



TOMATO POMACE WASTE AS SAFE FEED ADDITIVE FOR POULTRY HEALTH AND PRODUCTION – A REVIEW

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Abstract

Tomato cultivation and industrial processing produce a considerable amount of tomato pomace, peels, and seeds, which are difficult to handle. These by-products contain a variety of minerals and bioactive substances, and may thus be further valorised, generating additional revenue for processing plants while also decreasing environmental issues caused by their buildup. The inclusion of tomato pomace in poultry feed has been shown to produce promising effects in poultry growth and health, however the results are largely inconsistent. Literature has documented improvement in growth, egg production and quality, immunological and antioxidant effects in poultry. This review has compiled the impacts of tomato pomace on the growth and health indices of poultry.

Key words: growth, health, production, tomato pomace

Tomato (*Solanum lycopersicum* L.) is a widely grown vegetable in the world. Major portion of tomatoes is sold as fresh. Around one third of them are converted into commercial products such as juice, paste, sauces and ketchup (Figure 1). Tomato processing produces large quantity of residues, known as tomato pomace, which account for 2–10% of the total fresh tomato by weight (Gustavsson et al., 2011). Tomato pomace is usually consisting of seed, peel, and a little amount of pulp (Ventura et al., 2009; Mizael et al., 2020). The chemical composition of tomato pomace is given in Table 1. The massive quantity of trash generated by commercial tomato processing has created a serious problem. In the tomato industries, 5–10% of the tomato weight is converted into waste. According to an estimate, tomato pomace contains around 16% crude protein, 44% acid detergent fibre, 57% neutral detergent fibre, 24% lignin and 8% ether extract (Marcos et al., 2019), however, some authors have observed larger levels of waste after tomato processing. Various stages of processing (grinding, pasteurization and pressing) produce tomato waste to the tune of 20 to 42% of the fruit's weight, depending on the type of processing (Løvdaal et al., 2019). Food wastes are attracting a lot of attention these days since they are a constant threat to the environmental pollution and a severe operational concern for the food industry. Industrial wastes, such as tomato pomace, might, nevertheless, be a source of potentially beneficial substances that could be used as functional additives in poultry diets across the food chain.

Tomato pomace is a highly nutritious product and can be used as a natural source of fibres (60–70%), protein (10–20%), and lipids (5–10%). Bioactive components found in tomato waste include lycopene and β -carotene, which have been demonstrated to have substantial antioxidant capacity (Szabo et al., 2019). Because of their diverse phytochemical composition, tomato pomace is considered a possible natural source of antioxidants. Tomato is a valuable source of phenolic molecules and carotenoids, which help the body manage a variety of metabolic and physiological processes. According to a recent study (Concha-Meyer et al., 2020), tomato seeds are high in phenolic acids, flavonoids, carotenoids and nucleosides. In many regions of the globe, the use of alternative feed components like tomato pomace in chicken diets is an essential component for improved poultry production. Previously, feed additives such as prebiotics (Chand et al., 2016, 2019; Haq et al., 2020), probiotics (Khan and Naz, 2013; Khan et al., 2013 a, b; Alam et al., 2020; Shah et al., 2020), enzymes (Abd El-Hack et al., 2018; Jabbar et al., 2021; Hafeez et al., 2021), organic acids (Hayat et al., 2014; Sultan et al., 2015; Abudabos et al., 2017; Chand et al., 2016; Khan et al., 2022), and phytogenics (Khan et al., 2012 a, b, c, d; Mushtaq et al., 2013; Dhama et al., 2015; Tanweer et al., 2014; Shahid et al., 2015; Alzawqari et al., 2016; Alhidary et al., 2017; Wahab et al., 2019; Hafeez et al., 2020 a, b, c; Ahmad et al., 2020; Chand et al., 2021; Israr et al., 2021; Khan et al., 2021 a, b; Ullah et al.,

2022) have been reported for substantial improvement in growth and health benefits in poultry. The objective of the present review was to review multiple beneficial

effects of tomato pomace waste in safeguarding and improving the growth and health of poultry and have been summarized in Table 2 and Figure 2.

Table 1. Chemical composition of tomato pomace (Azabou et al., 2020)

Parameters	Tomato pomace
Moisture (%)	7.90±0.78
Ash ¹	7.01±0.50
Potassium ²	808.54±14.30
Sodium ²	191.68±4.25
Calcium ²	371.52±6.01
Magnesium ²	3.08±0.07
Iron ²	10.98±0.98
Zinc ²	1.83±0.07
Copper ²	0.09±0.00
Proteins ¹	20.14±0.25
Fats ¹	8.83±0.24
Total dietary fibers ¹	64.12±0.56
Soluble dietary fibers ¹	5.56±0.34
Insoluble dietary fibers ¹	58.54±0.75
Total phenol content ³	55.10±0.42

¹In %, dry matter basis; ²In mg/100 g of dry matter; ³In mg GAE/g of dry matter.

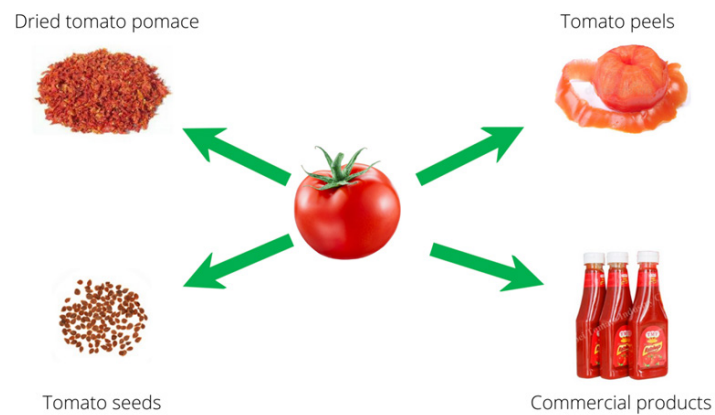


Figure 1. Different parts and preparations of tomato

Table 2. Effects of tomato pomace on multiple parameters in poultry

Parameters	Species	Dose of tomato pomace	Effects	Reference
1	2	3	4	5
Egg yield and quality				
Egg production	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Layer	71.7 g/kg	Increased	Tomeczynski (1978)
	Layer	10%	Increased	Nobakht and Safamehr (2007)
	Layer	16%	Increased	Jalalinasab et al. (2014)
	Layer	100 g/kg	No effect	Mansoori et al. (2008)
	Layer	120 g/kg	No effect	Dotas et al. (1999)
	Layer	150 g/kg	No effect	Yannakopoulos et al. (1992)
	Layer	150 g/kg	No effect	Gregoriades et al. (1984)
	Layer	16% to 20%	No effect	Calislar and Uygur (2010)
	Layer	15%	No effect	Tufarelli et al. (2021)
	Layer	above 5%	Decreased	De Souza Loureiro et al. (2007)

1	2	3	4	5
Egg weight	Layer	10%	Increased	Nobakht and Safamehr (2007)
	Layer	71.7 g/kg	No effect	Tomczynski (1978)
	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Layer	16% to 20%	No effect	Calislar and Uygur (2010)
	Layer	above 5%	Decreased	De Souza Loureiro et al. (2007)
	Layer	120 g/kg	No effect	Dotas et al. (1999)
Yolk color	Layer	100 g/kg	Increased	Mansoori et al. (2008).
	Layer	150 g/kg	Increased	Yannakopoulos et al. (1992)
	Layer	8 and 12%	Increased	Mlodkowski and Kuchta (1998)
	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Layer	8 or 15%	Increased	Dotas et al. (1999)
	Quail	20 g/kg	Increased	Karadas et al. (2006)
	Layer	16%	Increased	Jalalinasab et al. (2014)
	Layer	15%	Increased	Tufarelli et al. (2021)
Egg shell weight, egg shell thickness, Haugh unit	Layer	100 kg/ton	Increased	Jafari et al. (2006)
Egg quality	Layer	190 g/kg	No effect	Salajegheh et al. (2012)
Structural characteristics	Layer	16 to 20%	No effect	Calislar and Uygur (2010)
Overall egg quality		16 to 20%	No effect	Nobakht (2007)
Yolk weight	Layer	above 5%	Decreased	De Souza Loureiro et al. (2007)
Antioxidant activity				
Serum MDA	Broiler	1%	Decreased	Selim et al. (2013)
	Layer	1, 2 and 3%	Decreased	Saed et al. (2018)
	Broiler	5%	Decreased	Hosseini-Vashan et al. (2016)
Hemolysate activities of GPx and SOD	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
Serum, breast and leg MDA	Quail	2.5 or 5%	Decreased	Sahin et al. (2008)
Liver MDA concentration	Quail	2.5 or 5%	Decreased	Sahin et al. (2011)
	Layer	15%	No effect	Tufarelli et al. (2021)
Serum GPx MDA, TSOD and T-AOC	Layer	15%	No effect	Tufarelli et al. (2021)
Feed Intake and feed efficiency				
Feed intake	RIR grower chicks	20%	Increased	Yitbarek et al. (2013 a)
	Broiler	Above 20%	Increased	Lira et al. (2010)
	Layer	16%	Increased	Jalalinasab et al. (2014)
	Broiler	8 or 16%	Increased	Dorra et al. (2011)
	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Quail	2.5%	Increased	Shehata et al. (2018)
	Broiler	0.5%	Increased	Selim et al. (2013)
	Broiler	5, 10, 15 & 20%	Increased	Al-Betawi (2005)
	Broiler	30%	Increased	King and Zeidler (2004)
	Broiler	8%	No effect	Hady et al. (2018)
	Broiler	5, 10 and 15%	No effect	Ghazi and Drakhshan (2002)
	Broiler	5, 10 and 15%	No effect	Ayhan and Aktan (2004)
	Broiler	4 and 6%	No effect	Mohammed et al. (2021)
	Broiler	2.5%	Decreased	El- Hassan (1999)

1	2	3	4	5
Feed conversion ratio	RIR grower chicks	20%	Increased	Yitbarek et al. (2013 a)
	Broiler	8%	Increased	Hady et al. (2018)
	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
	Broiler	Above 20%	Increased	Lira et al. (2010)
	Layer	150 kg/ton	Increased	Jafari et al. (2006)
	Broiler	0.5%	Increased	Selim et al. (2013)
	Broiler	5, 10, 15 and 20%	Increased	Al-Betawi (2005)
	Broiler	2.5%	Decreased	El- Hassan (1999)
	Layer	120 g/kg	Increased	Dotas et al. (1999)
	Layer	5, 10, 15 and 20%	No effect	De Souza Loureiro et al. (2007)
	Broiler	4 and 6%	No effect	Mohammed et al. (2021)
	Layer	15%	No effect	Tufarelli et al. (2021)
	Broiler	15%	Decreased	Persia et al. (2003)
	Broiler	3% in starters to 9% in finisher	Decreased	Tabeidian et al. (2011)
	RIR chicken	24%	Decreased	Rahmatnejad et al. (2009)
	Broiler	8 or 16%	Decreased	Dorra et al. (2011)
	Layer	150 g/kg	Decreased	Yannakopoulos et al. (1992)
	Weight Gain and growth performance			
Weight gain	Broiler	8 or 16%	Increased	Dorra et al. (2011)
	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Broiler	0.5%	Increased	Selim et al. (2013)
	Broiler	20%	Increased	Lira et al. (2010)
			(29–42 days)	
	Broiler	20%	Increased	Wongsuthavas et al. (2013)
	Broiler	5%	Increased	Nasr El-Deen (2007)
	RIR grower chicks	5%	Increased	Yitbarek et al. (2013 a)
	Broiler	2.5 and 5%	Increased	El- Hassan (1999)
	Broiler	10%	Increased	Boushy and Poel (2000)
	Broiler	8%	Increased	Hady et al. (2018)
	Layer	16 to 20%	No effect	Calislar and Uygur (2010)
	Broiler	10 and 15%	No effect	Ghazi and Drakhshan (2002)
	Broiler	10%	No effect	Al-Betawi (2005)
	Broiler	20%	Decreased	Lira et al. (2010)
	Broiler	15%	Decreased	Persia et al. (2003)
	Broiler	20%	Decreased	Nasr El-Deen (2007)
Performance	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
	Layer	100 kg/ton	Increased	Jafari et al. (2006)
	Quail	2.5 and 5%	Increased	Sahin et al. (2008)
	Broiler chicken	20%	Increased	Lira et al. (2010)
			(29–42 days)	
	Broiler	0.5%	Increased	Selim et al. (2013)
	Broiler	8%	Increased	Hady et al. (2018)
	Layer	190 g/kg	No effect	Salajegheh et al. (2012)
	Broiler	20%	No effect	Rezaeipour et al. (2012)
	Broiler	50 g/kg	No effect	Rezaeipour et al. (2012)
	Broiler	16%	No effect	Rahmatnejad et al. (2011)
	Layer	16 to 20%	No effect	Calislar and Uygur (2010)
	Layer	15%	No effect	Tufarelli et al. (2021)
	Broiler chicken	20%	Decreased	Lira et al. (2010)
			(1–28 days)	
	Broiler	3% in starters to 9% in finisher	Decreased	Tabeidian et al. (2011)

1	2	3	4	5
Carcass traits/ Meat Quality				
Carcass yield	RIR grower chicks	5%	Increased	Melkamu (2013)
Carcass yield	Broiler	8%	No effect	Rahmatnejad et al. (2011)
Carcass weight	Broiler	8%	No effect	Rahmatnejad et al. (2011)
Yield of breast, thigh, abdominal fat, heart, liver and gizzard	Broiler	8%	No effect	Rahmatnejad et al. (2011)
Carcass yield	Broiler	17.5%	No effect	Lira et al. (2010)
Carcass yield	Broiler	20%	No effect	Lira et al. (2010)
Carcass yield	Broiler	8 or 16%	No effect	Dorra et al. (2011)
Dressing percentage	RIR grower chicks	20%	No effect	Yitbarek et al. (2013 b)
Carcass yield	RIR grower chicks	20%	No effect	Yitbarek et al. (2013 b)
Dressed carcass weight	Quail	2.5%	No effect	Shehata et al. (2018)
Dressing percentage	Broiler	0.5%	No effect	Selim et al. (2013)
Thickness of breast muscles	Broiler	0.5%	No effect	Selim et al. (2013)
Abdominal fat	Broiler	8%	Decreased	Hady et al. (2018)
Decreased carcass weight and yield, yield of breast and thigh	Broiler	16 and 24%	Decreased	Rahmatnejad et al. (2011)
Carcass yield	Quail	2, 4, 6 and 8%	Decreased	Jouzi et al. (2015)
Wings, breast, drumstick	Quail	2, 4, 6 and 8%	Decreased	Jouzi et al. (2015)
Immune response				
Antibody response to SRBCs	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
Antibody response to NDV	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
Heterophil/lymphocyte ratio	Broiler	5%	Decreased	Hosseini-Vashan et al. (2016)
Relative weight of bursa of Fabricius	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
Antibody response to NDV	Broiler	1%	Increased	Selim et al. (2013)
Antibody response to IB	Broiler	1%	Increased	Selim et al. (2013)
Heterophil/lymphocyte ratio	Broiler	1%	Decreased	Selim et al. (2013)
<i>Staphylococcus aureus</i> in both refrigerated and frozen breast samples	Broiler	1%	Decreased	Selim et al. (2013)
Total bacteria count in frozen breast meat samples	Broiler	1%	Decreased	Selim et al. (2013)
Inflammatory, cutaneous basophil hypersensitivity	Layer	420 and 840 mg/kg	No effect	Olson et al. (2008)
Antibody response	Layer	420 and 840 mg/kg	No effect	Olson et al. (2008)
Indices of the thymus, bursa of Fabricius and spleen	Breeding hens	20, 40, or 80 mg/kg diet	Increased	Sun et al. (2014)
Antibody response to NDV	Broiler	8%	Increased	Hady et al. (2018)
Phagocytic activity	Broiler	8%	Increased	Hady et al. (2018)
Blood biochemistry				
Serum GPT, GOT and AP	Broiler	15%	Increased	Rao and Shen (2002)
Triglycerides	Laying hen	1, 2 and 3%	Decreased	Saed et al. (2018)
HDL cholesterol concentration	Laying hen	1, 2 and 3%	Increased	Saed et al. (2018)
Pcv%	Laying hen	3%	Increased	Saed et al. (2018)
WBCs	Laying hen	1, 2 and 3%	Decreased	Saed et al. (2018)
Serum glucose	Laying hen	1, 2 and 3%	Decreased	Saed et al. (2018)
Total protein	Laying hen	1, 2 and 3%	Increased	Saed et al. (2018)
Blood albumin	Layer	16%	Increased	Jalalinasab et al. (2014)
Total protein	Layer	16%	Increased	Jalalinasab et al. (2014)
Serum ALP and lipase	Broiler	5%	Decreased	Hosseini-Vashan et al. (2016)
LDL	Broiler	5%	Decreased	Hosseini-Vashan et al. (2016)

1	2	3	4	5
HDL	Broiler	5%	Increased	Hosseini-Vashan et al. (2016)
Total lipids, LDL cholesterol, and HDL cholesterol.	Broiler	0.5–1%	No effect	Selim et al. (2013)
Serum lycopene	Quail	2.5 or 5%	Increased	Sahin et al. (2008)
Serum vitamin C, vitamin E, and vitamin A	Quail	2.5 or 5%	Increased	Sahin et al. (2008)
Liver concentrations of lycopene	Quail	2.5 or 5%	Increased	Sahin et al. (2011)
Liver concentrations of SOD, GPx and catalase	Quail	2.5 or 5%	Increased	Sahin et al. (2011)
Serum GSH-Px activity, MDA, TSOD and T-AOC	Layer	15%	No effect	Tufarelli et al. (2021)
Yolk cholesterol	Quail	2.5 or 5%	Decreased	Sahin et al. (2006 a, b)
Serum cholesterol	Quail	2.5 or 5%	Decreased	Sahin et al. (2006 a, b)
Miscellaneous				
Ash and Ca contents of the tibia bone	Broiler	5%	No effect	Hosseini-Vashan et al. (2016)
Liver weight, heart weight, gizzard weight, and spleen weight	Quail	2.5%	No effect	Shehata et al. (2018)
Liver, gizzard, heart, abdominal fat	Broiler	0.5%	No effect	Selim et al. (2013)
Intestine weight	Broiler	0.5%	No effect	Selim et al. (2013)
Thickness of breast muscles	Broiler	0.5%	No effect	Selim et al. (2013)

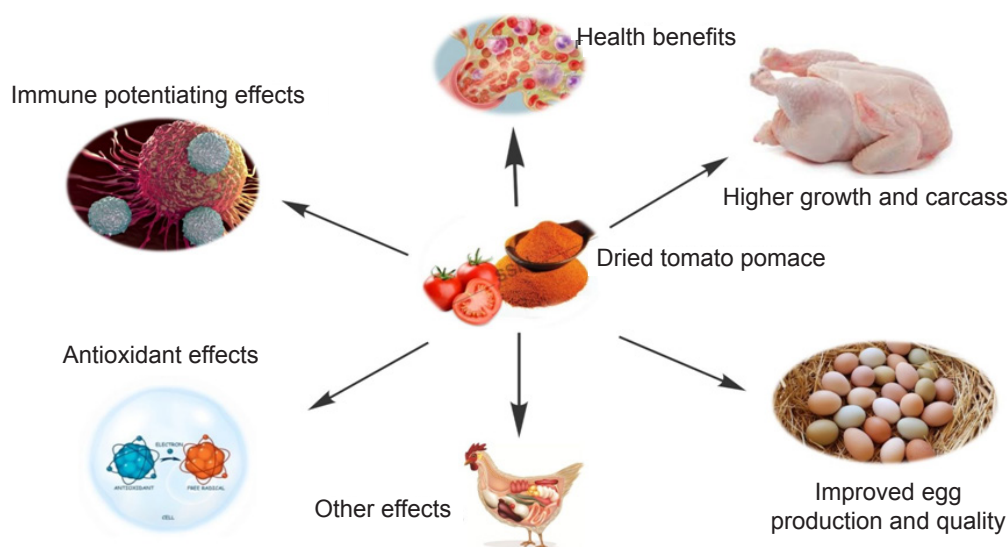


Figure 2. Multiple beneficial effects of tomato pomace

Feed intake and feed efficiency

The feed intake and efficiency of 20% tomato pomace supplemented groups in RIR grower chicks were better than those fed on basal feed, according to Bezabih Yitbarek et al. (2013 a). Lira et al. (2010) reported that using more than 20% tomato pomace in the diet of broiler chicken for a period of 1 to 28 days may increase feed intake and decrease feed conversion ratio (FCR). Similarly, Hosseini-Vashan et al. (2016) found that supplementing tomato pomace at a rate of 5% increased broiler feed conversion ratio (FCR) during heat stress. Inclusion of tomato pomace at dose up to 100 kg/t in laying hen diets

during 27 to 38 weeks of life increased daily feed intake, while addition of tomato pomace at a higher level (150 kg/t of diet) increased FCR by 2.9% (Jafari et al., 2006). The fact that tomato pomace contains lysine, an essential amino acid that promotes the formation of body muscle protein and hence improves weight gain, might explain the increased feed efficiency (Sayed et al., 2009; Shengfa et al., 2015). In contrast, Dotas et al. (1999) discovered that addition of 120 g/kg tomato pomace had no effect on laying hen FCR. In 52-week-old hens, Yannakopoulos et al. (1992) reported that larger dose of dietary tomato pomace inclusion (150 g/kg) resulted in worse feed ef-

iciency. In another study, the inclusion of 16% tomato pomace to laying chicken diets boosted feed consumption (Jalalinasab et al., 2014). The addition of 15% tomato waste in ration to broiler diets had no effect on feed consumption, according to Al-Betawi (2005). Similarly, De Souza Loureiro et al. (2007), used tomato waste at the levels ranging from 5 to 20% in commercial laying hen feeds and showed no significant influence on FCR. Persia et al. (2003) discovered a 15% reduction in feeding efficiency in broiler chicks aged 8 to 21 days due to inclusion of tomato pomace. According to Dorra et al. (2011), birds fed tomato pomace at 8% and 16% levels had considerably higher feed intake and a lower FCR than the control group. Mohammed et al. (2021) found that supplementing broiler chicks with 4 and 6% tomato pomace had no effect on FCR or daily feed consumption. According to Shehata et al. (2018), adding 2.5% tomato pomace to the quail diet increased feed intake. Tabeidian et al. (2011) found that feed efficiency in broilers has been reduced at an inclusion rates of 3% in starters to 9% in finishers. According to Yitbarek et al. (2013 a), diets containing dried tomato pomace (5, 10, 15, and 20%) elevated feed consumption and enhanced FCR compared to the control birds. The elevation in feed intake might be linked to the presence of ascorbic acid in dried tomato pomace, which enhances appetite and hence feed intake. A meal containing seed and tomato pomace (30%) resulted in increased feed consumption compared to a control group (King and Zeidler, 2004). According to Ghazi and Drakhshan (2002) and Ayhan and Aktan (2004), intake of feed containing varied quantities of tomato pomace supplemented to birds and the control group did not vary. Increased levels of liver enzymes result in continued growth and improved feed conversion efficiency in birds by increasing protein concentration in the blood serum due to the antioxidant activity of lycopene, which protects the protein from oxidation and reduces the risk of free radicals (Rao and Shen, 2002). In broiler chicks, El-Hassan (1999) found that adding 2.5% dried tomato pomace into the ration reduced feed consumption and enhanced feed efficiency. Rahmatnejad et al. (2009) found that a ration supplemented with 24% tomato pomace had the poorest FCR in RIR chicken. Tufarelli et al. (2021) observed that adding 15% tomato powder to the diet of layers had no significant effect on FCR.

Several opinions are available regarding higher feed intake and feed efficiency in response to tomato pomace supplementation in poultry. Genetic variations may account for the large disparities in FCR and average feed consumption between different poultry breeds (Amao et al., 2011). According to an opinion, the increased feed consumption might be related to the high fibre content in the diets causing expansion of the gut, potentially due to extension in the retention time for digestion of the meal (Colombino et al., 2020). According to Shehata et al. (2018), including tomato pomace into broiler diets results in increased feed consumption owing to a larger fibre content to fulfil the animal's energy requirements.

Fiber potentially boosts faecal size, speeds up feed transit time resulting in healthier gut (Anderson et al., 2010). It is possible that the lower FCR in the case of a diet supplemented with higher level of tomato pomace is attributed to a greater level of crude fibre. Fibre is the insoluble part of plant that requires enzymes for digestion. It can partly be digested by gastrointestinal microflora in monogastric animals (Damron and Sloan, 2009). According to Johnston et al. (2005), high fibre inclusions are usually limited due to low metabolizable energy contents, which affect chicken performance and nutrient utilization.

Weight gain and growth performance

Dorra et al. (2011) found that 5% tomato by-product meal (TBM) resulted in better live body weight in broilers. According to Hosseini-Vashan et al. (2016), adding 5% tomato pomace to broiler diets enhanced body weight and performance under heat stress. Inclusion of tomato pomace (100 kg/t) in the ration of layers from 27 to 38 weeks of age increased weight gain (Jafari et al., 2006). The higher weight gain in broiler might be due to higher feed consumption. Lira et al. (2010) used more than 20% tomato waste in broiler chicken feeds from 1 to 28 days, which reduced body weight gain and performance, while increased weight gain from 29 to 42 days. According to Salajegheh et al. (2012), the addition of tomato pomace up to 190 g/kg had no negative influence on the performance of chickens. Wongsuthavas et al. (2013) discovered that feeding broiler chicks with 20% tomato pomace boosted their daily weight gain. According to Sahin et al. (2008), supplementing heat stressed quails with tomato powder (2.5 and 5%) improved performance metrics. In another experiment, heat-stressed broilers treated with 0.5% tomato pomace showed substantial weight gain and growth performance (Selim et al., 2013). Persia et al. (2003) found that when the tomato waste level increased, the weight gain of broiler hens decreased significantly at 8–21 days of age. Kelley (1958) discovered that 5% dried tomato seed cake outperformed in terms of growth in broilers. According to Nasr El-Deen (2007), giving broilers 5% TBM resulted in significant live body weight and weight increase, while broilers fed 20% TBM had the lowest performance. Rezaeipour et al. (2012) found that ration consisting of 20% tomato pomace during 29 to 42 days, and a higher dose when fed to chicks aged 1–42 days, did not impair growth efficiency. According to Rahmatnejad et al. (2011), up to 16% tomato pomace may be added to diets without affecting broiler chicken performance. In another case, Tabeidian et al. (2011) found that growth performance was lowered even at modest inclusion rates (3% in the starter phase and 9% in finisher). Calislar and Uygur (2010) discovered that tomato pomace levels ranging from 16 to 20% had no influence on body weight or performance. Interestingly, according to Yitbarek et al. (2013 a) a diet containing 5% tomato pomace resulted in considerably greater body weight than a diet containing 20% tomato pomace or a control diet. While in another experiment, compared to the con-

trol group, Ghazi and Drakhshan (2002) did not find any significant change in weight gain in chickens given 10 and 15% tomato pomace. Al-Betawi (2005) found that broilers fed alkali mixed, heated, and sun-dried tomato pomace at a 10% level gained equal live body weight to the control group. El-Hassan (1999) found that broiler chicks fed 2.5 and 5% tomato pomace in the starter and finisher phases had considerably higher live body weight than those fed a control diet. According to Boushy and Poel (2000), adding 10% tomato pomace to the food enhances the body weight gain of broiler chickens. Tufarelli et al. (2021) found that adding 15% tomato powder to the layers' diet had no significant effect on the growth performance.

The antioxidant activity of tomato pomace is associated with lycopene, which is an important part of it. Lycopene is a powerful antioxidant that can protect muscle cells from the damaging effects of reactive oxygen species and biomolecule destruction (Aref Mezban et al., 2019). It is speculated that the growth in poultry in response to tomato pomace supplementation may be the result of its antioxidant activity. Second, tomato pomace is an excellent source of vitamins and rich in carotenoids (Mansoori et al., 2008; Nour et al., 2018). Lycopene, one of the carotenoids, stimulates the liver to produce more insulin-like growth factors, which boosts protein synthesis in cells and improves broiler productivity (Vrieling et al., 2007; Englmaierová et al., 2011). It is also thought that increased body weight might be owing to the presence of slightly more crude protein in tomato pomace, which can then be taken into the bloodstream and utilized for muscle building (Jeffre and Firman, 2004). Lysine, methionine, tryptophan, glycine, and arginine are the most typically deficient amino acids in grower chicken diets (Gillespie, 1992). These amino acids can be found in tomato pomace, which may be sufficient to meet their needs. They also require lipids and carbohydrates, as well as vitamins and minerals, which cannot be obtained from high-fibre diets (Burton and Silverman, 2009). Lower body weight and growth performance in case of higher tomato pomace supplemented diet may be linked to the higher amount of crude fibre. Crude fibre is the insoluble part of plants, which is not digested by endogenous enzymes but can be partly digested by gut microflora in chickens (Damron and Sloan, 2009).

Immunological response

The avian immune system has two functional immunological aspects: humoral and cell-mediated immunity, which provide the foundation for microbe prevention and protection (Khan et al., 2012 e). The adaptive function of the immune system is the humoral immune response. Antibodies are created as a result of antigenic stimulation. Immunity mediated by cells includes the immune system's response to cells infected with a foreign substance, such as a virus, and bacteria are eliminated (Khan et al., 2012 f). According to Hosseini-Vashan et al. (2016), adding 5% tomato pomace to broiler diets

improved immunity by boosting overall antibody titres to sheep red blood cells and Newcastle disease virus (NDV) and decreased the heterophil to lymphocytes ratio (H/L) ratio in heat-stressed broilers. In broilers grown under summer circumstances, Selim et al. (2013) found that adding tomato pomace at a rate of 1% enhanced the levels of blood titres against infectious viruses and lowered the ratio of H/L. According to Selim et al. (2013), a 1% tomato pomace supplementation decreased the load of *Staphylococcus aureus* in both refrigerated and frozen breast samples, as well as the overall bacteria count in frozen breast meat samples.

The phenolic chemicals (flavonoids, phenolic acids) in tomato pomace have anticancer, antibacterial, antimutagenic, and anti-inflammatory properties, might explain the improved immunity. They are capable of carrying out these functions on their own or in conjunction with other components found in tomato seeds. By altering numerous cellular signal transduction pathways and initiating endogenous defensive activities, phenolic substances exhibited promising protective effects (Silva et al., 2019). The inclusion of carotenoids (carotene and lycopene), which have immune modulatory properties, might explain the improved immunity (Milani et al., 2017). The rise in white blood cells, particularly the proportion of lymphoid cells, as well as a decline in the proportion of lymphoid cells differentiation could be due to lycopene's antioxidant activity (Rzuqi, 2017). The presence of lutein in tomato might explain the increased antibody titre in the tomato pomace supplemented groups. Lutein is a carotenoid that affects immunological response by enhancing immune activity and lymphocyte proliferation, resulting in a rise in antibody titre against NDV (Ribaya-Mercado and Blumberg, 2004). The presence of genistein in tomato pomace leads to higher relative weight of lymphoid organs, which exhibit larger responses to antibodies against viral antigens. In broilers, genistein, a chemical found in tomato pomace, increased the number of lymphocytes in the blood and boosted immunological competence (Rasouli and Jahanian, 2015). Because of their lipophilicity, phenolic compounds might pass the bacteria's membrane and enter the interior of the cell, resulting in a reduction in microbial activity (Helander et al., 1998).

Egg production and egg quality

In response to tomato pomace, a number of authors have observed increased egg production and quality. Tomato by-products contain significant levels of carotene, lutein, lycopene and cis-carotene, which may explain the reason of improved egg quality. Dots et al. (1999) showed that chickens fed diets including tomato pomace at levels up to 120 g/kg had no detrimental impacts on egg production and had no influence on egg weight after two decades. When laying hens were fed diets containing up to 150 g/kg tomato pomace, Gregoriades et al. (1984) as well as Yannakopoulos et al. (1992) found no significant variations in egg production when compared to hens fed a control diet. In laying hens fed diets con-

taining up to 150 g/kg tomato pomace, Yannakopoulos et al. (1992) found a substantial increase in weight gain and yolk colour. Nobakht and Safamehr (2007) found that increasing the tomato pomace level to 10% boosted egg production rate and egg mass. The addition of 100 g/kg tomato pomace to the diet had no influence on egg production, but it did raise the yolk colour score (YCS) of the eggs produced (Mansoori et al., 2008). The presence of significant levels of carotenoid pigments, notably lycopene, was most likely responsible for a significant rise in YCS of eggs in response to dietary inclusion of tomato pomace in this experiment. The red colour of tomatoes and tomato pomace is due to lycopene (Mansoori et al., 2008). In fact, feeding tomato by-products to laying hens can result in about 5.8% dietary lycopene being transferred to the egg yolk (Knoblich et al., 2005; Karadas et al., 2006). Quails fed meals supplemented with 20 g/kg tomato powder had higher YCS levels of eggs (Karadas et al., 2006). Inclusion of tomato pomace in layers diets at levels up to 100 kg/t boosted egg production, egg mass, egg shell weight and thickness, Haugh unit, and yolk colour (Jafari et al., 2006). Tomato pomace is a valuable source of protein and vitamins, rich in carotenoid colours, widely available, and low-cost (Mansoori et al., 2008). Proteins (32%) are the most abundant nutrient in tomato seeds, followed by total fat (27%) and fibre (18%), leading to increased egg production. Decreased egg production might be related to the increased fibre content of tomato pomace, since a high fibre diet can impair nutrient availability in chicken, resulting in poor egg production (Lesson and Summers, 2001).

The addition of 16% tomato pomace to laying chicken diets boosted egg production and yolk colour in native laying hens, according to Jalalinasab et al. (2014). Salajegheh et al. (2012) discovered that adding tomato pomace up to 190 g/kg to laying hen feed had no negative influence on egg quality. When employing levels above 5% tomato meal in the ration, De Souza Loureiro et al. (2007) noticed a reduction in egg production, egg and yolk weight in laying hens. Calislar and Uygur (2010) discovered that tomato pomace levels ranging from 16 to 20% had no influence on egg production, egg weight, or other structural properties. Nobakht (2007) found that supplementing eggs with 16 to 20% tomato pomace had no influence on overall egg quality. Tufarelli et al. (2021) found that supplementing a layer's diet with 15% tomato powder had no influence on egg production, but did improve egg quality by enhancing egg yolk colour. According to Yannakopoulos et al. (1992), the higher egg weight might be due to the high lysine content of tomato meal. Others think that incorporation of tomato pomace in laying hen diet may provide a high level of nutrients, particularly certain amino acids like lysine (Nobakht and Safamehr, 2007).

Antioxidant effects

Several reasons have been forwarded to the antioxidant capacity of tomato pomace. Bioactive components

found in tomato waste include lycopene and β -carotene, which have been demonstrated to have substantial antioxidant capacity in several studies (Szabo et al., 2019). Unsaponifiable chemicals found in tomato seeds include alpha and gamma tocopherols, as well as demethylsterols. Two important compounds in tomato seeds are citrostadienol and 5-avenasterol which have excellent antioxidant activities (Gordan and Magos, 1983). Others have attributed the antioxidant activity of tomato pomace to the presence of carotenoids (Pérez-Gálvez et al., 2020). Carotenoids (carotene, lycopene) have enormous antioxidant potential due to their capacity to scavenge free radicals. Antioxidant compounds such as condensed tannins, flavonoids, phenols, tocochromanols, ascorbic acid and carotenoids have been found in tomato seeds (Ilahy et al., 2016; Durante et al., 2017). The inclusion of ferulic acid, caffeic acid, quercetin-3-O-glycoside, chlorogenic acids and quercetin might also explain the increased antioxidant activity (Fuentes et al., 2013). According to Gharbi et al. (2017), the presence of tocopherols in tomato pomace resulted in increased free radical inhibition values.

Under heat stress circumstances, Selim et al. (2013) found that adding 1% tomato pomace increased antioxidant activity and lowered malondialdehyde (MDA) value in broiler chicks. According to Saed et al. (2018), levels of 1, 2, and 3% tomato pomace increased antioxidant status by lowering MDA levels in heat stressed laying hens. Hosseini-Vashan et al. (2016) found that supplementing broilers with 5% tomato pomace resulted in enhanced antioxidant status, higher antioxidant enzymes, and a decrease in MDA levels in their plasma. Under thermoneutral and high temperatures, Sahin et al. (2008) found that diet supplemented with 2.5 or 5% tomato powder improved antioxidant status by lowering MDA levels in the blood, breast, and leg of quails. The antioxidant quality of broiler diets supplemented with 2.5 and 5% tomato powder was improved by lowering liver MDA levels (Sahin et al., 2011). Tufarelli et al. (2021) found that supplementing the diet of layers with 15% tomato powder reduced liver MDA levels while having no impact on antioxidant enzymes or antioxidant capacity. Quails exposed to heat stress and supplemented with 2.5 and 5% tomato powder reduced liver MDA while increasing liver concentrations of lycopene, superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (Sahin et al., 2011). Tufarelli et al. (2021) found that adding 15% tomato powder to the diet of layers had no effect on blood GPx activity, MDA, SOD, or antioxidant capacity.

The antioxidant activity of tomato seeds extract was mostly attributed to lycopene, carotene, polyphenols, and tocopherols. Tomato seeds' better radical scavenging and antioxidant activity might be due to their protein components. Omega-6 fatty acid found in tomato seeds, also acts as a precursor for the production of additional polyunsaturated fatty acids with antioxidant effects. Tomato pomace contains antioxidant substances such as flavonoids, lycopene, α -tocopherol, vitamins, carotene, folate,

and phenolic acids, which may explain the increase in antioxidant effects as reported by Sahin et al. (2008), Hosseini-Vashan et al. (2016) and Selim et al. (2013). Tomato products can impact the state of various micro-constituents in bodily tissues, as well as maintain antioxidant vitamins due to their antioxidant properties (Sahin et al., 2008). The fact that phenolic chemicals found in tomato pomace react with lipid and hydroxyl radicals and transform them into stable molecules may explain the increase in antioxidant activity (Kahkonen et al., 1999). At the molecular level, polyphenols activate signal transduction pathway by enhancing Keap-1 dissociation from Nrf2 that occurs in response to stressors, which is associated with lipid peroxidation suppression and antioxidant enzyme activity elevation (Sahin et al., 2010). Lian and Wang (2008) found that lycopene increases the expression of nuclear Nrf2 which results in greater production of antioxidant enzymes.

Blood biochemistry

In heat challenged laying hens, Saed et al. (2018) found that levels of 1, 2, and 3% tomato pomace improved certain blood parameters, lowered triglycerides and elevated high density lipoprotein (HDL) cholesterol concentration. In response to 3% tomato pomace, Saed et al. (2018) found greater packed cell volume, lower leucocyte count, serum glucose, triglyceride, and cholesterol, as well as the greatest total protein and serum HDL concentration. According to Jalalinasab et al. (2014), adding 16% tomato pomace to laying chicken diets boosted blood albumin and total protein levels in native laying hens. According to Hosseini-Vashan et al. (2016), adding 5% tomato pomace to broiler meals lowered the activity of serum alkaline phosphatase (ALP) and lipase to the levels seen in non-stressed broilers. In addition, when compared to the other broilers, the broilers treated with 5% tomato pomace exhibited reduced triglyceride and higher HDL cholesterol levels. According to Selim et al. (2013), supplementing heat-stressed broilers with tomato at a rate of 0.5–1% had no significant impact on total lipids, cholesterol, triglyceride, LDL and HDL cholesterol. Under thermoneutral and high temperatures, Sahin et al. (2008) found that diet supplemented with tomato powder reduced MDA levels in the blood, breast, leg, and liver while increasing serum vitamins (C, E and A) and lycopene in quails. According to Shao et al. (2013), tomato pomace has a larger potential for application as bioactive dietary components that decrease blood and liver cholesterol. Seed protein in tomato has also been regarded to be a high-quality plant protein source, with globulin (approximately 60% of seed protein) being the most common protein type (Sogi et al., 2002). As a result, it is possible that the protein in tomato pomace contributed to the observed cholesterol reduction. Tomato seeds also contain a variety of polyphenols, primarily kaempferol, quercetin, naringenin, isorhamnetin, and chlorogenic acid (Ferrerres et al., 2010; Preedy et al., 2011). Through the control of hepatic gene expression relevant to lipid

metabolism, several phenolic compounds are associated with hypocholesterolemic and antiobesity activities (Chang et al., 2011; Jung et al., 2012). As a result, phenolic chemicals, as well as protein and dietary fibre, may have a role in the tomato pomace's lipid-lowering actions. More attention is needed to establish the real role of tomato pomace to reduce cholesterol. It is speculated that the hypocholesterolemic effect of tomato is associated with suppression of 3-hydroxy-3-methylglutaryl co-enzyme A (HMG-CoA) activity in liver cells (Paloza et al., 2012).

Conclusion

Tomato pomace can be an excellent source of protein, fibre, carbohydrates, and carotenoids for poultry. As an alternative to traditional feeds, fresh tomato by-products can be utilized in the raw form in poultry diets. Their high moisture content, however, restricts their use. Due to increase in the concentration of bioactive substances and nutrients, fatty acid profile, and lipid oxidation, among other favourable changes, incorporating tomato pomace in poultry diets can positively impact meat and egg quality. Because poultry has limited ability to utilize fibres, the recommended inclusion levels are often less than 10 to 15% of total food. Increased use of tomato pomace in chicken feed could decrease feed cost and generate circular bioeconomy while minimizing the environmental consequences of their management and disposal. The development of low-cost, effective strategies to circumvent the moisture level constraint in tomato pomace will substantially aid their utilization as chicken feed components.

Conflict of interest

Authors declare no conflict of interest.

Ethical approval

This study was approved by the Departmental Committee on Ethics and Animal Welfare, Faculty of Animal Husbandry and Veterinary Sciences, The University of Agriculture, Peshawar.

Authors contribution

Conceptualization: RUK. Methodology: SN, RUK. Software: MDM, RUK. Validation: AK, RUK. Writing original draft: AK, SN. Visualization: SN, AK. Supervision: RUK. Project administration: SN, RUK.

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