Research Article

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Meta-analysis of the benefits of dietary *Saccharomyces cerevisiae* intervention on milk yield and component characteristics in lactating small ruminants

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Abstract: Milk yield and components in small ruminants fed *Saccharomyces cerevisiae* (SC) have been investigated, but results were not consistent among investigators. Hence, this trial aimed to explore the efficacy of SC supplementation in improving milk yield and components (i.e., milk proteins, fat, lactose, total solids and ash) in small ruminants. A search performed in Scopus, PubMed and Google Scholar databases yield 1,826 studies, of which 26 met the inclusion criteria. Random-effects model was used to aggregate milk production variables. Meta-regression analysis examined the effect of the following moderators: SC type, ruminant type (sheep or goat), diet type, breed, duration of supplementation and supplementation levels on outcome measures. Subgroup analysis explored the influence of the following moderators: SC type and ruminant type on outcomes measures. SC had positive moderate effect on milk yield (standardised mean difference [SMD] = 0.72; p < 0.001; heterogeneity [I^2] = 73%) and small effect on milk proteins (SMD = 0.46; p = 0.004; I^2 = 83%), milk lactose (SMD = 0.17; p = 0.007; I^2 = 0%) and fat (SMD = 0.28; p = 0.016; I^2 = 70%). Subgroup analysis revealed that SC improved milk yield, lactose and proteins in lactating sheep and milk yield and fat in lactating goats. Our results show that moderators influenced the results of the meta-analysis and explained most of the sources of heterogeneity. In conclusion, SC should be included in small ruminant diets as it had small-to-moderate effects on milk yield and aspects of milk components.

Keywords: yeast, sheep and goats, milk variables, meta-analysis, meta-regression

1 Introduction

Small ruminants (sheep and goats) contribute immensely in improving food security (meat and dairy products) and represent the main source of income for smallholder farmers [1,2]. The demand for dairy products is increasing in developing countries due to rapid population growth, and this is envisaged to continue in the coming years [1]. Goat and sheep milk are vital sources of essential nutrients in human nutrition. Given the increasing consumer demand for high-quality milk and the fact that milk price is determined by milk quality, there is a need to improve milk production and quality using feed additives [3,4].

Saccharomyces cerevisiae (SC), an eco-friendly feed additive has been shown to encourage the proliferation of fibre-digesting microbes in the rumen (paunch), which in turn influence milk production and component yield in ruminants [3,5]. Three different types of SC utilised in ruminant nutrition are active SC (also called live SC), SC culture (also known as fermented SC, SC hydrolysate, scrap SC and SC extract) and inactive SC. Active SC contains pure culture of metabolically active cells, whereas inactive SC has no active cells and is commonly referred to as nutritional yeast. SC culture is a product of SC fermentation. Live SC works by reducing the concentrations of oxygen in the paunch, thereby assisting in the proliferation of bacteria that degrade fibre in the paunch [6,7]. Live yeast also secretes metabolites which bacteria that degrade fibre in the paunch used as nutrient sources [8]. Although SC culture lacks the ability to reduce the

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concentration of oxygen in the paunch, it produces metabolites that increase rumen microbial activity, alter its fermentation trend, enhance movement of nutrients to the abomasum and stimulate digestion processes [8,9]. SC feed additive promotes healthy rumen environment by inhibiting the growth of lactate-synthesizing microbes and supporting the multiplication of lactate-using microbes [10], which in turn transforms lactate to volatile fatty acids (VFAs) causing a drop in lactate content and a rise in ruminal pH [11,12]. Pinloche et al. [13] reported that SC encourages the growth of *trans*-11 hydrogenating bacteria in the paunch by inhibiting the number of lactate-producing microbes, which stimulates the production of *trans*-11 and *cis*-9, *trans*-11-conjugated linoleic acid (CLA) in the paunch, thereby aiding milk fat synthesis. Bauman et al. [14] also confirmed that SC modifies ruminal pH by stimulating the activities of ruminal biohydrogenation microbes. The action of SC on milk yield and component characteristics in small ruminants is, however, inconsistent [15–23] and may be influenced by factors such as SC type, quantity of SC added to the diets, analytical methods, parity and stage of lactation. In spite of the fact that the mechanisms by which SC increases milk production in small ruminants are not clear. SC may enhance milk yield and quality by increasing the growth of *trans*-11-hydrogenating bacteria in the rumen via competitive exclusion and antagonism, stabilisation of ruminal pH, improvement in dry matter intake and increase in nutrient digestion and absorption [3,24,25].

The utilisation of meta-analytical approach to resolve divergence in research findings across studies has been encouraged [26–28]. This is a statistical technique that employs explicit methods to pool results from published studies with conflicting findings to increase statistical power, detect patterns and identify research gaps that would not be possible in a single study [29–31]. However, literature on the meta-analytic effect of SC on performance of lactating small ruminants, to the best of our knowledge, is lacking. Therefore, the purpose of this trial was to perform a meta-analysis asking the research question: what is the effect of diets with and without SC on milk yield and component characteristics of small ruminants?

2 Materials and methods

2.1 Study design and data sources

This investigated adhered to the protocols of the preferred reporting items for systematic review and meta-analyses provided by Moher et al. [32] as shown in Figure 1. Other detailed protocol for conducting this study was not used. Authors methodically searched Scopus, Google Scholar and PubMed databases from February 4 to March 10, 2022, for published trials that examine the impact of SC on production indices in small ruminants. Our search was not constrained by publication year and language. Search terms were sheep, goats, SC, milk yield, milk ash, proteins, lactose, total solids and fat, while search queries were AND and OR. Reference sections of identified studies were also searched for related articles.

Ethical approval: The conducted research is not related to either human or animal use.

2.2 Inclusion criteria

Selection criteria were centred on PICO criteria, where the letters in PICO stand for Population (i.e., small ruminants), Intervention (i.e., SC supplementation), Control group or comparison (i.e., diets with and without SC) and Outcomes (i.e., milk yield, proteins, lactose, fat, ash and total solids). Studies that reported the influence of diets with and without SC supplementation on at least one of the outcome measures in small ruminants were included in this analysis. For an article to be used for the investigation, the experimental diets must be free of antibiotics and other growth-enhancing agents. Study must report the mean, number of goats and sheep and dispersion metric such as standard error (SE), standard deviation (SD) or 95% confidence interval (CI). The initial search result yielded 1,826 articles. Figure 1 shows the overall screening process and number of studies excluded. A total of 1,595 studies were excluded due to duplication based on title and abstract review. One hundred and twenty-seven of the remaining 231 articles were removed after full-text screening due to the articles not being in small ruminant. Out of the 104 studies remaining, 78 were excluded for being review (10), not in measured outcomes (62) and having no extractable data (6). Twenty-six studies were used in the investigation (Figure 1). All identified studies, after exclusion of duplicates, were evaluated and disagreements resolve by consensus.

2.3 Data synthesis

Database of the 26 studies used for the investigation is presented in Table 1. Author's name, publication year,

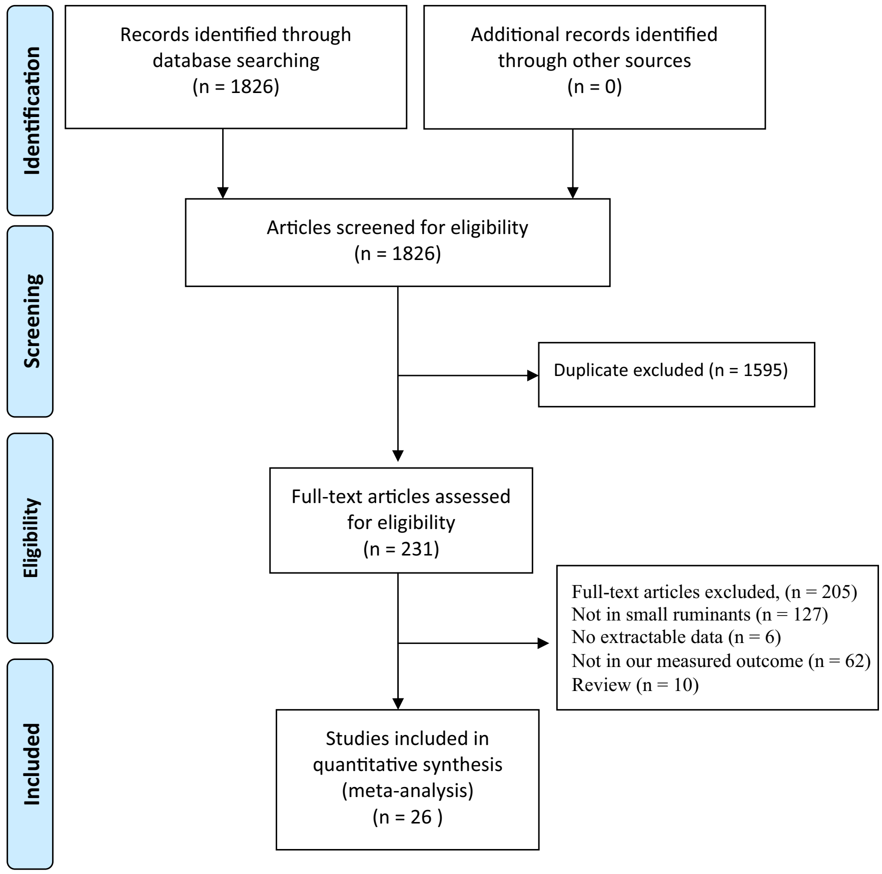

Figure 1: Study selection flow chart for the meta-analysis.

study country, studied moderators (SC type [active, culture and inactive], ruminant type [sheep versus goat], breed, diet type [forage, concentrate or both], duration of SC supplementation and supplementation level) and measures of variance (SD, SE and 95% CI) were extracted from the 26 publications that were suitable for the study. Information on the mean values of our outcomes of interest for the SC and control groups and the number of animals included in the experimental and control groups were retrieved. SD was estimated from SE following the method of Higgins and Deeks [33] where SE was stated instead of SD. The extracted data were keyed into an excel sheet and transformed to a CSV file which is the only format recognised by the Open Meta-analyst for Ecology and Evolution (OpenMEE) software.

2.4 Statistical analysis

OpenMEE, cross-platform software built by Wallace et al. [34], was used for the analysis. Results were pooled and presented as standardised mean difference (SMD) at 95% CI. SMD was deemed significant when the CI did not overlap [30]. SMD was designated small effect $0.2 \leq |SMD| < 0.5$, moderate effect $0.5 \leq |SMD| < 0.8$ and large effect $|SMD| \geq 0.8$ using the classification methods of Cohen [35]. All the forest plots were built with OpenMEE software. Random-effects model (REM) was employed to examine the impact of diets with and without SC on milk characteristics in sheep and goats following the procedures of DerSimonian and Laird [36]. The REM was considered more appropriate instead of the fixed effect model since the 26 studies used for the trial were heterogeneous [37]. Heterogeneity was explored via *Q*-statistic. Heterogeneity was quantified using I^2-statistic [38] and categorised as small (25%), moderate (50%) and high (≥75%) heterogeneity [39]. The value of 0% suggests the absence of heterogeneity. We used sensitivity analysis (SA) to assess the impact of studies deemed to have an unwarranted influence on the analysed outcomes [40]. It was performed when there is evidence of heterogeneity across studies utilised for the analysis. SA involves completing the same analysis but leaving out one study in each iteration [40].

Subgroup analysis was executed to assess the influence of ruminant type (sheep versus goats) on milk variables. We carried out meta-regression analysis to explore

Table 1: Database of studies used for the meta-analysis

References	Location	Design	Studied moderators						Milk yield and milk components
			Diet type	SC type	RT	Breed	DOS (day)	Supplementation levels (SL)	
Giger-Reverdin et al. [41]	France	RCBD	F + C	Live	1	Alpine/Saanen	42	0, 2	MY, MP, MF, ML, MA
Hadjipanayiotou et al. [15]	Cyprus	—	F + C	Culture	1, 2	Damascus $^{+}$/Chios $^{++}$	48	0, 5	MY, MP, MF, MTS, MA
Salama et al. [42]	Spain	—	F + C	Culture	1	**	84	0, 10	MY, MP, MF, MTS
Abd El-Ghani [43]	Egypt	—	F + C	Culture	1	Zaraibi	120	0, 3, 6	MY, MP, MF, ML, MTS, MA
Stella et al. [44]	Italy	—	F + C	Live	1	Saanen	105	0, 0.2	MY, MP, MF, ML
Ahmed et al. [45]	Egypt	—	F + C	Culture	1	Zaraibi	180	0, 1, 2	MY, MP, MF, ML, MTS, MA
Mahrous et al. [46]	Egypt	—	F + C	Live	1	Zaraibi	120	0, 3	MY, MP, MF, ML, MTS, MA
Masek et al. [16]	Croatia	—	F + C	Live	2	*	140	0, 3, 6	MY, MP, MF, ML, MTS
Baiomy [18]	Egypt	—	F + C	Live	2	Ossimi	42	0, 3, 6	MY, MP, MF, ML, MTS
Lima et al. [47]	Brazil	CRD	F + C	Culture	1	Saanen	90	102, 229	MY, MP, MF, ML, MTS
Macedo et al. [48]	Mexico	—	F + C	Culture	2	Pelibuey ewes	49	0, 14	MP, MF, ML, MTS
Gomes et al. [49]	Brazil	CRD	F + C	Inactive	1	Saanen	200	0, 97.2, 234.1	MY
Zaleska et al. [50]	Poland	—	F + C	Culture	2	—	28, 70	0, 3, 50	MP, MF, ML
Zicarelli et al. [17]	Italy	—	F + C	Culture	1	Cilentana	120	0, 2	MY, MP, MF, ML
Kholif et al. [51]	Egypt	LSD	F + C	Live	1	Nubian	22	0, 4	MY, MP, MF, ML, MTS, MA
Ma et al. [52]	China	—	F + C	Live	1	Saanen	56	0, 5	MY, MP, MF, ML, MTS
Aazami et al. [19]	Italy	CRD	F + C	Culture	1	Saanen	15	0, 3, 5	MY, MP, MF, ML
Elaref et al. [22]	Egypt	—	F + C	Live	2	Sohagi ewes	105	0, 5, 10	MY, MP, MF, ML, MTS
Aaliya et al. [53]	India	CRD	F + C	Live	1	Boar x local cross	182	0, 2.5, 4	MP, MF, MTS
Abbas et al. [20]	SA	—	F + C	Live	1	Beetal	60	0, 5, 10	MY, MP, MF, ML, MTS
Alshanbari et al. [54]	SA	RCBD	F + C	Culture	1	Ardi	90	0, 2.5, 3.5, 4.5	MY, MP, MF, ML
Mavrommatis et al. [21]	Greece	—	F + C	Live	2	Chios ewes	84	0, 2	MY, MP, MF, ML
Sahoo et al. [55]	India	—	nr	Live	1	Beetal	30	0, 2	MY
Khan et al. [23]	Pakistan	CRD	F + C	Live	1	Beetal	45	0, 1.5, 3	MY, MP, MF, ML, MTS, MA
Tayeb [56]	Iraq	CRD	C	Culture	2	Awassi ewes	84	0, 0.3, 0.6, 0.9	MY, MP, MF, ML
Almallah et al. [57]	Iraq	CRD	C	Culture	2	Awassi ewes	17	0, 10	MY, MP, MF, ML

SC – *Saccharomyces cerevisiae*; SA – Soudi Arabia, 1 – Goat; 2 – Sheep; * Istrian Sheep × East Friesian; ** Murciano-Granadina; RT – ruminant type; C – concentrate; LSD – Latin square design; CRD – complete randomised design; RCBD – randomised complete block design; F – forage; nr – not reported; DOS – duration of supplementation in days; SL – supplementation level, in g/kg feed; MY – milk yield; MP – milk protein; MF – milk fat; ML – milk lactose; MTS – milk total solids; MA – milk ash.

the relationships between SC type, breed, diet type, ruminant type, duration of SC supplementation and supplementation level as moderators and milk production parameters as outcomes. The influence of study design, milking frequency, parity, mode of milking (manual versus machine) and age on milk production and quality in lactating small ruminants fed SC-supplemented diets in this investigation were not tested because of missing data. In addition, we could not consider the effect of the following potential covariates: intake, nutrient digestibility, lactation stage and rumen fermentation on our measured outcomes in lactating small ruminants on dietary SC supplementation due to insufficient data. Attempts made to get the missing information from the corresponding authors failed. Publication bias was determined using Rosenberg's failsafe number (Nfs) [58] and funnel plot [59]. Funnel graph resembles an inverted symmetrical funnel when there was no publication bias. However, when there is the presence of publication bias the plot would resemble an asymmetrical funnel with spaces in the bottom corner of the funnel [60].

3 Results

3.1 Overview of the meta-analysis

Twenty-six quantitative articles met our selection criteria (Figure 1 and Table 1). The most commonly studied SC type was live SC (13) followed by SC culture (12) and inactive SC (1). The dose level of SC ranged from 0.2 to 234.1 g/kg feed. The studies included in the analysis spanned 25 years (1996–2021). The included articles were performed in 17 countries that cut across five continents, with Egypt having the highest number of studies followed by Italy. Nine studies were from Europe while the remaining 17 were from Africa, Asia, South America and North America.

3.2 Milk yield and proteins

Results showed that SC had positive moderate effect on milk yield (SMD = 0.72; $p < 0.001$ and $I^2 = 73\%$; Table 2) and milk protein (SMD = 0.46; $p = 0.004$; $I^2 = 83\%$; Table 2) relative to controls. Subgroup analysis revealed that SC had positive moderate influence on milk yield in goats (SMD = 0.51; $p = 0.002$; $I^2 = 66\%$; Table 3) and large effect on sheep (SMD = 1.15; $p < 0.001$; $I^2 = 74\%$; Table 3) compared to controls. Live SC had a positive large effect on milk yield (SMD = 1.38; $p < 0.001$; Table 4), whereas SC culture had a moderate effect on milk yield (SMD = 0.53; $p = 0.002$; Table 4) compared to controls. Lactating goats fed diets with and without SC had similar milk protein content (SMD = 0.08; $p = 0.460$; Table 3). In contrast, SC had a large influence on milk protein content (SMD = 0.89; $p = 0.005$; $I^2 = 93\%$; Table 3) in lactating sheep compared to controls. Our results also show that SC culture had a moderate influence on milk protein yield (SMD = 0.60; $p = 0.037$; Table 4) in small ruminants. We found significant heterogeneity across trials that explored the effect of SC on milk yield and proteins as indicated by the I^2 values of 73–83% (Table 2). Results of the relationship between SC supplementation level and milk yield and components are presented in Table 5. Results found no significant relationship between SC supplementation level and milk variables (milk yield and milk proteins). In contrast, duration of supplementation (DOS), ruminant type, SC type and breed were limiting factors in the present investigation and explained most of the variability in milk yield. There were significant associations between milk proteins and studied moderators (DOS, ruminant type, diet type and breed).

Table 2: Effect of SC on milk yield and components in small ruminants

Outcomes	Model results				Heterogeneity	
	SMD	95% CI		$p < 0.05$	I^2-test (%)	$p < 0.05$
Milk yield	0.72	0.44	2.00	<0.001	73	<0.001
Milk protein	0.46	0.15	0.77	0.004	83	<0.001
Milk lactose	0.17	0.05	0.30	0.007	0	0.860
Milk fat	0.28	0.05	0.51	0.016	70	<0.001
Milk total solids	0.11	−0.05	0.26	0.173	0	0.975
Milk ash	0.17	−0.08	0.41	0.176	0	0.980

SC – *Saccharomyces cerevisiae*; SMD – standardised mean difference; CI – confidence interval.

3.3 Milk lactose, fat, total solids, ash yield and analysis of publication bias

Results demonstrated that SC had small effect on milk lactose (SMD = 0.17; $p = 0.007$; $I^2 = 0\%$; Table 2) and milk fat (SMD = 0.28, $p = 0.016$; $I^2 = 70\%$; Table 2) in small ruminants. The effect of ruminant type on milk lactose and fat is described in Table 3. Subgroup analysis suggested that SC treatment had a small impact on milk

Table 3: Effect of ruminant type on milk yield and components in small ruminants fed SC supplemented diets

Parameters	Goats				Sheep			
	SMD	95% CI		$p < 0.05$	SMD	95% CI		$p < 0.05$
Milk yield	0.51	0.19	0.83	0.002	1.15	0.72	1.584	<0.001
Milk protein	0.08	−0.12	0.27	0.460	0.89	0.27	1.512	0.005
Milk lactose	0.13	−0.11	0.38	0.283	0.18	0.01	0.339	0.037
Milk fat	0.30	0.05	0.55	0.019	0.201	−0.19	0.606	0.306
Milk total solids	0.04	−0.19	0.26	0.734	0.17	−0.04	0.387	0.118

SC – *Saccharomyces cerevisiae*; SMD – standardised mean difference; CI – confidence interval.

Table 4: Subgroup analysis of the effect of SC type on milk yield and components in small ruminants

Parameters	Live SC				SC culture			
	SMD	95% CI		$p < 0.05$	SMD	95% CI		$p < 0.05$
Milk yield	1.38	1.03	1.73	<0.001	0.53	0.20	0.86	0.002
Milk protein	0.16	−0.08	0.40	0.198	0.60	0.04	1.15	0.037
Milk lactose	0.12	−0.09	0.33	0.273	0.19	0.02	0.36	0.027
Milk fat	0.28	0.06	0.49	0.012	0.20	−0.18	0.58	0.295
Milk total solids	0.20	0.00	0.41	0.049	−0.03	−0.27	0.21	0.827

SC – *Saccharomyces cerevisiae*; SMD – standardised mean difference; CI – confidence interval.

lactose content in sheep (SMD = 0.18, $p = 0.037$) and milk fat in does (SMD = 0.30, $p = 0.019$) compared to controls. In converse, SC did not improve milk lactose in goats and fat yield in sheep. Our results as shown in Table 4 indicate that SC culture (SMD = 0.19; $p = 0.027$) had a small influence on milk lactose yield in small ruminants. Furthermore, live SC had a small impact on milk fat (SMD = 0.28, $p = 0.012$; Table 4) and milk total solids (SMD = 0.20, $p = 0.049$; Table 4). Data on the impact of studied moderators on milk lactose, total solids and fat yield are presented in Table 5. Meta-regression revealed that DOS and breed are predictors of the study effect on milk fat. There was significant relationship between milk lactose and breed. However, there is no relationship between moderators and milk total solids. There is minimal sign of publication bias as displayed in Figures S1–S5. The Rosenberg Nfs for the database is 510, which is 3.6 times higher than the 140 ($5 \times n + 10$) required to proclaim the results of analysis robust in the face of publication bias.

4 Discussion

Results showed that systematic search performed in the three online databases yielded 26 studies published in 17 study countries spanning five continents, with most of the studies published between 2016 and 2021. The continuous yearly increase in SC-based feed additive research in this study could be linked to the growing campaign on the use of biotherapeutic agents as a replacement for antibiotics in animal feed, which have been reported to increase the spread of antibiotic resistant strains of bacteria to the environment and humans via consumption of animal products with antibiotic residues [61].

Our search on available literature revealed that this study could be the first attempt to use meta-analytic method to assess the efficacy of SC administered via feed on milk yield and components in lactating small ruminants. The low-to-medium milk yield and component fractions (milk lactose, protein and fat) found in animals on SC intervention in this study compared to controls suggest that SC-based diets were moderately utilised for milk yield and protein by the lactating small ruminants. The observed moderate effect of SC on milk yield and the small effect on milk composition could be partly explained by SC's ability to stimulate rumen fermentation, increase the production of VFAs and enhance digestion of fibre in the rumen. Most milk proteins are synthesised within the mammary epithelial cells using the substrates extracted from blood such as free amino acids and peptide-bound amino acids [62]. The mechanism by which SC regulates milk protein yield in lactating ruminants

Table 5: Relationship between moderators and milk production variables in lactating small ruminant

Measured outcomes	Moderators	Q_M	df	$p < 0.05$	R^2 (%)
Milk yield	DOS	112	19	0.001	94
	SL	22	18	0.234	14
	Ruminant type	5.27	1	0.022	17
	SC type	32.4	2	9.41×10^{-08}	55
	Diet type	1.22	1	0.269	1
	Breed	58.8	13	8.69×10^{-10}	71
Milk proteins	DOS	204	22	0.001	96
	SL	15.1	16	0.519	12
	Ruminant type	6.16	1	0.013	13
	SC type	1.33	1	0.248	3
	Diet type	4.21	1	0.040	40
	Breed	30.3	14	0.007	100
Milk lactose	DOS	24.7	18	0.132	0
	SL	23.4	16	0.104	100
	Ruminant type	0.02	1	0.879	0
	SC type	2.00	1	0.658	0
	Diet type	0.09	1	0.759	0
	Breed	22.8	12	0.030	0
Milk fat	DOS	34.7	21	0.031	37
	SL	26.6	19	0.114	19
	Ruminant type	0.25	1	0.621	0
	SC type	0.54	1	0.463	0
	Diet type	0.22	1	0.642	0
	Breed	52.7	15	4.28×10^{-06}	100
Milk total solids	DOS	11.3	17	0.841	0
	SL	6.27	8	0.617	0
	Ruminant type	0.71	1	0.400	0
	SC type	2.05	1	0.152	0
	Breed	9.20	10	0.513	0

p – probability; Q_M – coefficient of moderators; SC – *Saccharomyces cerevisiae*; df – degree of freedom; R^2 – amount of heterogeneity explained by the moderators; DOS – duration of supplementation; SL – supplementation level.

is yet to be properly documented. However, the reported ability of SC to improve the nutrient digestion and assimilation of amino acids may partly explain the moderately higher milk proteins observed in this study when compared to the controls [24]. The result of this study also demonstrated that SC had a small positive effect on milk lactose and fat content, suggesting that SC supplementation had minimal impact on milk lactose and fat. Our results indicate that milk total solids and ash content in lactating small ruminants were not affected by SC supplementation. Few studies [15,34,41,43,46,51] were used to compute the effect of SC on milk ash yield in the present meta-analysis, and the result, therefore, should be interpreted with caution.

The subgroup analysis results revealed that lactating small ruminants that received SC-supplemented diets produced more milk than those on controls. This agrees with Stella et al. [44], who recorded higher milk yield in goats offered SC in comparison with the controls. Contrary to the present finding, Uyeno et al. [25] found that addition of SC at 5 or 10 g/animal/day did not increase milk yield in lactating animals. This discrepancy may be due to differences in species of animal used, lactation stage and SC supplementation level. The significant differences in the milk protein content between goats and sheep might reflect the differences in genetics and physiological abilities to change their milk protein content according to changes in dietary constituents. This finding is consistent with Kanwal et al. [63], who reported higher protein yield in sheep milk than in goat milk.

The result of this meta-analysis suggests that the milk lactose content in lactating goats was not improved by SC additive. In contrast, our result showed that lactating sheep offered SC had significantly higher milk lactose content than controls. The increased milk lactose may be credited to the potential of SC to modulate the rumen environment to favour the production of propionate [64,65], which then enters the tricarboxylic acid cycle to produce oxaloacetate, which in turn produces glucose, a precursor of milk lactose. The observed small positive effect of SC on milk lactose of sheep in this meta-analysis corroborates the findings of Macedo et al. [48], who recorded a 13% increase in milk lactose in lactating Pelibuey sheep offered 14 g SC/head/day compared to those fed diets without SC supplementation.

Milk fat is an essential part of milk that can be easily influenced by nutritional management. Studies have shown that SC increases the concentration of acetate in the rumen [66,67], which according to Hanson and Ballard [68], is the precursor for fat synthesis in the adipose and mammary tissues. The small milk fat yield in lactating goats following SC supplementation in this study may be credited to the low potentiality of SC in increasing acetate level in the forestomach. In addition, this could be linked to the low capability of SC to modify rumen biohydrogenation pathway to favour the production of *trans*-11 and *cis*-9, *trans*-11-CLA known to enhance milk fat production.

Live SC had a positive large effect on milk yield, whereas SC culture had a moderate effect on milk yield when compared to controls. The exact mechanism underlying the observed positive large impact of live SC on milk yield in lactating small ruminants in the current study is not clear. However, this could be attributed to the capability of live SC to scavenge excess oxygen in the ruminal fluids, lower the redox potential and enhance the growth of cellulolytic bacteria [6,7], leading to an increase in milk yield. The improved milk protein content in lactating ruminants fed SC culture compared to those fed live SC in this study indicates that SC culture has the potential to produce metabolites that alter the fermentation trend, enhances nutrient digestibility and ammonia uptake and improves microbial protein production [8,9], resulting in higher milk protein content.

There is evidence of large heterogeneity in this meta-analysis as shown by the I^2 values [38]. This problem of heterogeneity was not resolved by subgroup analysis. The present study showed that DOS is a predictor of SC effect on milk yield and some of its constituents and accounted for 94, 96 and 37% of variations in milk yield, proteins and fat, respectively. Our meta-regression found that SC type is a significant predictor of the impact of SC on milk yield and accounted for 55% of the sources of heterogeneity among the studies utilised for the meta-analysis. Meta-regression analysis demonstrated that breed is a limiting factor among the studies included in the meta-analysis that led to the inconsistent results among investigators on the effect of SC supplementation on milk proteins and fats. The effects of factors such as lactation stage and milking frequency in our outcome measures not reviewed in this meta-analysis because of missing data may have accounted for the variations that could not be explained by the studied moderators. In addition, residual heterogeneity can be attributed to variables such as milking frequency, parity, study design, mode of milking, age, SC intake, nutrient digestibility and rumen fermentation, which were not examined in this study due to missing data. Publication bias defined as the tendency of authors or journal editors to publish studies with significant findings is one of the challenges in meta-analytical studies. There is publication bias in this study and the Rosenberg Nfs for the database is 3.6-fold beyond the threshold required to declare the pooled results robust. However, this is not an issue as it would take a relatively large number of unpublished articles to change the significant effects of SC on milk yield and component parameters in lactating small ruminants [69].

5 Future research direction and conclusion

Future research is therefore recommended to determine the effect of the following potential covariates: milking frequency, lactation stage, parity, age, digestibility and rumen fermentation on milk production and component characteristics in small ruminant fed SC supplemented diets that were not reported in this meta-analysis because of insufficient data. In conclusion, our pooled results suggested that SC can be added to the diets of lactating sheep and goats to improve milk yield and protein. This study could be used as a model for future research on the impact of SC on milk production and component yield in small ruminants.

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