Except on d 30 of storage, the lowest fat content was detected in the samples where 1.0% raspberry powder was added (Figure 3(b)) and the level at the beginning of storage was maintained. Although the same raw materials (chicken breast fillets, skin and fat) are

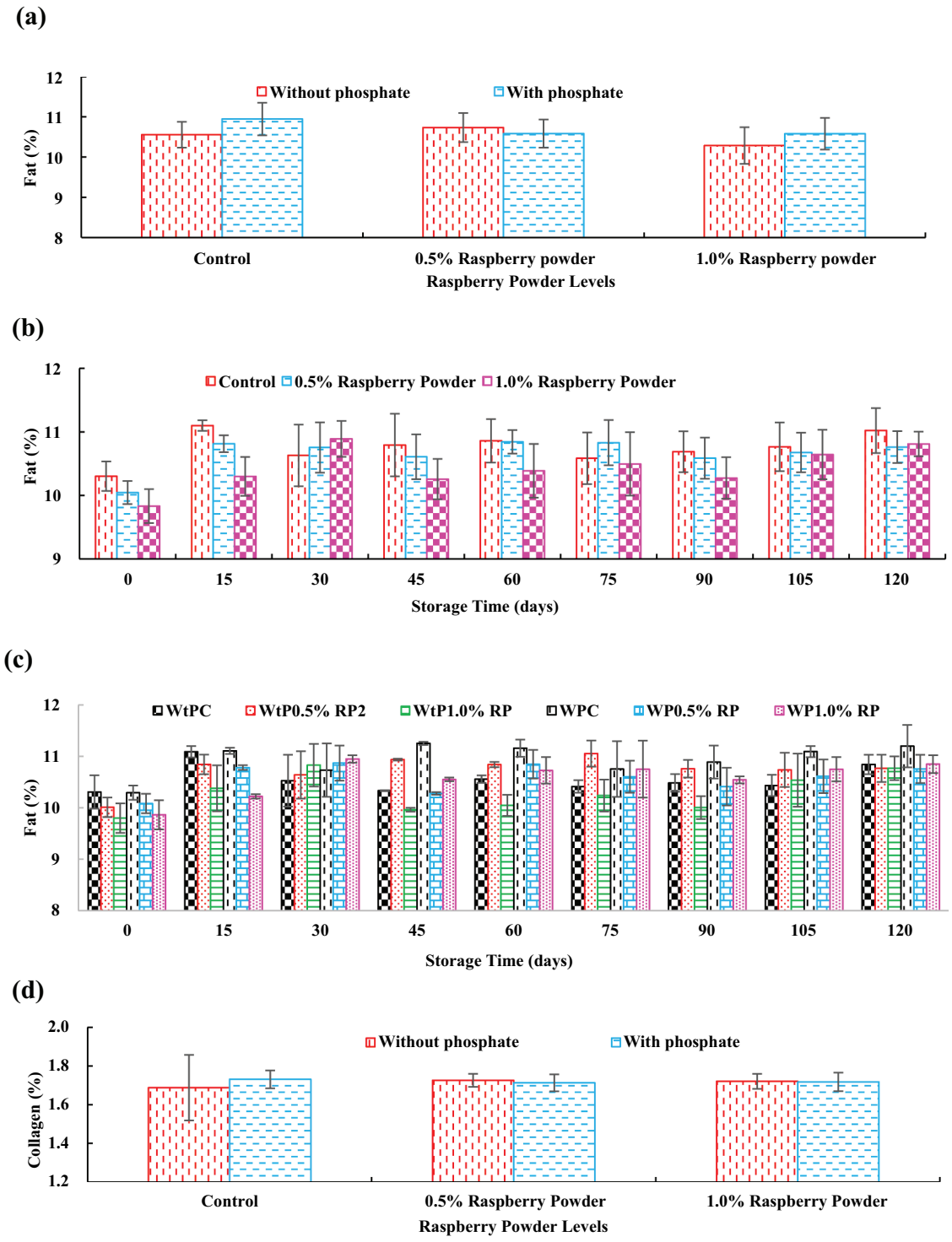

Figure 3. Effect of phosphate x raspberry powder level (a), raspberry powder level x storage time (b) and phosphate x raspberry powder level x storage time (c) interaction on the fat amount (%), and phosphate x raspberry powder levels (d) on the collagen (%) of nugget samples stored at 2.0 ± 0.5°C for 120 days.

used in nugget production, the differences in the amount of fat in the phosphate and raspberry-treated samples may have been due to the differences in the structure and emulsion stability of the oil that adhered to the products during frying. During nugget production, the amount of oil retained varied, depending on the frying temperature and time. The change in the layer formed on the outer surfaces of the nuggets depended on the temperature applied (Demiray 2023). While the amount of collagen in the samples was not affected by the addition of phosphate or ERP ($p < 0.05$), it significantly changed over the storage time ($p < 0.05$) and by the interaction of phosphate and ERP ($p < 0.05$; Table 1).

The highest collagen was detected at the beginning of storage and decreased over time ($p < 0.05$; Table 1). A greater amount of collagen was detected in the control nuggets with phosphate addition than in those without. In terms of the amount of collagen, there was no significant difference ($p < 0.05$) between the phosphate and non-phosphate groups in the samples with ERP added (Figure 3(d)).

During nugget production, the addition of ERP increased the salt amount ($p < 0.01$) and the highest values were 2.27 ± 0.1% in the 1.0% group. During storage, the highest values were 2.4 ± 0.09% at the beginning of storage ($p < 0.05$; Table 1). There was a decrease in salt for both the phosphate and non-phosphate groups in the first 15 d of the storage period, but no significant difference was observed (Figure 4(a)). A similar change was detected in the samples with the addition of ERP. During storage, generally higher salt concentrations were detected in the 1.0% ERP group (Figure 4(b)).

Water activity

Water activity is an important variable for determining the quality and storage properties of meat and related products. Chicken nuggets are products with high a_w values which affect microbiological and enzymatic activities. Both treatments had significant ($p < 0.01$) effects on the a_w of the nuggets. This was greater for nuggets containing both phosphate and raspberry additions ($p < 0.05$; Table 2). Higher a_w values were detected for nuggets with only phosphate added (Figure 4(c)) and on all days except d 15 of storage, the a_w was greater for phosphate than for the other treatments (Figure 4(d)). The addition of phosphate and ERP to chicken nuggets increased a_w. Phosphates act as water-binding agents, enhancing the ability to retain moisture in meat. This is due to their capacity to increase the ionic strength within the meat matrix, leading to better retention and increased juiciness. On the other hand, ERP contributes to natural sugars and organic acids, which can help to maintain a higher water activity by preventing water loss through the formation of a more cohesive structure. The combined effect of phosphates and ERP ensured that chicken nuggets remain moist and had an improved texture. Barros et al. (2018, 2019) reported that the a_w values of chicken nuggets were 0.957 and 0.97 for control samples.

Lipid oxidation

Lipid oxidation is an important quality criterion in fatty and deep-fried products, such as nuggets. High levels of lipid oxidation are critical control points for nuggets, since they can depreciate in quality and limit shelf life, resulting in the development of unpleasant flavours and odours, loss of nutritional value, discoloration and a reduction in the shelf life of the product. As a preventive measure against lipid oxidation, the industry usually uses antioxidant substances, such as curing salts, especially phosphate. However, these industrial measures are sometimes insufficient and shelf life can be extended by adding stronger antioxidant and natural vegetable extracts to various meat products. In the present study, lipid oxidation was decreased by the use of phosphate ($p < 0.01$) and ERP ($p < 0.01$) during nugget production. According to the TBARS values from the nugget samples, an advantage of 0.61 mg was achieved with the use of phosphate and 1.11 mg with the use of 1.0% ERP (Table 2). As shown in Figure 5(a), where the phosphate x ERP interaction graph on the TBARS value is presented, although the highest values were determined in the control samples, levels in the samples containing phosphate were lower than those without phosphate, and the difference was approximately 1 unit. A striking point here was that the TBARS values determined in nuggets produced using only 0.5% and 1.0% ERPs without the use of phosphate were lower than those in products produced using only phosphate. The TBARS value, which was 2.547 mg MDA/kg in the non-phosphate control, was 1.018 in the without phosphate + 1.0% ERP added group. The TBARS value, which was 2.547 mg MDA/kg in the non-phosphate control, was 1.018 in the group treated with 1.0% ERP only. However, in the phosphate groups, the values were 1.453 and 0.753 mg MDA/kg, respectively. These significant differences showed that ERP was more effective than phosphate in controlling lipid oxidation. Storage time had a significant effect on TBARS ($p < 0.01$) whereby an increase was observed during storage. The lowest values were 0.81 ± 0.23 mg MDA/kg at the beginning of storage ($p < 0.05$; Table 2) and increased in both phosphate and non-phosphate nuggets during storage. However, the increase was greater in non-phosphate than in phosphate treated products (Figure 5(b)). There were significant differences in terms of TBARS between the control and ERP-treated nugget samples. During storage, the lowest values were seen in samples containing 1.0% ERP and the highest values for the control samples without ERP. However, the increase seen in the control samples between storage days was significantly greater than that in the ERP samples (Figure 5(c)), hence ERP had a strong effect on lipid oxidation. Aksu et al. (2023) determined that, due to their high bioactive content, raspberry powder addition to vacuum-packaged ground beef had a dose-dependent inhibitory effect on lipid oxidation during storage. As shown in Figure 5(d), the highest increase in the TBARS during storage occurred for samples without the addition of phosphate or ERP. The TBARS in these nuggets, was 1.118 mg MDA/kg at the beginning of storage, which increased to 3.595 mg MDA/kg on d 120. In phosphate control samples, these values were 0.872 mg MDA/kg and 2.091 mg MDA/kg, respectively. During storage, although the lowest TBARS values were detected in the 1.0% ERP samples, the increase in the phosphate groups of these samples was lower. The TBARS determined on d 0 and 120 of storage in nuggets with phosphate + 1.0% ERP were 0.638 and 0.896 mg MDA/kg, respectively. This showed that lipid

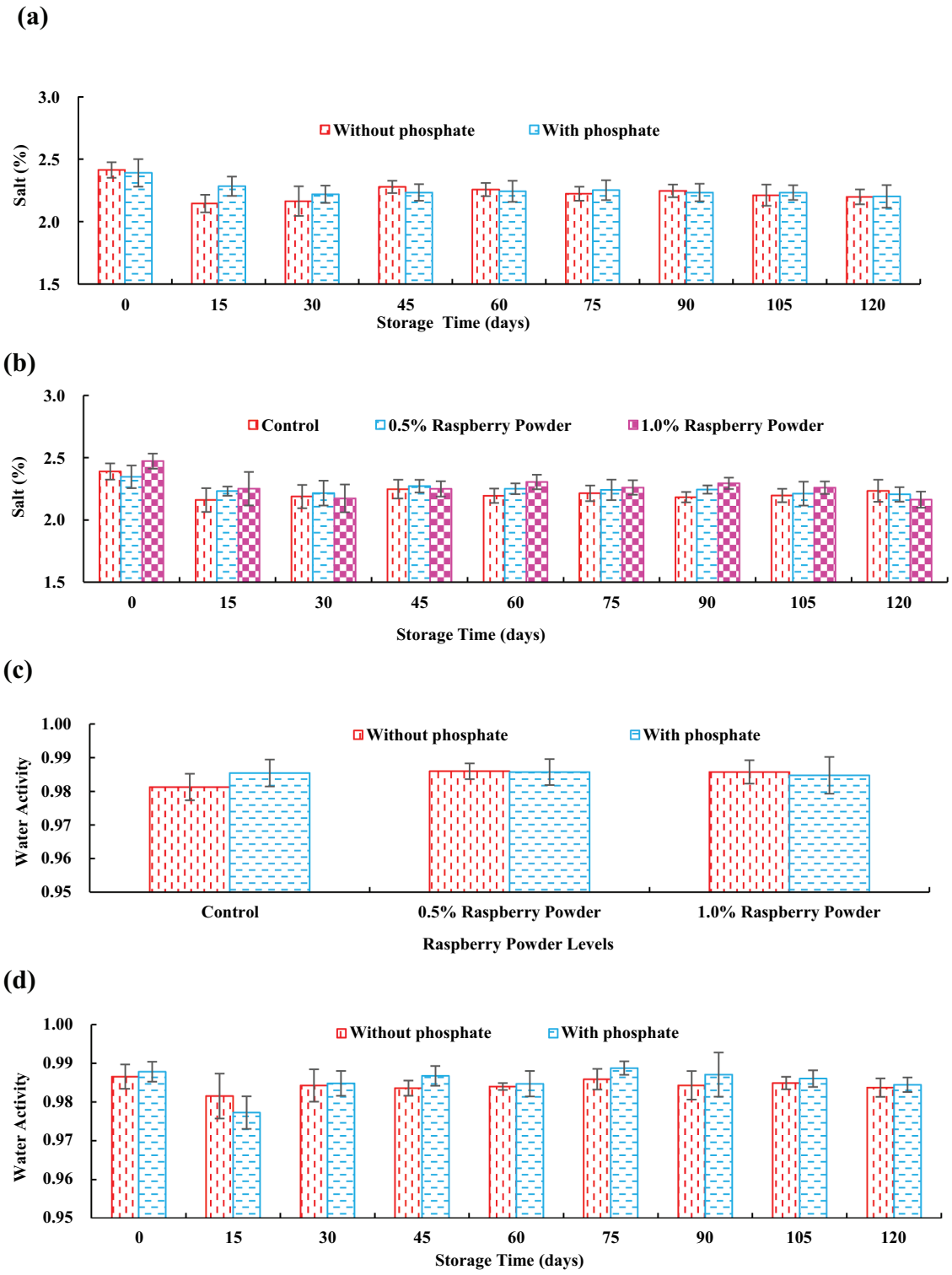

Figure 4. Effect of the phosphate x storage time (a), raspberry powder level x storage time (b) the interaction term on the salt amount (%), and the phosphate x raspberry powder level (c) and phosphate x storage time (d) on the water activity (a_w) of nugget samples stored at 2.0 ± 0.5°C for 120 days.

oxidation can be largely prevented by using the combination of phosphate + ERP in oxidation-prone products, such as nuggets, during long-term storage. An important point is that the nuggets were stored in MAP (40% CO_2 + 60% N_2) and the combination of phosphate + ERP prevented lipid oxidation in environments where the oxygen-level increased, especially after d 75 of storage. The TBARS in chicken nuggets increased during storage, which may have been due to lipid oxidation and volatile metabolites produced in the presence of oxygen. In general, this increase could be prevented by different treatments, storage temperatures and packaging methods used in nugget production (Aksu et al. 2023; Domínguez et al. 2018; Lorenzo et al. 2014; Madane et al. 2019). For this reason, vacuum and MAP packaging provide advantages due to the restriction of the amount of oxygen in contact with the product. Natural antioxidants, such as ERP, increase the functional properties of the product in terms of health and provide advantages by preventing

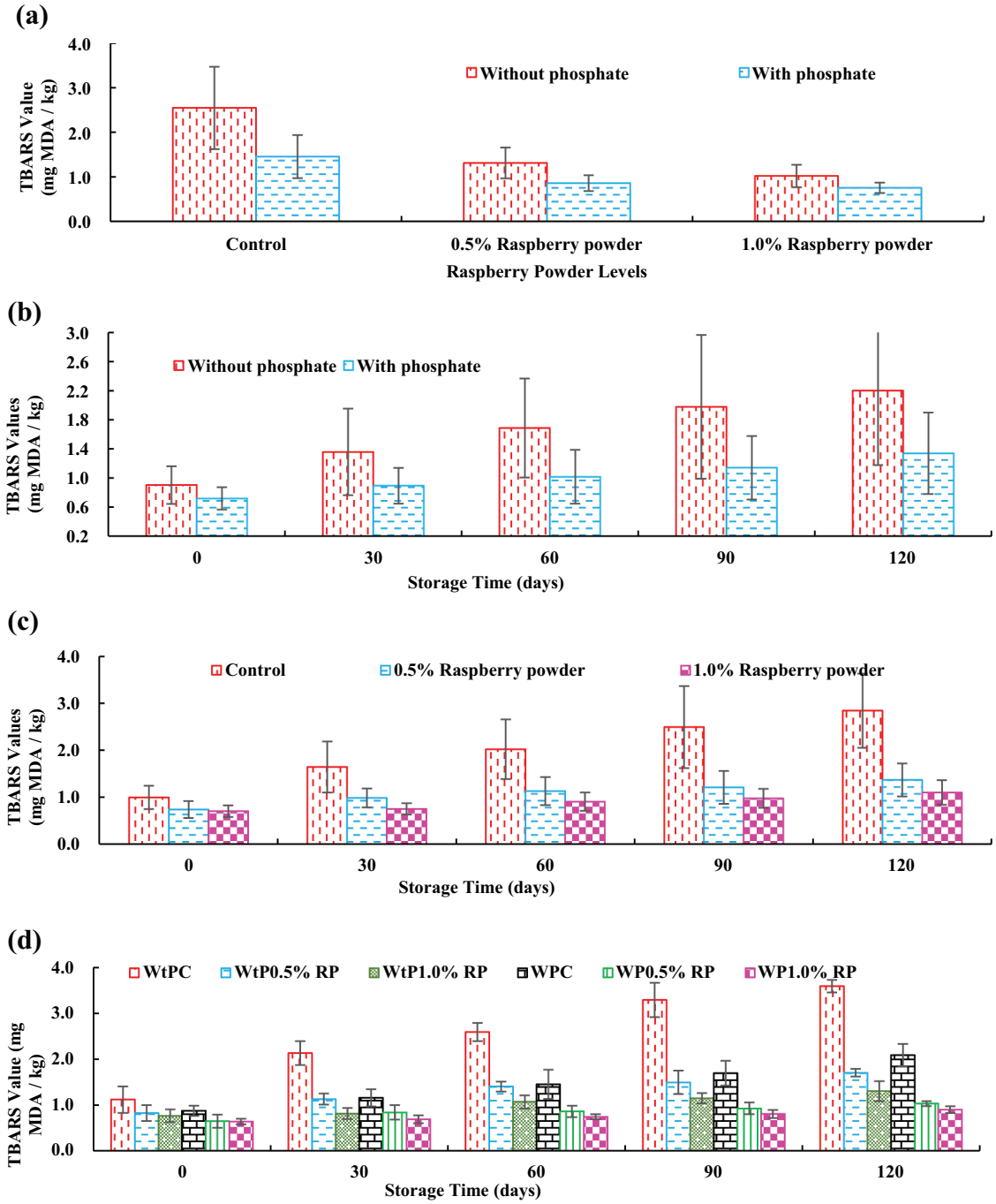

Figure 5. Effect of phosphate x raspberry powder level (a), phosphate x storage time (b), raspberry powder level x storage time (c) phosphate x raspberry powder level x storage time (d) interaction on the TBARS values (mg MDA/kg) of nugget samples stored at 2.0 ± 0.5°C for 120 days. WtPC: Without Phosphate Control, WtP0.5%RP: Without Phosphate + 0.5% raspberry powder, WtP1.0 %RP: Without Phosphate + 1.0% raspberry powder, WPC: With Phosphate Control, WP0.5 %RP: With Phosphate + 0.5% raspberry powder, WP1.0 %RP: With Phosphate + 1.0% raspberry powder.

the effectiveness of oxygen. Madane et al. (2019) reported that the TBARS in chicken nuggets stored for 20 d in aerobic packaging increased from 0.37 ± 0.01 to 1.94 ± 0.05 mg MDA/kg. The TBARS essentially provides information about secondary lipid oxidation products, such as aldehydes and carbonyls, in hydrocarbons (Juntachote et al. 2006). These compounds cause undesirable tastes and odour in meat and related products. For this reason, it has been associated with sensory analysis and has become a criterion for the acceptability of products. The researchers stated that while the acceptable limit of 1 mg was exceeded within 15 d of storage in control samples, this level was not exceeded at the end of storage in samples containing 1.0% and 2.0% *Moringa flower* extract. Similarly, Tarladgis et al. (1960) stated that the threshold for rancid odour detection for TBA was between 0.5 and 1.0. Unlike Madane et al. (2019) and Tarladgis et al. (1960), Raeisi et al. (2021) stated that the acceptable limit for the TBARS in nuggets during storage is 1–2 mg MDA/kg. In the present study, when the shelf life periods were determined by taking TBARS into consideration as 1 mg, 30 d were allowed for nuggets with 0.5% ERP added without phosphate and 60 d for products with 1.0% added without phosphate. TBARS values are within acceptable limits for all samples when 0.5% or 1.0% ERP is added in addition to phosphate. Considering that the acceptable limit is 2 mg, all the ERP alone and phosphate + ERP samples gave acceptable control. In the control samples without phosphate, this limit was exceeded in the first 30 d. These

findings showed that lipid oxidation in MAP-packaged nuggets can be prevented by using ERP in addition to phosphate after 120 d of storage.

Gas composition in MAP

Modified atmosphere packing technology consists of removing or replacing the atmosphere around the product with a known mixture of gases, such as O_2, N_2 and CO_2 (Rodrigues et al. 2018; Zhang et al. 2015). Although CO_2 and O_2 are generally used in red meat and their products depending on the product characteristics, the CO_2 + N_2 gas mixture is generally preferred in poultry products due to its low myoglobin level. In products such as nuggets, the use of CO_2 is preferred due to its bacteriostatic properties. Since O_2 promotes oxidative changes, it is not suitable for use in these products. Depending on the product characteristics, storage conditions and product/gas ratio, the composition of MAP changes during storage. In the present study, the MAP gas composition was affected by phosphate ($p < 0.01$), ERP ($p < 0.01$) and storage time ($p < 0.01$; Table 2). While the O_2 and N_2 ratio was low in nuggets containing both phosphate ($p < 0.05$) and ERP ($p < 0.05$) the amount of CO_2 ($p < 0.05$) was high. As expected, the amount of O_2 and N_2 increased, and the amount of CO_2 decreased during storage ($p < 0.05$).

The O_2 ratio was relatively high in the phosphate samples until d 60 of storage and was less than 1% until d 75. However, after d 75, there was a rapid increase in the ratio of O_2, more so without phosphate products (Figure 6(a)). This increase was due to the breakdown of CO_2, especially after d 60 of storage and the fact that for non-phosphate nuggets, CO_2 is structurally more stable than in phosphate nuggets (Figure 6 (b)). This conclusion was confirmed by the fact that the CO_2 levels in the phosphate-treated nuggets were greater than those in the control group, especially after d 75 of storage. As seen from the phosphate x storage time interaction (Figure 6(c)) there was a change in the nitrogen ratio in MAP, and the 60% nitrogen ratio was maintained during the first 30 d of storage. In the following period, the nitrogen ratio gradually increased, depending on storage time. ***This increase was lower in phosphate-containing nugget samples than in those without phosphate after the 75th day. The increase in nitrogen content in MAP paralleled the increase in microbial activity during storage (Table 3). In this process, especially owing to proteolytic microorganisms, protein-bound nitrogen was released, increasing the ratio of nitrogen in MAP. Aksu and Alp (2012) reported that the growth of psychrotrophic bacteria and *Pseudomonas* was inhibited in fresh meat by the combination of sodium tripolyphosphate (STP) + MAP, thus extending the shelf life of the meat.

The interaction between the ERP level and storage time was significant for O_2 ($p < 0.01$; Figure 7(a)), CO_2 ($p < 0.01$; Figure 7(b)) and N_2 ($p < 0.01$; Figure 7(c)) ratios (Table 2). Lower O_2 values were observed in the samples until d 15 of storage. There was a rapid increase in the O_2 ratio after d 90 of storage, but the increase in O_2 content in the samples with 1.0% added ERP was lower than that in the other groups (Figure 7(a)). This was due to the delay in spoilage of the samples containing 1.0% ERP. As mentioned above, the active gas in MAP storage is CO_2. During 120 d of storage, the ratio of CO_2 determined in the packaging of the ERP-treated samples was greater than that in the control ($p < 0.05$; Figure 7(b)). However, changes in the N_2 ratio differed between the control

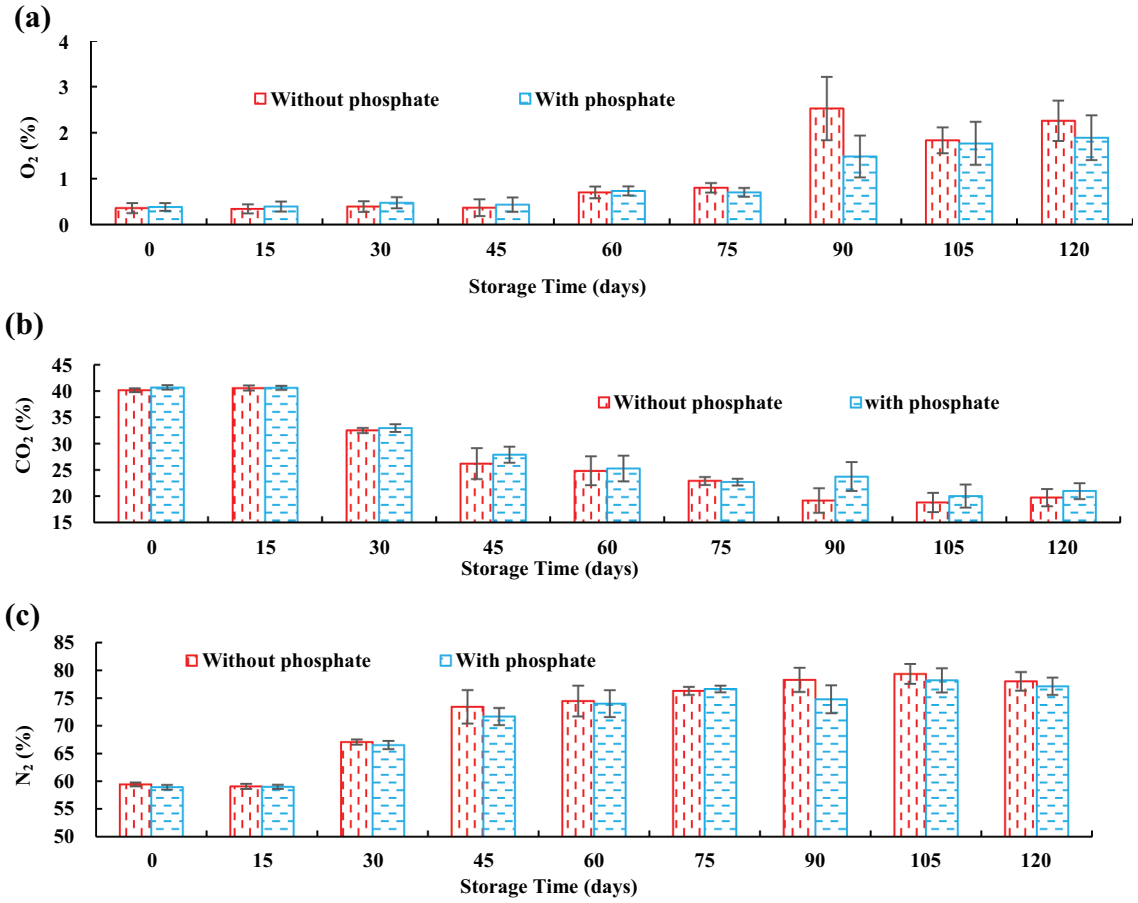

Figure 6. Effect of phosphate x storage time interaction on the O_2 (a), CO_2 (b) and N_2 (c) of MAP during storage at 2.0 ± 0.5°C for 120 days.

Table 3. Effect of ERP treatment and storage period on microbial counts (log CFU/g) of nugget samples during chilled storage.

	Total aerobic mesophilic bacteria	Mould-yeast	*Enterobacteriaceae*	*Listeria monocytogenes*	*Salmonella* spp.
Phosphate (P)					
Without phosphate	4.60[a]	4.39[a]	<2.00	Negative	Negative
With phosphate	3.87[b]	3.74[b]	<2.00	Negative	Negative
SEM	0.023	0.029			
P	**	**			
Encapsulated Rasberry Powder Levels (ERPL)					
Control	4.70[a]	4.63[a]	<2.00	Negative	Negative
0.5%	4.21[b]	3.96[b]	<2.00	Negative	Negative
1.0%	3.79[c]	3.60[c]	<2.00	Negative	Negative
SEM	0.028	0.036			
P	**	**			
Storage period (days. SP)					
0	<2.00	<2.00	<2.00	Negative	Negative
15	<2.00	<2.00	<2.00	Negative	Negative
30	2.18[g]	<2.00	<2.00	Negative	Negative
45	3.26[f]	2.44[f]	<2.00	Negative	Negative
60	3.64[e]	3.36[e]	<2.00	Negative	Negative
75	4.38[d]	3.75[d]	<2.00	Negative	Negative
90	4.93[c]	4.67[c]	<2.00	Negative	Negative
105	5.56[b]	4.95[b]	<2.00	Negative	Negative
120	5.69[a]	5.22[a]	<2.00	Negative	Negative
SEM	0.044	0.050			
P	**	**			
Interactions					
P x ERPL	**	**			
P x SP	**	**			
ERPL x SP	**	**			
P x ERPL x SP	**	**			

**: $p < 0.01$.

a–f: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of treatments.

a–h: Means in the same column and in the same section with the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of the storage periods.

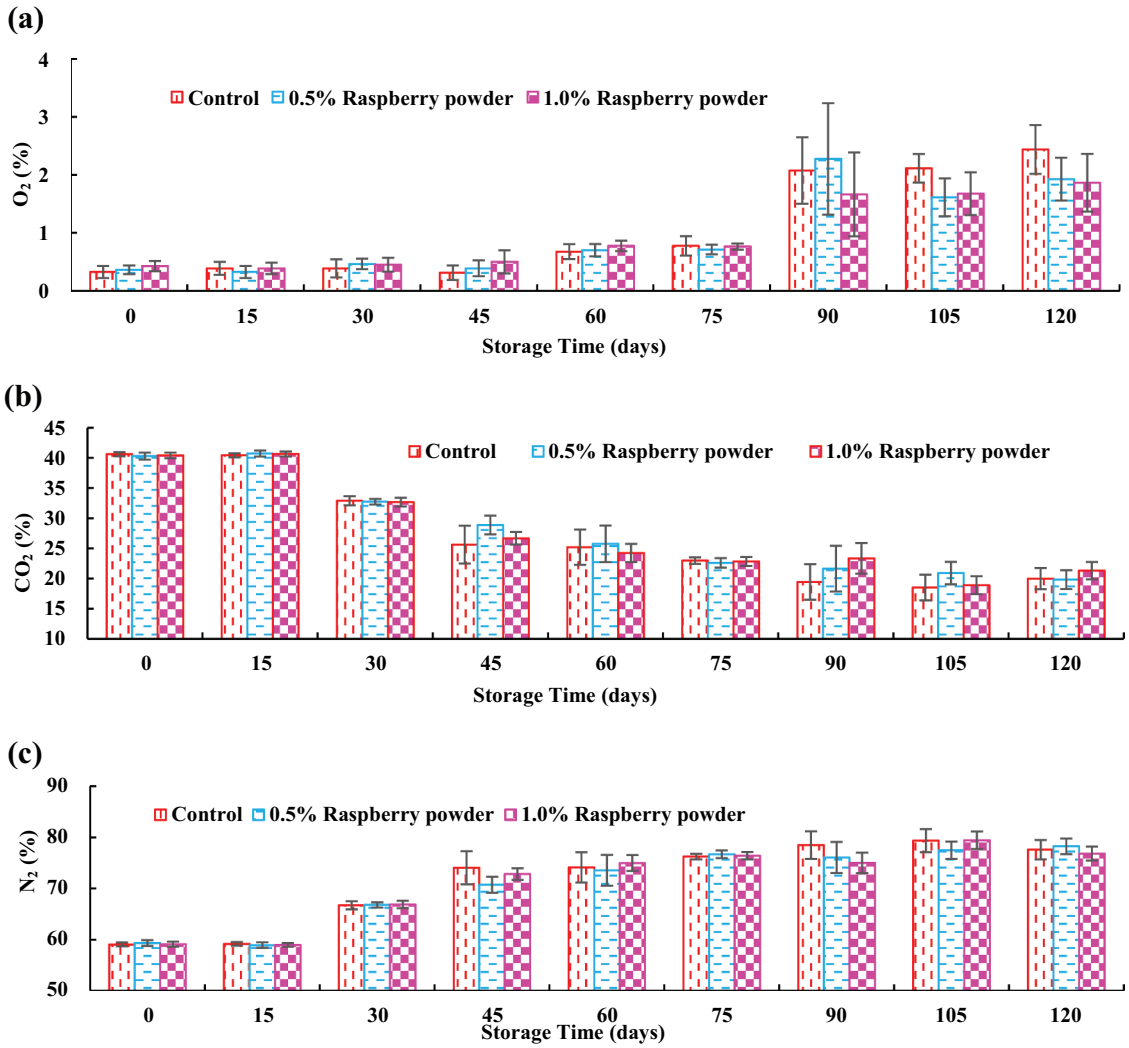

Figure 7. Effect of raspberry powder x storage time interaction on the O_2 (a), CO_2 (b) and N_2 (c) of MAP during storage at 2.0 ± 0.5°C for 120 days.

and ERP treatments (Figure 7(c)). The lower N_2 ratio in the samples with ERP was due to its antimicrobial effects.

Microbial counts

Table 3 shows the microbiological counts from the chicken nuggets prepared with different concentrations of ERP and phosphate during storage. The addition of 0.3% phosphates had a significant effect on the total aerobic mesophilic bacteria (TAMB; $p < 0.01$) and yeast mould ($p < 0.01$) in the nugget. The addition of phosphate and ERP caused a decrease in both groups of microorganisms ($p < 0.01$). The counts of TAMB reached the detectable limit (>2.0 log CFU/g) on d 30 of storage and the count of yeast-mould reached the detectable limit on d 45 of storage (Table 3). Similar findings have been reported by Aktepe (2019), who observed no variation in the TAMB or yeast-mould count from chicken nugget samples stored under refrigeration for 28 d. Yılmaz and Yılmaz (2018) reported that the counts of TAMB bacteria in nugget samples were between 3.70 and 1.9 log CFU/g. Contrary to the current findings, in some studies (Gülüm et al. 2019; Madane et al. 2019; Raeisi et al. 2021), the counts of TAMB were >2 log CFU/g at the beginning of storage in nuggets stored aerobically at 4°C for 15–20 d. It is thought that this difference arose from the raw materials used, production conditions, heat treatments applied during production and the effect of MAP.

As shown in Figure 8(a), the addition of ERP in addition to phosphate to the mixture further reduced the count of TAMB. Counts were 0.78 log CFU/g lower in phosphate-containing control samples than in non-phosphate-containing samples. This difference was 0.93 log CFU/g between phosphate and non-phosphate treatment with 1.0% ERP addition. The TAMB counts determined during storage in

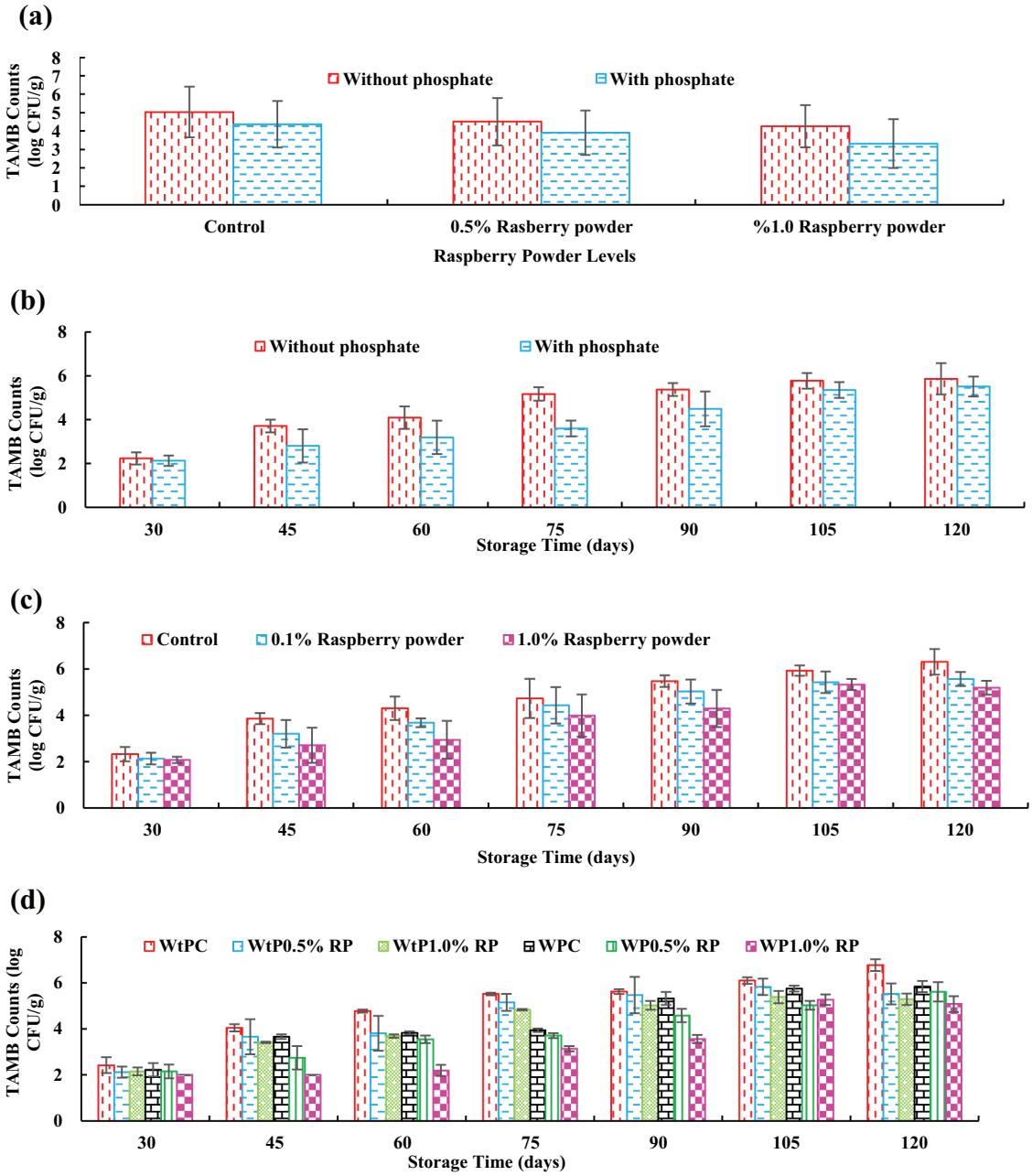

Figure 8. Effect of phosphate x raspberry powder level (a), phosphate x storage time (b), raspberry powder level x storage time (c) phosphate x raspberry powder level x storage time (d) interaction on the total aerobic mesophilic bacteria (log CFU/g) in nugget samples stored at 2.0 ± 0.5°C for 120 days. WtPC: Without Phosphate Control, WtP0.5%RP: Without Phosphate + 0.5% raspberry powder, WtP1.0 %RP: Without Phosphate + 1.0% raspberry powder, WPC: With Phosphate Control, WP0.5 %RP: With Phosphate + 0.5% raspberry powder, WP1.0 %RP: With Phosphate + 1.0% raspberry powder.

nuggets with phosphate (Figure 8(b)) and ERP (Figure 8(c)) were lower than those in the control samples.

While there was no significant difference in TAMB between samples with and without phosphate or between the control and ERP-treated samples on d 30 of storage, the increase in the counts in the phosphate-free and control samples in the later days of storage compared to those in the other groups was due to the antimicrobial effects of both phosphate and ERP. The TAMB counts decreased depending on the level of ERP added to the nugget and exceeded 6 log CFU/g only in the control samples on d 120 of storage (Figure 8(c)). Aerobic mesophilic bacteria have an accepted maximum of 6–7 log CFU/g in meat and meat products and when this is exceeded, an unpleasant odour occurs (Aksu and Turan 2021; Bedir and Kuleasan 2021; de Souza et al. 2022; Prommachart et al. 2020; Raeisi et al. 2021). Considering that the acceptable limit for nuggets produced from chicken meat is 6 log CFU/g, this count was within acceptable limits until the end of storage for all nuggets to which phosphate and ERP were added (Figure 8(c,d)). This limit was exceeded only in the samples without phosphate on d 105 and 120 of storage and was determined to be 6.10 and 6.78 log CFU/g, respectively.

Similarly, Madane et al. (2019) and Raeisi et al. (2021) reported that the count of TAMB in chicken nuggets increased during storage. The yeast-mould count from the nugget samples containing phosphate and ERP was lower than nuggets without phosphate and ERP (Figure 9(a)). However, these differences were preserved throughout storage (Figure 9(b)). Although the count of yeast-mould

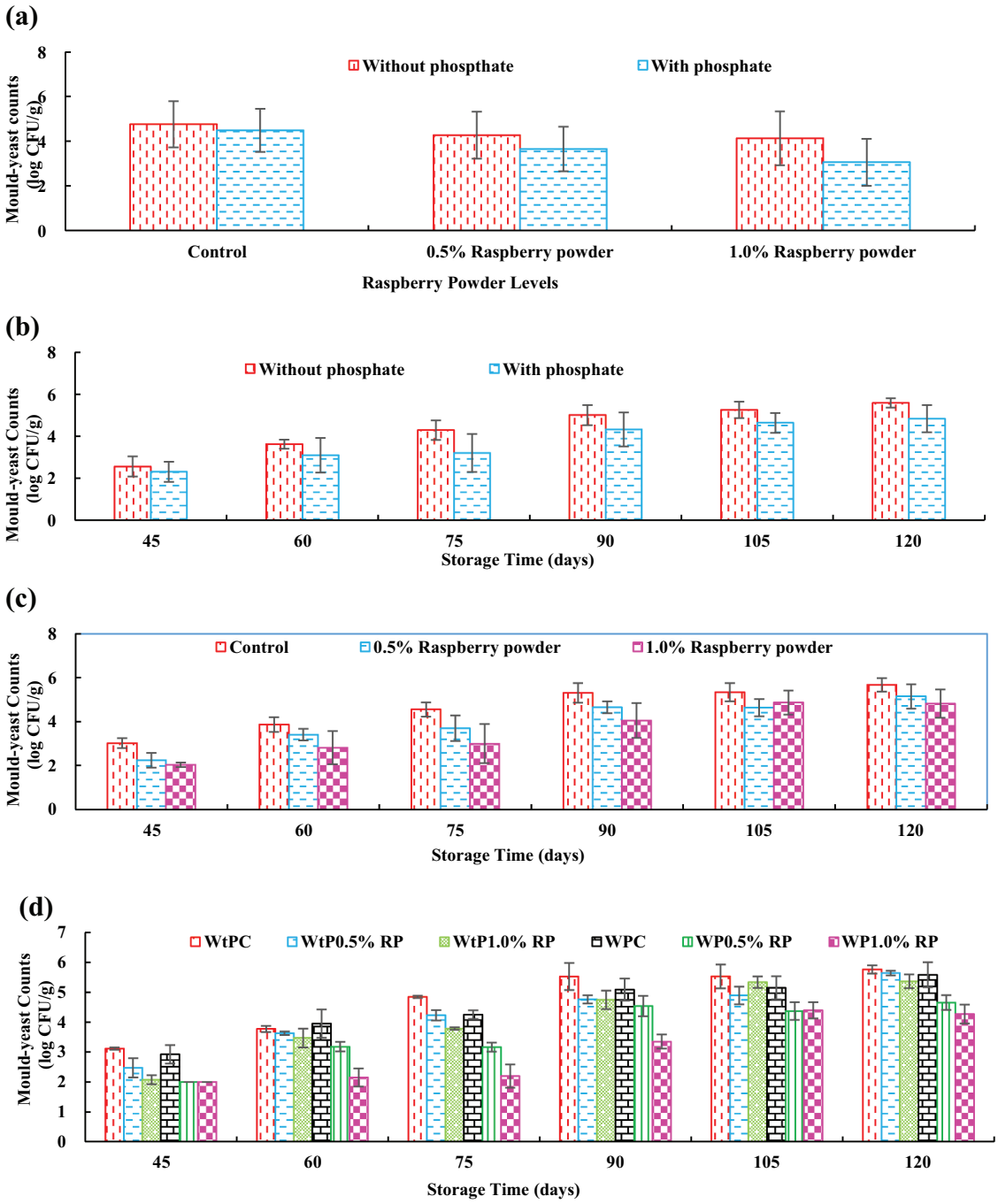

Figure 9. Effect of phosphate x raspberry powder levels (a), phosphate x storage time (b), raspberry powder level x storage time (c) phosphate x raspberry powder level x storage time (d) interaction on the mould-yeast counts (log CFU/g) in nugget samples stored at 2.0 ± 0.5°C for 120 days. WtPC: Without Phosphate Control, WtP0.5%RP: Without Phosphate + 0.5% raspberry powder, WtP1.0 %RP: Without Phosphate + 1.0% raspberry powder, WPC: With Phosphate Control, WP0.5 %RP: With Phosphate + 0.5% raspberry powder, WP1.0 %RP: With Phosphate + 1.0% raspberry powder.

increased during storage, this was greater in the control samples than in the ERP-treated samples (Figure 9(c)). However, during storage, lower yeast-mould counts were detected in samples containing phosphate + ERP (Figure 9 (d)). A noteworthy issue in the present study is that there was visible mould growth, albeit small counts, on the samples after d 60 of storage in the phosphate-free control samples and after d 75 of storage in the phosphated samples. Mould growth was observed in nuggets containing only 0.5% ERP after d 90 of storage. However, there was no mould growth on the surfaces of the samples containing phosphate +1.0% ERP during storage. These results showed that yeast-mould growth, which is an important factor in the spoilage of nuggets with high a_w and pH, can be prevented by the addition of phosphate + ERP. In parallel with this, Nohynek et al. (2006) reported that lyophilised raspberry extracts had an antifungal effect on *Candida albicans*, although this was disputed by Demirbas et al. (2017). Similarly, Aksu et al. (2023) reported that raspberry powder had no inhibitory effects on *C. albicans* or *S. cerevisiae*. *Salmonella* spp. and *Listeria monocytogenes* tests were negative (-) for all nugget samples during storage. The counts of *Enterobacteriaceae* spp. was determined to be below the detectable limit (<2.0 log CFU/g). In the study by Aksu et al. (2005), the count of *Enterobacteriaceae* spp. in chicken breast fillets was 3.43 ± 0.93 log CFU/g. Although these microorganisms are present in the raw material, they are inactivated depending on production and storage conditions. These results may be because ERP are rich in polyphenolic compounds (Aksu and Arslan 2024) that have antimicrobial effects on many pathogenic bacteria (Aksu et al. 2023).

Conclusions

In the present study, MAP chicken nuggets with or without ERP and phosphate were evaluated for oxidative and microbiological stability during storage for 120 d at 2.0 ± 0.5°C. The addition of ERP to chicken nuggets extended the shelf life of the product and protected it from oxidative deterioration even without phosphate. The use of ERP in combination with phosphate for nugget production prevents lipid oxidation and delays microbial spoilage. During storage, the lowest TBARS values and TAMB counts were determined for the samples treated with phosphate +1.0% ERP. The values determined for these combination products did not exceed the acceptable limits for TBARS (<1 mg MDA/kg) or TAMB (6 log CFU/g) during storage. For these reasons, an important result from the present research was that the shelf life can be increased to 120 d by using 1.0% ERP in addition to 0.3% phosphate in the production of chicken nuggets. This can be maintained for 45–60 d under commercial conditions, as with only MAP. The ERP improved nugget quality, as its incorporation contributed substantially to the prevention of lipid oxidation, microbial spoilage and extended shelf life. In this context, determining the textural and sensory properties of products during shelf life is important for commercial application. As a result, ERP has a high potential for incorporation into poultry meat products.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author contributions

Muhammet İrfan Aksu: conceptualisation, data curation, methodology, investigation, funding acquisition, project administration, visualisation, and writing – review & editing; Hicran Arslan: resources, visualisation, methodology, and formal analysis.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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