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Dietary inclusion of pistachio wastes (*Pistacia vera* L.) to fattening male goat kids' feeding: Chemical-mineral compositions, *in vitro* ruminal fermentation, *in vivo* digestibility, hemato-biochemical profile, and growth performance

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ABSTRACT

Pistachio (PW, *Pistacia vera* L.) wastes are a collection of favorite materials that are produced in the pistachio processing factories, in combination with its industry derivatives of clusters, soft hull, leaves, hard shell, and kernel. Two experiments were carried out; in the 1st one, the chemical and mineral compositions, *in vitro* ruminal-digestive fermentation activities, and buffering capacity parameters were determined for PW and its derivatives. For the 2nd experiment, the nutritional effects of an aluminosilicate (AS) and polyethylene glycol (PEG), at 10 g/kg dietary dry matter (DM), on PW-based diets were investigated. However, forty Mahabadi male goat kids [5 months, 22 ± 2.0 kg body weight (BW)] were randomly divided into the four experimental diets: control (a basal diet without PW); PW (replaced 40 % of control ingredients with PW); PW + PEG (PW diet + 10 g PEG/kg DM); and PW + AS (PW diet + 10 g AS/kg DM). Crude protein content, dry matter digestibility (DMD), gas production, and metabolizable energy were increased ($P < 0.001$) in kernel rather than other treatments. Hard shell exhibited the lowest ($P < 0.001$) DMD and/or organic matter digestibility (at 24 and 96 h), and highest ($P < 0.001$) neutral detergent fiber, acid detergent fiber, and iron concentrations. In leaves, total phenolic and tannins, calcium, magnesium, and manganese had the highest ($P < 0.001$) concentrations *versus* other PW derivatives. Soft hull has the greatest ($P < 0.001$) acid-base buffering capacity among the evaluated derivatives. Dietary supplementation with 40 % PW decreased ($P < 0.001$) dry matter intake, final BW, average daily gain, nutrient digestibility, ruminal total volatile fatty acids, propionate, and acetate, but with an increase ($P < 0.001$) in those parameters in PW + PEG and PW + AS diets. Blood urea nitrogen and total protein decreased ($P < 0.05$) by dietary PW. The inclusion of 40 % PW in the diet reduced the growth performance and diet nutritive value, but improved plasma antioxidant status (total antioxidant capacity: and malondialdehyde). Addition of PW in goat kids' diets with PEG or AS improved the digestibility and ruminal fermentation activities and enhanced growth performance. In conclusion, it is recommended to use PW at the dietary level of 40 % in fattening goat kids, provided that it is accompanied by adding AS or PEG to the diet.

1. Introduction

Due to the ever-increasing need for livestock products and the lack of feed in recent years, the use of by-products in feeding domestic animals has received special attention from nutritionists. Pistachio (*Pistacia vera* L.) is one of the most important agricultural products that has been

Abbreviations: ADF, acid detergent fiber; ADG, average daily gain; AS, aluminosilicate; b_{gas}, potential gas production; BUN, blood urea nitrogen; BW, body weight; c_{gas}, fractional rate of gas production; CP, crude protein; DM, dry matter; DMI, dry matter intake; EE, ether extract; Hb, hemoglobin; DMD, dry matter digestibility; OMD, organic matter digestibility; MDA, malondialdehyde; ME, metabolizable energy; NDF, neutral detergent fiber; NEl, net energy for lactation; NFC, non-fiber carbohydrates; NH_3–N, ammonia nitrogen; PEG, polyethylene glycol; PW, pistachio wastes; TAC, total antioxidant capacity; TMR, total mixed ration; TP, total phenols; TT, total tannins; TVFA, total volatile fatty acids; VFA, volatile fatty acids; WBC, white blood cells.

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distributed in regions with low rainfall. Cultivation of this product has been common in many dry and desert regions of the world for a long time. According to FAO statistics, pistachio production in Iran in 2021 was 135 thousand tons with 125,544-hectare area under cultivation, which placed this country in second place in the world. Before Iran, the United States was in the first place with the production of 523,900 tons with 165,518-hectare area under cultivation, and Turkey was in the third place with the production of 119,355 tons and 389,451-hectare area under cultivation (FAO, 2021). Yearly, a large number of pistachio wastes (PW) remain in cleaning factories, which are usually disposed of in the surroundings and margins of pistachio orchards. The PW are usually left wet, despite containing valuable nutrients, provide a suitable environment for the growth of microbes. This factor will cause environmental problems and several fungal contaminants in the surrounding of pistachio orchards. It has been reported that PW has a high content of non-fiber carbohydrates (36.9–40.4 %) with medium crude protein (11.4–13.0 %) and neutral detergent fiber (30.9–33.3 %) and is rich in polyphenolic and tannin compounds (Shakeri et al., 2014; Ghaffari et al., 2014a). It is a favorite source of energy and protein for ruminants because of its low cost and availability (Shakeri, 2016). Recently, different amounts of PW have been supplemented in the diets of sheep (Hajalizadeh and Dayani, 2021; Ebadi and Mahdavi, 2023), dairy cows (Mokhtarpour et al., 2012), growing calves (Shakeri et al., 2014), broiler chickens (Ahmadi Kohanali et al., 2022), and Saanen dairy goats (Ghaffari et al., 2014a, 2014b; Kordi et al., 2022). However, the utilization of PW for the phenolic and tannin compounds is limited in the diet of ruminants (Bohluli et al., 2008). A different range of total phenolic compounds (7.5–14.2 %) have been reported for dried PW, depending on the variety and different growth stages (Bohluli et al., 2008; Bagheripour et al., 2008). However, tannins are complex groups of polyphenolic compounds that can be beneficial or detrimental to ruminants, depending on how they are consumed, the chemical structure and molecular weight, and the physiology of the consuming animals (Hagerman and Butler, 1991). Supplementation of lambs' diet with tannins at high concentration (> 50 g/kg DM) can have a decreasing effect on dry matter intake (DMI) due to astringency in the diet and lower nutrient digestibility (de Lima Júnior et al., 2010; Mazza et al., 2020). Polyethylene glycol (PEG) is an inert, synthetic, and high molecular weight polymer that is poorly digested and absorbed in the intestines of animals (Grosell and Genz, 2006; Salem et al., 2006). It has been extensively used as a raw material in the food and pharmaceutical industries (He et al., 2019; Knop et al., 2010). Due to its high affinity with tannins, PEG can bind with tannins and form a tannin-PEG complex (Makkar et al., 1995a, 1995b). Aluminosilicate (AS) is a type of clay with a porous structure made of aluminum oxide and silicon dioxide which have a high specific surface to absorb a wide variety of cations such as ammonium, and medication for many gastrointestinal problems (Limpitlaw, 2010; Herremans et al., 2019). Different methods (electron irradiation by Fatehi et al., 2020; gamma irradiation by Valizadeh et al., 2019; ensiling by SoltaniNezhad et al., 2016, and Hajalizadeh and Dayani, 2021) and materials (PEG by Kordi et al., 2022) have been used to reduce the adverse effects of phenolic and tannin compounds of PW in diet of ruminants. Moreover, different management strategies have been proposed to moderate the effects of tannins, which can be drying, crushing, using chemical methods, and the use of bonding agents such as PEG and polyvinyl pyrrolidine (Bagheripour et al., 2008). Kemboi et al. (2023) reported that bentonite clay as an inactivating agent can be used due to its low cost compared to PEG and its activity to absorb or bind anti-nutritional factors such as tannins in animal feeds. There is no comprehensive information about the nutritional potential of different parts of PW wastes, and also, no scientific reports of dietary inclusion of AS or PEG in kids PW feeding. Therefore, the objectives of this study were, firstly to evaluate the nutritional potential of the total PW and its different parts (clusters, soft hull, leaves, hard shell, and kernel) by standard laboratory methods as well as *in vitro* evaluation. Secondly, an *in vivo* evaluation of PW dietary inclusion on the growth performance, nutrient digestibility, animal health, and ruminal fermentation parameters of growing goat kids at 40 % PW in their diets with the addition of 10 g of PEG or AS per kg of dietary DM was investigated.

2. Material and methods

2.1. Pistachio waste collection

The wastes of pistachio (*i.e.,* PW) were supplied in September 2021 from different de-hulling factories located in Feyzabad city, Razavi Khorasan province, Iran. The purchased PW were dried in a roofed area for several days, packed in nylon bags, and transported to the experimental site. The fresh samples of PW derivatives including clusters, soft hull (mesocarp), leaves, hard shell (endocarp), and kernel were prepared from the purchased total amount of PW (6000 kg) and samples were transferred to the laboratory for further analysis. The PW contained about 1.33 % kernel, 3.22 % hard shell, 4.49 % leaf, 17.3 % cluster, and 73.5 % soft hull (Fig. 1).

2.2. Laboratory procedures

For dry matter (DM) determination, the fresh samples of PW and its derivatives were moved to an air-forced oven (Behdad Co., Iran) at 60 °C for 48 h (method no. 930.15) until the weight was fixed (AOAC, 2005). Then the samples were ground through a mill fitted with a 1-mm screen for ash (method no. 942.05) determination by putting the samples in an electrical furnace at 550 °C for 4 h (AOAC, 2005). The crude protein (CP) concentration was determined by the Kjeldahl method (N × 6.25, method no. 954.01, AOAC, 2005), while the neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to the reagents suggested by Van Soest et al. (1991) and using Ankom (ANKOM, model A2001, New York, USA) fiber analyzer (Ankom Technology, 2005, 2006a, 2006b). The soxhlet apparatus was employed for ether extract (EE, method no. 991.36) determination (AOAC, 2005). The content of non-fiber carbohydrates (NFC) was determined by subtracting CP, NDF, EE, and ash from total DM (Sniffen et al., 1992). Atomic absorption Spectroscopy (SavantAA, GBC, Australia) was used to determine the concentration of specific minerals (calcium, sodium, potassium, magnesium, manganese, iron, and zinc) in samples (*i.e.,* PW and its derivatives). A spectrophotometer (UV–Vis array Spectrophotometer, Photonix-Ar-2017, Iran) along with the molybdovanadate method was employed for total phosphorus determination. The protocol of Jasaitis et al. (1987) was used for the determination of buffering capacity parameters. Total phenols (TP) and total tannins (TT) were also determined in samples according to the procedure described by Makkar (2003b).

2.3. In vitro protocols

The procedure of Menke and Steingass (1988) was employed for running the *in vitro* gas test technique. Ruminal fluid was obtained from three fistulated goats (35 ± 4 kg) receiving a total mixed ration (TMR) at the maintenance level. The rumen fluid samples were collected 3 h after the morning feeding, strained through four layers of silky cloth, and kept immediately at 39 °C under continuous flushing with CO_2 until the experiment started. The samples of PW and its derivatives with rumen liquor, and artificial saliva (30 mL, 1:2 ratio) were moved to the 100–mL lubricated syringes (Häberle Labortechnik, Lonsee, Germany). Five syringes were applied for each treatment The end of each glass syringe was closed by a plastic clip to prevent gas leakage. All glass syringes were slowly flicked and moved to a water bath at a temperature of 39 °C for 3, 6, 9, 12, 24, 48, 72, 96, and 120 h (Menke and Steingass, 1988). The gas test was replicated in two runs, and at each run, five blanks without samples (only rumen fluid + artificial saliva) were used to correct the values for gas released from the residual substrates. A culture medium similar to that prepared for the *in vitro* gas test was employed to

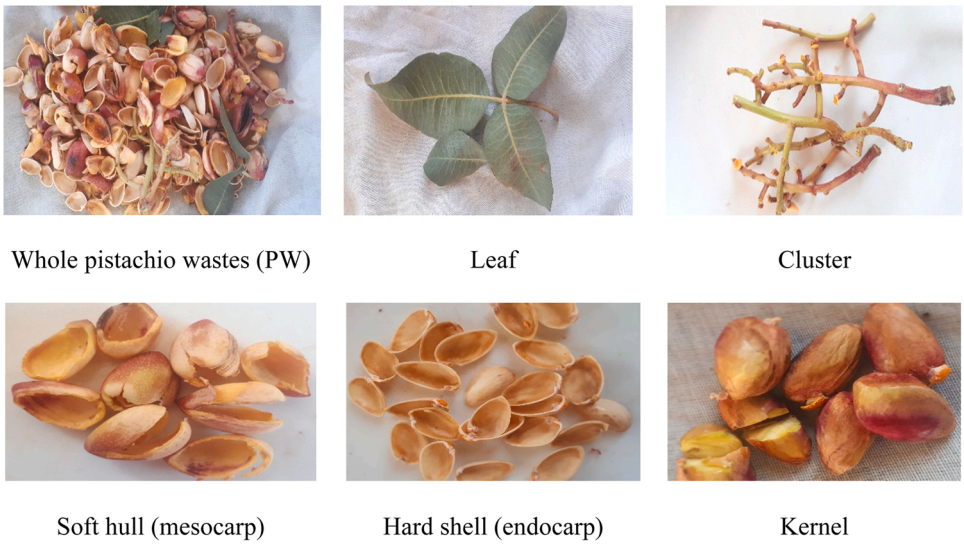

Fig. 1. Photos of whole pistachio wastes (PW) and its derivatives.

determine organic matter digestibility (OMD) and dry matter digestibility (DMD) following 24 and 96-h incubation. Briefly, after 24 and 96 h incubation, the entire content of each syringe was strained employing a vacuum pump and a Buchner funnel equipped with a polyester cloth (45-micron pore size) and Buchner flask, and then the residuals were transferred into the pre-weighted crucibles (Kazemi and Ghasemi Bezdi, 2021). After drying the crucibles in a forced-air oven for 48 h (60 °C), the weight differences between incubated samples (200 mg) before and after incubation were used for final DMD and OMD determination. The fluid gathered in the Buchner flask from each syringe was used for the determination of pH, total volatile fatty acids (TVFA), and ammonia nitrogen (NH_3–N) after 24 h incubation. However, the technique described by Komolong et al. (2001) was used for NH_3–N analysis, while the method of Getachew et al. (2004) was employed for preparing and preserving TVFA. Markham's device (Markham, 1942) was used to determine *in vitro* TVFA based on John et al. (1957) method.

2.4. *In vivo experiment and the protocols*

The *in vivo* experiment was run at a semi-industrial goat husbandry farm in Kashmar City, Razavi Khorasan province, Iran. The experimental period lasted for 90 days, preceded by a two-week adaptation. Forty Mahabadi male goat kids [5 months, 22 ± 2 kg body weight (BW), n = 10 per treatment] were randomly assigned to the four experimental treatments. The dietary treatments were: control (a basal diet without PW); PW (replaced 40 % of control ingredients with PW); PW + PEG (PW diet + 10 g PEG/kg DM); and PW + AS (PW diet + 10 g AS/kg DM). Ingredients and chemical compositions of experimental diets fed to fattening male goat kids are presented in Table 1. A mixture of AS (Zarin Binder, Vivan group, Iran) was supplied by Vivan Company, which contained (%): 64.5 SiO_2, 12.7 Al_2O_3, 2.67 Na_2O, 2.65 CaO, 2.57 MgO, and 2.34 Fe_2O_3. The PEG (PEG 4000, Merck, Darmstadt, Germany) was purchased from lab equipment and supplies. The experimental diets were balanced in terms of energy and protein according to NRC (2007). Kids were kept in individual cages (2 m × 2 m) with a concrete floor according to guidelines suggested by the Iranian Council of Animal Care (1995). The cages were cleaned, washed, and disinfected before the experiment started. Animals were vaccinated against common contagious diseases, and they were administered orally Albendazole (2.5 %, Royan, Iran). Diets were fed twice daily *ad libitum* (07.30 a.m. and 5.30 p.m.), and animals had free access to fresh and clean water. The amount of 10 g of PEG was fed to the kids daily through drinking water. The amount of 10 g AS was also added daily to the TMR diets as mixed with the diet. The residual feed was collected daily before the morning meal, and the daily feed intake was calculated. The residual and offered feed samples were dried in an oven at 65 °C for 48 h and kept in nylon bags for the subsequent analysis. Animals were weighed before the morning feeding at the beginning of the experiment and weighing was repeated every 15 days. After that, the recorded weights were employed to determine the final BW changes. The total fecal of each kid was gathered into the leather bags in the days of 80–90 of the experiment. Before fecal collection, the animals were adapted to the bags for two consecutive days. The leather bags were discharged twice a day entirely.

Table 1
Ingredients and chemical compositions of experimental diets fed to fattening male goat kids.

Item	Treatments			
	Control	PW	PW + PEG	PW + AS
Ingredients (g/kg DM)				
Alfalfa hay	309	68.5	68.5	68.5
Barley straw	72.5	64.5	64.5	64.5
Corn silage	136	88	88	88
Corn grain, ground	218	121	121	121
Barley grain, ground	218	121	121	121
Canola meal	16.5	107	107	107
PW	0.00	400	400	400
Salt	10	10	10	10
Vitamin-mineral premix[a]	10	10	10	10
Calcium carbonate	10	10	10	10
Chemical composition (g/kg DM)				
Dry matter (g/kg of fresh sample)	730	740	740	740
Crude protein	144	144	144	144
Neutral detergent fiber	317	300	300	300
Non-fiber carbohydrates	444	436	436	436
Ether extract	35	40	40	40
Metabolizable energy (Mcal/kg DM)	2.49	2.49	2.49	2.49
Calcium	7.0	6.5	6.5	6.5
Phosphorus	3.0	3.5	3.5	3.5
Total phenols	0.0	37	37	37
Total tannins	0.0	20	20	20

Control: basal diet without pistachio wastes; PW: diets containing 40 % pistachio wastes; PW + PEG: diets containing 40 % pistachio wastes + 10 g polyethylene glycol; PW + AS: diets containing 40 % pistachio wastes + 10 g aluminum silicates; PW: pistachio wastes.

[a] Per kg of premix (DM basis) containing 330,000 IU of vitamin A, 60,000 IU of vitamin D, 1000 IU of vitamin E, 160 g Calcium, 85 g phosphorus, 2100 mg zinc, 1500 mg manganese, 63 g sodium, 45 g magnesium, 535 mg copper, 45 mg iodine, and 12 mg selenium.

The collected feces samples for each animal (days 80–90) were mixed completely, and a sub-sample was moved into a freezer at − 20 °C for the subsequent analysis. The DMI and residual were regularly recorded for the determination of final nutrient digestibility. The feces samples were dried in a forced-air oven at 65 °C for 48 h until the weight was fixed, and they ground to pass through a 1-mm screen and finally preserved for the subsequent analysis. The analytical procedures were done according to those described in the laboratory procedures section. Feed conversion ratio was calculated as the proportion of daily feed intake to average daily gain (ADG).

The rumen fluid was collected 3 h post morning meal *via* an esophagus pipe connected to a vacuum pump in the 88–90th days of the experiment and then strained through four layers of silky cloth. The pH of the rumen liquor was measured using a pH meter (Hanna, Model HI 2210-01, USA), and then the rumen fluid residuals were pretreated (Getachew et al., 2004) and preserved at − 18 °C for NH_3–N and volatile fatty acids (VFA) measurement. The concentration of ruminal NH_3–N was determined by the Kjeldahl protocol (Komolong et al., 2001). The concentration of VFA was determined by gas chromatography equipped (YL6100 GC; Young Lin Instrument, Anyang, South Korea) with a 50-m silica-fused (0.32 mm ID) column (CP-Wax Chrompack Capillary Column, Varian, Palo Alto, CA, USA). In each run, the crotonic acid (trans-2-butenoic acid) as an internal standard and helium as carrier gas were applied. The temperatures of the detector and injector were both adjusted at 250 °C. The initial and final temperatures of the oven were 55 °C and 195 °C, respectively (Kazemi and Ghasemi Bezdi, 2021). Individual blood samples were taken 2 h after the morning feeding at the 88th and 90th of the experimental day, from the jugular vein into heparin-containing tubes, then centrifuged at 3000 × *g* for 15 min and stored in a freezer at − 18 °C for further analysis. All plasma metabolites including glucose, triglyceride, cholesterol, blood urea nitrogen (BUN), albumin, total protein, aspartate aminotransferase, and alanine aminotransferase were analyzed by the commercial kits (BioSystems, Spain) using an automatic biochemistry analyzer (A15, Biosystems, Spain). The hematology parameters including hemoglobin (Hb), packed cell volume, red blood cells, mean corpuscular hemoglobin, mean corpuscular volume, Mean corpuscular hemoglobin concentration, and white blood cells (WBC) were measured using an automated hematology analyzer (CellTac a, MEK-6450, Nihon Kohden, Japan). The total antioxidant capacity (TAC) was determined using a colorimetric antioxidant assay kit (Cayman Chemical Company, USA), at the absorbance of 405 nm with a microplate reader according to the manufacturer's protocol (Item no. 709001). The concentration of malondialdehyde (MDA) was measured as thiobarbituric acid-reactive substances according to Placer et al. (1996).

2.5. Calculations and statistical analysis

Metabolizable energy [ME (MJ/kg DM): 1.06 + 0.157 × Gas 24 h + 0.0084 × CP + 0.022 × EE – 0.0081 × Ash] and net energy for lactation [NEl (MJ/kg DM): − 0.36 + 0.1149 × Gas 24 h + 0.0054 × CP + 0.0139 × EE – 0.0054 × Ash] were calculated according to the equations proposed by Menke and Steingass (1988). In the above equations, gas 24 h, CP, and EE were 24 h cumulative gas production, crude protein, and ether extract, respectively. The data for *in vitro* gas production were fitted to the equation of Ørskov and McDonald (1979): $[Y = b(1 - e^{-ct})]$ where: Y is the gas production at time t, c is the fractional rate of gas production (c_{gas}, %/h), and b is the potential of gas production (b_{gas}, mL/200 mg DM). The data of *in vivo* and *in vitro* were analyzed in a completely randomized design using the GLM procedure of SAS (2002) with the following model: $Y_{ij} = \mu + T_i + e_{ij}$, where Y_{ij} is the value of each observation, μ the overall mean, T_i the treatment effect and e_{ij} the experimental error. The data relating to the *in vitro* and *in vivo* sections were replicated five and ten times, respectively. The Duncan's test was employed for means comparison.

3. Results

3.1. Chemical composition and in vitro fermentation

A different range of chemical composition was observed among PW derivatives. Hard shell exhibited the highest ($P < 0.001$) DM (755 g/kg fresh weight), NDF (875 g/kg DM), and ADF (504 g/kg DM) contents. The highest and lowest ($P < 0.001$) concentration of CP were related to kernel (12 g/kg DM), and hard shell (210 g), respectively. Ash content differed ($P < 0.001$) from 16.4 g/kg DM in the hard shell to 122 g/kg DM in the soft hull. The highest ($P < 0.001$) contents of EE (472 g/kg DM) and NFC (485 g/kg DM) were in the kernel and soft hull, respectively. The leaves had the greatest ($P < 0.001$) contents of phenolic (154 g/kg DM) and tannin (89.3 g/kg DM) compounds (Table 2).

Regarding the mineral composition, the leaves available in PW had the highest ($P < 0.001$) concentrations of calcium (27 g/kg DM), magnesium (6.55 g/kg DM), and manganese (27.5 mg/kg DM). Soft hull had the highest ($P < 0.001$) potassium (40 g/kg DM) and sodium (2.26 g/kg DM) concentrations. The highest ($P < 0.001$) phosphorus (4.34 g/kg DM) and zinc (24.5 mg/kg DM) concentrations were observed in the kernel. The iron content differed from 214 mg/kg DM for the cluster to 561 mg for the hard shell (Table 3).

The 24 h ruminal pH was not affected by the treatments ($P > 0.05$). The highest ($P < 0.001$) TVFA, DMD, OMD (at 24 and 96 h), ME, NEl, b_{gas}, and cumulative gas production at 12, 24, 48, 72, 96, and 120 h of incubation were in the kernel *versus* other PW derivatives. Ruminal NH_3–N concentration differed ($P < 0.001$) from 13.1 mg/dL (in hard shell) to 16.2 mg (in leaves), while the soft hull had the highest ($P < 0.001$) c_{gas} compared to other derivatives (Table 4).

The pH and buffering capacity parameters of PW and its derivatives samples are presented in Table 5. The PW leaves had the highest ($P < 0.001$) pH, however, the concentrations of titratable alkalinity (661 mEq × 10^{-3}), titratable acidity (361 mEq × 10^{-3}), base-buffering capacity (155 mEq × 10^{-3}), acid-buffering capacity (459 mEq × 10^{-3}), and acid-base buffering capacity (614 mEq × 10^{-3}) were highest ($P < 0.001$) in the soft hull (Table 5).

3.2. In vivo experiment

Compared to the control group, dietary supplementation with 40 % PW to male kids decreased DMI ($P < 0.001$), final BW ($P = 0.05$), and ADG ($P = 0.002$). However, the dietary addition of PEG or AS enhanced DMI, final BW, and ADG *versus* 40 % PW diet. Nutrient digestibility of DM, OM, NDF, and CP decreased ($P < 0.001$) by the 40 % PW dietary inclusion *versus* other groups. The ruminal pH ($P < 0.001$), NH_3–N ($P < 0.001$), TVFA ($P < 0.001$), acetate ($P = 0.01$), and propionate ($P = 0.05$) were also decreased in kids fed on 40 % PW *versus* control. Dietary supplementation with PEG and/or AS, to the 40 % PW diet, improved all the previously mentioned parameters. Other individual ruminal VFA (butyrate, valerate, isovalerate, and acetate/propionate) concentrations were not affected by the treatments ($P > 0.05$, Table 6).

Regarding the plasma metabolites and hematology of fattening male goat kids, the concentrations of BUN ($P < 0.001$) and total protein ($P < 0.001$) decreased when some of the dietary ingredients were substituted with PW during 90 days of the experiment. However, dietary inclusion with 40 % PW to diets increased plasma TAC ($P = 0.004$) and decreased MDA ($P = 0.030$) *versus* other treatments (Table 7).

4. Discussion

4.1. Chemical-mineral compositions, buffering capacity, and in vitro fermentation

The content of dietary fiber is essential for maintaining rumen health and as a source of energy for ruminants. Changes in chemical composition may be related to different conditions of pistachio cultivation,

Table 2
Chemical compositions (g/kg DM) of whole PW and its derivatives.

Item	Derivatives						SEM	*P*-value
	Whole wastes	Leave	Cluster	Soft hull	Hard shell	Kernel		
DM	265^{e}	440^{d}	592^{b}	254^{e}	755^{a}	490^{c}	42.7	< 0.001
CP	109^{d}	126^{c}	149^{b}	98^{e}	12^{f}	210^{a}	14.5	< 0.001
Ash	92.3^{b}	81.8^{c}	56.5^{d}	122^{a}	16.4^{f}	27.5^{e}	8.9	< 0.001
NDF	273^{d}	307^{c}	350^{b}	204^{e}	875^{a}	92.3^{f}	60.4	< 0.001
ADF	188^{b}	175^{c}	193^{b}	139^{d}	504^{a}	66.7^{e}	33.5	< 0.001
EE	85.3^{b}	47.2^{c}	81.7^{b}	90.8^{b}	10.5^{d}	472^{a}	37.6	< 0.001
NFC	440^{b}	438^{b}	362^{c}	485^{a}	86.5^{e}	198^{d}	35.7	< 0.001
TP	92^{c}	154^{a}	104^{b}	99.3^{bc}	15.8^{d}	10.5^{d}	12.4	< 0.001
TT	49.0^{c}	89.3^{a}	53.5^{b}	49.3^{c}	5.93^{d}	2.00^{e}	7.26	< 0.001

Different letters along the same row are significantly different according to *P*-value indicated.
DM (g/kg of fresh weight): dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; EE: ether extract; NFC: non-fiber carbohydrates; TP: total phenols; TT: Total tannins; SEM = standard error of the mean.

Table 3
Mineral compositions of PW and its derivatives.

Item	Derivatives						SEM	*P*-value
	Whole wastes	Leaves	Cluster	Soft hull	Hard shell	Kernel		
Ca (g/kg DM)	4.28^{b}	27.0^{a}	2.90^{c}	2.34^{c}	0.49^{d}	3.05^{c}	2.23	< 0.001
P (g/kg DM)	1.77^{c}	1.37^{d}	1.02^{e}	2.13^{b}	0.082^{f}	4.34^{a}	0.32	< 0.001
Na (g/kg DM)	1.10^{bc}	1.38^{b}	1.22^{b}	2.26^{a}	0.92^{c}	0.079^{d}	0.16	< 0.001
Mg (g/kg DM)	3.81^{b}	6.55^{a}	1.86^{d}	0.40^{e}	3.81^{b}	3.08^{c}	0.46	< 0.001
K (g/kg DM)	27.8^{b}	7.91^{c}	9.88^{c}	40.0^{a}	1.92^{d}	9.95^{c}	3.25	< 0.001
Fe (mg/kg DM)	284^{b}	287^{b}	214^{b}	244^{b}	561^{a}	290^{b}	29.9	< 0.001
Mn (mg/kg DM)	10.8^{b}	27.5^{a}	7.65^{c}	7.06^{cd}	5.79^{d}	10.1^{b}	1.80	< 0.001
Zn (mg/kg DM)	7.07^{bc}	8.07^{bc}	9.11^{b}	5.94^{c}	9.35^{b}	24.5^{a}	1.55	< 0.001

Different letters along the same row are significantly different according to *P*-value indicated.
Ca: calcium; P: phosphorus; Na: sodium; Mg: magnesium; K: potassium; Fe: iron; Mn: Manganese; Zn: zinc; SEM = standard error of the mean.

Table 4
The digestive-fermentative and gas production parameters of PW and its derivatives following incubation in a culture medium.

Item	Derivatives						SEM	*P*-value
	Whole wastes	Leave	Cluster	Soft hull	Hard shell	Kernel		
pH 24 h	6.78	6.89	6.76	6.95	6.82	6.87	0.037	0.75
TVFA 24 h (mM)	65.9^{c}	67.5^{b}	61.1^{d}	64.9^{c}	59.3^{e}	74.5^{a}	1.20	< 0.001
NH_3–N (mg/dL)	15.4^{ab}	16.2^{a}	15.2^{ab}	14.3^{bc}	13.1^{c}	15.3^{ab}	0.28	0.011
DMD 24 h	474^{d}	538^{b}	420^{e}	498^{c}	129^{f}	671^{a}	40.1	< 0.001
OMD 24 h	491^{c}	554^{b}	446^{d}	515^{c}	143^{e}	691^{a}	40.4	< 0.001
DMD 96 h	587^{c}	625^{b}	531^{d}	608^{b}	194^{e}	790^{a}	43.7	< 0.001
OMD 96 h	627^{c}	660^{b}	566^{d}	642^{bc}	207^{e}	825^{a}	45.6	< 0.001
ME (MJ/kg DM)	6.96^{b}	6.78^{bc}	6.13^{d}	6.50^{cd}	3.21^{e}	19.2^{a}	1.24	< 0.001
NEl (MJ/kg DM)	3.74^{b}	3.67^{bc}	3.10^{d}	3.41^{c}	1.19^{e}	11.8^{a}	0.82	< 0.001
b_{gas}	42.6^{b}	47.4^{b}	29.0^{cd}	33.9^{c}	25.8^{d}	58.2^{a}	2.77	< 0.001
c_{gas}	0.040^{c}	0.038^{c}	0.040^{c}	0.067^{a}	0.029^{d}	0.051^{b}	0.0031	< 0.001
Gas 12 h	16.2^{b}	17.3^{b}	11.0^{c}	17.9^{b}	7.47^{d}	26.5^{a}	1.46	< 0.001
Gas 24 h	24.5^{bc}	27.3^{b}	15.8^{d}	22.9^{c}	12.4^{e}	39.9^{a}	2.16	< 0.001
Gas 48 h	35.1^{bc}	38.8^{b}	24.3^{d}	33.1^{c}	18.9^{e}	51.0^{a}	2.53	< 0.001
Gas 72 h	39.4^{b}	42.7^{b}	27.1^{d}	33.5^{c}	22.5^{d}	55.9^{a}	2.71	< 0.001
Gas 96 h	42.0^{b}	46.2^{b}	27.7^{d}	33.7^{c}	23.6^{d}	58.4^{a}	2.90	< 0.001
Gas 120 h	43.5^{c}	48.7^{b}	30.2^{e}	36.0^{d}	25.2^{f}	59.9^{a}	2.87	< 0.001

Different letters along the same row are significantly different according to *P*-value indicated.
TVFA: total volatile fatty acids; NH_3–N: ammonia nitrogen; DMD 24 and 96 h (g/kg DM): dry matter digestibility after 24 and 96 h incubation; OMD 24 and 96 h (g/kg DM): organic matter digestibility after 24 and 96 h incubation; ME: metabolizable energy; NEl: net energy for lactation; b_{gas} (mL/200 mg DM): potential gas production); c_{gas} (%/h): fractional rate of gas production; Gas 12, 24, 48, 72, 96, and 120 h (mL/200 mg DM): the cumulative gas production after 12, 24, 48, 72, 96, and 120 h. SEM = standard error of the mean.

different weather conditions and keeping procedures, and different pistachio cultivars. A high content of TT (49 g *versus* 73.2 g/kg DM) and TP (92 *versus* 109.2 g g/kg DM) for PW has been reported before by Moradi et al. (2015) and Shakeri et al. (2016). These results can be defined the PW as agricultural wastes naturally rich in polyphenols and tannins (Shakeri et al., 2016). The higher content of fiber (NDF and ADF) in the hard shell may be attributed to a very fibrous structure with a combination of amorphous and crystalline polymers that have been reported by Piness (2010). However, when pistachios are harvested, a large amount of PW with 70–75 % humidity is produced which accelerates its rapid spoilage in a short time (Shakeri et al., 2016). Moreover, a significant part of the PW is NFC, which averaged about 445, 485 and 412 g/kg DM in fresh, dry and silage PW samples, respectively. It also observed that the highest concentrations of tannin and phenolic compounds were in pistachio leaves, which help and give the plant a defense system against pathogenic agents and pests (Latif et al., 2020; Tlak

Table 5
The pH of samples and buffering capacity parameters (mEq × 10^{-3}) of PW and its derivatives.

Item	Derivatives						SEM	*P*-value
	Whole wastes	Leaves	Cluster	Soft hull	Hard shell	Kernel		
pH	4.69^{c}	4.97^{a}	4.89^{b}	4.73^{c}	4.72^{c}	4.72^{c}	0.02	< 0.001
Titratable alkalinity	613^{b}	426^{e}	527^{c}	661^{a}	58.0^{f}	530^{d}	48.8	< 0.001
Titratable acidity	222^{b}	101^{d}	123^{c}	361^{a}	15^{e}	240^{b}	27.1	0.011
Base-buffering capacity	142^{b}	106^{d}	139^{b}	155^{a}	13.5^{e}	124^{c}	11.5	< 0.001
Acid-buffering capacity	305^{c}	105^{e}	138^{d}	459^{a}	21.2^{f}	332^{b}	36.5	< 0.001
Acid-base buffering capacity	447^{b}	211d	277^{c}	614^{a}	34.7^{e}	456^{b}	45.8	< 0.001

Different letters along the same row are significantly different according to *P*-value indicated.
SEM = standard error of the mean.

Table 6
The effect of experimental diets on DMI, growth performance, nutrient digestibility, and ruminal fermentation parameters of fattening male goat kids.

Items	Treatments				SEM	*P*-value
	Control	PW	PW + PEG	PW + AS		
DMI (kg/day)	1.22^{a}	1.00^{b}	1.14^{a}	1.21^{a}	0.020	< 0.001
Final BW (kg)	32.4^{a}	30.1^{b}	31.9^{ab}	32.3^{a}	0.35	0.05
ADG (g/day)	121^{a}	100^{b}	116^{a}	118^{a}	2.05	0.002
FCR	10.2	10.1	9.97	10.35	0.25	0.97
Nutrient digestibility (g/kg DM)						
Dry matter	682^{a}	650^{c}	669^{b}	674^{ab}	2.57	< 0.001
Organic matter	711^{a}	682^{b}	700^{a}	707^{a}	2.68	< 0.001
Crude protein	633^{a}	600^{c}	621^{b}	632^{a}	2.82	< 0.001
Neutral detergent fiber	466^{a}	404^{b}	464^{a}	461^{a}	4.73	< 0.001
Ruminal fermentation parameters						
pH	6.47^{a}	6.40^{b}	6.48^{a}	6.50^{a}	0.0077	< 0.001
NH_3–N (mg/dL)	18.2^{a}	16.0^{b}	17.5^{a}	13.7^{c}	0.32	< 0.001
TVFA (mM)	86.7^{a}	84.3^{b}	87.8^{a}	87.6^{a}	0.31	< 0.001
Individual VFA (mol/100 mol)						
Acetate	62.6^{a}	61.1^{b}	62.9^{a}	63.0^{a}	0.23	0.01
Propionate	21.7^{a}	20.4^{b}	20.5^{ab}	20.9^{ab}	0.21	0.05
Butyrate	14.0	14.9	14.6	14.1	0.15	0.15
Valerate	1.37	1.50	1.46	1.42	0.023	0.20
Isovalerate	0.34	0.46	0.41	0.39	0.020	0.25
Acetate/ Propionate	2.89	2.99	3.08	3.04	0.034	0.24

Different letters along the same row are significantly different according to *P*-value indicated.
Control: basal diet without pistachio wastes; PW: diets containing 40 % pistachio wastes; PW + PEG: diets containing 40 % pistachio wastes+ 10 g polyethylene glycol; PW + AS: diets containing 40 % pistachio wastes + 10 g aluminum silicates.
DMI: dry matter intake; BW: body weight; ADG: average daily gain; FCR: feed conversion ratio; NH_3–N: ammonia nitrogen; TVFA: total volatile fatty acids; SEM = standard error of the mean.

Table 7
Plasma metabolites and hematology of fattening male goat kids fed on different experimental diets.

Items	Treatments				SEM	*P*-value
	Control	PW	PW + PEG	PW + AS		
Plasma metabolites (mg/dL)						
Glucose	68.3	66.8	67.9	67.7	0.27	0.25
Triglyceride	39.2	38.3	38.6	38.5	0.17	0.30
Cholesterol	70.3	70.8	70.0	69.9	0.28	0.71
BUN	19.5^{a}	15.8^{b}	19.0^{a}	19.3^{a}	0.32	< 0.001
Albumin (g/dL)	2.97	2.88	2.94	3.01	0.024	0.31
Total protein (g/dL)	6.87^{a}	6.43^{b}	6.96^{a}	6.93^{a}	0.045	< 0.001
AST (U/L)	53.8	57.3	55.6	55.5	0.58	0.21
ALT (U/L)	34.1	35.9	33.7	33.6	0.40	0.15
MDA (nmol/mL)	2.80^{a}	2.20^{b}	2.75^{a}	2.65^{a}	0.082	0.030
TAC (mmol/L)	0.56^{b}	0.71^{a}	0.66^{a}	0.68^{a}	0.015	0.004
Hematology parameters						
Hb (g/dL)	9.76	9.46	9.78	9.65	0.053	0.13
PCV (%)	30.2	28.7	29.6	29.7	0.27	0.33
RBC (× 10^6/μL)	7.52	7.19	7.41	7.40	0.054	0.18
MCH (pg)	13.0	13.2	13.2	13.1	0.12	0.95
MCV (fL)	40.2	40.0	40.0	40.2	0.41	0.97
MCHC (g/dL)	32.5	33.0	33.1	32.6	0.35	0.91
WBC (× 10^3/μL)	9.58	9.93	9.82	9.87	0.28	0.066

Different letters along the same row are significantly different according to *P*-value indicated.
Control: basal diet without pistachio wastes; PW: diets containing 40 % pistachio wastes; PW + PEG: diets containing 40 % pistachio wastes + 10 g polyethylene glycol; PW + AS: diets containing 40 % pistachio wastes + 10 g aluminum silicates.
BUN = blood urea nitrogen; AST = aspartate aminotransferase; ALT = alanine aminotransferase; MDA: Malondialdehyde; TAC = total antioxidant capacity, Hb = hemoglobin; PCV: packed cell volume; RBC = red blood cell; MCH = mean corpuscular hemoglobin; MCV = mean corpuscular volume; MCHC: Mean corpuscular hemoglobin concentration; WBC = white blood cell; SEM = standard error of the mean.

Gajger and Dar, 2021). Bohluli et al. (2010) found that the most dominant component among the various derivatives of PW is in the soft hull. Soft hull as the dominant derivative of PW is quantitatively and qualitatively more important in analyzing the chemical composition of the whole wastes. The kernels constitute only 1.33 % of total PW and due to their high percentage of fat and protein, (Bohluli et al., 2010) generally increase the nutritional value of PW.

Minerals are essential for the normal functioning of most metabolic processes in ruminants. Deficiencies of major and trace minerals can result in substantial economic losses in animal productivity and health. Considering the minerals in PW, it seems that they can provide a large part of the mineral requirements of goats. Following the determination of nitrogen and mineral contents in the kernels of 20 pistachio genotypes (Tayefeh Aliakbarkhani et al., 2017), were ranged as follows: manganese (5.73–17.33 mg/kg), iron (17–62.4 mg/kg), zinc (6.76–30.3 mg/kg), sodium (0.06–0.13 %), potassium (0.68–1.35 %), phosphorus (0.42–0.73 %), nitrogen (2.6–4.29 %), magnesium (0.11–0.17 %) and calcium (0.23–0.47 %), which some of mineral values were within the current composition of PW kernel. It has been also reported that the energy and calcium contents of soft shells available in PW are between straw and alfalfa, but still, it is closer to alfalfa in terms of cell wall and phosphorus contents (Mahdavi et al., 2008).

A higher *in vitro* fermentability for PW kernel in TVFA, b_{gas}, DMD, and OMD, which some of this increase can be attributed to the lower content of NDF and ADF compared to other ingredients. The DMD of PW has been reported on average at about 520–565 g/kg DM (Shakeri et al., 2016), which is consistent with current results. The results showed that

the digestibility of PW is entirely dependent on its derivatives, and the interpretation of the digestibility of PW should be based on the characteristics of its derivatives. The lower 24 h DMD (129 *versus* 221 g/kg DM) has been observed in hard shell (Shakeri et al., 2016), and also a much lower in 96 h gas production (33.7 *versus* 12.5 mL/200 mg DM) was reported by Bohluli et al. (2010) compared to the result of the present study. A lower ME (5.86 MJ/kg DM *versus* 6.50 MJ) has been reported for soft hull compared to the current results (Bakhshizadeh et al., 2014). A relatively similar amount of 96 h gas production (33.7 mL/200 mg DM *versus* 35.7 mL) has been reported for soft hull (Bakhshizadeh et al., 2014). Bagheripour et al. (2008) reported that 24 h gas production of PW was about 35 mL/g OM which was lower than the value reported for PW in this study (24.5 mL/200 mg DM). The lower NH_3–N in the hard shell can be attributed to the lower CP content. Except for hard shell (12 g/kg DM), the CP content of other derivatives of PW was more than 80 g/kg DM (range: 98–210 g/kg DM), which was based on Norton's (1998) report, should provide ruminal NH_3–N levels above the minimum required by ruminal microbes to support optimum growth rate.

The buffering capacity of feedstuffs had a crucial role in balancing the ruminal pH. Introducing a forage with a preferred buffering capacity may increase the nutrient's digestibility in the digestive tract, improve digestive tract health, and ultimately increase animal performance. Different buffering capacities among the PW derivatives can be attributed to their different chemical compositions. The initial pH and titratable acidity of feedstuffs are the most critical determinants of ruminal pH (Kazemi and Valizadeh, 2023). It was observed the highest titratable acidity in the soft hull (361 mEq $\times 10^{-3}$), indicating high resistance to acidification. Higher acid-base buffering capacity (614 mEq $\times 10^{-3}$) in soft hull supports a suitable material for balancing the ruminal pH after ingesting.

4.2. *In vivo experiment*

It is generally believed that feeding with more than 50 g/kg of tannin reduces DMI, and when the concentration is lower, it seems to have no such effect (Waghorn et al., 1994; Salem et al., 2013). Decrease of DMI in 40 % PW diets can be attributed to the astringent property of PW and due to their high tannin contents, which was also reported by Muller--Harvey and McAllan (1992). Contrary to these results, diets containing 10 % dried PW or 14 % ensiled PW increased feed intake in Afshari male lambs (Mahdavi et al., 2008) and Kermani sheep (Hajalizadeh et al., 2014), respectively. Increased DMI in PW + PEG and PW + AS can be attributed to the high affinity of PEG (Salem et al., 2006; Shakeri et al., 2016) or AS (Kordi et al., 2022) with tannins, which neutralizes the adverse effects of high tannin levels in the PW diet. Addition of PEG to diets containing 32 % PW prevented the reduction of protein digestibility in Saanen dairy goats (Sedighi-Vesagh et al., 2015). It was also observed that a decrease in nutrient digestibility following the supplementation of diets with 40 % PW. In this regard, it has been reported that tannins react with salivary mucoproteins and cause contraction of tongue sensory receptors (McLeod, 1974). Tannins adversely affect the digestion of nutrients, and by filling the rumen due to the reduction of digestibility, they subsequently reduce feed intake (Makkar et al., 1995a, 1995b; Kamel et al., 2019). Contrary to the present study, the results of most studies have shown that the use of PW up to 15 % of the diet does not affect the digestibility of nutrients (Vahmani et al., 2006; Shakeri et al., 2016). However, dietary inclusion of PW silage at the level of 18 % in beef cattle, decreased the CP, NDF, and ADF digestibility (Shakeri et al., 2014). When 32 % of PW was fed to dairy goats, only CP digestibility was decreased, and this decrease was compensated by adding PEG to the diet (Sedighi-Vesagh et al., 2015). It also observed a positive effect of PEG and/or AS following the dietary addition in kids with an increase in nutrient digestibility compared to a 40 % PW diet. Furthermore, tannins affect animal performance through several procedures, including the constitution of strong complexes with feed ingredients, such as proteins and minerals (Chung et al., 1998; Salem et al., 2013), loss of endogenous proteins (Mansoori and Acamovic, 2007), and inactivation of digestive enzymes, thus interfering with nutrient digestibility (Chung et al., 1998, Mandal and Ghosh, 2010). The increase in nutrient digestibility of diets containing PW following the addition of AS can probably be attributed to the adsorption and neutralization effects of tannins by AS. It has been reported that the addition of sodium bentonite (as an AS) can be accounted as an appropriate replacement for PEG as a tannin-deactivation material in diets containing 30 % PW in Saanen dairy goats feeding (Kordi et al., 2022). Zimmer and Cordesse (1996) observed a decreased DM, OM, and NDF digestibility following supplementing diets with hydrolyzable tannins. Digestibility of CP, DM, OM, and NDF were increased with dietary inclusion of 40 PW, and this improvement is similar to the report of Bagheripour et al. (2008), who showed that tannins decreased the OMD of pistachio hull, while the addition of PEG improved *in vitro* OMD. In contrast to the present findings, Ghasemi et al. (2012) reported an increase in CP, EE, and OM digestibility of diets containing 50 % PW. In the present study, lower CP digestibility in goats fed PW may have resulted from lower nitrogen intake and nitrogen balance.

The decrease of NH_3–N in diets containing 40 % PW with or without AS may be due to the nitrogen compounds of the feedstuffs being degraded by microbial proteases in the rumen, and finally ammonia is produced. In the presence of tannins, hydrophobic hydrogen bonds are formed between the phenolic groups of tannin and proteins and reduce the ruminal breakdown of proteins (McNabb et al., 1996), which can be a reason for the reduction of nitrogen in diets containing 40 % of PW. It has also been reported that sodium bentonite, due to its high affinity, can reduce the ruminal NH_3–N and improve the passage of feed and microbial protein to the small intestine (Abdl-Rahman., 2010). The reduced NH_3–N in diets containing AS can be attributed to the absorption properties of AS. Tannin can change the microbial population of the rumen, nutrient digestibility, the profile of VFA, ruminal NH_3–N concentration, methane production, and finally, alter animal performance and feed efficiency (Krueger et al., 2010; Shakeri et al., 2016). A reduction of TVFA concentration in the present study might be related to lower ruminal microbial activity in the presence of tannins (Bhatta et al., 2009; Ghasemi et al., 2012). Silanikove et al. (1996) reported a reduction in VFA yield when different forms of tannin were added to diets in the *in vivo* and *in vitro* conditions. The ruminal pH of kids was also affected by the dietary inclusion of 40 % PW, which can be attributed to different produced TVFA between treatments. Contrary to the present finding, West et al. (1993) reported that ruminal pH remained unchanged by increasing tannin concentration from 1.72 to 6.20 (% DM) in cows fed on a peanut skins-based diet. Beauchemin et al. (2007) reported a decrease of ruminal TVFA and NH_3–N in calves with increasing dietary tannin concentration (0–1.8 %, Quebracho condensed tannin). As seen in the current study, the decrease in NDF digestibility resulted in a reduction in the production of VFA, and it is also reported that the lower rate of carbohydrate digestion can decrease ruminal TVFA content (Patra et al., 2006; Beauchemin et al., 2007).

Nevertheless, polyphenols were considered as anti-nutritional compounds, and with their intake, liver necrosis, and methemoglobinemia have been reported (Shakeri et al., 2016). In addition, when their concentration in the bloodstream exceeds the detoxification capacity of the liver, the toxic effects resulting from the absorption of their by-products appear (Makkar, 2003a). Recently, these substances have been known as active molecules with antioxidant, anti-inflammatory, and anti-mutation properties (Patra and Saxena, 2011); moreover, long-term feeding of animals with some plants containing phenolic compounds can harm their health (Adedapo et al., 2005; Salem et al., 2012; Kamel et al., 2018).

Except for the significant effect of dietary inclusion of 40 % PW on plasma TAC, MDA, BUN, and total protein, it was not observed changes in the normal levels of plasma and hematology parameters. The adverse effects, of dietary replacement of some ingredients with PW in ruminant

animals, on blood metabolites and hematology parameters have not been reported (Ghasemi et al., 2012; Ghaffari et al., 2014b; Shakeri et al., 2016). In the same context, a decrease in plasma total protein content of lambs fed on 15 and or 30 % PW has been reported by Rahimi et al. (2013). Several studies showed a decrease in plasma total protein content by adding tannin to the diet (Mousa, 2011; Vasta et al., 2009). The formation of a complex between tannin and protein decreases the accessibility of ruminal microorganisms to protein, and sometimes, this complex remains stable even after the passaging the rumen and prevents the digestibility and absorption of the protein into the bloodstream (Mousa, 2011). The dietary inclusion of 32 % PW (DM basis) in Saanen dairy goats did not affect some hematological parameters such as hematocrit, Hb, and WBC count (Sedighi-Vesagh et al., 2015). Valizadeh et al. (2010) found that dietary inclusion with 30 % of PW in Baluchi lambs does not affect the hematocrit, the number of WBC, neutrophils, lymphocytes, and monocytes. Despite some minor differences in some reports for blood parameters, there is no concern about the adverse effect of using PW on blood metabolism, hematopoietic tissue activity, and liver enzymes. Emami et al. (2015), Ghavipanje et al. (2016), and Kazemi and Valizadeh (2021) have reported that polyphenol-tannin-rich agricultural wastes can alter TAC and or MDA in favor of animal health.

5. Conclusion

In terms of nutritional value (lower NDF and ADF, and higher in phosphorus, zinc, b_{gas}, TVFA, DMD, and OMD), the kernel was superior rather than other PW derivatives, while the hard shell showed the lowest nutritional merits for ruminant feed. Except for TAC and MDA, dietary supplementation of male kids with 40 % PW adversely affected DMI, growth performance, nutrient digestibility, and ruminal VFA. The dietary addition of 10 g of AS or PEG had beneficial aspects in mitigating the adverse effects on the above parameters. The *in vivo* fermentation results also showed that up to 40 % of PW can be used in the diet of Mahabadi goats, provided that AS or PEG are supplemented at the amount of 10 g/day. Considering that the dietary inclusion of PW up to 40 % of DM revealed antioxidant activity, it is recommended to use a lower and normal level of PW in kids' diets to represent both beneficial effects on animal health and growth performance.

CRediT authorship contribution statement

mohsen kazemi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Abdelfattah Zeidan Mohamed Salem:** Writing – review & editing, Writing – original draft, Validation, Project administration. **Reza Valizadeh:** Writing – review & editing, Project administration, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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