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Phytogenic additives increase the performance and improve the tenderness of lamb meat: a meta-analytical and systematic review approach

Aditivos fitogênicos elevam o desempenho e melhoram a maciez da carne de cordeiros: uma abordagem de revisão sistemática e meta-analítica

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Highlights

Phytogenic additives (PA) are essential oils, plants and leaves extracts.
The PA supply increase average daily gain of lambs.
The supply of PA increases the tenderness of the lamb's meat.
We recommend the PA inclusion in the lamb' diet.

Abstract

This study aimed to verify how supply phytogenic additives (PA) can influence ruminal fermentation, digestibility, performance, carcass traits, and meat quality of lamb through a systematic review and meta-analysis. Data were extracted from 39 peer reviewed studies and analyzed using the F test when presented in a normal distribution, or the Kruskal-Wallis test when not presented in a normal distribution. Essential oils are most frequently used in the feed of lambs. The botanical species most used as source in the diet of lambs were *Origanum vulgare* (23.08%), *Salvia rosmarinus* (12.82%), and *Allium sativum* (7.69%). The PA supply didn't interfere (P>0.05) with the intake of crude protein and neutral detergent fiber (NDF) and increased (P = 0.011) crude protein digestibility from the lamb's diet. There was an increase (P = 0.020) of 5.77% in the average daily gain, and an increase (P = 0.053) of 8.9% in the rib eye area of the carcasses of sheep fed PA. The supply of PA reduced (P = 0.047) 5.4% of meat shear force and increased (P = 0.041)

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3.3% of meat cooking losses. We recommend the inclusion of phytogenic additives in the diet of lambs since it does not change nutrient intake, improves crude protein digestibility, and increases the average daily gain.
Key words: Alternative additives. Essential oils. Feedlot. Zootechnical additives.

Resumo

Objetivou-se verificar como a adição de aditivos fitogênicos (AF) influenciou na fermentação ruminal, digestibilidade, desempenho, características de carcaça e qualidade da carne de ovinos de corte por meio de uma revisão sistemática e meta-análise. Os dados foram extraídos de 39 estudos revisados por pares e analisados pelo teste F, quando apresentados em distribuição normal, ou pelo teste Kruskal-Wallis, quando não apresentavam distribuição normal. Óleos essenciais são os AF mais frequentemente utilizados na alimentação de ovinos de corte. As espécies botânicas mais utilizadas como fontes de AF na dieta de ovinos foram *Origanum vulgare* (23,08%), *Salvia rosmarinus* (12,82%) e *Allium sativum* (7,69%). O fornecimento de AF não interferiu (P>0,05) na ingestão de proteína bruta e fibra em detergente neutro (FDN) e aumentou (P = 0,011) a digestibilidade da proteína bruta da dieta dos ovinos. Houve incremento (P = 0,020) de 5,77% no ganho médio diário (GMD) e aumentou (P = 0,053) em 8,9% a área de olho de lombo das carcaças dos ovinos que receberam AF na dieta. A oferta de AF reduziu (P = 0,047) em 5,4% a força de cisalhamento da carne e elevou (P = 0,041) em 3,3% as perdas por cocção da carne (PPC) dos ovinos. Recomendamos a inclusão de aditivos fitogênicos na dieta de ovinos, uma vez que não altera o consumo de nutrientes, melhora a digestibilidade da proteína bruta e aumenta o ganho médio diário.
Palavras-chave: Óleos essenciais. Aditivos alternativos. Aditivos zootécnicos. Ovinos confinados.

Introduction

The rations formulated for feedlot lambs are similar to those provided for feedlot steers and are composed of grain and grain by-products, making the lambs greater susceptibility to develop metabolic diseases arising from the diet (i.e., acidosis, tympanism, laminitis, etc.) (Pinto & Millen, 2018; Asín et al., 2021). Therefore, nutritional strategies that minimize metabolic risks of feedlot sheep, such as additives added to the diet, can improve ruminal health conditions and increase the animals' feed efficiency (R. N. S. Torres et al., 2021).

Even with consistent increases in animal performance, diet additives have been condemned for presenting a risk of residues in products and by-products of animal origin. In 2017, the World Health Organization discussed the indiscriminate use of growth promoters, highlighting the worsening of bacterial resistance and promoting a significant risk to human and animal health. In this context, alternatives that do not cause a risk to human and animal health and still improve ruminal health and animal performance without leaving residues in the final product and are low cost for the producer are sought (Kholif et al., 2017; Morsy et al., 2021; Jahani-Azizabadi et al., 2022).

Phytogenic additives belong to a relatively heterogeneous group of substances (i.e., organic acids, aldehydes, ketones, esters, phenolic compounds, etc.) present in extracts, resins, or essential oils from a wide variety of vegetables. Plants normally secrete secondary substances in their metabolism, accumulating in the leaf, stem/stalk, root, fruit, and seed. When ingested by herbivores, they have modulating effects on the animal's endogenous microbiota, similar to growth-promoting antibiotics (Patra & Saxena, 2010; Morsy et al., 2021; (R. N. S. Torres et al., 2021; Jahani-Azizabadi et al., 2022).

Studies indicate that including phytogenic additives, mainly essential oils, increases lamb's performance without interfering with dry matter intake (Klevenhusen et al., 2011; Michailoff et al., 2020; Bhatt et al., 2021;). Other studies report no influence of phytogenic additives on animal performance (Y. A. Silva et al., 2021; Muñoz-Cuautle et al., 2022). In this sense, the effect of these phytogenic additives of sheep performance is not yet established. Therefore, the objective of this study was to evaluate whether phytogenic additives have a performance-enhancing effect in sheep through a systematic review and meta-analysis.

Material and Methods

Article search

A literature search was conducted using five databases: Science Direct, Scielo, PubMed, Google Scholar, and EBSCO. The publications were retrieved using the following search terms: "Essential oil and performance and lambs", "essential oils and carcass and sheep", and "phytogenic additives and performance and sheep". The keywords used in the search engines were written without quotation marks. Only articles that met the pre-determined eligibility criteria according to the peak criteria (participants, interventions, comparisons, results, and study design) were included in the analysis. In addition, only primary papers in English were considered, excluding review papers, systematic reviews, and simple abstracts.

Data extraction

The articles included in the meta-analysis met the following criteria: (a) provide the full text of the work; (b) present the composition and/or source of phytogenic additives (PAs); (c) present control treatment without any additive; (d) provide the period of supplementation and the supplemented dose; (e) evaluate the in vivo diets; (f) evaluate dry matter intake (DMI), feed conversion (FC), average daily gain (ADG), ruminal fermentation parameters (total volatile fat acids and individual values of acetate, propionate, and butyrate, pH, and ammonia N), and carcass evaluation parameters (hot carcass weight, carcass yield, rib eye area); and (g) detail the methodology used.

Based on these criteria, 39 publications were classified by type of additive, the form of administration, the dosage used, animal breed, sex, weight, age, type of study, and experimental period. The survey was last conducted on May 22nd, 2022.

Quality criteria

The quality criteria of the articles in both databases were established according to the methodology described by Moreira et al. (2020): Randomization – a randomized study scored 2 points, while a non-randomized study (or when the randomization was not clearly described in the text) scored 1 point; Control group - studies with a control group scored 2 points, while studies without a control group (or when it was not clearly described in the text) scored 1 point; Breed - studies that mention breed scored 2 points, while studies that do not mention or clearly describe in the text scored 1 point; Concentration of the essential oil or plant extract used - studies that present the concentrations used scored 2 points, while studies that do not provide this type of information scored 1 point; Form of administration - studies that inform the form of administering essential oils or plant extracts scored 2 points, while studies that do not inform this scored 1 point; Ethics Committee with animal use - studies approved by the Ethics Committee scored 2 points, while studies that were not approved or did not report an approval scored 1 point; Duration period - studies that reported the duration of the experiment scored 2 points, while studies that did not contain this type of information scored 1 point; Weight and age - studies that mentioned the weight and age of the animals scored 2 points, while studies that did not report this scored 1 point. The high-quality studies obtained 16 points the highest score on the scoring scale. (Table 1).

Table 1
Evaluation of article quality according to the established criteria

Author/year	A	B	C	D	E	F	G	H	Total
Al-Azzawi and Rasheed (2021)	2	2	2	2	1	1	2	1	13
Baruh and Kocabağli (2017)	2	2	2	2	2	2	2	1	15
Bertolini et al. (2019)	2	1	2	2	1	1	2	2	13
Bhatt et al. (2021)	2	2	2	2	2	2	2	2	16
Chaves et al. (2011)	2	2	2	2	2	1	2	1	14
Ding et al. (2021)	2	2	2	2	2	2	2	2	16
Dorantes-Iturbide et al. (2022)	2	2	2	2	2	2	2	2	16
El-Essawy et al. (2019)	2	2	1	1	1	1	2	2	12
Estrada-Angulo et al. (2021)	2	2	2	1	2	2	2	1	14
Guerreiro et al. (2019)	2	2	2	2	2	2	2	2	16
Gümüş et al. (2017)	2	2	2	2	2	2	2	2	16
Guney et al. (2021)	2	2	2	2	2	1	2	2	15
Khayyal et al. (2021)	2	2	2	1	1	1	2	2	13
Klevenhusen et al. (2011)	2	1	2	2	2	1	2	1	13
Koyuncu and Conbolat (2012)	2	2	2	2	1	1	2	1	13

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Lima et al. (2020)	2	2	2	2	1	2	2	2	15
Lodi et al. (2019)	2	2	2	2	2	2	2	2	16
Malekkhahi et al. (2014)	2	2	2	2	2	2	2	2	16
Michailoff et al. (2020)	2	2	2	2	2	2	2	1	15
Moura et al. (2017)	2	2	2	2	2	2	2	2	16
Odhaib et al. (2021)	2	2	1	2	1	1	2	2	13
Okoruwa and Aidelomon (2020)	2	2	2	2	1	1	2	2	14
Ortiz et al. (2020)	2	2	2	2	1	2	2	1	14
Orzuna-Orzuna et al. (2021)	2	2	2	2	2	2	2	2	16
Ozdoğan et al. (2011)	2	2	2	2	2	1	2	2	15
Parvar et al. (2018)	2	2	2	2	2	2	2	2	16
Passetti et al. (2021)	2	2	2	2	1	2	2	2	15
Sahraei et al. (2014)	2	2	2	2	2	2	2	1	15
Shaaban et al. (2021)	2	2	2	2	2	2	2	2	16
C. S. Silva et al. (2017)	2	1	2	2	2	1	2	1	13
Simitzis et al. (2014)	2	2	2	2	2	2	2	2	16
Smeti et al. (2017)	2	2	2	2	2	2	2	1	15
Sun et al. (2022)	2	2	2	2	2	2	2	2	16
Ünal and Kocabağli (2014)	2	1	2	2	2	2	2	1	14
Ünlü et al. (2021)	2	2	2	2	1	2	2	2	15
Vahabzadeh et al. (2020)	2	2	2	2	1	1	2	2	14
Zamiri et al. (2015)	2	2	1	2	2	2	2	2	15
Zeola et al. (2021)	2	1	2	2	1	2	2	2	14

Abbreviations: A, Randomization; B, Control group; C, Breed; D, Concentration of the essential oil or plant extract used; E, Form of administration; F, Ethics Committee with animal use; G, Duration period; H, Weight and age. The articles classified as high quality received 16 points.

Statistical analysis

A systematic review was carried out by means of a descriptive data analysis, including collection, organization and description of the compiled data in the bases. The meta-analysis was carried out according to the methodology proposed by Sauvant et al. (2008) for base construction, definition of dependent and independent variables and data coding. The data were submitted to the Shapiro-Wilk Test at the level of 5% probability to verify data normality. Data that did not present normal distribution were normalized using the PROC RANK procedure of the SAS statistical package (9.3). Non-normalized data were compared by the Kruskal-Wallis test at 5% probability. Data with normal distribution were compared using the analysis of variance F-test considering a significant effect less than or equal to 5% probability and a tendency between 5% and

10%, expressed in the model: Yijk = μ + £l + Ꞡj + εijk. Where Yijk = observations of the effect of phytogenic additives i, replicate j and experiment k; μ = overall mean; £i = random effect of the publication; Ꞡj = fixed effect of the cold carcass weight, hot carcass weight or subcutaneous fat thickness; εijk = random error related to each observation, considered independent, identically distributed and normal with 0 mean and σ variance.

Results

Systematic review

The searches conducted in the five databases resulted in 57 pre-selected articles. Only 39 works were included in this review, resulting in three databases: performance and digestibility, carcass evaluation, and ruminal fermentation. Different species were examined regarding the use of phytogenic additives in lambs' diets, mainly: *Origanum vulgare* (25.95%), *Salvia rosmarinus* (9.75%), and *Allium sativum* (7.32%) (Table 2).

Of the 39 publications, 64.10% provided additives in the form of essential oil (EOs), while 17.95% used dry extracts, 10.26% used aqueous extract, and 7.69% used leaf hay.

All breeds used in the selected studies were fit for meat production, meeting one of the requirements of the present study. The Dorper breed and its crosses represented 12.82% of the 39 articles reviewed, while 7.69% of the studies used animals of the Kivircik breed. Animals without defined race were also included, totaling 7.69%. Four articles (10.26%) did not inform the breed of animals used in their experiments. Sixty-two percent of the studies were carried out with lambs (animals between 2 and 7 months old), 18% of the articles were carried out with adult animals and eight articles (21%) did not inform the age of the animals evaluated. The vast majority (78%) of the animals evaluated in the 39 articles were males.

Quality criteria were implemented to characterize each study to evaluate the quality and reliability of the articles presented in this review (Table 1). Of the 39 studies evaluated, 13 received 16 points, the highest score on the scoring scale. Only one work received the minimum score of 12 points (El-Essawy et al., 2019).

All works satisfied the randomness principle. In this database, 87.18% of the studies presented a control group, while the other studies did not specify this information in the treatment topic. Of the 39 articles selected, 89.74% reported the breeds used in the respective experiments, and 10.26% did not present this information, thus disregarding factors linked to the genetic stem of each individual.

The concentrations of essential oils and plant extracts were presented in 92.30% of the analyzed studies. A small portion of the articles (7.69%) did not clarify this information. Regarding the supply of additives to animals, 66.67% of the studies mentioned the form of administration, while 33.33% did not.

The approval of procedures by an Ethics Committee for animal experimentation was reported in 66.67% of the selected articles. All articles reported the duration of the experiments. Of the articles selected, 69.23% provided information on the weight and age of the populations.

Table 2
Description of publications included in the database

Author	Extract type	Supply	Breed
Al-Azzawi and Rasheed (2021)	*Mentha*	Essencial oils	Awassi
Baruh and Kocabağli (2017)	*Origanum vulgare*	Essencial oils	Kivircik
Bertolini et al. (2019)	*Schinus terebinthifolia*	Essencial oils	Dorper×Santa Inês
Bhatt et al. (2021)	*Cymbopogon citratus and Murraya koenigii*	Leaf hay	Malpura
Chaves et al. (2011)	*Cinamaldeíldo*	Essencial oils	Arcot
Ding et al. (2021)	*Allium mongolicum*	Dust	Small-tailed Han
Dorantes-Iturbide et al. (2022)	*T. cordifolia, O. sanctum, W. somnifera, A. paniculata and A. indica*	Essencial oils	Pelibuey × Katahdin
El-Essawy et al. (2019)	*Pimpinella anisum, Syzygium aromaticum e Thymus vulgaris*	Essencial oils	Not identified by the authors
Estrada-Angulo et al. (2021)	*Timol, eugenol and valinina*	Essencial oils	Pelibuey × Katahdin
Guerreiro et al. (2019)	*Cistus ladanifer L*	Aqueous extracts	Merino Branco × Romane
Gümüş et al. (2017)	*Origanum vulgare*	Essencial oils	Akkaraman
Guney et al. (2021)	*Salvia rosmarinus*	Essencial oils	Norduz
Khayyal et al. (2021)	*Salvia rosmarinus and Laurus nobilis*	Leaf hay	Rahmani × Finnish Landrace
Klevenhusen et al. (2011)	*Allium sativum*	Essencial oils	Swiss Black-Brown Mountain
Koyuncu and Conbolat (2012)	*Carvacrol*	Essencial oils	Kivircik
Lima et al. (2020)	*Macleaya cordata and Magnolia officinalis*	Aqueous extracts	Dorper×Santa Inês
Lodi et al. (2019)	*Cymbopogon citratus*	Essencial oils	Non-descript breed
Malekkhahi et al. (2014)	*Timol, Eugenol, Citral and Cinamaldeído*	Essencial oils	Baluchi
Michailoff et al. (2020)	*Cardanol, cardol and ácido ricinolêico*	Essencial oils	Non-descript breed
Moura et al. (2017)	*Copaifera langsdorffii*	Essencial oils	White Dorper
Odhaib et al. (2021)	*Curcuma*	Dust	Not identified by the authors

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Okoruwa and Aidelomon (2020)	*Zingiber officinale and Citrus limon*	Dust	West African dwarf sheep
Ortiz et al. (2020)	*W. somnifera, O. tenuiflorum, T. cordifolia and E. officinalis*	Essencial oils	Suffolk × Dorper
Orzuna-Orzuna et al. (2021)	*S. officinarum, B. roxburghi, A. concinna. and S. officinarum*	Dust	Dorper × Katahdin
Ozdoğan et al. (2011)	*Copaifera langsdorffii*	Essencial oils	Karya
Parvar et al. (2018)	*Curcuma*	Dust	Afshari
Parvar et al. (2018)	*Curcuma*	Dust	Afshari
Passetti et al. (2021)	*O. vulgare, Citrus spp., e Echinacea spp. + Capsicum spp., Cinnamomum spp. and Eugenia caryophyllata*	Dust	Suffolk × Arcot
Sahraei et al. (2014)	*Salvia rosmarinus*	Essencial oils	Ghezel
Shaaban et al. (2021)	*Thymus vulgaris and Apium graveolens*	Dust	Barki
C. S. Silva et al. (2017)	*A. sativum, Coriandrum sativum, O. vulgare, Prosopis juliflora*	Aqueous extracts	Non-descript breed
Simitzis et al. (2014)	*Cinnamon*	Essencial oils	Karagouniki
Smeti et al. (2017)	*Salvia rosmarinus*	Essencial oils	Barbarine
Sun et al. (2022)	*Origanum vulgare*	Essencial oils	Sewa
Ünal and Kocabaği (2014)	*Origanum vulgare*	Essencial oils	Kivircik
Ünlü et al. (2021)	*Origanum vulgare and Capsicum*	Essencial oils	Ile de France x Kivircik
Vahabzadeh et al. (2020)	*Origanum vulgare*	Leaf hay	Kermani
Zamiri et al. (2015)	*Timol*	Essencial oils	Not identified by the authors
Zamiri et al. (2015)	*Carvacrol*	Essencial oils	Not identified by the authors
Zeola et al. (2021)	*Salvia rosmarinus, Camellia sinensis var assamica, O. vulgare*	Aqueous extracts	Ile de France

Meta-analysis

The supply of PA did not influence (P>0.05) the dry matter intake but decreased the organic matter intake (OMI) of sheep (P = 0.010) (Table 3).

Table 3
Effect of the inclusion of phytogenic additives in the diet on sheep performance

Item	Without phytogenic additive	With phytogenic additive	SEM	P-value
Initial weight (kg)	22.93	22.91	0.61	0.904
Final weight (kg)	37.55	38.42	1.01	0.480
Feed conversion	5.26	5.32	0.26	0.914
Average daily gain (g day^{-1})[1]	273.22	289.0	13.35	0.020
Dry matter intake (kg day^{-1})	1.18	1.13	0.03	0.371
Organic matter intake (kg day^{-1})[2]	1.90	1.85	0.04	0.010
Crude protein intake (g day^{-1})	184.83	179.05	7.43	0.494
Insoluble fiber in neutral detergent intake (g day^{-1})	621.03	608.10	28.50	0.749
Insoluble fiber in acid detergent intake (g day^{-1})	419.50	388.13	13.62	0.219
Organic matter digestibility (%)	70.28	69.32	0.85	0.631
Dry matter digestibility (%)[3]	72.58	71.92	0.90	0.559
Crude protein digestibility (%)	98.99	104.47	1.27	0.011
Ether extract digestibility (%)	71.71	68.28	2.20	0.303
Insoluble fiber in neutral detergent digestibility (%)	57.29	58.29	1.08	0.543
Insoluble fiber in acid detergent digestibility (%)	49.51	51.05	2.33	0.873

Abbreviations: SEM, Standard error of the mean.

Adding PA to the diet did not interfere (P>0.05) with the intake of crude protein and neutral detergent fiber (NDF). However, it increased (P=0.011) crude protein digestibility (CPD) of the diet by 5.5%. The addition of PA in the diet did not influence NDF digestibility, final body weight, and feed conversion (P>0.05). However, there was an increase (P=0.020) of 5.77% in average daily gain (ADG).

The inclusion of PA in the sheep diet did not influence pH, ammonia-N, total fatty acids, acetate, propionate, and butyrate of the sheep rumen (P>0.05) (Table 4).

Table 4
Effect of the inclusion of phytogenic additives in the diet on ruminal parameters of sheep

Item	No phytogenic additive	Without phytogenic additive	SEM	P-value
pH	6.38	6.41	0.05	0.907
Ammonia-nitrogen (mg dL^{-1})	16.38	16.52	1.07	0.952
VFA's (mmol L^{-1})[1]	102.69	94.67	5.51	0.609
Acetic (mmol L^{-1})	54.01	51.40	2.12	0.535
Propionic (mmol L^{-1})	22.14	21.98	1.47	0.582
Butyric (mmol L^{-1})	11.38	10.31	0.79	0.269

Abbreviations: [1]VFA's, Volatile fatty acids total; SEM, Standard error of the mean.

The use of PA did not influence (P>0.05) carcass pH, the weights of the hot and cold carcasses, hot carcass yield, and the subcutaneous fat thickness of the carcass (Table 5).

Table 5
Effect of including phytogenic additives in the diet on sheep carcass and meat characteristics

Item	No phytogenic additive	Without phytogenic additive	SEM	P-value
Carcass pH_{24h}	5.77	5.77	0.16	0.811
Hot carcass weight (kg)	19.02	19.46	0.66	0.845
Hot carcass yield (%)	44.34	43.04	1.80	0.317
Cold carcass weight (kg)	16.74	16.66	1.34	0.672
Subcutaneous fat thickness (mm)	4.61	3.76	1.34	0.722
Rib eye area (cm^2)[1]	11.97	13.04	1.00	0.053
Shear force (kgf)[2]	37.26	35.32	2.77	0.047
Cooking loss (%)[3]	24.81	25.63	1.81	0.041

Abbreviations: [1]Cold carcass weight was used as a co-variable; [2]Hot carcass yield was used as a co-variable; 3Subcutaneous fat thickness was used as a co-variable; SEM, Standard error of the mean.

The supply of PA provided a tendency to increase (P = 0.053) the rib eye area (REA) of the sheep carcasses by 8.9%, reduced (P=0.047) the shear force (SF) of the meat by 5.4%, and increased (P = 0.041) the meat cooking losses by 3.3%.

Discussion

Systematic review

Origanum vulgare and Salvia rosmarinus essential oils have a high content of phenolic compounds. Carvacrol and thymol monoterpenes are the primary ones responsible for oregano's antibacterial and antioxidant activities. Carcinol, carnosic acid, rosmanol, and rosmarinic acid are the antioxidant and antimicrobial substances present in Rosemary (Borges et al., 2012; Guney et al., 2021).

Garlic (Allium sativa) is widely recognized for its therapeutic benefits (Agarwal, 1996). In vivo and in vitro studies demonstrated the existence of two major substances: allicin (Cavallito & Bailey, 1944) and garlicin, both of which work against gram-positive and gram-negative microorganisms in a manner similar to ionophore antibiotics.

Concern for the spread of antibiotic resistance has increased the attention to functional plant products in animal health. Veterinary herbal medicine has expanded because many plant metabolites have a high antimicrobial capacity (Kuralkar & Kuralkar, 2021). However, the reason for using herbs and spices and their extracts in animal nutrition is not only for their antimicrobial activity to replace antibiotics in feed, plant extracts, and phytochemicals. They also have antioxidant and immunomodulatory activity, which can improve, for example, the digestion and absorption of nutrients, bringing considered growth and productivity enhancers (Upadhaya & Kim, 2017).

Herbal ingredients, extracts, and botanical preparations used as feed additives must comply with all appropriate requirements of national food and feed legislation regarding composition and safety. Extract quality and production consistency are specifically relevant when a quantitative claim is made for a botanical or specific component. Thus, identity and quality control are essential (Franz et al., 2020).

According to Kuralkar & Kuralkar (2021), phytogenics can be classified as herbs (products of flowering plants, used whole or only some parts) and botanicals (extracts and essential oils). Herbs can be used in solid form (in the form of hay) or dried and crushed (in the form of powder). It can be used whole or only the leaves and/or small stems (Franz et al., 2020). In turn, plant extracts can be obtained from any part of the plant and are usually dehydrated and subjected to the crushing/grinding process. They can be presented as liquid extracts, obtained without eliminating or partially eliminating the solvent, and dry extracts, obtained with the elimination of the solvent (Lee et al., 2004).

Essential oils are products of plant origin obtained by physical process (steam distillation, distillation under reduced pressure, or another suitable method). They can be present in isolation or mixed. They are formed by volatile substances, usually lipophilic, comprising chemical groups such as terpene hydrocarbons, alcohols, esters, aldehydes, ketones, and oxides in different concentrations. They have antimicrobial, anti-inflammatory, antioxidant, and coccidiostatic properties (Nascimento et al., 2020; Lee et al., 2004; Omonijo et al., 2018; Franz et al., 2020).

Despite the varied extraction, presentation, and supply forms, functional additives of phytogenic origin are highlighted by improving food digestion and stimulating the production of gastric secretions and digestive enzymes (Lee et al., 2004; Jang et al., 2007; Kuralkar & Kuralkar, 2021). A small portion of the articles (7.69%) did not make clear the concentration of the extracts used in the experiments. According to Ceylan and Fung (2004), being aware of the essential oil or plant extract concentration is extremely important since the active ingredients can perform one or more biological activities.

Most studies have described the method of administration to animals. This knowledge is quite relevant. According to Fascina et al., (2012), various factors can influence the efficiency of each additive's active ingredients, including the form of administration, degrees of inclusion, and preparation. Because these chemicals are derived from plants, they can emit powerful fragrances and, depending on the form administered to the animal, can directly influence dry matter intake (Dong & Pluske, 2007; Gabbi et al., 2009), although this was not detected in the results of our meta-analysis.

The presentation of experimental procedures to an Ethics Committee became necessary due to current animal welfare requirements in production systems and experimentation. All articles reported the duration of the experiments. This information is extremely relevant since the ruminant animal requires a period of adaptation to diets before the experimental period begins so that sudden changes in the ruminal environment do not impact the microbiota.

Studies evaluating body weight and average daily gain require informing the weight and age of the animals that will be used in the experiments. Of the articles selected, 69.23% provided information on the weight and age of the populations. Knowledge of this nature is necessary since it refers to the animal's maturity, given that the physiological responses of young individuals differ from mature animals.

Meta-analysis

PA, especially EOs, destabilizes prokaryotes' selective membrane permeability. This effect is marked in bacterial groups with only one lipid bilayer, such as gram-positive ones, which usually produce acetate as a by-product of rumen fermentation (Torres et al., 2018; Babii et al., 2018; Seibert et al., 2019). The lower OMI of sheep receiving PA can be attributed to increased propionate production in the rumen. Propionate is converted to glucose in the liver, and insulin secreted in response to increased blood glucose has a hypophagic effect in animals (Allen et al., 2009).

The higher crude protein digestibility in sheep treated with PA can be attributed to lower deamination in these animals' rumen. PA normally selects microbial groups that perform a lower ruminal proteolysis, resulting in lower ruminal ammonia production and nitrogen losses via feces and urine (Wang et al., 2024). In addition, the lower ruminal ammonia production is related to the greater synchronism between carbohydrates and proteins degradation, which increases the efficiency of ruminal microbial protein synthesis (Van Soest, 1994; Rodríguez et al., 2010). Different results were obtained by R. N. S. Torres et al. (2020) in a meta-analytical study evaluating the inclusion of EOs in the diet of sheep, who verified a reduction in crude protein digestibility. They highlighted possible toxicity with dosages of EOs greater than 100mg kg DM-1, contributing to reduced digestion and nutrient absorption.

The sheep receiving PA in the diet gained more weight, probably due to the increase in the use efficiency of metabolizable energy. Andri et al. (2020) published a meta-analysis study evaluating EOs as growth promoters in small ruminants, finding that EOs increased ADG without changing DMI. PA increases propionate production and reduces methane production in the rumen of sheep (Morais et al., 2011). Energy losses by enteric methane represent up to 12% of digestible energy not used in ruminant metabolism (Schulman & Valentino, 1976; Ungerfeld, 2018; Nehme et al., 2021). Also, converting propionate to glucose and using this hexose as an energy source is interesting for the tissue anabolism of ruminants (Buterry, 1983).

The addition of PA in the diets of beef sheep did not alter the ruminal fermentation variables, which can be interpreted positively, especially when verifying some improvement in animal performance is possible.

In this study, there was no increase in the production of volatile fatty acids (VFAs). However, the animals showed higher ADG, suggesting that adding PA in the diet improves the efficiency of nutrient use. Belanche et al. (2020) found similar results when evaluating the use of PA in the form of EOs for dairy cows through a meta-analysis study, highlighting that there was no change in ruminal parameters. However, there was an improvement in nutrient digestibility and increased milk production.

The formation of this database was complex due to the variety of measurement units used by the authors. Some studies expressed the amount of VFAs in mmol L^{-1}, others in meq L^{-1}, and other authors in mol 100 mL^{-1}. This lack of standardization in measurement units hinders data interpretation and may cause an increase in the values of the coefficients of variation.

The pH is widely used to indicate final meat quality since the decrease in muscle pH from approximately 7.0 to values between 5.3 and 5.9 in sheep meat (Warner et al., 2010) significantly influences meat quality. The reduction of pH and temperature during the development of rigor mortis can influence meat color, texture, and water-holding capacity (Matarneh et al., 2017). This can lead to changes such as cold shortening or DFD (dark, firm, and dry) and PSE (pale, soft, and exudative) meats (Lonergan et al., 2010; Braden, 2013). The addition of PA in the diet of beef sheep in this study did not influence the pH of the carcasses but reduced the shear force. A similar result was found by Dorantes-Iturbide et al. (2022), who verified a reduction in shear strength without changing the pH of sheep meat supplemented with EOs, suggesting, as in the present study, that the intake of PA improves the tenderness of sheep meat. Furthermore, the lower age at slaughter can reduce the shear force, since younger sheep have fewer collagen cross-links in the muscle and, therefore, a greater potential for gelatinization of this fraction, producing softer meat (Smith & Judge, 1991; Feijó, 2011; Yusuf et al., 2018).

Although the addition of PA did not influence the weight of the cold carcass, the REA was greater in the carcasses of sheep that received PA in the diet. Bertoloni et al. (2020)

found similar results to this study, in which the authors reported that dietary inclusion of EOs increased REA without changing cold carcass weight. REA represents the degree of muscularity of the carcass and, indirectly, the proportion of muscle in the body weight of animals (Vargas et al., 2014; Akbaş et al., 2018). In this sense, we suppose that the carcasses of sheep treated with PA may have been more muscular due to the increase in protein and metabolizable energy of the diets.

The higher meat cooking losses of the sheep treated with PA can be attributed to the higher muscle contents and lower fat contents in the sheep carcass. This increase in cooking losses may be related to the lower slaughter age of the animals since sheep slaughtered younger produce less fatty carcasses (Lawrie, 2006). Furthermore, the absence of changes in the production of ruminal acetate, the primary precursor of adipose tissue in ruminant animals (Laliotis et al., 2010), directly reflects the thickness of subcutaneous fat, which can cause an increase in losses due to cooking. Unlike our results, Smeti et al. (2017) provided rosemary EOs in the diet of sheep and found no change in this parameter.

Conclusions

We recommend the inclusion of phytogenic additives in the diet of sheep since it does not change nutrient intake, improves crude protein digestibility, and increases the average daily gain of sheep while maintaining ruminal parameters in balance. It also improves aspects related to carcass traits, such as REA. Therefore, the phytogenic additives has similar benefits to growth-promoting antibiotics, that is, it improves performance characteristics and maintains ruminal parameters.

Conflict of interest

The authors declare that there are no competing interests.

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