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Effects of orange peel powder on performance and egg quality parameters of laying Japanese Quail

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ABSTRACT: This research was conducted to determine the effects of adding different doses (0%, 1%, 2%, and 3%) of Jafa orange peel powder (OPP) to the diets of laying Japanese quail (*Coturnix coturnix japonica*) on their laying performance and egg quality parameters. A total of 160 quail were used in four treatment groups with five replications, each containing 6 females and 2 males. While the effect of OPP supplementation on feed intake (FI) was significant at week 4 (P<0.05), the feed conversion ratio (FCR) was not improved in the 1% and 2% OPP-supplemented groups as feed intake increased. No significant differences were found between groups in terms of egg weight, eggshell breaking strength, shape index, albumen index, yolk index, Haugh unit, or shell thickness (P>0.05). Significant differences were observed in shell weight and egg yolk density at week 2 and in shell thickness and yolk weight at week 4 (P<0.05). In conclusion, it was determined that the addition of OPP to Japanese quail diets at doses of 1 and 2% resulted in a quadratic increase in FI during weeks 3 and 4. However, this addition did not result in a significant improvement in FCR or the quality of internal or external egg parameters.

Keyword: Quail; orange peel powder; egg quality; feed intake; feed conversion; performance

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INTRODUCTION

Fruit and vegetable wastes from agriculture-based industries contain rich nutrients that can be used as substitutes or additives in animal diets. In particular, citrus peels are rich in nutrients and bioactive compounds that can enhance digestibility when incorporated into poultry and quail diets. In oranges, the peel constitutes approximately 30% of the fruit, and the highest concentrations of flavonoids are found in the peel (Sawalha et al., 2009; Vlaicu et al., 2020; Seidavi et al., 2020; Saini et al., 2022; Suri et al., 2022; Garcia et al., 2024; Saed et al., 2024). As demonstrated in the relevant literature, citrus peels contain significant amounts of bioactive compounds including, but not limited to, phenolic acids (e.g. ferulic acid, p-coumaric acid, chlorogenic acid) (Zou et al., 2016), flavonoids (e.g.hesperidin, naringin, nobiletin, tangeretin), and essential oils (D-limonene, linalool, α-terpinol) (Mahato et al., 2009; Khan and Dangles, 2014). Citrus peels contain 20–50 mg/g polyphenols (e.g., hesperidin) and 15.1% crude fiber (Turhan et al., 2006), enhancing digestibility via pectin-mediated gut health modulation (Ghasemi et al., 2010). Research has shown that these by-products are effective in providing nutrition to both laying and broiler chickens, which can reduce animal feeding costs as well as prevent environmental pollution (Yeniçeri et al., 2022). Additionally, fruit wastes enhance the palatability and digestibility of feeds, promoting feed consumption and reducing costs (Chaudry et al., 2004).

Feed additives and growth stimulants are used to increase the growth and laying performance of poultry, and the effects of adding medicinal and aromatic plants to diets are being increasingly studied. The phenolic compounds in these plants are important as alternatives to antibiotics for enhancing performance and producing antioxidant-rich eggs (Goliomytis et al., 2018). Furthermore, fruit and vegetable residues (peels, leaves, seeds, pulp) have great potential as natural feed additives due to their rich antioxidant and phenolic contents (Wadhwa and Bakshi 2013; Barbosa et al., 2021; Erinle and Adewole 2022; Untea et al., 2023; Zeng et al., 2023).

Research has indicated that citrus by-products have the potential to improve feed utilization, support intestinal health, and enhance the quality of animal products (Bampidis and Robinson, 2006; Ebrahimi et al., 2015; Vlaicu et al., 2020). Orange peel powder is rich in flavonoids, phenolic compounds, and essential oils, which can support the immune system of poultry and increase feed digestibility (Ghasemi et al., 2010; Readh et al., 2023). Because of their antioxidant properties, these substances also provide protection against stress factors. Orange peel powder added to laying quail diets can increase antioxidant activity without affecting egg quality (Yıldız et al., 2023). However, since high doses of additives may produce toxic effects, the dosage should be carefully evaluated. In broilers, doses above 4% have been associated with liver stress due to limonene accumulation (Abd El Latif et al., 2023).

In Turkey's 2.3 million tons of orange production, Adana has the highest share, with 27%, followed by Antalya (25%) and Hatay (21%) (Aygören et al. 2025). In addition, 85% of production is concentrated in the Mediterranean region and 15% in the Aegean region. Washington Navel, Valencia, and Jaffa are the main orange varieties grown in Turkey. The Jaffa variety, in particular, stands out for its thick peel and aromatic properties. Jaffa peels were selected due to their higher hesperidin content (12.3 mg/g vs. 8.7 mg/g) and thicker peel structure compared to the Valencia cultivar. This structural feature ensures the preservation of phenolic compounds during drying (Afifi et al., 2023) while also contributing to feed stability. Dried orange peel, with high contents of vitamin C, flavonoids, and essential oils, can positively affect animal health and performance. Orange peel consists of the flavedo layer, which contains carotenoid pigments on the outside, and the albedo layer, which contains nutrients, pectin, and water-carrying vessels on the inside (Manthey et al., 2001; Liu et al., 2012; Marín et al., 2007; Ladaniya, 2010). The dried peel is ground into powder, while oil is obtained from oil cells in the flavedo layer (Turhan et al., 2006). Orange peel oil contains 1.48% essential oil, which has more than 200 components (Kamaliroosta et al., 2016). This oil is also rich in phytochemicals such as d-limonene, hesperetin, and naringenin. Naringenin and hesperetin, in particular, stand out for their chemical protective and anticholesterolemic properties (Palazzolo et al., 2013). The amount and effect of active substances depend on the variety of orange and the soil and climate characteristics of the region where it is grown (Filik and Kutlu, 2015). However, studies on the addition of dried and powdered forms of orange by-products to diets have generally been conducted in laying hens and broilers, with limited research on Japanese quail (*Coturnix coturnix japonica*). Most studies have focused on orange peel oil and extract, and reported that low-dose use improves performance and egg quality parameters (Eratak et al., 2023). Various studies have demonstrated that the incorporation of orange peel, in amounts ranging from 0.1% to 12% of the diet of laying hens (Yang and Choung, 1985; Chowdhury et al., 2008; Nazok et al., 2010; Ahmed et al., 2022) and quails (Florou-Paneri et al., 2001; Hasin et al., 2006; Goliomytis et al., 2018; Sevim et al., 2021; Yıldız et al., 2023) has a positive impact on feed intake and egg quality traits such as shell thickness and yolk color. Moreover, this addition does not have a detrimental effect on hatchability or embryo viability, and reports have indicated that it can increase yield performance without harming animal health (Yang and Choung, 1985; Florou-Paneri et al., 2001; Hasin et al., 2006; Chouwdhury et al., 2008; Nazok et al., 2010; Goliomytis et al., 2008; Sevim et al., 2021; Ahmed et al., 2022; Yıldız et al., 2023).

Recently, microbial fermentation has gained significant interest in the utilization of agro-industrial residues due to its capacity for large-scale treatment and enhancement of the nutritional value and functional attributes of these residues. It has been reported that microbial fermentation could improve the digestibility and palatability of agricultural by-products, alongside the reduction in toxic components of the by-products (Munteka et al.,2021). Co-fermentation of citrus residue with Aspergillus Niger, Candida tropicalis, Lactobacillus plantarum, and Bacillus subtilis significantly enhanced the protein content while substantially reducing the crude fiber content of citrus residue (Mei et al., 2022). In addition, several studies have demonstrated that the incorporation of microbial fermented citrus peel meal as a partial substitute for corn in chicken diets can significantly enhance growth performance, reduce the feed-to-gain ratio, and exhibit potential improvements in oxidative stability of unsaturated fatty acids in meat (Oyewole et al., 2012; Ahmed et al.,2014; Hu et al., 2022; Saed et al., 2024; Liu et al., 2024).

Quail (*Coturnix coturnix japonica*) is a frequently used model species in poultry research due to its rapid growth, short production cycles, and sensitivity to environmental factors (Baer et al., 2015). In laying quail, performance, egg quality characteristics, hatching efficiency, and embryonic development are important indicators for evaluating the success of production systems and the effectiveness of feed additives. As it is known, quality parameters such as egg weight, shell thickness, albumen ratio, and yolk color intensity are directly affected by nutrition.

A review of the extant literature about the performance and egg quality characteristics of laying quails reveals a significant paucity of research on the potential effects of citrus peels. The studies were generally conducted on ruminant animals or focused on the use of orange peel in laying hens (Yang and Choung, 1985; Hasin et al., 2006; Couwdhury et al., 2008; Nazok et al., 2010; Goliomytis et al., 2018; Ahmed et al., 2022). In particular, the effects of Jaffa orange peel on laying Japanese quail have not been sufficiently investigated. Studies focused on quail have emphasized performance metrics (feed intake and feed conversion ratio) and egg quality parameters as critical indicators for evaluating the efficacy of feed additives (Baer et al., 2015). However, systematic evaluations of the effects of citrus by-products in quail diets are still insufficient. Few studies in the literature have examined the use of orange peel powder in poultry feeding, particularly in terms of the nutrition of Japanese quail. Therefore, this research aims to contribute to the existing literature in related fields with the findings obtained and to contribute to field applications in this regard by using orange peel powder as an alternative feed additive in poultry feeding.

The objective of this study is to investigate the impact of incorporating different doses of Jaffa orange peel powder, which has not been investigated before, into the diets of laying Japanese quail (Coturnix coturnix japonica) on feed intake, feed conversion rate, and internal and external egg quality parameters.

MATERIALS AND METHODS

Feed materials

Jaffa oranges (250 kg) were purchased from Niğde Fruit and Vegetable Wholesale Market. After washing the oranges in water, they were drained, and their peels were removed. The orange peels were blended, weighed, placed in aluminium foil containers, and kept in a drying cabinet (Memmert UF 1060) for two days (48 hours) at 55°C and 60% humidity. During this period, the samples were mixed twice a day. The dried samples were then ground in a grinder (RETSCH, ZM 200; 16,000 rpm) to pass through a 2.0 mm sieve to create a powder. The dried orange peel powder (OPP) was stored in light-protected, airtight containers in a refrigerator at +4°C until use to minimize oxidative degradation of polyphenols

(Singleton et al., 1999) and (d-limonene Moufida and Marzouk, 2003) whilst preserving their antioxidant properties (Del Caro et al., 2004). This approach aligns with studies demonstrating the effectiveness of cold storage for preserving antioxidants in citrus by-products (Lario et al., 2004) and other fruit peels (Deng et al., 2018), where low temperature and limited oxygen exposure were critical factors.

Analysis and nutrient content of dried orange peel powder and layer hen feed

Approximate analysis of the OPP and commercial layer hen diet, including dry matter (DM), crude protein (CP), ether extract (EE), and crude ash (CA) were conducted according to AOAC (1998). Nitrogen content of feeds was determined by Kjeldahl according to (AOAC, 2005); Method 984.13). Crude fiber (CF), acid detergent fiber (ADF) and neutral detergent fiber (NDF) of OPP were determined using the method of Van Soest et al. (1991). The ingredients and composition of nutrients in the commercial layer hen feed are detailed in Table 1, while the nutrient content of OPP is presented in Table 2.

The total phenolic content was determined by employing the spectroscopic Folin–Ciocalteu colorimetric method at 765 nm, with the results expressed as Gallic acid equivalents (GAE) following the methodology described by Spanos and Wrolstad (1990). The samples were placed into a solution of Folin–Ciocalteu reagent and sodium carbonate. The resulting mixture was vortexed and then incubated in a dark environment at room temperature for two hours. The TPC value was determined by extrapolating the calibration line and expressed as gallic acid (mg) equivalents/mL sample (GAE/g sample). The Trolox equivalent antioxidant capacity (TEAC) of the samples was determined according to the method described by Re et al. (1999).

Experimental design and management

This experiment was conducted in accordance with the guidelines for the Care and Use of Animals and was approved by the Animal Research Ethics Committee of Niğde Ömer Halisdemir University (date: 12/01/2023, approval number: 2023/02).

In total, 160 eight-week-old quails were randomly allocated to four treatment groups, with each group consisting of five replicates of eight birds each (six females and two males per replicate). Each replicate group was housed in a 92 × 45 × 25 cm cage equipped with automatic waterers and feeders. The cages were kept in a completely enclosed, fan ventilated building with a daily light schedule of 16 hours of light and 8 hours of darkness. During eight weeks experimental period, quails were fed a commercial layer hen diet containing 16% CP and 2750 kcal metabolisable energy (ME)/kg (Table 1), supplemented with OPP at 0%, 1%, 2%, or 3% levels.

Feed was offered to the quails daily and the feed intake (FI) was recorded. Eggs were collected daily, their weights were recorded, and the numbers of eggs per replicate were recorded. The feed conversion ratio (FCR) was calculated by dividing the amount of feed consumed by the weight of eggs produced by each replicate in each treatment group. Feed intake and FCR were calculated by following formulas:

$$Feed\ intake\ (FI) = \text{Feed intake of 30 quails}$$

$$FCR = \frac{\text{Weekly feed intake (g)}}{\text{Weekly egg weight (g)}}$$

Internal and external egg quality characteristics were analyzed biweekly in 20 eggs collected from each group. The collected eggs were weighed using a 0.01 g precision scale, and the lengths and widths of the eggs were measured using a digital calliper.

Egg Shell Breaking Strength (kg/cm²): The shell breaking strength was determined using an Egg Force Reader (Orka Food Technology, Israel). Pressure was applied to the blunt end of the egg, and the breaking resistance was recorded in kg/cm².

Egg Shell Weight (g): After removing the egg white and yolk, the eggshells were cleaned with cotton and left on a clean surface for 24 hours. Then, they were weighed using an electronic scale with 0.01 g precision.

Shell Thickness (mm): Eggshells without membranes were left at room temperature for 1 day. Shell thickness was calculated by taking mean of the blunt, middle, and pointed parts of the shell, and measurements were performed using a micrometer.

Shape Index (Egg SI)): The width and length of the egg were measured using a caliper with 0.001 mm precision. The value was calculated using the following formula (Anderson et al., 2004):

$$Egg\ SI\ (\%) = \frac{\text{Egg width}}{\text{Egg length}} x100$$

The heights of the egg whites and yolks were measured using a tripod micrometer (Doyon et al., 1986).

Table 1. Ingredients and nutrient composition of the layer feed mixture

Feed ingredients (%)	
Corn	59.299
Sunflower meal	22.190
Extruded full-fat soybean	7.970
Limestone	8.856
DCP 18	0.733
Lysine HCL	0.188
Organic Acid	0.185
Methionine 99%	0.059
Salt	0.225
Na Sulfate	0.060
Trace Mineral Premix	0.100
Enzyme+Vitamin Premix	0.100
Toxin Binder	0.100
Choline Chloride	0.035
Nutrient composition of compound feed	
ME (kcal/kg)	2750
DM (%)	89.00
CP (%)	16.00
CF (%)	5.90
EE (%)	4.00
CA (%)	12.37
Calcium (%)	4.11
Available phosphorus (%)	0.75
Digestible Lysine	0.65
Digestible Methionine (%)	0.33
Digestible Methionine + Cystine (%)	0.60

*A 2,5 kg vitamin mixture contains 12,000,000 IU Vit. D3, 30,000 mg Vit. E, 5,000 mg Vit. K3, 3,000 mg Vit. B1, 6,000 mg Vit. B2, 5,000 mg Vit. B6, 30 mg Vit. B12, 40,000 mg Nicotinamide, 10,000 mg Calcium-D-pantothenate, 750 mg Folic acid, 75 mg D-Biotin, 375,000 mg Choline Chloride. **A 1 kg mineral mixture contains 80,000 mg iron, 60,000 mg zinc, 8,000 mg copper, 500 mg iodine, 200 mg cobalt, 150 mg selenium, 10,000 mg antioxidant. ME = Metabolizable Energy; DM = Dry Matter; CP = Crude Protein; CF = Crude Fiber; EE = Ether Extract; CA = Crude Ash; M+C = Methionine+Cystine.

Using the values obtained above, the yolk and albumen index and Haugh unit (HU) were calculated following formulas:

$$Egg\ yolk\ index\ (\%) = \frac{\text{Height of egg yolk (mm)}}{\text{Average length and width of egg yolk (mm)}}\ x100$$

$$Egg\ albumen\ index\ (\%) = \frac{\text{Height of egg white (mm)}}{\text{Average length and width of egg white (mm)}}\ x100$$

$$HU = 100 \log \left[h + 7.57 - 1.7\ W^{0.37}\right]$$

Table 2. Nutritional composition of orange peel powder (OPP), and experimental diet with different OPP levels included.

Nutrients	OPP	Calculated nutrient content of experimental diet with different OPP levels included		
		1% OPP	2% OPP	3% OPP
ME (kcal/kg)	2858	2751.08	2752.16	2753.24
DM (%)	95.34	89.06	89.13	89.19
CP (%)	4.86	15.89	15.78	15.67
CF (%)	15.10	5.95	6.00	6.05
EE (%)	0.73	3.97	3.93	3.90
CA (%)	11.00	12.28	12.19	12.09
ADF (%)	14.25			
NDF (%)	18.11			
TPC (mg, GAE/g)	615.00±1.83			
AC (µmol trolox/g)	522.73			

OPP = Orange Peel Powder; ME = Metabolizable Energy; DM = Dry Matter; CP = Crude Protein; CF = Crude Fiber; EE = Ether Extract; CA = Crude Ash; ADF = Acid Detergent Fiber; NDF = Neutral Detergent Fiber; TPC = Total Phenolic Content; AC = Antioxidant Capacity; GAE = Gallic Acid Equivalent.

Where HU: Haugh unit, h: albumen height (mm), and W: weight of the egg (g).

Yolk Weight, g: The yolks of the measured eggs were separated from the albumen and weighed using an electronic scale with a precision of 0.01 g.

The colour of the egg yolk was measured using a colourimeter (CR-300, Minolta, Osaka, Japan), which uses reflectometry data in the L*, a*, and b* colour space to describe colour. Within this colour space, L* indicates the clarity of the colour, with L* = 0 for black and L* = 100 for white and a* quantifies the colour position between green and red, with b* < 0 for bluer colours and b* > 0 for yellower colours (Mertens et al., 2010).

Statistical Analysis

The collected research data were compiled using Microsoft Excel (Version 2016; Microsoft Corp.). Internal and external egg quality traits, feed consumption, and feed conversion ratio in laying Japanese quails were subjected to variance analysis through the One-Way ANOVA procedure using the SAS statistical package program (Version 9.4; (Lewis, 2016)), in accordance with the following experimental model (Regression Analysis). Polynomial contrast analysis was applied within the same software to determine linear, quadratic, and cubic relationships among the experimental groups (control, 1%, 2%, and 3% groups). For multiple comparisons of means, Duncan's Multiple Range Test was employed (Lewis, 2016).

The mathematical model of the experimental design is given below (Ünalan, 2023):

Model 1 (Fixed Effects):

$Yij=\mu+\tau i+\varepsilon ij$

where

Yij: Observed value of the *j*-th observation in the *i*-th group (egg quality traits, feed intake, feed conversion ratio).

μ: Overall mean.

τi: Effect of the *i*-th group (deviation from the mean due to treatment: control, 1%, 2%, or 3%).

εij: Random error.

Model 2 (Polynomial Contrast) (Ünalan, 2023):

$Yij=\beta_0+\beta_1X_i+\beta_2X_i^2+\beta_3X_i^3+\varepsilon ij$

where

Yij: Observed value of the *j*-th observation in the *i*-th group.

β_0: Intercept.

β_1: Linear coefficient.

β_2: Quadratic coefficient.

β_3: Cubic coefficient.

X_i: Dose/concentration level of the *i*-th group (1%, 2%, or 3%).

εij: Random error.

RESULTS

Performance traits of quails

Feed intake and feed conversion ratio

The effects of increasing OPP levels on FI and FCR in laying quails are presented in Tables 3 and 4, respectively. During the first three weeks of the experiment, the effect of the treatment on feed intake was found to be insignificant (P>0.05). However, in the 3rd and 4th weeks, FI was quadratically affected by OPP inclusion (quadratic effect; P <0.05). Feed intake increased with the use of 1% OPP but decreased with higher inclusion levels. Similar to the initial weeks, the effect of OPP on feed intake was insignificant (P> 0.05) in the 5th, 6th, 7th, and 8th weeks of the experiment. Regarding the FCR, no statistically significant effect of OPP was observed in any week of the 8-week experiment (P>0.05). All treatment groups demonstrated similar efficiency in converting feed into eggs.

Determination of egg quality characteristics

Evaluation of external egg quality parameters

Effect of OPP on external egg quality traits, including egg weight, shell breaking strength, shell weight, shape index, and shell thickness, at different time points were presented in Table 5. Throughout the experimental period, egg weight remained statistically unaffected by OPP supplementation (P > 0.05), with all treatment groups producing eggs of comparable weights. The impact of OPP on eggshell breaking strength was generally non-significant (P > 0.05), although a significant quadratic effect was observed at week 8 (P < 0.05).

Shell thickness, a crucial determinant of egg durability, was found to be statistically significantly higher in the control group than in the OPP groups (P<0.01). Notably, at week 6. OPP supplementation exhibited significant linear, quadratic, and cubic effects on shell thickness (P < 0.05).

Egg shell weight demonstrated significant changes at week 4 (P < 0.05) and week 8 (P < 0.05). While the egg shape index remained largely unaffected by OPP treatment (P > 0.05), significant linear, quadratic, and cubic trends were observed across all experimental weeks when comparing the different treatment groups (control, 1%, 2%, and 3% OPP; P < 0.05).

Internal Egg Quality Characteristics

The effects of different doses of orange peel powder on internal egg quality parameters, including the yolk index (%), albumen index (%), Haugh unit (%), yolk weight (g), and yolk color measurements, were presented in Table 6.

The effect of OPP supplementation on the yolk index and albumen index was not statistically significant in any week (P>0.05). During the experimental period, the effect of adding orange peel powder to the ration on egg yolk weight was not statistically significant at week 2, week 4, or week 6 (P>0.05), but it was significant at week 8 (P<0.05). However, the effects of treatments were found to be quadratically significant at week 6 and week 8 (Q, P<0.05). Throughout the 8-week experiment, the effect of OPP supplementation on Haugh unit values was not statistically significant (P>0.05). While the effects of OPP supplementation on egg yolk color values (L, a, b) did not show statistically significant differences in terms of L and b* values throughout the 8 weeks (P>0.05), OPP had a statistical effect on the a* value during the first 2, and 4, weeks (P<0.05); however, this effect disappeared at week 6 and 8 (P>0.05).

DISCUSSION

A review of the existing literature on the performance and egg quality characteristics of laying quails reveals a significant lack of research into the potential effects of citrus peels. This study aimed to determine the impact of incorporating various concentrations (0%, 1%, 2% and 3%) of Jafa orange peel powder (OPP) into the diets of Japanese quail (Coturnix coturnix japonica) on their FI, FCR and external and internal egg quality. However, it was found that adding OPP to the diets of Japanese quail did not significantly improve FI, FCR, or the quality of internal or external egg parameters. Although the findings of various studies about the impact of orange peel and its by-products on feed intake (FI), feed conversion ratio (FCR), and both internal and external egg quality parameters were subject to variation. Sevim et al. (2020) stated that supplementation of different levels of orange peel oil to the laying quail diets did not affect the performance and eggshell quality parameters, except for eggshell thickness. Eggshell thickness was significantly reduced with the addition of orange peel oil to the diet. In another study Sevim et al. (2021) reported that incorporating lemon peel essential oil (LKY) in the diet of laying quail resulted in a notable reduction in feed intake (FI). Furthermore, the combined addition of orange peel (PKY) and lemon peel essential oils (LKY) significantly decreased both egg production and egg mass compared to the control group. Conversely, the study found that the inclusion of LKY and the PKY + LKY combination significantly enhanced the eggshell breaking resistance in comparison to the control group. Ahmed et al. (2022) reported that incorporating 5% and 10% dried orange peel in laying hen diets significantly reduced FI and FCR (P < 0.05), although no significant effects were observed on egg production, egg weight, or egg mass. In a recent study, the incorporation of lemon peel powder (LPP) at varying levels of 0, 1, 2, 3, 4, or 5 g/kg into the quail diet demonstrated no significant impact on performance parameters or egg production (Garcia et al., 2024).

The supplementation of orange peel powder (OPP) demonstrated no significant effects on feed intake (FI), with the exception of the third and fourth weeks, during which a quadratic effect was noted (P < 0.05). There was a non-significant numerical trend of increased feed intake for the group receiving 1% OPP, whereas higher inclusion levels resulted in a similar, non-significant decrease in feed intake (see Table 3). In contrast to the non-significant effects of OPP inclusion on FI in the present study, Goliomytis et al. (2018) reported that inclusion of 9% orange peel in the diets of laying hens led to a significant decrease in feed consumption. In the literature, it has been stated that limonene and flavonoids found in orange peel affect feed palatability and can reduce FI (Goliomytis et al., 2018; Sevim et al., 2020).

In this study, OPP addition to the ration did not statically effected on the FCR (Table 4). The elevated, yet statistically non-significant, feed conversion ratio (FCR) observed in the 1% OPP group during weeks three and four can be attributed to a significant increase in feed intake (FI) of this group during the same period (quadratic effect, P < 0.05). Faiz et al. (2017) reported that as the citrus waste percentage in the feed of the broiler was increased, its FI and body weight decreased, but the citrus waste had a non-significant effect on the feed conversion ratio of the broiler birds. In a separate study conducted by Hussein et al. (2023), it was observed that the incorporation of dried orange pulp (in amounts of 7% and 10%) into the diets of laying hens, at incremental levels, resulted in enhanced feed intake (FI) and reduced feed conversion ratio (FCR), in comparison with the control group. In contrast, Ahmed et al. (2022) reported that incorporating 5% and 10% dried orange peel in laying hen diets significantly reduced FI and FCR (P < 0.05), although no significant effects were observed on egg production, egg weight, or egg mass. In a recent study, the incorporation of lemon peel powder (LPP) at varying levels of 0, 1, 2, 3, 4, or 5 g/kg into the quail diet demonstrated no significant impact on performance parameters or egg production (Garcia et al., 2024).

In the present study throughout the experimental period, egg weight remained statistically unaffected by OPP supplementation (P > 0.05). It has been reported that adding orange peel (PKY), lemon peel essential oil (LKY), and a combination of PKY and

Table 3. Weekly feed intake in laying quails (g)

		Feed Intake (FI) in Laying Quails (g/day/30 birds)							
		Weeks							
Groups	N	1	2	3	4	5	6	7	8
Control	30	1885.34	1727.40	1592.50	1538.19	1462.74	1551.17	1466.34	1374.84
1% OPP	30	1943.70	1766.92	1832.23	1814.31	1680.38	1707.38	1666.12	1497.68
2% OPP	30	1824.71	1730.60	1760.96	1819.17	1639.16	1614.52	1604.16	1464.44
3% OPP	30	1824.81	1751.63	1657.10	1690.93	1524.10	1597.80	1620.17	1382.68
	SEM	0,478	0,411	0,587	0,588	0,597	0,608	0,552	0,515
	P	0,382	0,906	0,170	0,038	0,255	0,685	0,253	0,464
Effects[¥]	L	0,236	0,854	0,728	0,159	0,704	0,911	0,222	0,973
	Q	0,601	0,835	0,041	0,011	0,061	0,363	0,210	0,130
	C	0,243	0,503	0,433	0,665	0,623	0,442	0,296	0,712

L: linear effect; Q: quadratic effect; C: cubic effect; *: P<0.05; **: P<0.01; P>0.05; SEM: Standard Error of Means; OPP: orange peel powder; N: 30 quails/treatment. The study was arranged in a completely randomized design with four treatment groups (control, 1%, 2%, and 3% OPP) and five replicate pens per group (6 female quails/pen; N=30). Pens were the experimental units for statistical analysis.

Table 4. Feed conversion ratio in laying quails.

		Feed Conversion Ratio (FCR; g feed/g egg)							
N:120		Experimental Weeks							
Groups		1	2	3	4	5	6	7	8
Control		4.40	4.01	3.30	3.38	3.21	3.31	3.03	2.80
1% OPP		3.90	3.70	3.60	3.70	3.07	3.14	3.17	2.90
2% OPP		4.82	3.50	3.32	3.54	3.00	3.03	3.02	2.90
3% OPP		4.45	3.81	3.05	3.41	3.00	3.07	3.04	2.81
	SEM	0,250	0,150	0,090	0,800	0,800	0,080	0,060	0,070
	P	0,700	0,690	0,230	0,570	0,740	0,660	0,820	0,950
Effects¥	L	0,630	0,600	0,240	0,960	0,320	0,290	0,840	0,890
Effects¥	Q	0,920	0,290	0,110	0,210	0,650	0,530	0,640	0,580
Effects¥	C	0,280	0,840	0,510	0,550	0,980	0,900	0,440	0,870

L: linear effect; Q: quadratic effect; C: cubic effect; *: P<0.05; **: P<0.01; P>0.05; SEM: Standard Error of Means; OPP: orange peel powder; N: 30 quails/treatment. The study was arranged in a completely randomized design with four treatment groups (control, 1%, 2%, and 3% OPP) and five replicate pens per group (6 female quails/pen; N=30; Total=120). Pens were the experimental units for statistical analysis.

Table 5. Effects of orange peel powder on external egg quality characteristics of Japanese quail

N:80	External Quality Traits of Japanese Quail Eggs							¥Effects		
Parameters	Measurement	Control	1% OPP	2% OPP	3% OPP	SEM	P	L	Q	C
Egg Weight (g)	Week 2	14,29	14,16	14,43	14,26	0,210	0,830	0,843	0,914	0,366
	Week 4	14,02	14,12	14,28	14,04	0,177	0,728	0,796	0,347	0,558
	Week 6	14,32	14,80	13,06	14,45	0,529	0,115	0,567	0,393	0,027
	Week 8	14,41	14,42	13,51	14,45	0,421	0,325	0,676	0,279	0,146
Eggshell Strength (kg/cm²)	Week 2	1,220	1,230	1,310	1,190	0,071	0,640	0,972	0,368	0,353
	Week 4	1,220	1,280	1,400	1,200	0,070	0,171	0,875	0,066	0,205
	Week 6	1,330	1,450	1,240	1,290	0,076	0,279	0,354	0,664	0,095
	Week 8	1,380	1,180	1,220	1,360	0,080	0,216	0,954	0,038	0,757
Eggshell Thickness (mm)	Week 2	0,26	0,23	0,24	0,23	0,006	0,000	0,159	0,159	0,159
	Week 4	0,25	0,23	0,24	0,23	0,005	0,000	0,126	0,192	0,188
	Week 6	0,24	0,24	0,21	0,23	0,007	0,151	0,009	0,012	0,023
	Week 8	0,23	0,17	0,16	0,13	0,008	0,000	0,420	0,466	0,643
Eggshell Weight (g/egg)	Week 2	1,090	1,310	1,310	1,280	0,210	0,864	0,546	0,569	0,840
	Week 4	1,810	1,670	2,020	1,870	0,078	0,020	0,122	0,975	0,006
	Week 6	1,850	1,800	1,720	1,890	0,078	0,490	0,910	0,185	0,427
	Week 8	1,950	1,800	1,600	1,610	0,081	0,008	0,001	0,300	0,478
Egg Shape Index (%)	Week 2	81,04	78,45	80,38	78,84	0,072	0,098	0,019	0,046	0,045
	Week 4	79,77	79,10	78,60	78,81	0,058	0,445	0,024	0,025	0,025
	Week 6	80,52	78,45	70,93	79,14	0,133	0,072	0,011	0,035	0,035
	Week 8	79,32	78,22	75,60	78,31	0,113	0,614	0,005	0,009	0,010

L: linear effect; Q: quadratic effect; C: cubic effect; *: P<0.05; **: P<0.01; P>0.05; SEM: Standard Error of the Mean; OPP: orange peel powder; N: number of eggs.

Table 6. Effect of orange peel powder on internal quality traits of Japanese quail eggs

N:80	Internal quality traits of Japanese quail eggs								¥Effects		
Parameters	**Measurement**		**Control**	**1% OPP**	**2% OPP**	**3% OPP**	**SEM**	**P**	**L**	**Q**	**C**
Yolk Index (%)	Week 2		52,72	55,50	53,84	53,94	0,564	0,385	0,694	0,239	0,221
	Week 4		51,45	52,06	50,70	52,68	0,389	0,319	0,507	0,381	0,129
	Week 6		57,60	55,50	57,13	58,41	0,494	0,192	0,352	0,088	0,358
	Week 8		44,00	44,70	45,40	44,40	0,267	0,338	0,412	0,126	0,493
Albumen Index (%)	Week 2		7,40	7,75	8,34	7,53	0,461	0,491	0,631	0,213	0,432
	Week 4		7,81	8,14	8,87	7,59	0,484	0,274	0,970	0,103	0,270
	Week 6		8,61	9,52	9,00	8,28	0,434	0,220	0,434	0,069	0,535
	Week 8		8,70	7,60	8,50	10,60	1,150	0,325	0,655	0,651	0,080
Yolk Weight (g)	Week 2		4,09	4,03	4,00	3,80	0,269	0,883	0,456	0,795	0,868
	Week 4		3,95	4,46	4,24	4,37	0,161	0,138	0,150	0,247	0,143
	Week 6		4,35	4,20	3,79	4,51	0,211	0,105	0,937	0,043	0,148
	Week 8		4,50	4,10	3,50	4,30	0,224	0,026	0,293	0,016	0,107
Haugh Unit (%)	Week 2		79,86	79,91	80,58	79,67	0,848	0,883	0,978	0,573	0,564
	Week 4		79,85	80,27	81,17	79,74	0,844	0,621	0,881	0,275	0,461
	Week 6		80,62	81,36	79,99	80,38	0,892	0,739	0,604	0,844	0,333
	Week 8		81,00	79,60	79,80	80,90	0,904	0,598	0,970	0,176	0,875
Egg Yolk Color	Week 2	L	51,50	53,78	52,78	52,81	0,604	0,075	0,284	0,066	0,114
		a	12,49	13,83	14,35	14,00	0,394	0,008	0,006	0,035	0,979
		b	25,87	28,63	28,49	28,25	0,896	0,106	0,085	0,098	0,489
	Week 4	L	54,30	55,12	53,16	54,29	0,693	0,264	0,524	0,824	0,062
		a	12,29	13,83	13,05	13,07	0,372	0,044	0,348	0,046	0,067
		b	31,64	31,56	29,53	29,20	1,264	0,373	0,102	0,922	0,519
	Week 6	L	53,34	54,35	47,86	53,44	1,922	0,077	0,475	0,238	0,026
		a	15,17	14,09	12,40	14,11	0,554	0,007	0,053	0,014	0,109
		b	28,37	28,78	24,93	27,78	1,165	0,092	0,283	0,299	0,039
	Week 8	L	51,80	52,50	48,50	52,10	1,461	0,201	0,628	0,320	0,065
		a	14,50	15,10	14,10	14,80	0,563	0,589	0,956	0,919	0,170
		b	27,50	28,40	26,50	29,30	1,164	0,355	0,487	0,413	0,148

L: linear effect; Q: quadratic effect; C: cubic effect; *: P<0.05; **: P<0.01; P>0.05; SEM: Standard Error of the Mean; OPP: orange peel powder; N: number of eggs; The color parameters were measured using the CIE L*ab** system, where L* represents yolk lightness/brightness, a* indicates the green–red spectrum value, and b* denotes the blue–yellow spectrum value of the yolk.

LKY (150 mg/kg each, totaling 300 mg/kg) to the diets of laying quails has significant effects. Feed intake with the addition of LKY to the diet, egg production and egg mass with the addition of PKY + LKY decreased significantly compared to the control group, and the eggshell breaking resistance with the addition of LKY and PKY + LKY increased significantly compared to the control group (Sevim et al., 2021).

In this experiment eggshell breaking strength was generally non-significant (P > 0.05). In 1% and 2% OPP groups, eggshell strength showed a non-significant elevation in the second and fourth weeks compared to the control and 3% OPP groups. In contrast to our study's results, Sevim et al. (2021) found that the eggshell breaking strength significantly increased with the addition of LKY and PKY + LKY when compared to the control group. Garcia et al. (2024)

reported that eggshell-breaking strength improved by adding 2 g/kg LPP to the diet, but worsened at 5 g/kg.

In our study the egg shell thickness of the control group was significantly greater than that of the OPP groups (P < 0.01). A notable reduction in eggshell thickness was recorded in the groups that received OPP supplementation, with the most significant decrease observed in the group receiving 3% OPP at week eight (P<0.05). The eggshell weight in the groups receiving OPP was significantly lower than in the control group at week 8 (P < 0.05). These findings suggest that a high fiber intake, along with the presence of antinutritional factors, may negatively impact calcium absorption (Aydın ve ark., 2018). The influence of OPP demonstrated variability based on the supplementation level of OPP (Nazok et al., 2010). One reason for this decrease might be that adding 3% OPP to the compound feed reduced the total Ca ratio in the ration compared to the Ca content of the original compound feed (4.11%; Table 1). A calcium level below 3.5-4.5%, which is optimal for eggshell formation (Atik and Ceylan, 2009), can negatively affect shell quality. Additionally, OPP contains high amounts of fiber (15.1%), ADF (14.25%), and NDF (18.11%). According to NRC (NRC, 1994), the Ca/P ratio in laying Japanese quail is 7.1%. When the OPP dose increases to 3%, the total fiber ratio in the ration significantly increases, potentially reducing mineral absorption (especially Ca and P), which may decrease the availability of nutrients necessary for shell formation in quail eggs. Citrus peels may contain antinutritional factors such as phytic acid and oxalate, which inhibit mineral absorption, similar to the effect of high fiber content. The addition of high doses of OPP (3% OPP) to the compound feed may cause these components to bind to minerals important for shell formation, such as calcium and phosphorus, increase intestinal transit time, and reduce nutrient absorption and bioavailability (Oluremi et al., 2007; Mateos et al., 2012; Ebrahimi et al., 2014). Additionally, tannins can bind to minerals and proteins. Phytates can form calcium-insoluble complexes (Ahmed et al., 2022). Another factor is that adding high amounts of citrus peel to poultry rations can cause pH changes in the digestive system. This can adversely affect calcium absorption and, consequently, shell formation. Yesilbag and Colpan (2006) stated that pH changes in the poultry digestive system directly affect calcium absorption and, therefore, can alter eggshell quality. The egg shape index demonstrated no alteration in response to OPP treatment (P>0.05).

The egg yolk index was found to be unaffected by OPP supplementation (P > 0.05). The groups supplemented with 1% and 3% orange peel powder (OPP) demonstrated numerically higher yolk index values compared to the control group until week eight. Orange peel powder is abundant in carotenoids, including β-carotene, lutein, and zeaxanthin, as well as flavonoids such as hesperidin and naringin. These bioactive compounds are believed to enhance egg yolk pigmentation and may have a positive impact on the yolk index (Chowdhury et al., 2008; Fan et al., 2020). The evidence presented herein suggests that OPP can offer beneficial effects at lower concentrations; however, its long-term advantages appear to be limited (Ahmed et al., 2022).

The albumen index was not significantly affected by OPP supplementation (P>0.05). However, the quality of the albumen in the present study was observed to improve numerically in the 1% and 2% OPP groups until week 8, though these improvements were not statistically significant. Antioxidants have been known to stabilize harmful reactive oxygen species (ROS) through electron donation, thereby preventing further cellular damage from oxidative stress processes (Aranda-Rivera et al., 2022; Jomova et al., 2023). It has been demonstrated that the flavonoid and antioxidant content of orange peel can enhance the quality of egg albumen (Erişir et al., 2015).

In present study the influence of OPP on egg yolk weight was non-significant, with the exception of the eighth week (P < 0.05). Hussein et al. (2023) reported that the inclusion of dried orange pulp at 7% and 10% in laying hen diet improved shell weight and shell thickness, as well as egg yolk score.

Over the eight-week study, the impact of OPP supplementation on Haugh unit values was statistically insignificant (P > 0.05). While there were no statistically significant differences concerning egg yolk color values (L, a, b) throughout the eight-week duration for L and b* values (P > 0.05), a statistically significant effect of OPP was observed on the a* value during the second, and fourth weeks (P < 0.05). However, this effect was not observed in weeks six and eight (P > 0.05). In week eight, a numerical trend showing higher "a" values was noted in the groups supplemented with 1% and 3%. Garcia et al. (2024) found that the relative weight of eggshell and yolk L* value decreased with the treatments.

These analyses confirmed the dose-dependent effects of OPP (P<0.05) and highlighted the positive contributions of carotenoids and xanthophyll (Chowdhury et al., 2008; Fan et al., 2020; Hussein et al., 2023). These findings are consistent with existing literature and reveal that the effects of OPP vary based on dosage and duration of application.

CONCLUSION

This study was conducted to assess the effects of Jaffa orange peel powder (OPP) incorporated at various dosages (1%, 2%, and 3%) into the feed of laying Japanese quails (Coturnix coturnix japonica) on their performance and the quality parameters of both internal and external eggs. The findings indicated that the inclusion of OPP at 1% and 2% resulted in a quadratic increase in FI during weeks 3 and 4. However, this addition did not yield a significant enhancement in feed utilization or in the quality of the internal and external egg parameters. While there were no statistically significant differences observed in the L and b* values of egg yolk color throughout the 8-week study, OPP supplementation did exhibit a statistically significant impact on the a* value during the initial 2 and 4 weeks.

Although its significance appears to be non-continuous after the fourth week, a 1% (OPP) supplementation appears to have a positive effect on feed intake. A short trial duration and quail model limitations may influence the effect of OPP on feed. Further studies are needed to observe the antioxidant effect of OPP on hatchability and egg shelf life.

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