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Comparison between pelleted and unpelleted feed forms on the performance and digestion of small ruminants: a meta-analysis

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ABSTRACT. The present meta-analysis aimed to evaluate the effect of pelleted feeding on the growth and performance of small ruminants using a meta-analysis. The database was developed based on 29 studies containing 54 experiments. The data were analysed using the OpenMEE software, considering differences in pelleted feeding as fixed effects and individual studies as random effects. The results showed that the pelleted feed form enhanced dry matter intake ($P < 0.05$) and increased average daily gain of small ruminants ($P < 0.05$) as compared to the unpelleted form. Digestion of dry matter, organic matter and fiber was significantly lower for the pellet feed form ($P < 0.05$). In conclusion, pelleted feed can improve production performance of small ruminants, but it reduces nutrient digestibility.

Introduction

Animal feeds are composed of foods grown or developed for livestock and poultry. They are produced by precise selection and blending of ingredients to provide adequate nutrition that maintains animal health and improves the quality of final products such as milk, meat and eggs. Feed resources, processing and nutrition technology are the key components for organic and efficient ruminant feed production, mainly in the tropics. The diversity and distribution of roughage affect the performance of livestock. Feed processing technology is considered vital because it is related to the ease of feeding livestock transported to the islands. However, the lack of knowledge of farmers regarding efficient and inexpensive feed processing technologies can affect performance and increase stress in animals transported to the islands. Breeding cattle with standard immune systems in the tropics face more significant constraints than in sub-tropical or temperate climates, such as lower growth performance, low carcass quality and high mortality rates due to higher temperatures and humidity that increase heat stress responses (Tirawattanawanich et al., 2011; Awad et al., 2020; He et al., 2020). The lack of mobile pellet pressing, high processing costs and limited improvements regarding power feeders prevented interest in pellet feed. Recognition of the technology pelletisation benefit and the advantages for poultry and pig as a feeder is increasing interest. Currently, claims such as alfalfa pellets for increasing microbial biomass (Ishaq et al., 2019). Pelleting reduces the amount of material and shipping costs

(Adesogan et al., 2019). In addition, the application of pelletised concentrates is also common in ruminant production systems, such as the dairy industry (Shrinivasa and Mathur, 2020). Moreover, supplements used during winter outdoor feeding of sheep and cows are commonly pelletised to reduce environmental losses. However, complete feed pelletisation is not yet common in most ruminant production systems.

Economic mobility and increasing demand for livestock commodities have made transportation of livestock between islands, land, sea and air unavoidable. The negative effects of transporting livestock include, among others, stress and weight loss (Trisiana et al., 2021). Therefore, a feed processing technology is needed that could facilitate feeding during transport and meet livestock needs. Provision of feed supplements is also needed for livestock during the transport to the islands, e.g. in the form of wafers or feed biscuits (Retnani et al., 2014a; b). Pellet production, on the other hand, is one alternative feed production technology to address the problem of livestock transported to the islands. Pelleted feed has been reported to facilitate livestock transportation process between regions/islands without inducing unnecessary stress. The advantages of pelleted feeding include increased feed intake, reduced scattered feed, labour efficiency, prevention of sorting feed ingredients by animals, and decreased bulk density, especially in forage feeds (Abdollahi et al., 2013). Blending roughage and concentrates in a complete feed improve nutrient use efficiency and reduce feed losses, its cost, and labour expenses. A pelleted total mixed ration (TMR) is expected to have advantages over an unpelleted TMR, particularly in feeding systems where dietary ingredients are not mixed prior to feeding, but are offered separately. Due to the elimination of feed sorting and thorough mixing before pelleting (Malik et al., 2021), nutrient intake is more uniform in case of pelleted feed (Lailer et al., 2005). This stabilizes the rumen environment and consequently reduces the risk of acute and subacute rumen acidosis. However, reduction of physical fiber effectiveness due to pelleting may interfere with pH stabilization in the rumen.

In addition, pelleted feed exert positive effects on ruminants, including higher body weight and carcass weight compared to unpelleted feeds (Li et al., 2021). However, pellets have also been reported to cause some adverse effects on ruminants when administered continuously, including increasing rumen pH, resulting in acidosis. Although several experiments have been carried out on the effect of pelleted feed in ruminants, no meta-analysis study has attempted to quantitatively summarize such a relationship. A meta-analysis is a statistical technique that aggregates the results of scientific reports. Meta-analysis able to calculate effect size that is concerned with different studies and then combines all the studies into single analysis (St-Pierre, 2001; Sauvant et al., 2008). Therefore, the aim of this work was to evaluate the effect of pelleted feeding on production performance and nutrient digestibility of small ruminants by using the meta-analysis method.

Material and methods

Search strategy, inclusion criteria and data extraction

A comprehensive search of the literature published in English was conducted to identify experiments involving small ruminant diets in either unpelleted or pelleted form of both mix ration and forage feeds. The literature search was carried out using the Scopus (https://www.scopus.com/) and PubMed (https://pubmed.ncbi.nlm.nih.gov/) databases. The search was conducted between November and December of 2021 using terms with a set of the following key words in all searches: “pelleted”, “pelleting”, “feed”, “diet”, “fed”, “goat”, “sheep” and “lamb”.

These initial searches resulted in 1295 potential references. Subsequently, the following criteria were used for literature selection: (1) published in English as full-text articles, (2) published in peer-reviewed journals, (3) direct comparison between pelleted and unpelleted forms, (4) small ruminant feeds, including total mix ration and grass/forages, and (5) comparison of average daily gain, daily dry matter intake and digestibility, including dry matter, organic matter, crude protein, neutral detergent fiber and acid detergent fiber nutrients.

After the preliminary title screening, 1161 references were eliminated because their topic was not relevant to our research. After reviewing the abstracts, 134 documents were assessed and 14 duplicates were found. Subsequently, 91 articles were eliminated due to a lack of comparison of interest (42 documents), irrelevant parameters (26 documents), insufficient data for statistical meta-analysis (6 articles) and not meeting any inclusion criteria (17 documents). Ultimately, the screening yielded 29 articles for use in subsequent data coding and statistical data analysis. Details of the selection process are presented in the PRISMA-P flowchart in Figure 1, and studies included in this meta-analysis are listed in Table 1.

Table 1. Studies selected for meta-analysis

No.	Study	Initial body weight, kg	Starting age	Ended age	Phase	Animal	Grain source and level	Hay level	Unpelleted form	TMR/ Grass
1	Li et al. (2021)	5.04 ± 0.75	8 days pre weaning	35 days	Starter	Lamb	65% maize, 5% wheat bran	5%	Textured	TMR
2	Li et al. (2021)	5.04 ± 0.75	35 days post weaning	46 days	Starter	Lamb	65% maize, 5% wheat bran	5%	Textured	TMR
3	Karimizadeh et al. (2017)	26 ± 2.5	6 ± 1.5 months	6,5 ± 1.5 months	Finisher	Lamb	19% maize, 20 barley, 16 white bran	0% hay	Mash	TMR
4	Karimizadeh et al. (2017)	26 ± 2.5	6 ± 1.5 months	7 ± 1.5 months	Finisher	Lamb	19% maize, 20 barley, 16 white bran	0% hay	Mash	TMR
5	Karimizadeh et al. (2017)	26 ± 2.5	6 ± 1.5 months	7.5 ± 1.5 months	Finisher	Lamb	19% maize, 20 barley, 16 white bran	0% hay	Mash	TMR
6	Karimizadeh et al. (2017)	26 ± 2.5	6 ± 1.5 months	7.5 ± 1.5 months	Finisher	Lamb	19% maize, 20 barley, 16 white bran	0% hay	Mash	TMR
7	Coufal-Majewski et al. (2017)	24.6 ± 1.08	NA	duration 84 days	Grower	Lamb	53.9% barley grain, 30% alfalfa pellets, 16.8 canola meal, 1% canola oil	No alkaloid added	Mash	TMR
8	Coufal-Majewski et al. (2017)	24.6 ± 1.08	NA	duration 84 days	Grower	Lamb	53.8% barley grain, 30% alfalfa pellets, 16.8 canola meal, 1% canola oil	Low level alkaloid added	Mash	TMR
9	Coufal-Majewski et al. (2017)	24.6 ± 1.08	NA	duration 84 days	Grower	Lamb	53.6% barley grain, 30% alfalfa pellets, 16.8 canola meal, 1% canola oil	High level alkoloid added	Mash	TMR
10	Zhong et al. (2018)	23.3 ± 3.2	105 ± 8.3 days	175 ± 8.3 days	Finisher	Lamb	31% maize, 9% maize germ meal, 8% maize bran. 15% peanut shell, 14% barley malt roots	0% hay	Mash	TMR
11	Zhang et al. (2019)	34.9 ± 0.5	120 days	162 days	Finisher	Lamb	24% maize, 30% peanut vine, 13% Leymus, 15% SBM, 16.4% wheat bran	0% hay	Mash	TMR
12	Raju et al. (2021)	14.50 ± 0.41	3.5 ± 0.5 months	6.5 ± 0.5 months	Finisher	Sheep	50% sorghum stover, 10% maize, 8% cotton seed, 4% ground nut cake	0% hay	Mash	TMR
13	Raju et al. (2021)	14.50 ± 0.41	3.5 ± 0.5 months	6.5 ± 0.5 months	Finisher	Sheep	50% sorghum stover, 10% maize, 8% cotton seed, 4% ground nut cake	0% hay	Textured	TMR
14	Gipson et al. (2007)	31.9 ± 0.47	5 months	Duration 12 weeks	Finisher	Goat	Dehydrated alfalfa hay	Plus alfalfa hay	Loose	Grass
15	Gipson et al. (2007)	31.9 ± 0.47	5 months	Duration 12 weeks	Finisher	Goat	Dehydrated alfalfa hay	Plus alfalfa hay	Loose	Grass
16	Gipson et al. (2007)	31.9 ± 0.47	5 months	Duration 12 weeks	Finisher	Goat	Maize meal, ground oats, dehydrated alfalfa meal, cottonseed meal, maize chops, dehulled soybean meal, sunflower meal, fish meal, cane molasses, ammonium chloride, yeast culture, hemicellulose extract, processed grain by-product, roughage products, and others such as mineral and vitamin sources	0% alfalfa	Loose	TMR

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Table 1. continued

No.	Study	Initial body weight, kg	Starting age	Ended age	Phase	Animal	Grain source and level	Hay level	Unpelleted form	TMR/ Grass
17	Gipson et al. (2007)	31.9 ± 0.47	5 months	Duration 12 weeks	Finisher	Goat	Maize meal, ground oats, dehydrated alfalfa meal, cottonseed meal, maize chops, dehulled soybean meal, sunflower meal, fish meal, cane molasses, ammonium chloride, yeast culture, hemicellulose extract, processed grain by-product, roughage products, and others such as mineral and vitamin sources	0% alfalfa	Loose	TMR
18	Amaral et al. (2005)	3.4	15 days	45 days	Starter	Goat	Maize hay (40.0%), ground maize (29.3%), soybean meal (21.8%), molasses (4.8%), soybean oil (0.9%) and minerals (3.2%)	40% maize hay	Mash	TMR
19	Amaral et al. (2005)	3.4	45 days	60 days	Starter	Goat	Maize hay (40.0%), ground maize (29.3%), soybean meal (21.8%), molasses (4.8%), soybean oil (0.9%) and minerals (3.2%)	40% maize hay	Mash	TMR
20	Cooper et al. (1996)	13.95 [SD 0.863]	8 weeks	11 weeks	Grower	Sheep	Alfalfa (89.4), molasses (10.0%), monosodium phosphate (0.4%), premix (0.2)	NA	Chopper	Grass
21	Hatfield et al. (1997)	avg. BW = 36.3	6 months	6 months + 21 days	Finisher	Lamb	30% barley 70% alfalfa	NA	Chopper	Grass
22	Hatfield et al. (1997)	avg. BW = 36.3	6 months + 21 days	6 months + 50 days	Finisher	Lamb	30% barley 70% alfalfa	NA	Chopper	Grass
23	Hatfield et al. (1997)	avg. BW = 36.3	6 months	6 months + 50 days	Finisher	Lamb	30% barley 70% alfalfa	NA	Chopper	Grass
24	Li et al. (2021)	26.3 ± 3.1	3 months	3 months + 28 days	Finisher	Lamb	35% maize, 12% maize germ meal, 12% sunflower, 11.3% peanut shell, 7% rice hul, 3% cotton seed, 2% bentonite, 10% barley malt rootlets	0% hay	Mash	TMR
25	Li et al. (2021)	26.3 ± 3.1	3 months + 28 days	4 months + 67 days	Finisher	Lamb	35% maize, 12% maize germ meal, 12% sunflower, 11.3% peanut shell, 7% rice hull, 3% cotton seed, 2% bentonite, 10% barley malt rootlets	0% hay	Mash	TMR
26	Li et al. (2021)	26.3 ± 3.1	3 months	5 months + 67 days	Finisher	Lamb	35% maize, 12% maize germ meal, 12% sunflower, 11.3% peanut shell, 7% rice hull, 3% cotton seed, 2% bentonite, 10% barley malt rootlets	0% hay	Mash	TMR
27	Li et al. (2021)	43.8 ± 4.0	5 months	5 months + 24 days	Finisher	Lamb	35% maize, 12% maize germ meal, 12% sunflower, 11.3% peanut shell, 7% rice hull, 3% cotton seed, 2% bentonite, 10% barley malt rootlets	0% hay	Mash	TMR
28	Li et al. (2021)	24.9 ± 3.1	3 months	3 months + 29 days	Finisher	Lamb	35% maize, 12% maize germ meal, 12% sunflower, 11.3% peanut shell, 7% rice hull, 3% cotton seed, 2% bentonite, 10% barley malt rootlets	0% hay	Mash	TMR

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Table 1. continued

No.	Study	Initial body weight, kg	Starting age	Ended age	Phase	Animal	Grain source and level	Hay level	Unpelleted form	TMR/ Grass
29	Du et al. (2019)	28.83 ± 0.19	6 months	6 months + 75 days	Finisher	Lamb	99.6% fresh grass	0% hay	Chopper	Grass
30	Du et al. (2019)	28.83 ± 0.19	6 months	6 months + 75 days	Finisher	Lamb	99.6% hay grass	99.6% hay grass	Chopper	Grass
31	Economides et al. (1990)	18.2	42 days	119 days	Starter	Lamb	79% barley, 16% soy bean meal, 4% wheat bran, 0.8% limestone and 0.2% sodium chloride	0% hay	Mash	TMR
32	Economides et al. (1990)	16.3	42 days	119 days	Starter	Lamb	79% barley, 16% soy bean meal, 4% wheat bran, 0.8% limestone and 0.2% sodium chloride	0% hay	Mash	TMR
33	Tag Eldin et al. (2011)	22 ± 5.7	3.4 months	3.4 months + 74 days	Grower	Sheep	35% molasess, 20% sorghum grain, 15% sugarcane, 10% groundnut, 15.5% wheat grain, 2% calcium	0% hay	Mash	TMR
34	Malik et al. (2020)	27.4 ± 1.62	NA	NA	Finisher	Goats	23% maize grain, 10% wheat grain, 13% soy hulls, 20% maize gluten, 9.5% soybean meal, 15% wheat straws, 5% sugarcane molases	0% hay	Mash	TMR
35	Reddy et al. (2012)	NA	4 to 5 months	9–10 months	Starter/ weaned	Goats	35% red gram straw, 25% dried leucaena leaves, 5% ground nut cake, 30% maize	0% hay	Mash	TMR
36	Reddy et al. (2012)	NA	4 to 5 months	9–10 months	Starter/ weaned	Goats	50% red gram straw, 10% dried leucaena leaves, 8% ground nut cake, 14% maize, 5% wheat bran, 8% red gram husk	0% hay	Mash	TMR
37	Trabi et al. (2019)	26.80 ± 0.32	around 180 days	approx. 180 days + 42 days	Starter/ weaned	Lamb	23% oat straw, 7% alfalfa hay, 40.6%maize, 15.6% wheat bran, 9% SBM, 1.75% stone powder	0% hay	Mash	TMR
38	Xue et al. (2021)	26.80 ± 0.32	around 180 days	approx. 180 days + 60 days	Starter/ weaned	Lamb	30% mashed grain and 70% roughage	0% hay	Mash	TMR
39	Minatchy et al. (2020)	35.3 ± 1.59	1 years	1 years + 28 days	Finisher	Black Belly rams	*Dichanthium* spp. hay distributed *ad libitum*, combined with 500 g (dry matter) of green or pelleted cassava foliage	0% hay	Mash	Grass
40	Minatchy et al. (2020)	35.3 ± 1.59	1 years	1 years + 28 days	Finisher	Black Belly rams	*Dichanthium* spp. hay distributed *ad libitum*, combined with 500 g (dry matter) of green or pelleted cassava foliage	0% hay	Mash	Grass
41	Dahlan et al. (2000)	20.5 ± 0.5	7–8 months	NA	Finisher	Goats	Oil palm frond	NA	Chopper	Grass
42	de Vega et al. (2000)	33.8 ± 0.52	11 months	NA	Finisher	Ewes	Lucerne hay	NA	Chopper	Grass
43	de Vega et al. (2000)	33.8 ± 0.52	11 months	NA	Finisher	Ewes	Lucerne hay	NA	Chopper	Grass

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Table 1. continued

No.	Study	Initial body weight, kg	Starting age	Ended age	Phase	Animal	Grain source and level	Hay level	Unpelleted form	TMR/ Grass
44	Hejazi et al. (1999)	24 ± 1.0	NA	NA	Grower	Ewes lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
45	Hejazi et al. (1999)	25 ± 1.0	NA	NA	Grower	Ewes lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
46	Hejazi et al. (1999)	26 ± 1.0	NA	NA	Grower	Ewes lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
47	Hejazi et al. (1999)	24 ± 1.0	NA	NA	Finisher	Ram lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
48	Hejazi et al. (1999)	25 ± 1.0	NA	NA	Finisher	Ram lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
49	Hejazi et al. (1999)	26 ± 1.0	NA	NA	Finisher	Ram lambs	89.4% maize, 10% peanut or soybean hulls, 4% SBM, 2% blood meal, 2% CGM	NA	Whole shelled maize	TMR
50	Thomson and Cammell (1979)				Grower	Lamb	Lucerne hay	NA	Chopper	grass
51	Ishaq et al. (2019)	29 ± 5	NA	Duration 14 days	Finisher	Sheep	Alfalfa hay	NA	Loose hay	grass
52	Ishaq et al. (2019)	30 ± 5	NA	Duration 14 days	Finisher	Sheep	Alfalfa hay	NA	Loose hay	grass
53	Ishaq et al. (2019)	30 ± 5	NA	Duration 14 days	Finisher	Sheep	Alfalfa hay	NA	Loose hay	grass
54	Bu et al. (2021)	26.83 ± 0.26	6 months	Duration 60 days	Grower	Lamb	Native grassland, steppe flora of Xilinhot, Inner Mongolian Plateau	NA	Dried grass	grass

NA – information is not available, TMR – total mix rations, AVG BW – average body weight, SBM – soybean meal, CGM – corn gluten meal, SD – standard deviation

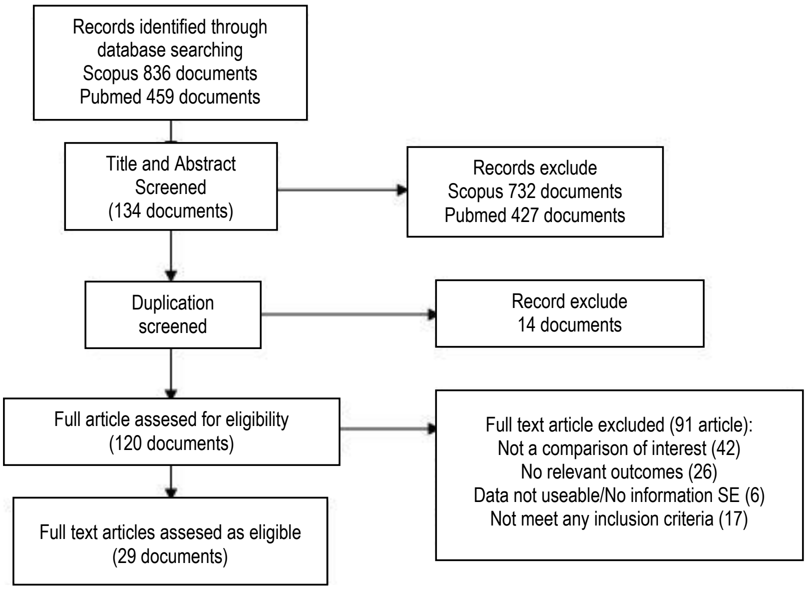

Figure 1. Flow chart of the literature selection process according to PRISMA protocols

Relevant data (Table 1) from each study were extracted into a spreadsheet using predefined criteria, including study type (randomized controlled studies), key experimental parameters (number of animals per treatment, age at the beginning of the study, duration of study), feed characteristics such as physical parameters (pelleted, mash, textured, chopped) and feed type (mix ration, 100% forage source). The test diets were as follows:

- "pelleted" – a form of ground complete feed that is mixed and then forced through a die to form elongated rods,
- "unpelleted" – divided into:
  - mash form – a complete feed that is finely ground and mixed,
  - textured form – a form of complete feed consisting of grains (whole, steamed flaked, rolled or cracked) combined with a pelleted supplement,
  - chopped form – cut pieces of grass.

Statistical analysis

The effect size as Hedges' (*d)* was applied to quantify the parameter distance between pelleted and unpelleted feed products. This method was selected for its ability to calculate the effect size regardless of the heterogeneity in sample size, measurement unit, and statistical test results, as well as its suitability for estimating the effect of paired treatments (Sanchez-Meca and Marin-Martinez, 2010). The unpelleted group was pooled into a control group (C) and the pelleted group was combined into an experimental group (E). The effect size (*d*) was calculated as follows:

$$d = \frac{(X^E - X^C)}{S} J,$$

where: X^E – mean value from the experimental group and X^C – mean value of the control group. Therefore, a positive effect size indicates that the observed parameter is greater in the unpelleted group and vice versa. J is the correction factor for small sample size, i.e.:

$$J = 1 - \frac{3}{(4(N^C + N^E - 2) - 1},$$

and S is the pooled standard deviation, defined as:

$$S = \sqrt{\frac{(N^E - 1)\,(S^E)^2 + (N^C - 1)\,((S^C)^2)}{(N^E + N^C - 2}},$$

where: N^E – sample size of the experimental group, N^c – sample size of the control group, S^E – standard deviation of the experimental group, S^C – standard deviation of the control group. The variance of Hedges' d (v_d) is described as follows:

$$V_d = \frac{(N^C + N^E)}{(N^C\, N^E)} + \frac{d^2}{(2\,(N^C + N^E))},$$

The cumulative effect size (d_{++}) was formulated as follows:

$$d_{++} = \frac{(\Sigma^n_{i=1} W_i\, d_i)}{(\Sigma^n_{i=1}\, W_i)},$$

where: W_i – inverse of the sampling variance: $W_i = 1/v_d$. The precision of the effect size was described using 95% confidence interval (CI), i.e. $d \pm (1.96 \times sd)$. All the above equations were derived from the study of Sanchez-Meca and Marin-Martinez (2010). The calculated effect size was statistically significant if CI did not reach a null effect size. A fail-safe number (N_{fs}) was calculated to identify publication bias caused by non-significant studies, which were not included in the analysis. Nfs > 5N + 10 was considered to provide evidence of a robust meta-analysis model. N_{fs} was calculated using the method of Rosenthal et al. (1979). The smallest sample size from individual studies was applied as N. Cohen's benchmarks were used as standard judgment borders for effect size assessment. These benchmarks were: 0.2 for small, 0.5 for medium and 0.8 for large effect size. All of the above effect size-related calculations were performed using OpenMEE 2.0.

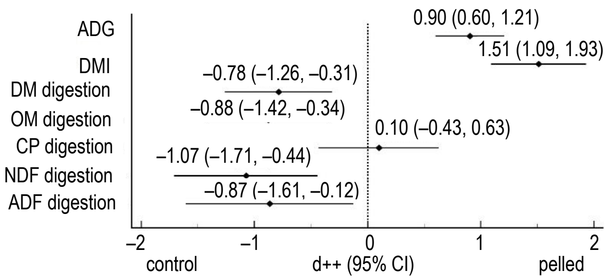

Figure 2. Forest plot of the effects of pelleted and unpelleted feed forms on production performance and nutrient digestibility of small ruminants

Results

Profile of selected studies

Due to conflicting research findings and small sample size, not all results can be considered reliable due to publication bias. Briefly, the fail-safe number (Nfs) indicates which studies are suitable to be included into the final strong conclusions. This number expresses how many sample study sizes should be added in order to change the initial effect size into a negligible variable. If Nfs > 5N + 10, where N is the study effect size used to calculate the initial effect size, then the result can be considered as the final robust conclusion (Rosenthal, 1979). According to these fail-safe number rules, robust parameters include average daily gain (ADG), dry matter intake (DMI), dry matter digestion (DM digestion), organic matter digestion (OM digestion) and neutral detergent fiber digestion (NDF digestion), while crude protein digestion (CP digestion) and acid detergent fiber digestion (ADF digestion) are among non-robust result parameters.

Pelleted vs unpelleted feed form

Figure 2 summarizes the results of meta-analysis, which showed that the pelleted feed form increased dry matter intake and average daily gain ($P < 0.05$) of small ruminants compared to the unpelleted form. On the other hand, pelleted feed decreased dry matter digestion and organic and fiber percentage ($P < 0.05$). For crude protein digestion, no significant effect of the pelleted process was observed. Table 2 shows the detailed meta-analysis results for seven parameters. Figure 2 shows summary of meta-analysis result that pelleted feed form enhances dry matter intake and average daily gain ($P < 0.05$) of small ruminants in comparison to the un-pelleted form. The result also indicated that dry matter intake and average daily gain were significantly higher for pelleted feed compared to the unpelleted form, with a large size effect, i.e. 1.51 ± 0.42. On the other hand, the pelleted feed form decreased dry matter digestion, as well as organic and fiber percentage ($P < 0.05$). The results also demonstrated that these parameters were significantly lower when pelleted feed was applied in comparison to the unpelleted form, with a large size effect, i.e. 1.07 ± 0.64. Crude protein digestion was not significantly affected by the pelleted process. Table 2 shows detail meta-analysis results for seven parameters tested according to Cohen's methodology.

Table 2. Meta-analysis of the effect of pelleted and unpelleted feeding on production performance and nutrient digestibility of small ruminants

No	Response variables	Doc	Unit	N	Estimate	Lower bound	Upper bound	SE	*P*-value	τ^2	Q	Het *P*-value	I^2
1	ADG	25	g/day	54	0.905	0.601	1.21	0.155	<0.001	0.958	353.069	<0.001	84.989
2	DMI	25	g/day	52	1.512	1.091	1.934	0.215	<0.001	1.852	394.227	<0.001	87.063
3	DM digestion	18	%	31	−0.785	−1.259	−0.311	0.242	0.001	1.257	126.913	<0.001	76.362
4	OM digestion	16	%	29	−0.877	−1.417	−0.338	0.275	0.001	1.566	125.296	<0.001	77.653
5	CP digestion	14	%	20	0.1	−0.432	0.631	0.271	0.714	0.974	75.628	<0.001	74.877
6	NDF digestion	14	%	24	−1.073	−1.707	−0.438	0.324	<0.001	1.769	122.156	<0.001	81.172
7	ADF digestion	10	%	18	−0.865	−1.606	−0.123	0.378	0.022	1.942	100.792	<0.001	83.134

Doc – document, N – number of data, SE – standard error, τ^2 – variance of the effect size parameters across the study populations, Q – weighted sum of squared deviations, Het *P*-value – *P*-value for heterogeneity, I^2 – heterogeneity level between studies, ADG – average daily gain, DMI – dry matter intake, DM digestion – dry matter digestion, OM digestion – organic matter digestion, CP digestion – crude protein digestion, NDF digestion – neutral detergent fiber digestion, ADF digestion – acid detergent fiber digestion

Discussion

Effect on production performance of small ruminants. This meta-analysis review evaluated the influence of pelleted and unpelleted forms on the performance and digestion of small ruminants. At the level of feed intake and average daily gain (ADG), small ruminants showed a significant response to feeding in pellets compared to the unpelleted form. Figure 2 shows forest plots regarding the impact of pelleted and unpelleted feed forms on starter feed intake and ADG in small ruminants across the studies included in the analysis.

The results of meta-analysis showed that administering the pelleted form increased feed intake in small ruminants compared to unpelleted feed. The process of pellet production begins with grinding of raw materials, whereby the fragmentation physically reduces the particle size of the material, while increasing the grain surface area, and facilitating the access of amylolytic microbes to starch granules, resulting in enhanced starch digestion in the rumen (Bateman et al., 2009).

A study by Ghaffari and Kertz (2021) showed that calves fed a textured starter feed mixed with hay had an increased intake by 87 g/h compared to a fine feed mixed with grass; however, ADG did not change. High levels of NDF in feed also contribute significantly to filling the digestive tract (gut) (Stobo et al., 1966; Jahn and Chandler, 1976). Ghaffari and Kertz (2021) reported that calves fed a textured feed mixed with hay showed a higher NDF intake with each bite and increased intestinal contents than calves fed textured feed alone, resulting in reduced feed intake. The increase in ADG by providing forage in the calf starter feed is due to an increase in intestinal filling (Hill et al., 2008; Mirzaei et al., 2015).

In addition, Li et al. (2021) found that sheep fed TMR in pellets produced higher ADG than without pellets, and the same results were also reported by Coufal-Majewski et al. (2017), Zhong et al. (2018) and Zhang et al. (2019). Growth performance is strongly dependent on total feed intake and the amount of nutrients animals can utilise per unit of feed. The increase in dry matter intake was mainly due to a reduction in rumen content in response to pelleting, which allowed higher feed intake to achieve satiety. The increased feed intake could explain the enhanced growth performance. According to Li et al. (2021), sheep fed pellets had higher body weight and carcass weight than those fed without pellets. This may be due to higher feed intake, leading to better growth performance of sheep administered pelleted feed.

Effect on nutrient digestibility of small ruminants. Feeding pellets did not affect the digestibility of either dry matter, organic matter or crude protein. The pelleted feed increase the number of gelatinized starch granules during the heating process and their palatability (Waigh et al., 2000; Crochet et al., 2005). In the process pelletisation, the feed mixture is heated at 75–87 °C for 15–20 s in a conventional conditioner, and this processing increases the gelatinized starch content (Soltani et al., 2020). Starter pellets do not have the appropriate particle size to stimulate mastication and rumination. Porter et al. (2007) found that calves fed starters with cracked maize and crushed wheat at an earlier age spent more time ruminating compared to animals fed milled and pelleted grains, resulting in a higher rumen pH. Li et al. (2021) demonstrated that feeding in the form of pellets resulted in a slight decrease in dry matter digestibility, but the other digestibility parameters were not affected.

No difference in digestibility was also reported by Zhang et al. (2019) and Coufal-Majewski et al. (2017). Moreover, Zhong et al. (2018) found that the digestibility of crude protein (CP), acid detergent fiber (ADF), ether extract (EE) and starch slightly increased in animals fed pellets, while the digestibility of dry matter (DM) and neutral detergent fiber (NDF) remained unchanged. Karimizadeh et al. (2017) reported that feed pelletisation increased digestibility of DM and ADF. Pelleted feed affects the digestibility of nutrients because the manufacturing process involving changes in temperature, time and water content have an effect on nutrient degradation (Bertipaglia et al., 2010; Castrillo et al., 2013; Ran et al., 2020). Pellets applied in various studies may be one of the reasons for the observed differences in digestibility response. In addition, differences in sheep breed, age, and sex across studies could be another reason. However, differences in digestibility and increased feed intake may be the main cause of improved growth performance.

Rumen pH is an important fermentation parameter influenced by various factors, including feed processing (Plaizier et al., 2018). Lower pH in sheep fed TMR in the form of pellets resulted in a faster feeding process (Karimizadeh et al. 2017) and increased feed intake (Karimizadeh et al., 2017; Zhong et al., 2018; Zhang et al., 2019). More feed ingested in a short period of time provides more substrate for the metabolism of rumen microorganisms. This was evidenced by higher concentrations of ammonia and total short chain fatty acids (SCFA) (Zhong et al., 2018). Lower rumen pH and higher total SCFA contents were also observed in pellet-fed cattle (Voelker and Allen, 2003). Although the concentration of SCFA in the study by Zhang et al. (2019) was higher in sheep receiving pelleted feed compared to TMR without pellets, rumen pH was not affected. Rumen pH was within the range required for normal physiological function and did not cause acidosis. Moreover, Li et al. (2021) argued that increasing growth performance would shorten the time required for livestock rearing. In addition, feed in the form of pellets can also reduce feed waste and increase labour efficiency, thereby increasing farmer profits.

Conclusions

The present meta-analysis have demonstrated that the form of the feed affects performance and digestion of small ruminants. The pelleted form had a positive effect on DMI and ADG and led to increased growth and livestock rearing rate. Interestingly, some digestion parameters were negatively affected by this type of feeding. A further identical meta-analysis may be the best option to evaluate and summarize the comparison of feed forms with respect to other aspects and type of feed processing for ruminants.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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