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Performance and meat quality characteristics of male quails (*Coturnix coturnix japonica*) fed diets supplemented with pomegranate seed oil

Ainhoa SARMIENTO-GARCÍA[1*], Seyit A. GÖKMEN[2], Behlül SEVIM[3] and Osman OLGUN[2]

[1]*Departmento de Construcción y Agronomía, Facultad de Ciencias Agrarias y Ambientales, Universidad de Salamanca, 37007 Salamanca, Spain.* [2]*Department of Animal Science, Faculty of Agriculture, Selcuk University, 42130 Selcuklu, Konya, Türkiye.* [3]*Eskil Vocational School, Aksaray University, 68800 Eskil, Aksaray, Türkiye.*

*Correspondence should be addressed to Ainhoa Sarmiento-García: asarmg00@usal.es

Abstract

Aim of study: Pomegranate seed oil (PSO) is a nutritive, antioxidant-rich by-product, and it has been tested as a feed ingredient for livestock. However, studies on quails are scarce. The current study investigated that the effect of PSO on the performance and meat instrumental quality of quails.

Area of study: Türkiye.

Material and methods: A total of 60 seventy-day-old male quails were equally subjected to 3 dietary treatments consisting of 20 birds (5 replicates with 4 birds each). The quails were fed a diet supplemented with 0, 100, and 200 mg kg^{-1} pomegranate seed oil (PSO). After 10 weeks, two birds per subgroup were randomly selected and slaughtered.

Main results: Supplementation of PSO reduced ($p<0.05$) feed intake and body weight gain linearly. However, there was no significant effect of PSO on carcass traits. For color parameters, the L* and b* values of breast and thigh meat increased with the addition of PSO to the diet ($p<0.05$). Cooking losses were highest in the thigh of quails fed 200 mg kg^{-1} PSO. On the other hand, in the breast, the lowest values for this parameter were observed in the groups that had received 100 mg kg^{-1} of PSO.

Research highlights: Including 100 mg kg^{-1} of PSO can improve some meat quality characteristics without affecting performance parameters. There is a possibility that meat quality could be negatively affected by values higher than this. Nevertheless, further research is needed to determine the optimal dose of PSO to improve quail meat quality and its performance.

Additional key words: meat and carcass quality; birds; quail performances; pomegranate oil.

Abbreviation used: FI (feed intake); PSO (pomegranate seed oil); WHC (water holding capacity).

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Introduction

Pomegranate (*Punica granatum* L.), from the family Punicaceae, is one of the oldest edible fruits and is commonly cultivated in many tropical and subtropical countries (Boroushaki et al., 2016; Białek et al., 2021a). Pomegranate fruits are mainly consumed fresh or processed, however, significant amounts of pomaces are generated during processing, which causes serious environmental hazards (Białek et al., 2021a). Recently, the utilization of these wastes as a source of valuable compounds which could be used as an ingredient in animal nutrition has received particular attention (Saki et al., 2014; Boroushaki et al., 2016; Białek et al., 2019, 2021a).

It is estimated that pomegranate seeds contain approximately 24% oil (Khoddami et al., 2014) and the fatty acids present in them are of particular interest (Białek et al., 2021a). Punicic acid (9-cis, 11-trans, 13-cis or trichosanic acid) is the dominant form of the C18:3 class, which has a positive effect on health due to its therapeutical properties (Khoddami et al., 2014; Boroushaki et al., 2016). Studies have shown that pomegranate seed oil (PSO) can affect multiple signaling pathways involved in inflammation, cellular transformation, hyperproliferation, angiogenesis, initiation of tumorigenesis, and eventually suppressing the final steps of tumorigenesis and metastasis (Sharma et al., 2017). For example, Białek et al. (2021b) and Teh et al. (2019) demonstrated that PSO could improve cardiovascular health by reducing total cholesterol. Likewise, Mehta & Lansky (2004) described that PSO could be a potential breast cancer prevention, and Lansky et al. (2005) proposed that PSO could be a potent inhibitor of human PC-3 prostate cancer cells.

Japanese quails are valuable animals for avian research. Their small size makes them easy to handle, which allows them to be stored in limited spaces (Minvielle, 2004; Alkan et al., 2010). Moreover, farmer interest in raising quail for marketing continues to grow in Japan, France, Indonesia, Spain and Brazil (Minvielle, 2004; Santos et al., 2011). Japanese quails are commonly raised not only to produce eggs but also to produce meat in some countries. It is expected that in the near future, quail will become the main poultry used for meat production, due to its widespread demand around the world (Sabow, 2020). Thus, researchers should focus on improving the meat quality and productive performance of these birds.

Changes in animals' feeding are the most commonly studied and applied way to modify meat properties and quality (Sarmiento-García et al., 2021; Vieira et al., 2021). It is also an indirect method of improving the diet, which in turn will have a health-promoting effect, and the appearance of the product (Saki et al., 2014). PSO also has significant effects on meat quality and the development of livestock species (Saki et al., 2014; Karampour & Kafilzadeh, 2016; Szymczyk & Szczurek, 2016; Emami et al., 2017; Białek et al., 2021b) no study has been conducted on the effects of pomegranate as a feed additive on the yield and instrumental meat quality of quails. The aim of this study was to evaluate the effects of dietary PSO on performance, carcass traits, as well as the instrumental quality of quail's thigh and breast meat.

Material and methods

Ethical approval

Criteria specified by European policy for protecting animals were followed during the experimental period (EU, 2010).

Birds, feeding, and management

The whole experiment was conducted on 60 male Japanese quails (*Coturnix coturnix Japonica*) for 10 weeks at Selçuklu, Konya, Türkiye (38°1'36, 32°30'45"). Quails with similar body weight (180.65±5.30 g) and 70 days of age were obtained from a commercial company. The trial was conducted in 3 experimental groups consisting of 5 replicates, each containing 4 male quails.

Animals were allocated randomly to different cages (30 × 45 cm) that had the same environmental conditions. Birds were housed in a well-ventilated room with a lighting program of 16 hours, and a temperature of 20±2.0 °C was maintained in each pen.

Three dietary treatments were tested consisting of three graded levels (0, 100, and 200 mg kg^{-1}). All iso-nitrogenous (24% crude protein) and iso-energetic (2900 kcal/kg metabolizable energy) diets were formulated according to the NRC (1994). During the experimental period, all quails received feed and water *ad-libitum.* PSO included in the diet was commercially available and purchased at a local market (Arı Mühendislik, Ankara, Türkiye)**.** It was stored at 4°C prior to the preparation of the experimental diets and administration to quails. A basal diet was prepared without soybean oil, and then the soybean oil and PSO required for each treatment were mixed and added to the diet. The chemical composition of the basal diet was analysed according to AOAC (2006) procedures: water content by drying at 105 ºC; protein content by the Kjeldahl method; fat content by Soxhlet extraction; and ash content by incineration. The ingredients and nutrient composition of the basal diet are shown in Table 1.

Determination of performance parameters

At the beginning of the experiment, the quails were randomly allocated to the three trial groups. Animals were weighed individually at the beginning and the end of the experiment with a precision weighing scale (±0.01 g). Experimental diets were given by weighing each subgroup, and subsequently, feed intake (FI) was calculated as the daily FI per quail (g). Then, average body weight gain (g/day) was calculated by subtracting initial body weight (g) from final body weight (g) over the study period.

Meat characteristics analysis

At the end of the experiment, all quails were weighed, and 30 quails (two birds from each subgroup) were randomly selected, slaughtered and then, the carcass yield was obtained by separating the head, feet, feathers, digestive organs and giblets. After 15 min post-mortem, abdominal fat, breast, and leg muscles, liver, pancreas, and heart were excised and weighed. Carcass yield was calculated as

Table 1. Ingredients and nutrient composition of basal diet.

Ingredients	%	Nutrient contents	
Corn	53.70	Metabolizable energy (kcal ME/kg)	2899
Soybean meal	40.00	Dry matter (%)	87.32
Soybean oil	2.50	Crude protein (%)	24.03
Limestone	1.06	Ether extract (%)	5.53
Dicalcium phosphate	1.90	Crude fiber (%)	3.70
Salt	0.35	Ash (%)	5.97
Premix [1]	0.25	Calcium (%)	1.00
DL methionine	0.24	Available phosphorus (%)	0.50
Total	100.00	Lysine (%)	1.31
		Methionine (%)	0.52
		Cystine (%)	0.44
		Methionine + cystine (%)	0.96

[1] Vitamin-mineral premix supplied per kilogram of diet: vitamin A (trans-retinol), 3.60 mg; vitamin D3 (cholecalciferol), 0.10 mg; vitamin E (α-tocopherol acetate), 75.00 mg; vitamin K3 (menadione), 5.00 mg; vitamin B1 (thiamine), 3.00 mg; vitamin B2 (riboflavin), 6.00 mg; vitamin B6 (pyridoxine), 5.00 mg; vitamin B12 (cyanocobalamin), 0.03 mg; nicotinic acid, 40.00 mg; pantothenic acid, 10.00 mg; folic acid, 0.75 mg; D-biotin, 0.00 mg; choline chloride, 375.00 mg; manganese (manganese oxide), 80.00 mg; iron (ferrous carbonate), 40.00 mg; zinc (zinc oxide), 60.00 mg; copper (cupric sulphate pentahydrate), 5.00 mg; iodine, 0.15 mg; selenium (sodium selenite), 0.30 mg.

the ratio of the eviscerated carcass mass to body weight. The breast (*Pectoralis major*) with keel bone and left thigh muscle and drumstick were weighed and carried out to the laboratory (Faculty of Agriculture, Selcuk University) for analysis. To determine the meat yield, breast, thigh and drumstick were calculated as a percentage of carcass weight. Carcass yield, abdominal fat, liver, heart and pancreas were calculated as a percentage of body weight.

Prior to the analysis, the skin of the breast and thigh were removed. Instrumental quality parameters on breast and thigh muscles were carried out according to Sarmiento-García et al. (2021) except for drip losses. All measurements were analysed in triplicate to minimize sampling error.

pH of muscles

Muscle pH was determined at 24 hours post-mortem with a Crison pH Meter Basic 20® (Hach Lange Spain, L'Hospitalet de Llobregat, Barcelona, Spain) equipped with a penetration glass electrode. It was inserted directly in the thickest part of both muscles. The pH meter was calibrated using the 2-point method against standard buffer solutions with pH values of 4.0 and 7.0.

Colour

For instrumental colour measurement, a colourimeter HunterLab MiniScan model XE Plus (Hunterlab, VA, USA) equipped with a 25 mm measuring head and diffuse/8° optical geometry was used. The meat colour was measured on the dorsal side of the breast and the medial (bone) side of the thigh, at 24 hours post-mortem, determining the parameters L* (lightness), a* (redness), and b* (yellowness) using a MiniScan XE Plus in the CIE L* a* b* space under D65, 10°, and Specular Component Included (SCI) conditions.

Cooking losses

To determine cooking losses, the muscles were stored at 4°C until 24 h post-mortem, weighed and packaged in plastic bags, and heated to 75°C (centcenterpiecer 30 min, and then cooled in cold running tap water for 20 min. The internal temperature of the muscles was measured with a ChecktemW1 digital thermometer (Hanna Instruments, Eibar, Spain). The mass changes were expressed as a percentage of the initial mass.

Drip losses

The drip losses of meat were estimated according to a modification of the method proposed by Zhang et al. (2015). Briefly, meat samples with a size of 3 cm (length) × 2 cm (width) × 1 cm (thickness), were weighed (W1) and suspended parallel to the longitudinal axis of the myofibers in netting and vacuumed bags and stored at 4°C. Samples

Table 2. Effect of pomegranate seed oil (PSO) supplementation to male quails' (70-140 days of age) diet on performance parameters.

Parameters	PSO (mg kg^{-1})			SEM	p-values		
	0	100	200		Anova	Linear	Quadratic
Initial body weight (g)	183.00	180.70	178.60	6.015	0.876	0.614	0.989
Final body weight (g)	213.70	209.80	194.60	5.903	0.093	0.041	0.450
Body weight gain (g)	30.70^{a}	29.10^{ab}	16.00^{b}	3.492	0.022	0.012	0.204
Feed intake (g/period/quail)	693.10^{a}	680.80^{ab}	610.10^{b}	20.813	0.032	0.015	0.274

$^{a,b;}$ Different superscripts indicate significant differences within a row ($p < 0.05$). SEM: standard error means.

were weighed after 24 h (W2). The difference in weight (W2-W1) corresponded to the drip loss and was expressed as the percentage of the initial muscle weight.

Statistical analysis

A one-way ANOVA was used to test the effect of the experimental diets on performance, carcass traits, and instrumental meat quality in the quails. If ANOVA showed significant differences among means (main effects), planned multiple comparisons of means were examined by Duncan's multiple range test. The statistical differences were defined as $p < 0.05$ and trends as $p < 0.10$. Orthogonal polynomial contrasts were used to assess the significance of linear and quadratic models to describe the response of the dependent variable to rising dietary PSO levels. All statistical analyses were carried out using the SPSS Package 23 (IBM SPSS Statistic, 2017).

Results

No mortality or illness symptoms were observed during the entire trial, and all quails were alive at the end of the experiment. According to the data in Table 2, the absence of statistical differences between the initial weights of the quails indicates that the subjects were randomly assigned to the experimental groups. PSO-supplemented diets linearly affected quail body weight gain and FI ($p<0.05$). These parameters decreased linearly with the addition of PSO to the diet. Likewise, a trend ($p=0.092$) was observed for final weight, which decreased as PSO concentration in the diet increased. However, a linear effect of PSO inclusion ($p<0.05$) on final weight was observed.

The effects of the dietary supplementation of PSO on the carcass traits are given in Table 3. Although there was a trend in final body weight between the experimental groups, no statistically significant differences in carcass traits were found between the groups ($p>0.05$). The minimum and maximum values for those parameters were as follows: carcass yield (59.39–60.38 %), abdominal fat (1.21–1.72 %), breast (53.04–54.28 %), thigh and drumstick (34.86–36.63 %), liver (1.33–1.43 %), heart (0.79–0.82 %), and pancreas (0.17–0.18 %).

The meat colour was expressed as lightness ($L*$), redness ($a*$), and yellowness ($b*$) values (Table 4). Breast meat from quail supplemented with PSO was paler and yellower than breast meat samples collected from control quails ($p<0.001$). Similar results were observed for the

Table 3. Effect of pomegranate seed oil (PSO) supplementation to male quails' (70-140 days of age) diet on carcass traits.

Parameters	PSO (mg kg^{-1})			SEM	p-values		
	0	100	200		Anova	Linear	Quadratic
Carcass yield [1,2]	59.98	59.39	60.38	0.823	0.700	0.739	0.447
Abdominal fat [1]	1.66	1.72	1.21	0.312	0.474	0.333	0.465
Breast [3]	54.24	53.04	54.28	0.867	0.533	0.975	0.272
Thigh and drumstick [3]	36.63	36.53	34.86	0.690	0.169	0.096	0.371
Liver [1]	1.33	1.43	1.36	0.101	0.779	0.848	0.506
Heart [1]	0.79	0.82	0.81	0.036	0.830	0.633	0.716
Pancreas [1]	0.17	0.17	0.18	0.006	0.178	0.269	0.129

[1] Calculated as a percentage of live body weight. [2] Carcass yield was obtained by separating the head, feet, feathers, digestive organs and giblets. [3] Calculated as a percentage of carcass weight. SEM: standard error means.

Table 4. Colour (L*, a*, b*) of breast and thigh meat from dietary experimental groups.

Parameters	PSO (mg kg^{-1})			SEM	p-values		
	0	100	200		Anova	Linear	Quadratic
Breast							
Lightness (L*)	36.20^{b}	39.14^{a}	39.07^{a}	0.563	0.004	0.004	0.050
Redness index (a)*	8.28	9.09	8.26	0.2932	0.116	0.967	0.042
Yellowness index (b*)	13.50^{b}	15.42^{a}	14.69^{a}	0.214	0.001	0.002	0.001
Thigh							
Lightness (L*)	36.87^{ab}	36.24^{b}	38.97^{a}	0.606	0.019	0.030	0.043
Redness index (a)*	6.78	7.18	6.65	0.195	0.183	0.652	0.078
Yellowness index (b*)	11.79^{b}	12.51^{ab}	12.82^{a}	0.243	0.030	0.011	0.500

^{a,b} Different superscripts indicate significant differences within a row (p<0.05). PSO: pomegranate seed oil. SEM: standard error means.

thigh meat, where the highest L* value (p<0.05) was observed in the group that had received the highest amount of PSO (38.97). The addition of PSO to the diet had a quadratic effect on redness index (a*) (8.26-9.09) of breast meat (p=0.042), but not of thigh meat (p>0.05). Moreover, increasing amounts of PSO in the diet caused a gradual rise (p<0.05) in the yellowness index (b*) in the thigh.

According to Table 5, breast meat's instrumental parameters had the following minimum and maximum values: pH (5.61-5.74), cooking losses (9.06-11.06 %), and drip losses (13.83-14.05 %). For the instrumental parameters of the thigh meat, the minimum and maximum values were as follows: pH (6.17-6.29), cooking losses (6.62-14.96%), and drip losses (14.17-15.76 %). As shown in Table 5, the pH of breast and thigh meat was higher for the control diet compared to the PSO diet. However, those differences were not significant (p>0.05). In the group supplemented with 100 mg kg^{-1} of PSO, breast cooking losses were reduced (p=0.022) compared to the control group (9.06 *vs.* 11.06). The highest cooking losses in thigh meat were found for the 200 mg kg^{-1} PSO treatment, compared to the control and 100 mg kg^{-1} PSO treatments. Regarding drip losses, no differences were observed between the study groups for either thigh or breast meat (p>0.05).

Discussion

Pomegranate by-products may have the potential to be a good source of nutrients and antioxidants for livestock nutrition (Emami et al., 2015). In the current experiment, PSO had an impact on some performance parameters such as body weight gain and FI. In addition, it was observed that levels of 200 mg kg^{-1} of PSO resulted in the lowest value of final body weight and abdominal fat. Although these differences were not significant (Table 3), a trend was observed for final body weight. Similar to the results of the current study, adding PSO to high-fat diets decreased body weight, body weight gain, fat, and biomarkers of cholesterol profile in rats (McFarlin et al., 2008; Vroegrijk et al., 2011). These authors proposed PSO supplementation in the diet would reduce leptin and increase adiponectin concentration, leading to lower weight and body fat content. Furthermore, McFarlin et al. (2008) speculated that PSO supplementation can alter the way that dietary fat interacts with the brain. These authors suggested that PSO could increase fat metabolism, resulting in the attenuation of weight gain that they observed. However, further research is needed to explain the effect of PSO on pathways that mediate body weight gain. These results were in disagreement with Szymczyk & Szczurek (2016) who have shown that body weight gain was not affected by PSO (from 5000 to 15000 mg kg^{-1}) supplementation to the diet in broilers, while Saleh et al. (2016) mentioned the addition of 100, 200, and 300 mg kg^{-1} of pomegranate peel extract or 1, 2, and 3 g kg^{-1} of pomegranate peel to the diet resulted in the reduction of growth performance for broilers up to 42 days. Nekooeian et al. (2014) showed that 200 or 600 mg kg^{-1} PSO per day did not cause significant changes in the body weight of diabetic rats. Probably, those differences could be attributed to the different animal species included in the trials and the total amount of PSO included in the diet.

In addition, this study showed that FI decreased linearly as dietary PSO levels increased. This fact seems likely to be related to the palatability of the feed. The decrease in FI also affected the final body weight and body weight change of male quails. Pomegranate is a rich source of hydrolysable tannins, although the content of tannins is lower in the seed (Bar-Ya'akov et al., 2019). The reduction in FI can be explained by reduced diet palatability due to the presence of tannin in the PSO (Gungor et al., 2021) and body weight gain and final body weight could be affected. In agreement with these results, the lowest FI was observed by previous authors at the highest concentration of PSO in laying hens (Kostogrys et al., 2017) and broilers (Gungor

Table 5. Instrumental quality parameters of breast and thigh meat from dietary experimental groups.

Parameters	PSO (mg kg^{-1})			SEM	p-values		
	0	100	200		Anova	Linear	Quadratic
Breast							
pH	5.74	5.61	5.67	0.047	0.185	0.136	0.120
Cooking losses (%)	11.06^{a}	9.06^{b}	9.71^{ab}	0.444	0.022	0.052	0.031
Drip losses (%)	13.83	13.88	14.05	0.719	0.974	0.830	0.946
Thigh							
pH	6.29	6.17	6.20	0.058	0.391	0.312	0.357
Cooking losses (%)	7.13^{b}	6.62^{b}	14.96^{a}	0.589	0.001	0.001	0.001
Drip losses (%)	15.76	14.17	14.43	0.48	0.080	0.074	0.142

^{a,b} Different superscripts indicate significant differences within a row ($p<0.05$). PSO: pomegranate seed oil. SEM: standard error means.

et al., 2021). Rezvani et al. (2018) found that PSO negatively affected FI and growth performance, especially in young broilers. There is a possibility that these results are due to the amount of pomegranate seed extract provided in the diet and that the animals may not be able to adapt to the new diets.

Dressed poultry carcasses, which are dead poultry bodies after being partially butchered without internal organs, heads, and legs, are influenced by both genetic and environmental factors including age, sex, line, and livestock management (Ali et al., 2019). The values obtained for carcass yield agree with those published by Ali et al. (2019) which are between 55.73 and 58.86 (%). Conversely, these results were relatively lower than those published by Raji et al. (2015) for mature Japanese quail, which can reach 89.82%. Several factors may contribute to this difference, including genetics and environment. In addition, carcass percentage may be directly affected by live body weight. A higher body weight of quail results in a higher dressed carcass weight and carcass percentage. These findings are consistent with those observed in our study, which showed a lower final weight of quails. The values obtained for breast percent (54.28 to 53.04%) were higher than those found by Raji et al. (2015), although these authors evaluated deboned breasts in their study. In line with the current findings are those published by previous authors for bone-in breast, which range from 40 to 50% (Alkan et al., 2012; Lukanov et al., 2018; Hussen, 2020). Similar results are observed for the thigh value, which was higher in the current study because the thigh and drumstick were evaluated together. The rest of the parameters evaluated (including organs and fat) are in line with those shown by Raji et al. (2015) for Japanese quails. However, slight differences can be found which, according to these authors, could be justified by the genetics of the quail. Quail meat with excellent dressed carcass characteristics could be produced by crossbreeding quails that are genetically superior to quail meat.

Despite the reduction in final body weight, no changes were observed in the slaughter yield of quails with the dietary addition of PSO at 100 and 200 mg kg^{-1}. Moreover, in the current study proportions of breast, thigh, drumstick, liver, heart, and pancreas in the carcasses did not differ among the groups. Also, the findings of the current study are consistent with those get by Szymczyk & Szczurek (2016) who replaced soybean oil with PSO in chicken diets. Those authors did not find significant differences in carcass yield, breast and leg muscles, liver, gizzard, and heart weights of chickens. The only exception was an abdominal fat percentage, which was found to be higher in broilers fed a diet containing 1500 mg kg^{-1} PSO. Banaszkiewicz et al. (2018) did not find any influence of PSO supplementation in the slaughter yield, proportions of breast, thigh, total muscle, and abdominal fat. In the same trend, Jankowski et al. (2012) observed no differences in slaughter yield or breast, thigh, and drumstick muscle yield in turkeys fed diets containing soybean, linseed, and rapeseed oils. In partial agreement with our feedback Hamady et al. (2015) proved that the supplementation of pomegranate peel powder did not influence liver, gizzard, or heart weight percentages of broiler chickens. However, those authors noticed that the addition of pomegranate peel powder to the diet increased thigh and breast weight percentages. The findings of the current study on carcass traits disagree with Akuru et al. (2021), who reported the hat thigh, breast, and heart weight of broilers improved with pomegranate peel powder supplementation in the diet. Those differences are probably due to the different compositions of the pomegranate co-product included in the diet.

Colour is one of the important quality traits influencing consumer preferences (Vieira et al., 2021). The addition of PSO led to significant differences in the colour parameters. Increased lightness (L*) was found in breast and thigh meat as PSO levels increased. According to Abdel Baset et al. (2022), meat weight might decrease due to reduced water-holding capacity (WHC), resulting in lighter meat, which is consistent with what was observed in this study. Moreover, an increase in yellowness index (b*) was observed in the breast and thigh when PSO was added to the diet. In different studies, pomegranate co-products had a colour stabilizing effect on muscle food. However, the results are not conclusive. For example, Devatkal et al. (2010) found that the incorporation of pomegranate rind powder was effective in reducing L-values, but no differences were observed among pomegranate seed powder and control for L values. Conversely, redness was reduced when using pomegranate rind powder and pomegranate seed powder compared with the control goat patties. Similar results have been described in frankfurter samples containing white pomegranate juice concentrate, red pomegranate juice concentrate, and pomegranate rind powder extract (Das et al., 2021). It was observed that the inclusion of these ingredients reduced the L* and a* values concerning to the control. In a similar way, Serdaroğlu et al. (2021) reported a decrease in these values when pomegranate seed powder was used in chicken meat emulsion. Contrary, Gungor et al. (2021) did not find any difference in breast colour (in terms of lightness, yellowness or redness) among different PSO diets. Pomegranate is a good source of bioactive substances such as tocopherol and xanthophyll (Madrigal-Carballo et al., 2009). The consumption of natural ingredients rich in these substances has been linked to changes in meat colour. Processing and storing of these ingredients may alter their oxidation levels, resulting in a change in FI and consequently, a change in xanthophyll deposition in meat (Pertiwi et al., 2022). The differences in meat colour found among the studies consulted could be justified for this reason.

According to Terlouw et al. (2008) normal pH of quail breast meat ranged between 5.4 and 6.0. The pH in the current study was on average 5.67, regardless of the diet received, which can be characterized as normal breast pH. On the other hand, the values for thigh pH (6.22) were slightly lower than those reported by Nasr et al. (2017), which ranged between 6.24-6.37. Those differences could be attributed to slaughter age, strain, or line. The use of PSO in the current study did not significantly affect the pH of breast and thigh muscles, but the addition of PSO numerically decreased the pH in the breast and thigh muscles. These results are in line with those published by Banaszkiewicz et al. (2018), who showed that the use of PSO in a broiler diet did not influence meat pH. Likewise, Akuru et al. (2021) pointed out that dietary supplementation of pomegranate peel powder meal at four levels (2, 4, 6 and 8 g/kg) did not influence the pH of the broiler breast meat compared to the control diet.

Water holding capacity is determined as drip losses and cooking losses. The lowest value of cooking losses in the breast was found for the 100 mg kg^{-1} dose. However, contrary to expectations, the value of cooking losses was increased in the thigh of quails that had received 200 mg kg^{-1} of PSO. Kaur et al. (2015) reported that with the increase in the ratio of pomegranate seed powder added to chicken nuggets, there was a significant decrease in emulsion stability and cooking efficiency. The authors propose a decrease in WHC as a consequence of lower pH. In contrast, Keşkekoğlu & Üren (2014) described that there were no significant differences between the controls and the pomegranate seed extract containing meatball samples, which is consistent with those described by Kurt (2017) for beef patties. Moreover, a trend was observed for drip losses, which decreased as the concentration of PSO in the diet increased. Similar results had been reported by Emami et al. (2015), who showed that the inclusion of pomegranate seed powder in a goat diet decreased drip loss of meat. Those authors suggest a negative correlation between intramuscular fat content and drip losses. Intramuscular fat may act as 'insulation' and reduce water loss in meat. The same behaviour was observed by several authors, who proposed that the incorporation of pomegranate coproducts in meat enhances the WHC of raw beef sausage (Gullón et al., 2020), beef meatballs (Morsy et al., 2018), and beef burgers (Abdel-Fattah et al., 2016). However, since our results are not conclusive for WHC in the different parts of the carcass evaluated, further research is required.

In summary, pomegranate seed oil supplementation at a level of 200 mg kg^{-1} reduced FI and body weight gain without affecting carcass traits. Compared to the control, PSO supplementation increased L* and b* in the thigh and breast meat. Likewise, dietary PSO at 100 mg kg^{-1} significantly improved some characteristics of cooked meat. According to these findings, the inclusion of PSO at 100 mg kg^{-1} level in the quails can be a promising method to increase some characteristics of meat quality, but a higher concentration has detrimental effects on quail performance and meat quality. Further research is needed to find the optimal dose of PSO for quails to improve these parameters.

Authors' contributions

Conceptualization: A Sarmiento-García, B Sevim, O Olgun.
Data curation: A Sarmiento-García, B Sevim, O Olgun.
Formal analysis: A Sarmiento-García, B Sevim, O Olgun.
Funding acquisition: B Sevim, O Olgun.
Investigation: B Sevim, O Olgun, SA Gökmen.
Methodology: A Sarmiento-García, B Sevim, O Olgun.
Project administration: B Sevim, O Olgun, SA Gökmen.
Resources: A Sarmiento-García, B Sevim, O Olgun.
Software: SA Gökmen.
Supervision: A Sarmiento-García, B Sevim, O Olgun.
Validation: A Sarmiento-García, B Sevim, O Olgun.
Visualization: A Sarmiento-García, B Sevim, O Olgun.
Writing – original draft: A Sarmiento-García.
Writing – review & editing: A Sarmiento-García, B Sevim, O Olgun, SA Gökmen.

References

Abdel Baset S, Ashour EA, Abd El-Hack ME, El-Mekkawy MM, 2022. Effect of different levels of pomegranate peel powder and probiotic supplementation on growth, carcass traits, blood serum metabolites, antioxidant status and meat quality of broilers. Anim Biotechnol 33: 690-700. https://doi.org/10.1080/10495398.2020.1825965

Abdel-Fattah A, Fattah AA, Abdel-Rahman NR, Abd El-Razik MM, El-Nashi B, 2016. Utilization of pomegranate peels for improving quality attributes of a refrigerated beef burger. Curr Sci Int 5: 427-441.

Akuru EA, Mpendulo CT, Oyeagu CE, Nantapo CWT, 2021. Pomegranate (*Punica granatum* L.) peel powder meal supplementation in broilers: effect on growth performance, digestibility, carcase and organ weights, serum and some meat antioxidant enzyme biomarkers. Ital J Anim Sci 20: 119-131. https://doi.org/10.1080/1828051X.2020.1870877

Ali A, Dewanti R, Wati AK, Nuhriawangsa AMP, Cahyadi M, 2019. Characteristics of carcass and non-carcass in F1 population crossbred brown and black Japanese quails. IOP Conf Ser: Earth Environ Sci 387: 012045. https://doi.org/10.1088/1755-1315/387/1/012045

Alkan S, Karabağ K, Galiç A, Karsli T, Balcioğlu MS, 2010. Determination of body weight and some carcass traits in Japanese quails (*Coturnix coturnix japonica*) of different lines. Kafkas Univ Vet Fak Derg 16: 277-280.

Alkan S, Karslı T, Galic A, Karabağ K, Balcıoğlu MS, 2012. Estimation of genetic parameters for body weight of Japanese quails (*Coturnix coturnix japonica*) using random regression model. Kafkas Üniv Vet Fak Derg 18: 935-939.

AOAC, 2006. Official methods of analysis association, 18th ed. Washington DC.

Banaszkiewicz T, Białek A, Tokarz A, Kaszperuk K, 2018. Effect of dietary grape and pomegranate seed oil on the post-slaughter value and physicochemical properties of muscles of broiler chickens. Acta Sci Pol Technol Aliment 17: 199-209. https://doi.org/10.17306/J.AFS.0563

Bar-Ya›akov I, Tian L, Amir R, Holland D, 2019. Primary metabolites, anthocyanins, and hydrolyzable tannins in the pomegranate fruit. Front Plant Sci 10: 620. https://doi.org/10.3389/fpls.2019.00620

Białek M, Białek A, Lepionka T, Paśko P, Galanty A, Tokarz A, Czauderna M, 2019. *Punica granatum* (pomegranate) seed oil and *Momordica charantia* (bitter melon) extract affect the lipid›s profile and oxidative stability of femoral muscles of rats. Eur J Lipid Sci Technol 121: 1800420. https://doi.org/10.1002/ejlt.201800420

Białek A, Białek M, Lepionka T, Tober E, Czauderna M, 2021a. The quality determination of selected commercial online purchased edible pomegranate seed oils with new argentometric liquid chromatography method. J Diet Suppl 18: 351-371. https://doi.org/10.1080/19390211.2020.1770394

Białek A, Białek M, Czerwonka M, Lepionka T, Tytz N, Kucharczyk K, et al., 2021b. Giblets and abdominal fat of pomegranate seed oil fed chickens as a source of bioactive fatty acids. J Anim Physiol Anim Nutr 105: 520-534. https://doi.org/10.1111/jpn.13464

Boroushaki MT, Mollazadeh H, Afshari AR, 2016. Pomegranate seed oil: A comprehensive review on its therapeutic effects. Int J Pharm Sci Res 7: 430-442.

Das AK, Nanda PK, Chowdhury NR, Dandapat P, Gagaoua M, Chauhan P, et al., 2021. Application of pomegranate by-products in muscle foods: Oxidative indices, colour stability, shelf life and health benefits. Molecules 26: 467. https://doi.org/10.3390/molecules26020467

Devatkal SK, Narsaiah K, Borah A, 2010. Anti-oxidant effect of extracts of kinnow rind, pomegranate rind and seed powders in cooked goat meat patties. Meat Sci 85: 155-159. https://doi.org/10.1016/j.meatsci.2009.12.019

Emami A, Nasri MF, Ganjkhanlou M, Rashidi L, Zali A, 2015. Dietary pomegranate seed pulp increases conjugated-linoleic and-linolenic acids in muscle and adipose tissues of kid. Anim Feed Sci Technol 209: 79-89. https://doi.org/10.1016/j.anifeedsci.2015.08.009

Emami A, Ganjkhanlou M, Fathi Nasri MH, Zali A, Rashidi L, Sharifi M, 2017. Antioxidant status of dairy goats fed diets containing pomegranate seed oil or linseed oil. Small Rum Res 153: 175-179. https://doi.org/10.1016/j.smallrumres.2017.06.018

EU, 2010. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes.

Gullón P, Astray G, Gullón B, Tomasevic I, Lorenzo JM, 2020. Pomegranate peel as suitable source of high-added value bioactives: Tailored functionalized meat products. Molecules 25: 2859. https://doi.org/10.3390/molecules25122859

Gungor E, Altop A, Erener G, Coskun I, 2021. Effect of raw and fermented pomegranate pomace on performance, antioxidant activity, intestinal microbiota and morphology in broiler chickens. Arch Anim Nutr 275: 137-152. https://doi.org/10.1080/1745039X.2021.1894065

Hamady GAA, Abdel-Moneim MA, El-Chaghaby GA, 2015. Effect of pomegranate peel extract as natural growth promoter on the productive performance and intestinal microbiota of broiler chickens. Afr J Agric Sci Technol 3: 514-519.

Hussen S, 2020. Quail production and breeding. Lambert Acad. Publ.

Jankowski J, Zdunczyk Z, Mikulski D, Juskiewicz J, Naczmanski J, Pomianowski JF, Zdunczyk P, 2012. Fatty acid profile, oxidative stability, and sensory properties of breast meat from turkeys fed diets with a different n-6/n-3 PUFA ratio. Eur J Lipid Sci Technol 114: 1025-1035. https://doi.org/10.1002/ejlt.201200003

Karampour A, Kafilzadeh F, 2016. The effects of pomegranate seed oil in the diet on digestibility, ruminal fermentation parameters and performance of fattening lambs. Anim Prod 18: 491-500.

Kaur S, Kumar S, Bhat SF, 2015. Utilization of pomegranate seed powder and tomato powder in the development of fiber enriched chicken nuggets. Nutr Food Sci 45:793-807. https://doi.org/10.1108/NFS-05-2015-0066

Keşkekoğlu H, Üren A, 2014. Inhibitory effects of pomegranate seed extract on the formation of heterocyclic aromatic amines in beef and chicken meatballs after cooking by four different methods. Meat Sci 96: 1446-1451. https://doi.org/10.1016/j.meatsci.2013.12.004

Khoddami A, Man YBC, Roberts TH, 2014. Physico-chemical properties and fatty acid profile of seed oils from pomegranate (*Punica granatum* L.) extracted by cold pressing. Eur J Lipid Sci Technol 116: 553-562. https://doi.org/10.1002/ejlt.201300416

Kostogrys RB, Filipiak-Florkiewicz A, Dereń K, Drahun A, Czyżyńska-Cichoń I, Cieślik E, et al., 2017. Effect of dietary pomegranate seed oil on laying hen performance and physicochemical properties of eggs. Food Chem 221: 1096-103. https://doi.org/10.1016/j.foodchem.2016.11.051

Kurt Ş, 2017. Investigation of the potential usage of pomegranate seed flour in the beef patties. Adıyaman Univ J Sci 7: 1-11.

Lansky EP, Harrison G, Froom P, Jiang WG, 2005. Pomegranate (Punica granatum) pure chemicals show possible synergistic inhibition of human PC-3 prostate cancer cell invasion across Matrigel TM. Invest New Drugs 23: 121-122. https://doi.org/10.1007/s10637-005-5856-7

Lukanov H, Genchev A, Dragolova I, 2018. Phenotypic characteristics of the GL sire line for production of autosexing Japanese quails. Trakia J Sci 1: 40-50. https://doi.org/10.15547/tjs.2018.01.008

Madrigal-Carballo S, Rodriguez G, Krueger CG, Dreher M, Reed JD, 2009. Pomegranate (*Punica granatum*) supplements: authenticity, antioxidant and polyphenol composition. J Funct Foods 1: 324-329. https://doi.org/10.1016/j.jff.2009.02.005

McFarlin BK, Strohacker KA, Kueht ML, 2008. Pomegranate seed oil consumption during a period of high-fat feeding reduces weight gain and reduces type 2 diabetes risk in CD-1 mice. Brit J Nutr 102: 54-59. https://doi.org/10.1017/S0007114508159001

Mehta R, Lansky EP, 2004. Breast cancer chemo preventive properties of pomegranate (*Punica granatum*) fruit extracts in a mouse mammary organ culture. Eur J Cancer Prev 13: 345-348. https://doi.org/10.1097/01.cej.0000136571.70998.5a

Minvielle F, 2004. The future of Japanese quail for research and production. Worlds Poult Sci J 60: 500-507. https://doi.org/10.1079/WPS200433

Morsy MK, Mekawi E, Elsabagh R, 2018. Impact of pomegranate peel nanoparticles on quality attributes of meatballs during refrigerated storage. LWT-Food Sci Technol 89:489-495. https://doi.org/10.1016/j.lwt.2017.11.022

Nasr MAF, Ali ESMR, Hussein MA, 2017. Performance, carcass traits, meat quality and amino acid profile of different Japanese quails strains. J Food Sci Technol 54: 4189-4196. https://doi.org/10.1007/s13197-017-2881-4

Nekooeian AA, Eftekhari MH, Adibi S, Rajaeifard A, 2014. Effects of pomegranate seed oil on insulin release in rats with type 2 diabetes. Iran J Med Sci 39: 130-135.

NRC, 1994. Nutrient requirements of poultry. National Research Council, Nat. Acad. Press.

Pertiwi H, Nur Mahendra MY, Kamaludeen J, 2022. Astaxanthin as a potential antioxidant to improve health and production performance of broiler chicken. Vet Med Inter 2022: 4919442. https://doi.org/10.1155/2022/4919442

Raji AO, Girgiri AY, Alade NK, Jauro SA, 2015. Characteristics and proximate composition of Japanese quail (*Coturnix japonica*) carcass in a semi arid area of Nigeria. Trakia J Sci 2: 159-165. https://doi.org/10.15547/tjs.2015.02.008

Rezvani MR, Sayadpour N, Saemi F, 2018. The effect of adding pomegranate seed extract to fat-containing diets on nutrients digestibility, intestinal microflora and growth performance of broilers. Iran J Vet Res 19: 310-317.

Sabow AB, 2020. Carcass characteristics, physicochemical attributes, and fatty acid and amino acid compositions of meat obtained from different Japanese quail strains. Trop Anim Health Prod 52: 131-140. https://doi.org/10.1007/s11250-019-01991-2

Saki AA, Rabet M, Zamani P, Yousegi A, 2014. The effects of different levels of pomegranate seed pulp with multi-enzyme on performance, egg quality and serum antioxidant in laying hens. Iran J Appl Sci 4: 803-808.

Saleh H, Golian A, Kermanshahi H, Mirakzehi MT, 2016. Effects of dietary α-tocopherol acetate, pomegranate peel, and pomegranate peel extract on phenolic content, fatty acid composition, and meat quality of broiler chickens. J Appl Anim Res 45: 629-636. https://doi.org/10.1080/09712119.2016.1248841

Santos T, Murakami A, Fanhani J, Oliveira C, 2011. Production and reproduction of egg-and meat-type quails reared in different group sizes. Braz J Poult Sci 13: 9-14. https://doi.org/10.1590/S1516-635X2011000100002

Sarmiento-García A, Palacios C, González-Martín I, Revilla I, 2021. Evaluation of the production performance and the meat quality of chickens reared in organic system. As affected by the inclusion of Calliphora sp. in the diet. Animals 11: 324. https://doi.org/10.3390/ani11020324

Serdaroğlu M, Yüncü Ö, Kavuşan HS, Sharefiabadi E, Seyedhosseini S, 2021. The effects of using pomegranate (*Punica granatum*) seed powder on quality parameters of model system chicken meat emulsions. Turk J Agri-Food Sci Technol 9: 1485-1494. https://doi.org/10.24925/turjaf.v9i8.1485-1494.4305

Sharma P, McClees SF, Afaq F, 2017. Pomegranate for prevention and treatment of cancer: An update. Molecules 22: 177. https://doi.org/10.3390/molecules22010177

Szymczyk B, Szczurek W, 2016. Effect of dietary pomegranate seed oil and linseed oil on broiler chickens performance and meat fatty acid profile. J Anim Feed Sci 25: 37-44. https://doi.org/10.22358/jafs/65585/2016

Teh HE, Yokoyama WH, German JB, Mchugh TH, Pan Z, 2019. Hypocholesterolemic effects of expeller-pressed and solvent-extracted fruit seed oils and defatted pomegranate seed meals. J Agri Food Chem 67: 6150-6159. https://doi.org/10.1021/acs.jafc.8b07186

Terlouw EMC, Arnould C, Auperin B, Berri C, le Bihan-Duval E, Deiss V, et al., 2008. Pre-slaughter conditions, animal stress and welfare: Current status and possible future research. Animal 2: 1501-1517. https://doi.org/10.1017/S1751731108002723

Vieira C, Sarmiento-García A, García J, Rubio B, Mart B, 2021. Quality and shelf life of fresh meat from Iberian pigs as affected by a new form of presentation of oleic acid and an organic-acid mix in the diet. Foods 10: 985. https://doi.org/10.3390/foods10050985

Vroegrijk IOCM, van Diepen JA, van den Berg S, Westbroek I, Keizer H, Gambelli L, et al., 2011. Pomegranate seed oil, a rich source of punicic acid, prevents diet-induced obesity and insulin resistance in mice. Food Chem Toxicol 49: 1426-1430. https://doi.org/10.1016/j.fct.2011.03.037

Zhang C, Luo J, Yu B, Zheng P, Huang Z, Mao X, et al., 2015. Dietary resveratrol supplementation improves meat quality of finishing pigs through changing muscle fiber characteristics and antioxidative status. Meat Sci 102: 15-21. https://doi.org/10.1016/j.meatsci.2014.11.014