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Properties of encapsulated raspberry powder and its efficacy for improving the pH, colour quality and shelf life of modified atmosphere packaged chicken nuggets

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ABSTRACT

1. Recent research has shown that encapsulated raspberry powder (RP) is a natural colourant for foodstuffs. However, no research has been conducted on its use in chicken nuggets. In addition, the effect of RP on products with and without phosphate addition is unknown. This study assessed the effects of RP (control, 0.5%, 1.0%) and phosphate (0.0%, 0.3%) on the pH and colour quality properties of nuggets.
2. In the production of RP, red raspberry (*Rubus ideaus* L.) juices were encapsulated using maltodextrin in a spray-dryer. Antioxidant activity, total anthocyanin, total phenolics, colour, moisture and pH analyses of the RP were performed.
3. Nuggets were packaged in modified atmosphere packaging (MAP; 40%CO_2 + 60%N_2) and were stored at 2.0 ± 0.5°C for 120 d. The pH and external and internal surface colour (L*, a*, b*, C* and h) values were measured on d 0, 15, 30, 45, 60, 75, 90, 105 and 120 of storage.
4. The addition of phosphate increased the pH in the samples, while these decreased with the addition of RP ($p < 0.05$). During storage, the highest pH were seen in the phosphate samples and the lowest in the nuggets with 1.0% RP addition ($p < 0.05$).
5. With the addition of phosphate, the external surface a* value of nuggets increased ($p < 0.05$). Depending on the level of RP added to the nuggets, the external surface L* value decreased and a* and b* values increased ($p < 0.05$). After d 30 of storage, the a* value increased in the samples with RP addition and this increase was higher in the with phosphate nuggets ($p < 0.05$).
6. The internal surface a* value increased with the addition of RP during nugget production ($p < 0.05$). The increase in a* value was greater in samples with added phosphate ($p < 0.05$). During storage, the highest a* values were seen in nuggets treated with phosphate + 0.1% RP ($p < 0.05$). The addition of RP to chicken nugget emulsion improved redness, colour stability and shelf life.

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Introduction

The use of natural extracts in meat and meat products is becoming increasingly common (Munekata et al. 2020). However, the properties of extracts vary depending on the production technology. Encapsulated extracts are more effective than non-encapsulated ones and therefore can be used as a natural preservative in meat and meat products (Feridoni and Shurmasti 2020). Thus, the use of encapsulated fruit powders produced by spray drying has become widespread in recent years. Encapsulated fruit powders are prone to colour changes and stickiness due to their content of sugars, such as glucose, fructose and sucrose and their glaceous properties. The powders produced by spray drying method are physically stable and do not stick. It is a continuous system and the bioactive components are better preserved. For these reasons, it is more preferred for industrial applications (Fang and Bhandari 2011; Konar et al. 2022; Roopesh et al. 2012).

Raspberry (*Rubus ideaus* L.) fruit is a member of the *Rosaceae* family and is a rich source of phytochemicals. This fruit, in addition to being a source of phenolic compounds from phytochemicals and anthocyanins from phenolic compounds, contains phenolic acids and other flavonoids (Wang et al. 2009). Anthocyanins (cyanidin-3-glucoside, cyanidin-3-rutinoside and cyanidin-3-sophoroside), which have been identified within the phenolic compounds, are responsible for the red colour in raspberries (Skrovankova et al. 2015). Various properties of extracts/powder produced from raspberry by both lyophilisation and spray drying methods have been determined and their usability in products, such as cemen paste used in the production of cured and fresh meat products, has been demonstrated. Lyophilised raspberry water extract has been reported to be effective in products such as cemen paste and clean-label pastırma (Aksu and Turan 2021; Aksu et al. 2022). In addition, raspberry powder (RP) has an effect on protection against discolouration and extension of shelf life in fresh meat products, such as ground beef (Aksu et al. 2023).

Chickens can be raised under all regional conditions, and is economical in terms of meat yield and they can reach a high live weight in a short time. It has the largest share among poultry meats consumed as human food (Aksu et al. 2005). At the same time, it provides animal protein to people at low cost. Due to these features, it has an important role in closing the protein gap between the world's countries. As well as poultry meat or standard-cut products, advanced processed goods have been increasingly preferred by consumers in recent years (Tamsen, Shekarchizadeh, and Soltanizadeh 2018). Among these products, the most common are reconstituted and coated products, such as schnitzel

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and nuggets. However, rapid chemical, microbiological and physical changes in the structural properties of both fresh poultry and its products can shorten their shelf life. Due to the use of poultry skin in nugget production, the desired stability in some quality features and colour cannot be achieved. Therefore, pH is increased by the use of phosphate in nugget production to improve stability.

Taking into account the reasons given above, it may be beneficial to use a naturally derived additive with strong colourant/antioxidant properties in nugget production. Even though this practice is already established, there is currently a demand for healthier products through the substitution of synthetic antioxidants with natural forms. There appears to be no literature regarding the use of RP in chicken products such as nuggets. Therefore, the objectives of the following study were to determine the benefits of encapsulated RP in the production of chicken nuggets without and with phosphate and its effects on the pH and colour quality characteristics and shelf-life.

Material and methods

Ethical statement

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

Preparation of encapsulated raspberry powder and storage

In the production of RP, fresh raspberries (*Rubus ideaus* L. cv. Heritage) purchased from the Eskisehir region were used as raw materials. Processing was conducted according to the methods described by Gagneten et al. (2019) and Aksu et al. (2023). Fresh red raspberry juices were encapsulated by using maltodextrin (12–16 DE; 40.0%, m/m) with a lab-scale spray-dryer (B-290, Buchi, Switzerland). The spray-dried RP (Figure 1) was stored at 20 ± 2°C until use.

Raspberry powder (RP) analyses

Total anthocyanin content (TAC; mg C3G/100 g), total amount of phenolics (TAP; mg GAE/100 g), DPPH radical scavenging activity (DPPH-RSA), ABTS radical scavenging activity (ABTS-RSA) and ferric reducing antioxidant power (FRAP) of RP water extract samples were analysed according to methods used by Lee et al. (2005), Singleton et al. (1999), Blois (1958), Re et al. (1999) and Benzie and Strain (1996), respectively. Instrumental colour values of RP were measured using a chromometer (Konica Minolta CR-400, Osaka, Japan, CIE, D_{65} illuminant, 11 mm measuring aperture with two standard observer conditions). Moisture content was calculated according to weight loss after being kept in the oven (at 70°C; Nüve FN500, Turkey). The pH values of the samples with distilled water added (1:10 w/v) were measured using a pH metre (HANNA Edge, Woonsocket, RI, U.S.A.).



Figure 1. Encapsulated raspberry powder (RP).

Production of chicken nugget

Nugget production was carried out in a special production facility (C.P. Standard Food Industry and Trade Inc., Bilecik/Turkey) and the production flow chart in detail is given in Figure 2. The phosphate levels (0.0% and 0.3%), RP levels (0.0%, 0.5% and 1.0%) and storage period (0, 15, 30, 60, 75, 90, 105 and 120 d) were chosen as the sources of variation. The nugget emulsion prepared in each phosphate group was divided into three groups and RP was added at 0.0%, 0.5% and 1.0%. Six groups of chicken nuggets, produced in two replicates were packaged in a modified atmosphere and stored for 120 d.

Packaging and storage of nuggets

The produced nuggets were packaged in a modified atmosphere packaging unit using a gas composition of 40% CO_2 +60% N_2. All nugget samples were placed in laminated PVC film packaging material (PVC+PE+EVOH+PEEL, thickness 500 µm +50 µm EVOHPE; Oxygen Transmission Rate (OTR): ≤ max 1 ml/m^2/day at 23°C, 90% RH; Water Vapor Transmission Rate (VWTR): ≤max 2 g/m^2/day 38°C, 90% RH). Then the upper of laminated PVC film were coated with PET+COEX EVOH ANTIFOGL film packaging material (thickness 65±%10 µm, Oxygen Transmission Rate (OTR): ≤3 ml/m^2/day.bar; N_2 Transmission Rate: ≤15 ml/m2/day.bar; Water Vapor Transmission Rate (VWTR): ≤2 g/m^2/day) and modified atmosphere packaged (MAP) using a MAP packing unit (GEA, Powerpack 420 with Lebeling and X Y Traverse Unit, 2009, 665/624, CFS Germany GmbH). Nuggets packaged modified atmosphere were stored at 2.0 ± 0.5°C for 120 d. The pH and external and sliced surface colour (L*, a*, b*, C* and h°) values were measured on d 0, 15, 30, 45, 60, 75, 90, 105 and 120 of the storage period.

Determination of pH

The pH values of the nugget samples were determined in the homogenised mixture, with 10 g of ground whole nugget samples containing coating material +100 ml of distilled water using Ultra-turrax IKA T25 (Aksu et al. 2017). The pH meter was calibrated with appropriate buffer solutions (pH 4, 7 and 10) before use.

Determination of external and cross section surface colour values

The colour intensities of nugget samples were measured in two different ways: the external and the internal surface. Colour intensities (L*, a*, b, *C** and *h*) were

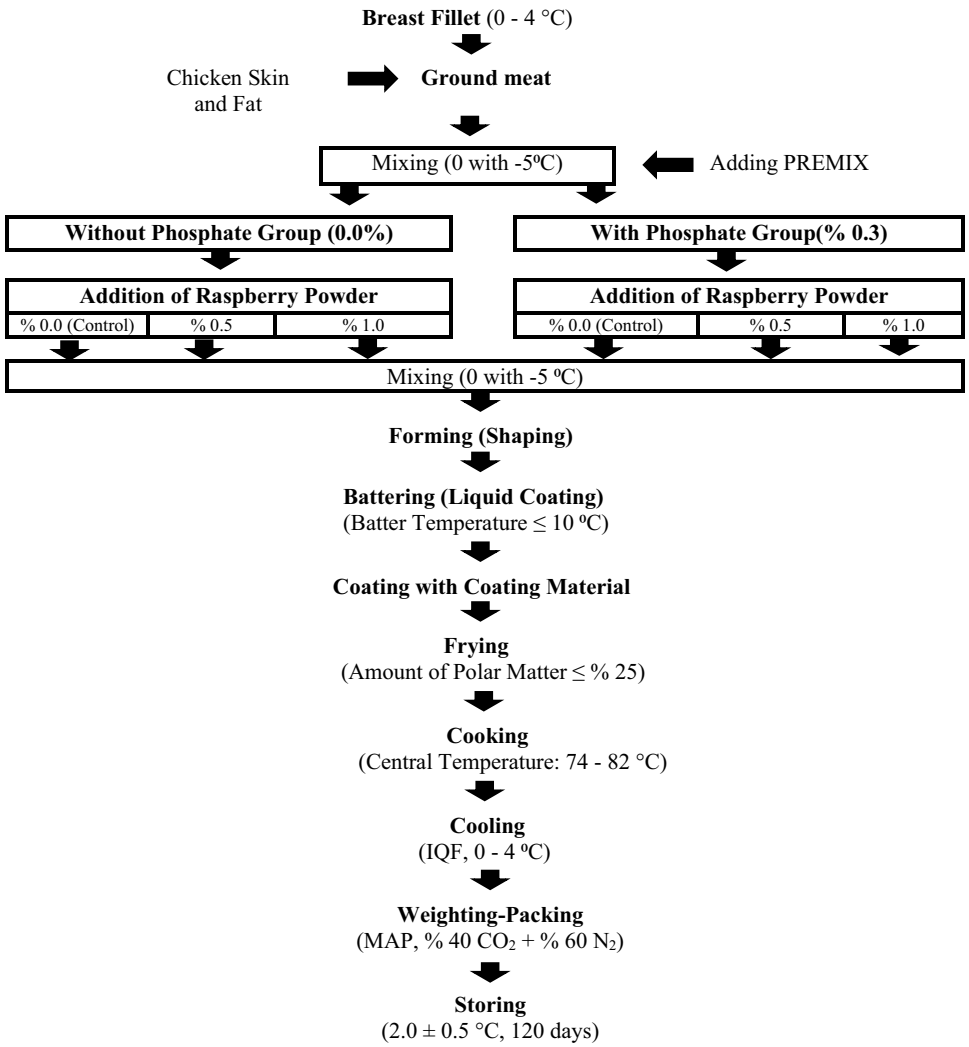

Figure 2. The chicken nugget production flow chart.

determined using a Minolta (CR-400, Minolta Co. Osaka, Japan) colorimeter on a white background. Colour intensities were made according to the criteria given by the International Illumination Commission CIELAB (Commision Internationele de I'e Clairage), which is based on three-dimensional colour measurement and according to the criteria L*; L* = 0, black; L* = 100, white (darkness or lightness); a*; +a=red, -a* =green and b*; +b*=yellow, -b*=blue indicating colour intensities.

Statistical analysis

The research was conducted according to a completely randomised block design, using two replicates. Analysis of variance by the general linear model of the SPSS 25.0 software (IBM SPSS Inc., Chicago, U.S.A.). To determine significant differences between treatment and storage time Duncan's multiple range tests at a 5% significance level ($p < 0.05$) were applied. The research model included the treatment (WtPC: Without Phosphate Control, WtP0.5%RP: Without Phosphate + 0.5% RP, 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) and storage period (0, 15, 30, 45, 60, 75, 90, 105 and 120 d) as main effects and all their interactions. The results of the statistical analysis were given as mean values and standard error in tables, and as mean values ± standard deviation figures.

Results and discussion

Properties of raspberry powders

The antioxidant activity of RP was determined as ABTS radical scavenging activity (ABTS-RSA), DPPH radical scavenging activity (DPPH-RSA) and ferric-reducing antioxidant power (FRAP). The IC_{50} values calculated for ABTS-RSA and DPPH-RSA were 45.87 ± 3.14 and 103.33 ± 2.02 µg/ml, respectively. The FRAP values were determined as 266.80 ± 10.30 µg TE/mg. The results determined for antioxidant activity were compatible with the literature (Aksu et al. 2023, 2024; Sadowska et al. 2020). The anthocyanin and phenolic content of RP were 130.14 ± 2.29 mg C3G/100 g and 602.42 ± 17.73 mg GAE/100 g, respectively. The high anthocyanin and phenolic content of RP increased its antioxidant capacity. This strong relationship has been stated as detail in various studies (Chen et al. 2013; Skrovankova et al. 2015). In the classification by Vasco et al. (2008), products with phenolic content over 500 mg (>500 mg GAE/100 g) are defined as products with

high phenolic content. In this context, RP is a rich source of phenolics.

The L*, a* and b* values of RP are 45.76 ± 0.43, 46.35 ± 0.12 and 14.10 ± 0.16, respectively; pH value was determined as 3.32 ± 0.06. The high a* value in RP was due to the high amount of anthocyanins and the increased red colour intensity of anthocyanins at low pH values (Aksu, Turan, and Sat 2020). The results of the present study were similar to the findings of Aksu et al. (2023) for RP produced by spray drying. The researchers determined the L*, a*, b* and pH values of RP produced by the spray drying method as 45.70, 46.40, 14.12 and 3.30, respectively. Although it was stated by Feridoni and Shurmasti (2020) that encapsulated extracts are more advantageous than non-encapsulated forms, the a* (46.91) and pH (3.36) values determined by Aksu et al. (2021) in lyophilised raspberry water extracts were close to the values determined in the current study. However, the L* (36.77) and b* (18.23) values were different.

The moisture values of RP were 4.49 ± 0.23%. These values are close to 4%, which is considered the ideal moisture level for edible powder products (Konar et al. 2023). Similarly, it was reported that the moisture values of RP produced by spray drying was 4.50% (Aksu et al. 2023). The spray drying method minimises moisture absorption in the final product. For this reason, the moisture level in the fruit powders obtained was low. This property increases stability in powder products and protects against degradation processes.

pH values in nuggets

In the current study, the effects of phosphate addition ($p < 0.01$) on pH of chicken nuggets containing coating material were determined and pH values were higher in the samples with phosphate than without phosphate ($p < 0.05$, Table 1).

However, as displayed in Figure 3(a), where the phosphate × raspberry interaction graph is given ($p < 0.01$), the pH value was higher in the nuggets containing RP together with phosphate. pH is an important factor in nugget production and quality preservation. In addition to meat, pH changes with the addition of leather, MDM meat, shaving waste meat and coating material to the composition of processed products. For these reasons, phosphates are often added to the composition of nuggets and similar products to ensure stability in terms of end-product properties. Polyphosphates, which are mainly effective through pH change, are mostly used in the meat industry due to their various functions, such as improving textural properties by increasing water holding capacity and preventing oxidative and microbial spoilage (Aksu and Alp 2012; Dziezak 1990; Lai et al. 1991; Ünal et al. 2004). The pH value of nugget samples was affected by the addition of RP ($p < 0.01$) and the pH value decreased ($p < 0.05$) as the level of RP increased.

The pH value, which was 6.53 ± 0.18 in control nuggets without RP, was 6.37 ± 0.21 in samples containing 1.0% RP. This was due to the low pH value of RP (Table 1). Additionally, pH values significantly changed ($p < 0.01$) during storage, as demonstrated in Table 1, and pH showed a steady rise ($p < 0.05$) from 0 to 75 d of storage, followed by a subsequent decline with increasing storage time. Decreasing pH value during the last periods of storage was probably due to the growth of acid-forming microorganisms, such as lactic acid bacteria and/or dissolution of CO_2 into meat (Kumar et al. 2011; Teruel et al. 2015). During this process (75–120 d), the pH decrease in RP-added samples was less than the control (Figure 3(c)), which indicated that RP prevented spoilage. During storage, pH in nuggets with added phosphate was higher than those without added phosphate ($p < 0.01$; Figure 3(b)). Significant effects ($p < 0.01$) due to RP addition × storage time interactions on pH were seen (Table 1; Figure 3(c)). The pH, which decreased depending on the amount of RP added during production and at the beginning of storage, were maintained throughout all storage times. In this context, the highest pH values were detected in the control samples and the lowest values were seen in the samples containing 1.0% RP during all days of storage (Figure 3(c)).

The pH values determined in the current study were partially compatible with the values determined in nuggets produced using various compositions or coating materials. The mean pH value in the control nugget samples produced in different studies was determined as 6.26 by Kumar et al. (2011), 6.36 by Kim et al. (2015), 6.30 by Teruel et al. (2015), 6.50 by Lishianawati et al. (2022) and 5.99 by Aktepe (2019). The average pH value of chicken breast fillets was 5.87 ± 0.80, as analysed by Aksu et al.

Table 1. Effects of phosphate, raspberry powder levels and storage period on mean pH values of nugget samples containing coating material during storage at 2.0 ± 0.5°C for 120 days.

Phosphate (P)		Raspberry Powder Levels (RPL)		Storage Period (days, SP)	
Without phosphate	6.42^{b}	Control	6.53^{a}	0	6.15^{h}
With phosphate	6.49^{a}	0.5%	6.45^{b}	15	6.26^{g}
SEM	0.005	1.0%	6.37^{c}	30	6.32^{f}
P	**	SEM	0.006	45	6.40^{e}
		P	**	60	6.59^{bc}
				75	6.63^{a}
				90	6.61^{ab}
				105	6.56^{cd}
				120	6.54^{d}
				SEM	0.010
				P	**
Interactions					
P x RPL			**		
P x SP			**		
RPL x SP			**		
P x RPL x SP			**		

**p <0.01.

a–h: Means of the same column and in the same section having the different letters are significantly different at $p < .05$ (Duncan's test) between the means of phosphate, raspberry powder levels and storage periods.

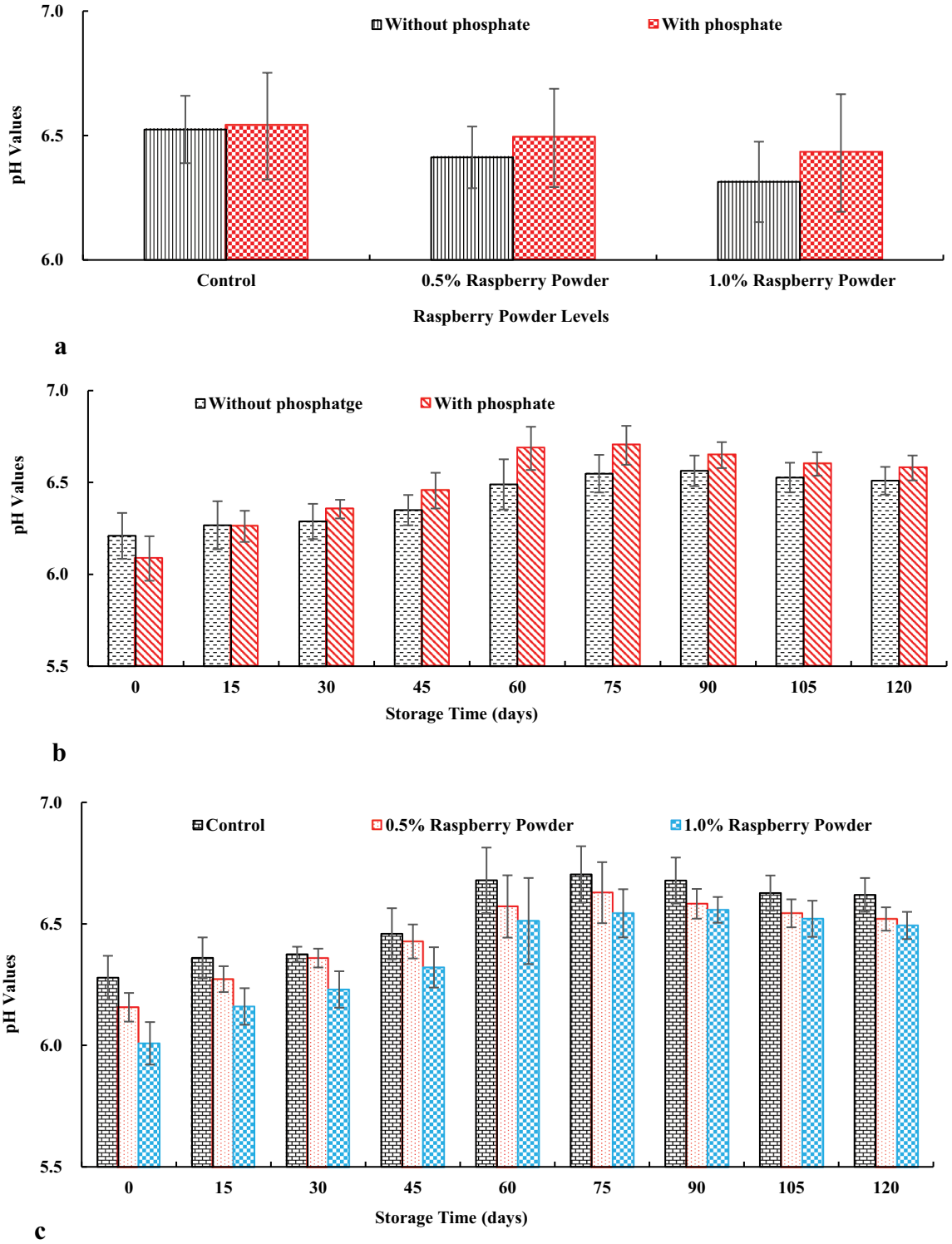

Figure 3. Effect of phosphate × raspberry powder levels (a), phosphate × storage time (b) and raspberry powder levels × storage time (c) interaction on the pH value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values.

(2005). The addition of skin and other ingredients can increase the pH value of the emulsion. In various studies, it has been observed that adding extracts with high acidic content causes a decrease in the pH value. Madane et al. (2019) observed that the addition of 1% and 2% Moringa flower extract decreased the average pH values of chicken nuggets with 0.3% phosphate from 6.30 ± 0.02 to 6.26 ± 0.01. The increase in pH value during storage was determined by Madane et al. (2019) and, in parallel with the current study findings, the increase in extracted samples was lower than in control samples. Teruel et al. (2015) stated that the addition of rosemary extract to chicken nuggets had no effect on the pH value during stored at −18°C for nine months.

External surface colour values of nugget samples

The L*, a*, b*, C* and Hu angle (h) values determined on the external surfaces of the nuggets produced in this study model during the storage period are given in Table 2.

While the external surface L* value of the samples was not affected by the addition of phosphate ($p > 0.05$), it was significantly affected by the addition of RP ($p < 0.01$) and storage time ($p < 0.01$). The addition of RP decreased the

Table 2. Effects of phosphate, raspberry powder levels and storage period on the external surface mean colour values of nugget samples during storage at 2.0 ± 0.5°C for 120 days.

	*L**	*a**	*b**	Chroma *(C*)*	Hue angle *(h°)*
Phosphate (P)					
Without phosphate	68.01	4.37^{b}	37.26	37.55	83.12^{a}
With phosphate	67.98	4.91^{a}	37.24	37.66	82.42^{b}
SEM	0.082	0.023	0.106	0.072	0.045
P	NS	**	NS	NS	**
Raspberry Powder Levels (RPL)					
Control	68.36^{a}	4.49^{b}	36.98^{b}	37.43^{b}	82.91^{a}
0.5%	67.58^{c}	4.53^{b}	37.15^{b}	37.45^{b}	82.78^{a}
1.0%	68.05^{b}	4.73^{a}	37.62^{a}	37.93^{a}	82.61^{b}
SEM	0.100	0.028	0.130	0.089	0.055
P	**	**	**	**	**
Storage period (days, SP)					
0	65.64^{e}	2.59^{h}	50.11^{a}	50.54^{a}	86.85^{a}
15	68.34^{bc}	3.97^{g}	37.55^{b}	37.85^{b}	83.98^{b}
30	68.22^{bc}	4.22^{f}	36.44^{c}	36.70^{c}	83.36^{c}
45	68.17^{bcd}	4.89^{de}	36.12^{cd}	36.43^{cd}	82.30^{d}
60	68.49^{b}	5.06^{c}	35.67^{de}	36.03^{de}	81.94^{e}
75	68.00^{bcd}	4.80^{e}	35.61^{de}	35.93^{e}	82.33^{d}
90	67.85^{cd}	5.56^{a}	35.20^{e}	35.64^{e}	81.02^{g}
105	69.62^{a}	5.23^{b}	34.18^{f}	34.58^{f}	81.31^{f}
120	67.64^{d}	4.97^{cd}	34.35^{f}	34.73^{f}	81.81^{e}
SEM	0.174	0.049	0.225	0.153	0.096
P	**	**	**	**	**
Interactions					
P x RPL	NS	**	**	**	**
P x SP	**	**	*	**	NS
RPL x SP	**	**	**	**	**
P x RPL x SP	**	**	NS	**	**

*L**: Lightness; *a**: Redness; *b**; Yellowness.
*$p < 0.05$, **$p < 0.01$, NS: Non significant.
a–c: Means of the same column and in the same section having the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of treatments.
a–h: Means of the same column and in the same section having the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of storage periods.

external surface L* value ($p < 0.05$). During storage, the lowest values were determined to be 65.64 ± 2.10 at the beginning of storage ($p < 0.05$; Table 2). The findings that RP reduced the L* value agreed with Aksu et al. (2023, 2024). Aksu et al. (2023) found that the L* value decreased from 47.63 (control) to 43.54 when adding 3.0% RP to vacuum-packaged ground beef samples. In another study, these authors stated that the L* value decreased depending on the level of RP added to cemen paste, and the value decreased from 46.4 + 2.70 in control samples to 42.2 ± 2.06 in samples with 5% RP added. The researchers stated that this decrease was due to the water-holding properties of RP (Aksu et al. 2024). In the current study, the low moisture value of RP (4.49 ± 0.23%) reduced the L* value by binding water in the nugget.

The effect of the phosphate × storage time interaction on the external surface L* value of nugget samples was important ($p < 0.01$; Table 2) and the interaction graph is shown in Figure 4(a). The lowest values were detected at the beginning of storage in both phosphate and non-phosphate added groups. The highest change, compared to d 0 of storage, was determined at the d 15 of storage. However, the highest values were determined on d 105 of storage. On the last day of storage, surface L* value decreased in both groups, but the decrease was greater in the phosphate added group (Figure 4(a)). Between d 75 and 105 days of storage, the L* values of nugget samples with phosphate addition were found to be higher than those without phosphate addition. It was thought that this was due to the fact that phosphates affected the pH of the product. In this study, the average pH value of the products was increased with the addition of phosphate and the pH value of 6.49 ± 0.22 was seen in phosphated products and was 6.42 ± 0.16 in products without phosphate (Table 2). Apart from pH, factors such as moisture loss, water holding capacity, oxidation level, growth of microorganisms, whether it is packaged or not and the gas composition inside the package are effective in changing the L* value of the external surface of the products. As seen from the RP level × storage time interaction (Figure 4(b)) there were significant differences among the external surface L* for the control and RP-treated samples. During storage, the highest external surface L* values were observed on the d 105 of storage. At this time, the L* values of the control, 0.5% and 1.0% RP-added samples were 69.75 ± 2.16, 69.77 ± 1.75 and 69.34 ± 1.28, respectively. As expected, the external surface L* values for nugget samples with RP decreased at the beginning of storage, depending on the level of RP added, and this effect continued until d 45 of storage (Figure 4(b)). It was thought that this effect was due to the fact that RP increases the water holding capacity of the products to which it is added (Aksu et al. 2023, 2024). These results suggested that both the RP levels and storage time have an effect on L* values, with varying degrees of effectiveness depending on inclusion and time. The RP added during nugget production showed a gradual increase in L* values over time.

Significant effects ($p < 0.01$) seen in phosphate x RP level x storage time interactions on external surface L* values of nugget samples were determined (Table 2). At the beginning of storage (d 0), the highest L* value was seen in control samples without phosphate and RP additions. On this storage day, the lowest L* values were detected in samples without phosphate and RP.

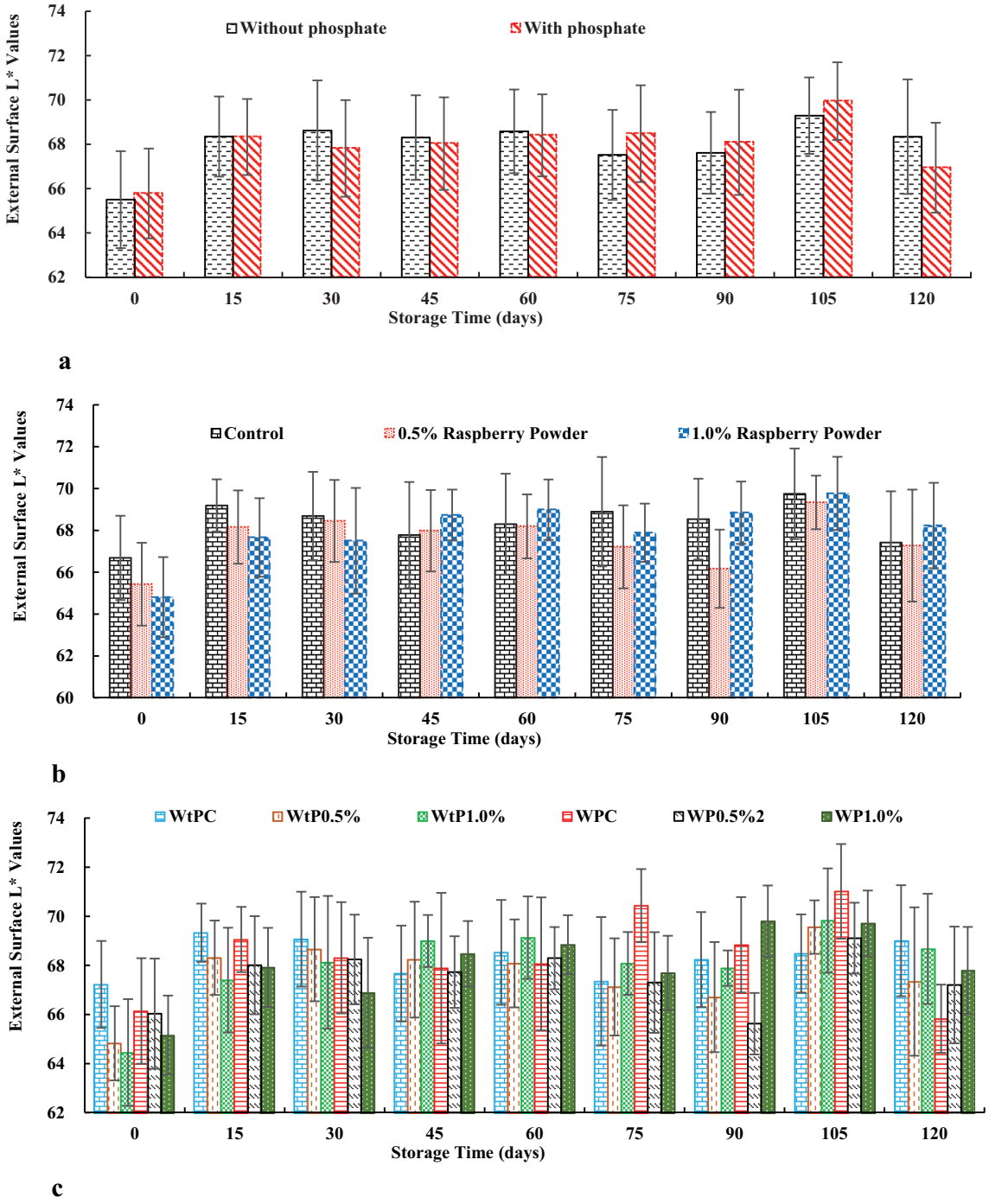

Figure 4. Effect of phosphate x storage time (a), raspberry powder levels × storage time (b) and phosphate × raspberry powder levels × storage time (c) interaction on the external surface L* value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values. 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.

Generally, L* values were lower in samples with RP added in both groups (without phosphate and with phosphate; Figure 4(c)). These results showed that pH-dependent product stability was better achieved and the L* value better maintained in groups with added phosphate than in groups without phosphate. Figure 4(c) shows that the highest change in both the phosphate and non-phosphate nugget samples during storage was in the control samples without RP addition. Considering these results, it can be stated that RP increases product stability. In the study conducted by Aktepe (2019), the external surface L* value of control nuggets produced using chicken meat was determined as 60.66 + 0.38 and the value increased to 64.56 + 0.13 during 28 d of storage. Barros et al. (2019) determined the L* values in the control samples of the chicken nuggets as 74.43.

Colour values are an important criterion used by both producers and consumers in choosing meat products. Among the colour values, the most important is the a* value, which expresses redness. However, the a* value in poultry products is quite low due to the lower myoglobin level compared to other meat products. Therefore, it is important to increase the a* value in order to increase product attractiveness. In this context, in the current study, phosphate ($p < 0.01$), RP levels ($p < 0.01$) and storage time ($p < 0.01$) had significant effects on the external surface a*

values of the chicken nuggets (Table 2). Higher a* values were determined in nuggets with added phosphate (4.91 ± 1.08) compared to nuggets without phosphate (4.37 ± 0.97; Figure 5(a)).

Adding RP increased the a* value of the nuggets. The highest a* value (4.73 ± 1.14) was found in nuggets containing 1.0% RP ($p < 0.05$). Although this difference was 0.2 units compared to the control, it was quite remarkable in terms of increasing the visual appeal of the products. There was no statistical difference ($p > 0.05$) between the control and the samples containing 0.5% RP. The high redness value of RP (46.35 ± 0.12; Figure 1) increased the external surface a* value of the nuggets. However, an important factor in the increase of the a* value was the lower pH value (Table 1) in the samples containing RP. The high acidity of RP affected the pH of the products and increased the red colour due to the anthocyanins. Because the effect of anthocyanins varied depending on pH and anthocyanins are responsible for the red colour formation in raspberries (Chen et al. 2013; Skrovankova et al. 2015).

In the current study, in which the significant effects ($p < 0.01$) of storage time on the a* value were determined, the value which was 2.59 ± 0.62 at the beginning of storage was 3.97 ± 0.74 on d 15 of storage. This value increased above 4.0 after d 30 of storage and exceeded 5.0 in subsequent storage. On d 120 of storage, it decreased below 5.0 again ($p < 0.05$), which was expected.

In nugget production, RP was added to the product emulsion to increase redness and improve product colour values and the outside of the product is coated with different materials. For this reason, the effect of redness from RP on the coating or outer layer of the product increased over time. This increased a* during storage. It is thought that the decrease in a* value in the last days of storage (120 d) was due to the change in the gas composition (40% CO_2 +60% N_2) in modified atmosphere packaging (MAP). As the amount of CO_2 decreased during storage (from 40.45 ± 0.47% to 20.36 ± 1.67% for 120 d), the amount of O_2 (from 2.08 ± 0.49% to 0.37 ± 0.10% for 120 d) and N_2 (from 59.18 ± 0.48% to 77.57 ± 1.65% for 120 d) increased in nugget samples in MAP stored for 120 d at 2.0 ± 0.5°C (Arslan and Aksu 2024). As stated by Aksu and Turan (2021), in this process an increase in the amount of oxygen will cause the oxidation of red compounds and decrease the a* value. High L* values and low a* values are desirable in products that are fried, such as nuggets. The low a* value, which results from frying these products, indicated that acrylamide formation is low (William et al. 2024). In the current study, the a* values determined in the nuggets to which RP was added at the end of production and on d 15 and 30 of storage were lower than the control, providing an advantage in terms of acrylamide formation. In other words, acrylamide formation was indirectly prevented by the addition of the extract.

The external a* colour of nugget samples were significantly ($p < 0.01$) affected by the phosphate x raspberry powder level interaction (Table 2). As displayed in Figure 5(a), the a* value of phosphate-free nuggets was lower than that of phosphated ones for all RP-added groups. In parallel with these findings, a* values of phosphated samples were found to be higher than those without phosphate during the 120 d storage period ($p < 0.05$; Figure 5(b)). The RP levels × storage time interaction on the external surface a* value of nugget samples was important ($p < 0.01$; Table 2). As can be seen from the interaction graph in Figure 5(c), RP added to the nugget composition until d 30 of storage had no effect on the a* value. The a* value of the control samples was found to be higher between 0 and 30 d of storage. However, the effect of RP was seen after d 45 and this effect continued until the end of storage. This change resulted from the nugget production method. When RP was added to the emulsion dough and then the outside was coated with coating material without supplementation, the ability of the RP in the nugget to increase or affect the redness on the external surface increased over time. The results of this study showed that RP could be effective in improving the external surface a* colour values of chicken nuggets. However, this effect was further increased by adding RP to the nugget coating material. The addition of phosphate had significant effects on the increase in a* value after the d 45 of storage ($p < 0.01$) where the a* values of nuggets with both phosphate and RP were found to be higher than those without phosphate addition and controls (Figure 5(d)). These results showed that the external surface a* values of the nugget samples could be increased by the combination of phosphate and RP which could be improved, depending on the storage time and RP level.

While phosphate addition had no effect on the b* value of nugget samples ($p > 0.05$), significant effects of RP addition ($p < 0.01$) and storage time ($p < 0.01$) were determined. The highest b* value was determined in samples with 1.0% RP addition ($p < 0.05$) and the value decreased during storage (from 50.11 ± 5.29 at 0 d to 34.35 ± 1.39 at 120 d; Table 2). Although the b* values of the samples without phosphate were lower than those of groups with phosphate, the values determined in the nuggets with phosphate + RP were higher than those of phosphate-free groups. The decrease in b* value during storage was large in both phosphate and non-phosphate groups between 0 and 15 d of storage. The decrease after d 15 was much slower compared to the first 15 d and continued throughout the storage period. A similar change in terms of b* colour value was detected during the storage period of the samples with RP addition. In this process, the lowest values were generally seen in the control samples. The use of chicken skin in nugget production affected the b* value. Karaoğlu et al. (2006) reported that the average b* value on the outer surface of post-mortem chicken carcasses was 13.48 ± 5.36. The external surface Chroma values (C*) of the nugget samples produced within the scope of the current study were higher in the samples with 1.0% RP addition than in other treatments ($p < 0.05$) and decreased during storage ($p < 0.05$; Table 2). Changes in C* value during storage were parallel to the b* value. In all treatments and samples, the greatest decrease was observed in the first 15 d of storage ($p < 0.05$). The h of the samples without phosphate and RP samples was approximately 1° greater than other treatments ($p < 0.01$). A decrease of approximately 5° occurred during the storage period (Table 2). The h was lower in all nuggets with phosphate and RP than in the samples without phosphate ($p < 0.05$). However, from d 60 until the end of storage, the lowest h was determined in the samples to which 1.0% RP was added ($p < 0.05$).

In various studies on chicken nugget production, there have been significant differences in external surface colour depending on product composition, coating material used in the product, storage temperature and duration. In the study conducted by Aktepe (2019), the external surface L*, a* and b* values in the control nuggets produced using chicken meat were 60.66 ± 0.38, 9.21 ± 0.31 and 50.59 ± 0.50 and, at

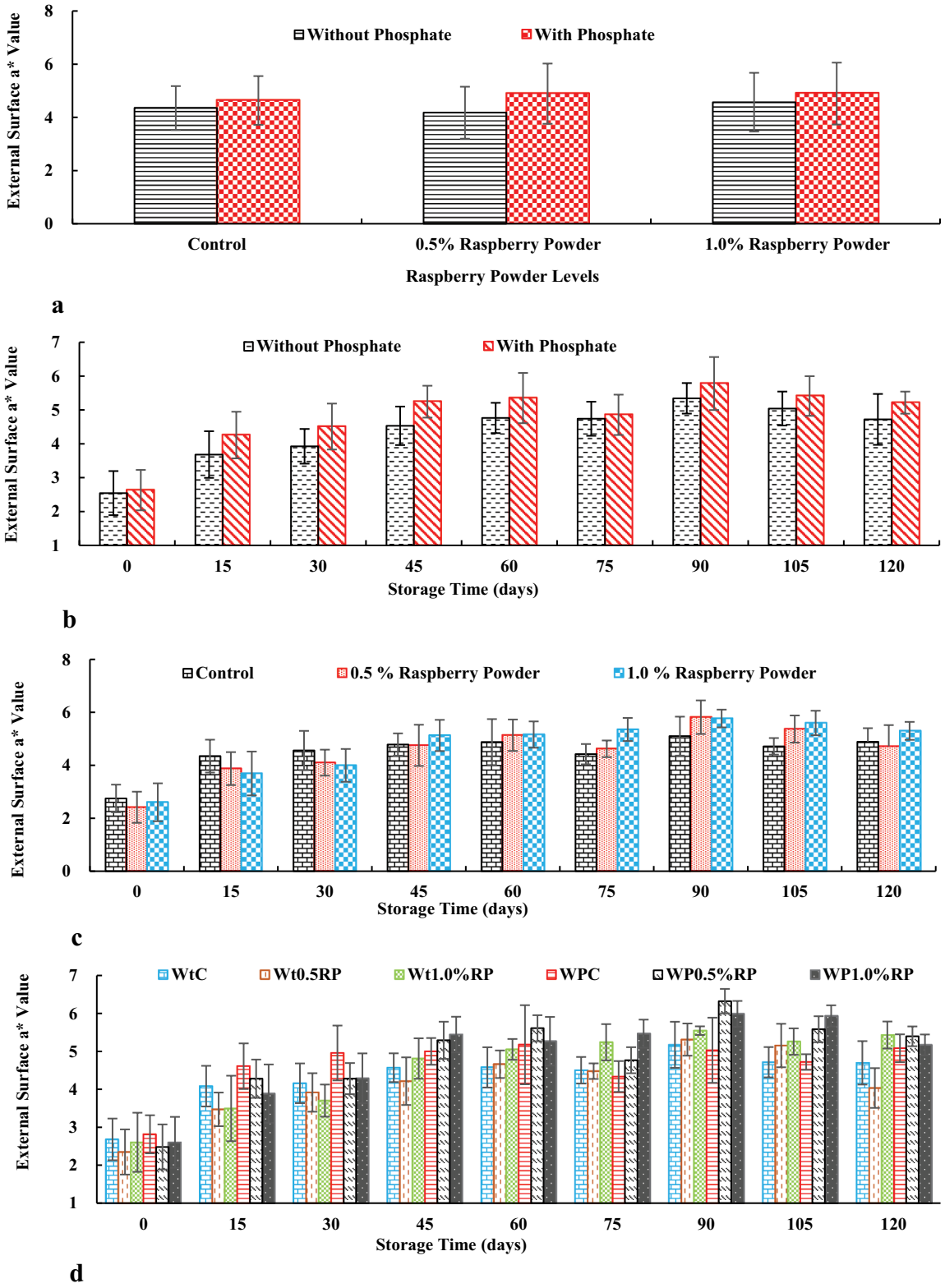

Figure 5. Effect of phosphate × raspberry powder levels (a), phosphate × storage time (b), raspberry powder levels × storage time (c) and phosphate × raspberry powder levels × storage time (d) interaction on the external surface a* value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values. 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 end of storage (28 d), they were 64.56 ± 0.13, 8.82 ± 0.03 and 50.02 ± 0.19, respectively. Barros et al. (2019) determined the L* a* and b* values in unmodified chicken nuggets to be 74.43, 1.99 and 17.97, respectively. In a different study, L*, a* and b* values in chicken nuggets produced were 29.95 ± 1.20, 13.77 ± 0.26 and 13.11 ± 0.26, respectively. The researchers found that the L*, a* and b* values in these samples were 22.52 ± 0.43, 5.11 ± 0.07 and 6.92 ± 0.17, respectively, after 20 d storage at 10°C (Madane et al. 2019).

Internal surface colour values of nugget samples

The mean internal surface L*, a*, b*, C* and h of chicken nugget samples, including phosphate and RP, determined during storage time are shown in Table 3.

The use of phosphate and RP in the nugget production and storage time had a significant effect ($p < 0.01$) on the internal surface L*. In the present study, there was generally a decrease in L* as the storage time, phosphate added and RP

Table 3. Effects of phosphate raspberry powder levels and storage period on the internal surface mean colour values of nugget samples during storage at 2.0 ± 0.5°C for 120 days.

	*L**	*a**	*b**	Chroma *(C*)*	Hue angle *(h°)*
Phosphate (P)					
Without phosphate	72.81^{a}	2.01^{b}	11.27^{b}	11.50^{b}	79.49^{a}
With phosphate	71.66^{b}	2.30^{a}	11.83^{a}	12.06^{a}	78.35^{b}
SEM	0.044	0.009	0.029	0.021	0.041
P	**	**	**	**	**
Raspberry Powder Levels (RPL)					
Control	75.83^{a}	1.70^{c}	14.20^{a}	14.034^{a}	83.16^{c}
0.5%	71.22^{b}	1.93^{b}	10.62^{b}	10.79^{b}	79.72^{a}
1.0%	69.65^{c}	2.83^{a}	9.83^{c}	10.20^{c}	73.89^{b}
SEM	0.054	0.011	0.035	0.025	0.050
P	**	**	**	**	**
Storage period (days, SP)					
0	72.54^{a}	2.15^{cd}	12.30^{a}	12.43^{a}	79.56^{a}
15	72.28^{abc}	2.10^{de}	11.57^{b}	11.80^{b}	79.23^{b}
30	72.21^{bc}	2.10^{de}	11.37^{cde}	11.59^{de}	79.05^{bc}
45	72.16^{c}	2.18^{bc}	11.29^{e}	11.53^{e}	78.56^{d}
60	72.46^{ab}	2.09^{e}	11.48^{bcd}	11.69^{bcd}	79.24^{b}
75	72.09^{c}	2.24^{a}	11.54^{bc}	11.79^{bc}	78.47^{d}
90	72.12^{c}	2.17^{bc}	11.58^{b}	11.81^{b}	78.85^{c}
105	72.03^{c}	2.17^{bc}	11.51^{bc}	11.74^{bc}	78.80^{c}
120	72.21^{bc}	2.22^{ab}	11.32^{de}	11.66^{cd}	78.52^{d}
SEM	0.093	0.019	0.061	0.044	0.087
P	**	**	**	**	**
Interactions					
P x RPL	*	**	**	**	**
P x SP	**	**	**	**	**
RPL x SP	**	**	**	**	**
P x RPL x SP	**	**	**	**	**

*L**: Lightness; *a**: Redness; *b*;* Yellowness.
*$p < 0.05$, **$p < 0.01$, NS: Non significant.
a–f: Means of the same column and in the same section having the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of treatments.
a–e: Means of the same column and in the same section having the same letters are not significantly different at $p > .05$ (Duncan's test) between the means of storage periods.

level increased ($p < 0.05$; Table 3). Internal surface L* in nugget samples which were phosphated and contained RP were lower than in samples without phosphate (Figure 6(a)). When the storage time × phosphate interaction was examined, the L* value was lower in phosphated samples during storage. However, after d 60 of storage, the difference in L* between the phosphate and non-phosphate groups increased. During storage, the lowest L* value was seen in the samples where 1.0% RP was added and the highest in the control samples. During this process, no significant change was observed, especially in the RP treated samples (Figure 6(c)). The interaction of phosphate × RP level × storage time (Figure 6(d)) was significant ($p < 0.01$) for L* (Table 3) and lower values were observed in samples with phosphate and RP added after d 15 of storage. Groups with phosphate + raspberry added during storage generally had lower L* (Figure 6(d)). This was explained by the combined effect of phosphate on pH and RP binding water in the nugget, reducing L*.

The instrumental colour measurements clearly indicated a significant ($p < 0.01$) effect of the phosphate on the internal surface a* in the chicken nugget. Nugget samples containing phosphate showed a significant ($p < 0.05$) increase in a* compared to those without (Table 3). Similarly, the addition of RP affected a* ($p < 0.01$) which increased, depending on the level added (Table 3). The lowest a* were for the control samples without RP ($p < 0.05$), and the average difference in a* between the control and the samples with 1% RP addition was approximately 1.2 units ($p < 0.05$). The level of RP added to the emulsion dough for the chicken nuggets increased the amount of anthocyanins and phenolics, which led to an increase in the total redness of the internal surface. Aksu et al. (2023) showed that the a* value increased depending on the added level in different meat products (ground meat) and cemen paste (Aksu et al. 2024) produced using encapsulated RP at different rates.

The interactions of phosphate × RP level ($p < 0.01$; Figure 7(a)), phosphate × storage time ($p < 0.01$; Figure 7(b)), RP level × storage time ($p < 0.01$; Figure 7(c)) and phosphate × RP level × storage time ($p < 0.01$; Figure 7(d)) on the internal surface a* values of the nuggets produced in the study were significant. The a* increased depending on the level of RP added to the nugget composition, produced both with and without phosphate. The a* were similar between control without and with phosphate but were lower in the 0.5% RP without phosphate than those with phosphate and higher in the 0.1% RP with phosphate compared to control and other samples (Figure 7(a)).

The a*, which was 1.410 in the control samples at the beginning of storage, was 1.898 and 3.128 in the nuggets containing 0.5% and 1% RP, respectively and the difference between the control and 1.0% groups was 1.718 units (Figure 7(c)). In other words, with the addition of 1.0% RP to the nugget composition, a* was increased by approximately 122% compared to the control. This difference, determined at the end of production (0 d), is important in terms of improving the product colour quality and this difference was preserved during storage. Consequently, the difference between the control and 1.0% RP samples was approximately 54% on d 60 of storage and 48% on d 120 of storage. This decrease was caused by the colour components in the nugget diffusing outwards during storage and increasing the a* in

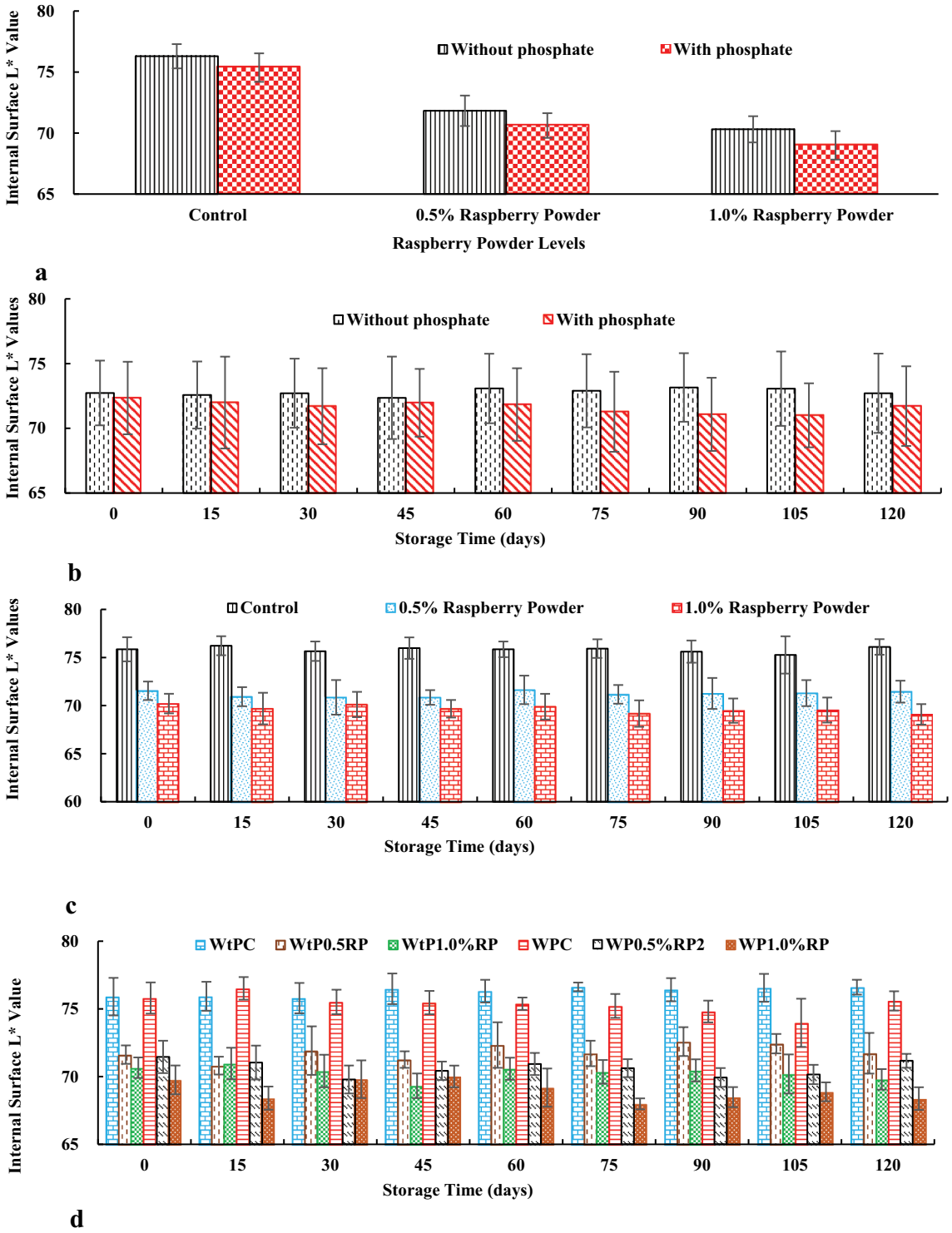

Figure 6. Effect of phosphate × raspberry powder levels (a), phosphate × storage time (b), raspberry powder levels × storage time (c) and phosphate × raspberry powder levels × storage time (d) interaction on the internal surface L* value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values. 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 coating. The increase in nugget external surface values after d 30 of storage was consistent with this result (Figure 5(c)).

The a* value increased with the addition of RP in both the nuggets without and with phosphate. However, during the 120 d storage period, the highest a* were seen in samples containing phosphate + RP (Figure 7(d)). With the addition of 1.0% RP, the pH of the nugget samples decreased (Figure 3(c)), which increased redness even more. While phosphate addition had no effect on the internal surface b* value of nugget samples, significant effects of RP addition ($p < 0.01$) and storage time ($p < 0.01$) were determined. The internal surface b* of nugget samples decreased by approximately 5 units depending on the level of RP added. The highest b* was seen in the control samples ($p < 0.05$), which changed during storage (from 12.30 ± 2.02 for 0 d to 11.32 ± 2.22 for 120 d; Table 3). However, b* for the control samples (13.83), 0.5% (10.36) or 1.0% (9.63) RP added without added phosphate were lower than those from nuggets treated with phosphate (14.57, 10.87, 10.03). During storage, the b* for

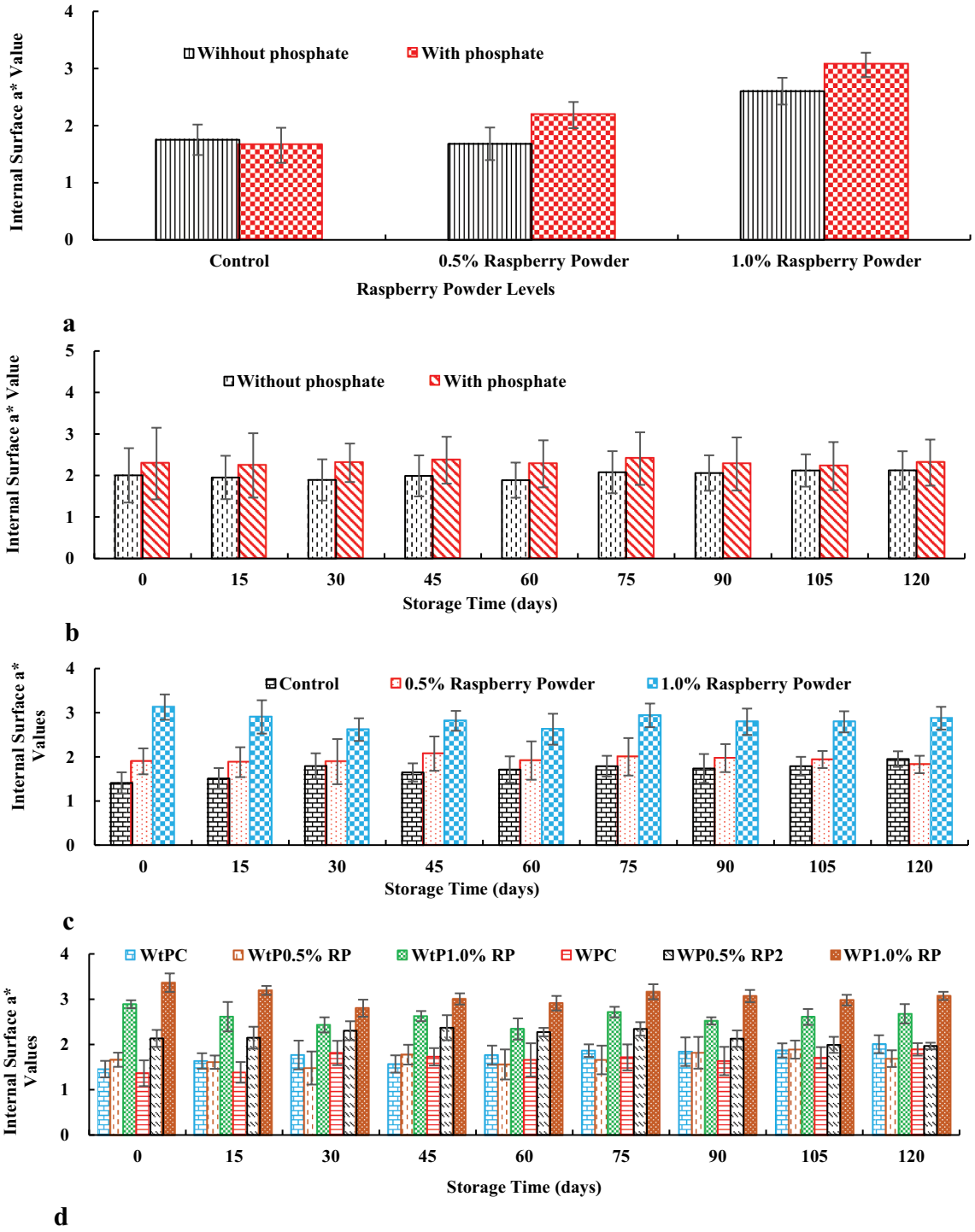

Figure 7. Effect of phosphate × raspberry powder levels (a), phosphate × storage time (b), raspberry powder levels × storage time (c) and phosphate × raspberry powder levels × storage time (d) interaction on the internal surface a* value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values. 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 phosphate-treated samples (from 12.61 for 0 d to 11.70 for 120 d) were higher than those without-phosphate (from 11.99 for 0 d to 10.93 for 120 d). As shown in Figure 8, b* decreased depending on the level of RP added to the nuggets, as values were similar between 0.5% and 1.0% RP at the beginning of storage (0 d), but lower in the 1.0% RP than in the 0.5% RP during storage (Figure 7). Madane et al. (2019) determined that, in chicken nuggets with 0.3% phosphate and 1% and 2% Moringa flower extract added, a* decreased and b* did not change, whereas L* increased, compared to the control. The researchers reported that colour (L*, a* and b*) decreased during 20 d of storage at 4°C, but a* was better preserved in nugget samples with added extract. In the study by Özvural (2019), the colour of both control and pre-deep-fried nuggets coated with olive leaf extract changed depending on the storage temperature. In the same study, L*, a* and b* were in the range 71.64–72.57, 3.01–1.87 and 23.85–24.24, respectively, on d 0 and d 21 of storage at 4°C.

The data indicated a significant ($p < 0.01$) effect of the phosphate on C* and h on the internal colour of nugget samples. While C* value increased with the addition of

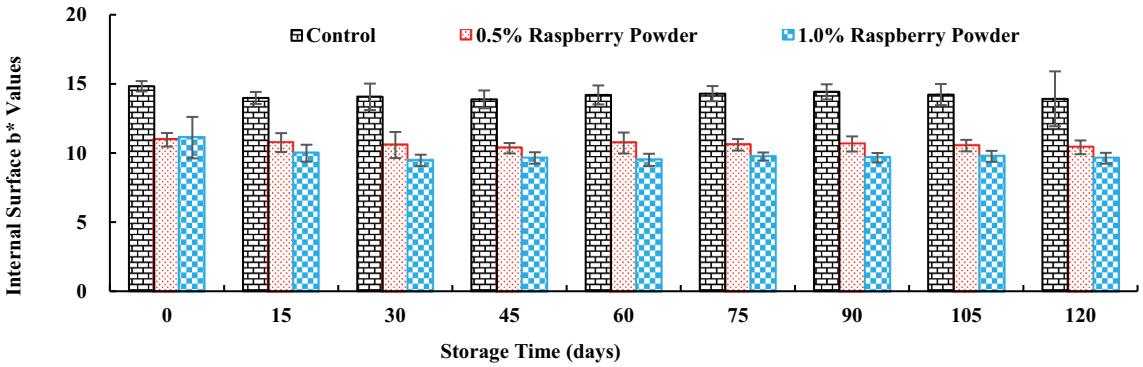

Figure 8. Effect of raspberry powder levels x storage time interaction on the internal surface b* value of nugget samples during storage at 2.0 ± 0.5°C for 120 days. Error bars represent standard errors of the mean values.

phosphate, h decreased ($p < 0.05$; Table 3). Significant effects ($p < 0.01$) of RP on these two properties showed the highest average C* in the control samples and h in the samples with 0.5% RP added (Table 3). The nugget samples with phosphate showed a significant increase in the C* values compared to those without during storage. Unlike C*, h was higher in those without phosphate. Both C* and h values for internal colour were determined to be the highest in the control samples during storage and the lowest in the samples with 1.0% RP added. Similarly, lower values were obtained in samples without phosphate +1.0% RP during storage than in other treatments. A greater decrease in storage time was observed in control samples compared to other samples.

Conclusions

According to the results, RP has a high anthocyanin and phenolic content and is a good source of natural colourant and antioxidants. To the best of our knowledge, this is the first work in using RP as an additive in chicken nugget emulsion formulations. The current study demonstrated that the pH, L* and b* from chicken nuggets decreased and the a* of external and internal surfaces increased with addition of RP to the emulsion. The increase in a* was an important result in terms of increasing quality characteristics. The decrease in the pH in the nuggets due to the addition of RP was effective in increasing a*. Discolouration and/or colour change was better preserved in samples with 1.0% RP addition during storage. However, the use of RP in addition to phosphate further increased colour properties and stability during 120 d of storage. The results showed that chicken nugget colour quality can be further increased by adding RP to the coating material as well as the nugget emulsion. Additionally, it was thought that the low external surface a*, especially in RP-added samples at the end of production and in the first 30 d of storage, was due to RP reducing the acrylamide formation caused by frying. Although RP could be used in chicken nugget emulsion production, it is important to consider other quality characteristics 120 d storage periods. This should include amount of acrylamide and other polycyclic aromatic hydrocarbons, microbial, organoleptic and physico-chemical properties of chicken nuggets such as TBARS value and peroxide values.

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Author contributions

MIA: Conceptualisation, data curation, methodology, investigation, funding acquisition, project administration, visualisation, writing – review & editing, HA: resources, visualisation, methodology, formal analysis. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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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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