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Systematic Review

Effect of Polyphenol Supplementation on Milk Composition and Fatty Acid of Dairy Animal: A Systematic Review

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Simple Summary: The usage of phenolic compounds as feed in ruminant production due to its potential in reducing enteric methane production in ruminant has been widely studied. Among the benefits of polyphenol incorporation in the feed are the ability to modify rumen fermentation without affecting animal performance, reducing oxidative stress of high-yielding dairy animals and improving animal health. Therefore, this study aims to assess the literature on polyphenol supplementation and its effect on milk composition and milk fatty acid in dairy animals. The obtained findings show polyphenol supplementation regardless of its polyphenol sources highly impact milk saturated fatty acid and milk medium-chained fatty acid produced. This review demonstrated that different sources of polyphenol supplement may impact the milk composition and milk fatty acid produce by dairy animals, differently.

Abstract: The aim of this study is to review the supplementation of polyphenol on milk composition and milk fatty acid content in dairy animal. A systematic review of literature was carried out by using Google Scholar, Scopus, and Science Direct databases. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines methodology was carried out and as a result, 21 articles were included. Results showed that polyphenol supplementation significantly affect milk saturated fatty acid content ($p < 0.00001$) and milk medium-chain fatty acid content ($p < 0.0001$). Meanwhile, polyphenol supplementation effects significantly in the subgroup of agro-industrial by-products ($p < 0.05$) for milk protein content, grain ($p < 0.05$) for milk lactose content, all the subgroup for milk saturated fatty acid content and both grain and agro-industrial by-products for milk medium-chain fatty acid content. In conclusion, milk saturated fatty acid is affected by polyphenol supplementation regardless of polyphenol sources. However, it is recommended to include more studies in future to obtained a higher heterogeneity.

Keywords: polyphenol; milk composition; milk fatty acid; systematic review

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1. Introduction

Plant secondary metabolism is a vast reservoir of natural chemical diversity, containing an enormous number of compounds and enzymes, as well as a diverse set of mechanisms for gene regulation and metabolite and enzyme transport. Phenolic compounds are the most widely distributed secondary metabolites, ubiquitously present in the plant kingdom: it is estimated that about 2% of all carbon photosynthesized by plants is converted into flavonoids or closely related compounds, amounting to about 1×10^9 t per annum [1].

Polyphenol in plants has been widely explored, used, and studied, in relation to animal production. Various attempt has been made in using plant bio-actives to mitigate the production of enteric methane from ruminant [2,3]. Polyphenols, essential oils, saponins and polysaccharide, are among plant bio-active compound that has been used to reduce methane production by manipulating ruminal microbial feed fermentation without interfering with ruminant production performance [4]. High-yielding dairy animals are prone to oxidative stress, which can be exacerbated by certain environmental, physiological, and dietary factors [5]. Phenolic compounds, including stress-related phytochemicals, have been linked to beneficial effects caused by fruit and vegetable consumption, particularly due to their antioxidant activity [6]. Meanwhile, a study by [7] found that an increase in milk yield with fat content reduction in the liver was found when green tea extract was fed to the heifers.

These naturally-rich polyphenol supplementation can be categorized in to three main group of different sources; mainly, seed, forages, and agro-industrial by-product. The availability of polyphenol supplementation from seeds and forages is easier to obtained compared with polyphenol supplementation from agro-industrial by-product sources which may have limited availability due to seasonal demand or produced. However, in terms of sustainability, polyphenol supplementation from agro-industrial by-product sources may help reduces the farming cost, as product disposal, minimizing wastages and contributes an added value to the dairy produces [8]. Polyphenol from seeds, for example coix seed extract quadratically increased goat milk protein content as higher coix seed extract supplementation level increased [9]. Meanwhile, polyphenol from agro-industrial by-product such as grape or tomato residue as reported in [8] shows milk fat content increased in goat while unaffected in sheep. Additionally, polyphenol from forages sources as reported in [10] showed a higher milk fat content in cows fed with perennial rye grass as compared to total mixed ration feeding system and clover-fed cow.

As of late, many reviews on plant extracts or plant components, such as saponins, tannins, and essential oils, as rumen modifiers have recently been published. However, they have mostly focused on the alterations in ruminal fermentation [11–16], ruminal microbial population [4,15], and their association with methanogenesis [4]. Lipid supplementation was also evaluated and compared in cattle and sheep for their effects on methane emission, digestibility, ruminal fermentation, and lactation performance. According to a recent meta-analysis study [17] the benefits of essential oil supplementation vary amongst ruminant species. Beef cattle, according to these authors, are more sensitive to essential oil than dairy cattle and small ruminants. Meanwhile, milk yield was improved with the supplementation of polyphenol-rich grape seed and marc extract in heifer [18]. Despite significant knowledge gained in recent years on the potential application of polyphenol-rich supplementation on rumen microbial fermentation modification and animal performances, the effects of polyphenol-rich supplementation to ruminant diets on their dairy performances such as milk compositions and fatty acid profiles are still lacking. Very few studies have reviewed and evaluated the changes in milk composition and milk fatty acid content when the animals been fed with phytochemicals and lipids in the feed. Hence, the objective of this study was to review and determine the extent of the effects of plant polyphenol supplementation on milk composition and fatty acid profile through a systematic review.

2. Materials and Methods

A database of previous studies involving polyphenol supplementation and milk fatty acid profile was created based on the guideline requirements of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [19]. The literature search was performed in several databases, including Google Scholar, Scopus, and Science Direct. The keywords used to search the databases were "feed" "milk fatty acid", "extract", "polyphenol", and "rumen". The keywords were chosen to identify publications with experiments that were appropriate for further exploration. The response of interest included total phenolic content, milk fat content, milk protein content, milk lactose content, milk saturated fatty acid (SFA) content and milk medium-chain fatty acid (MCFA) content. A total of 2214 studies were identified through database searches: Google Scholar (1980), Science Direct (156), and Scopus (78). The first round of exclusion excluded review articles, books, and encyclopedias, leaving 297 studies suitable for further screening. In the second round of screening, irrelevant articles were excluded which includes conference proceedings, short communication, in-vitro studies, and reviews, which resulted in 81 articles remaining. In these two stages, the title and, if necessary, the abstracts were reviewed. The final screening was performed to select eligible studies according to the following criteria: (1) the study was conducted between January 2008 and January 2023, (2) the study used a control group, (3) the study reported at least one of the outcome variables listed, and (4) the study reported the mean values and associated error. Only those manuscripts from which the authors of this review could extract the required data were included. Finally, 21 articles met the required criteria and were included in this systematic review. Figure 1 showed the search flow and data extraction process of the current study. The analysis was performed using Review Manager (RevMan version 5.3.5; The Cochrane Collaboration, The Nordic Cochrane Centre, Copenhagen, Denmark). The standard mean difference (SMD) approach RevMan implemented in the software was used as the basis of the comparison between the controls and treatments. Individual study weights were calculated as the inverse of the variance. Weighted averages and 95% confidence intervals (CI) were pooled and a random effect model was used to compute a summary of the effect across studies [20]. Given the different study locations covered by the review and the nature of the studies, assuming a single common fixed effect model was untenable. Heterogeneity among studies was evaluated using the Inconsistency index [21]. The I^2 value describes the percentage of total variation across studies that is due to heterogeneity rather than chance [21]. A classification of the I^2 values was used to interpret the heterogeneity magnitude: values around 25%, 50%, and 75% were considered as low, medium, and high heterogeneity respectively [21].

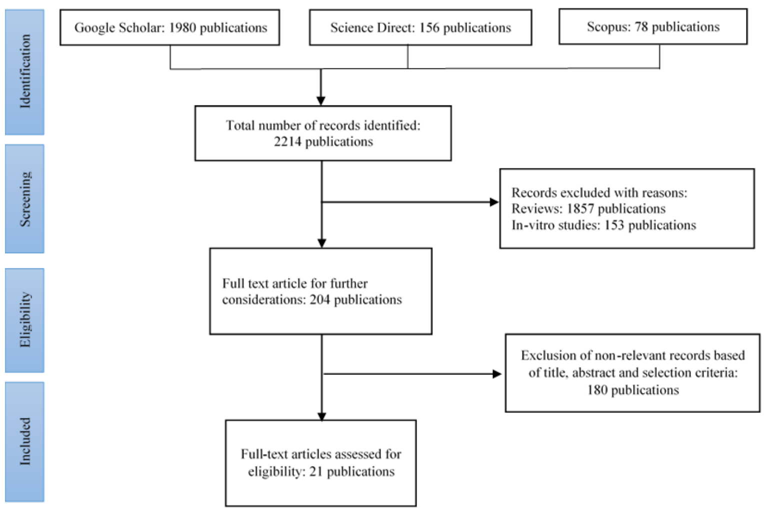

Figure 1. Literature retrieval flowchart.

2.1. Effect of Polyphenol Supplementation on Milk Fat Content

Nineteen research articles reporting 44 studies, were eligible to be included in the analysis to evaluate the effects of polyphenol supplementation on milk fat content. Subgroup analyses were conducted to see whether different sources of polyphenols affect the fat content in the milk. The different polyphenol sources were grain, forages and agro-industrial by-products, which constitute six, seventeen and twenty-one studies, respectively.

2.2. Effect of Polyphenol Supplementation on Milk Protein Content

A total of 44 studies from 19 research articles were eligible to be included in the study to evaluate milk protein content as affected by polyphenol supplementation in the diets. Subgroup analyses were conducted to see whether different sources of polyphenols affect the milk protein content. The different polyphenol sources were grain, forages and agro-industrial by-products, which constitute six, seventeen and twenty-one studies, respectively.

2.3. Effect of Polyphenol Supplementation on Milk Lactose Content

In the study to evaluate the effect of polyphenols supplementation on milk lactose content, thirty-seven studies from seventeen research articles were eligible to be included. Among the eligible publication, the number of studies belonging to grain, forages and agro-industrial by-products are only six, fourteen and seventeen studies, respectively.

2.4. Effect of Polyphenol Supplementation on Milk Saturated Fatty Acid Content

In the evaluation of milk saturated fatty acid content as affected by the supplementation of polyphenol, there are seventeen publications where the data from thirty-nine studies were incorporated in the review.

2.5. Effect of Polyphenol Supplementation on Milk Medium-Chained Fatty Acid Content

In this study, the data from twenty-one studies were extracted from nine publications in order to evaluate the content of MCFA in milk when the animals were fed with polyphenol-supplemented diet in the feed.

3. Results

The comprehensive database consisting of 70 dietary treatments in 21 publications was summarized, as shown in Table 1. Outcome measures examined in our systematic review included fat, protein, lactose, SFA, and MCFA content in milk. Characteristics of the selected studies are depicted in Table 1.

Table 1. Data tabulation of the chosen in-vivo experiments for the systematic review analysis.

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
1	[22]	-	Cow (Holstein)	Multi-parous	TMR [2]; 60:40 of forage to concentrate ratio (F:C) [1]	18% Soybean Meal	Agro-industrial by-product	0.202	15/5	2
		Yao et al. (UM) 2021				11% Unfermented yellow wine less	Agro-industrial by-product	0.582		
		Yao et al. (FM) 2021				11% Fermented yellow wine less	Agro-industrial by-product	0.676		
2	[23]	-	Goat (Nubian)	Multi-parous	40:60 (F:C) [1] Egyptian berseem clover and concentrates mixture.	Control	Forages	-	15/7	2
		Kholif et al. (ME10) 2018				10 mL *M. oleifera* leaves extract	Forages	0.6		
		Kholif et al. (ME20) 2018				20 mL *M. oleifera* leaves extract	Forages	1.2		
		Kholif et al. (ME40) 2018				40 mL *M. oleifera* leaves extract	Forages	2.4		
3	[24]	-	Cow (Holstein)	Multi-parous	TMR [2]	Corn silage	Forages	0.053	21/7	3
		Khosravi et al. 2018				Sorghum silage	Forages	1.698		
4	[25]	-	Goat (Alpine x Local breed)	n/a	Component feeding; 50:50 (F:C) [1]	Control	Forages	6.312	7/100	2
		Mitsiopoulou et al. WSS5 (2021)				5% of whole sesame seed	Seed/grain	9.43		
		Mitsiopoulou et al. WSS10 (2021)				10% of whole sesame seed	Seed/grain	12.603		
5	[26]	Cabiddu et al. 4 May 2009	Sheep (Sardinian)		Grazing Sulla-based pasture	Sulla pasture on 4th May	Forages	3.21	14/14	2
		Cabiddu et al. 17 May 2009				Sulla pasture on 17th May	Forages	3.55		
		Cabiddu et al. 1 Jun 2009				Sulla pasture on 1st Jun	Forages	3.42		

Table 1. *Cont.*

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
6	[27]	-	Sheep (Awassi)	Multi-parous	30:70 (F:C) [1] except Olive cake diet 20:80 (F:C) [1]	Control	Forages	0.67	10/50	2
		Abbeddou et al. (LS) 2011				Lentil straw	Forages	1.32		
		Abbeddou et al. (AL) 2011				Atriplex leaves	Forages	0.57		
		Abbeddou et al. (OL) 2011				Olive leaves	Forages	2.25		
		Abbeddou et al. (OC) 2011				Olive cake	Agro-industrial by-product	0.53		
		Abbeddou et al. (TP) 2011				Tomato pomace	Agro-industrial by-product	0.60		
7	[28]	-	Sheep (Comisana)	Multi-parous	Concentrates with *ad libitum* hay	Conventional concentrate as control concentrate	Agro-industrial by-product	0.194	14/21	2
		Campione et al. 2021				Experimental concentrate: with Cocoa bean shell	Seed/grain	0.52		
8	[29]	-	Sheep (Sarda)	Multi-parous	TMR [2]	Control (corn, soybean, pea)	Seed/grain	-	14/56	weekly
		Coreddu et al. (GS) 2016				Grape seed	Seed/grain	0.037		
		Coreddu et al. (LIN) 2016				Extruded linseed	Seed/grain	-		
		Coreddu et al. (MIX) 2016				Mixed of grape seed and extruded linseed	Seed/grain	0.038		
9	[30]	-	Cow (Holstein)	Primi-parous	TMR [2]; 32:68 (F:C) [1]	1.5% of palmitic acid-enriched fat with 8.7% pomegranate peel	Agro-industrial by-product	0.288	21/7	3
		Akhlaghi et al. (FO + PP) 2022				1.5% Ca salts of fish oil with 8.7% pomegranate peel	Agro-industrial by-product	0.357		
		Akhlaghi et al. (PAF + PP) 2022				1.5% of palmitic acid-enriched fat with 8.7% pomegranate peel	Agro-industrial by-product	0.23		
		Akhlaghi et al. (FO-PP) 2022				1.5% Ca salts of fish oil without pomegranate peel	Agro-industrial by-product	0.22		

Table 1. *Cont.*

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
10	[31]	-	Cow (Holstein)	Multi-parous	TMR [2]	0% of Pomegranate pulp silage (PPS) as control	Agro-industrial byproduct	0.078	20/5	1
		Kotsampasi et al. (P75) 2017				7.5% of PPS	Agro-industrial byproduct	0.226		
		Kotsampasi et al. (P150) 2017				15% of PPS	Agro-industrial byproduct	0.364		
11	[32]	-	Sheep (Valle del Belice)	Multi-parous	Component feeding; partial mixed ration (PMR) [3] of *ad libitum* hay with 600 g of concentrates daily with 1 kg of FLP replaced 200 g of concentrates	0% of Fresh lemon pulp (FLP) as control	Forages	0.84	14/7	1
		Todaro et al. (FLP1) 2017				9.01% of FLP	Agro-industrial by-product	1.132		
		Todaro et al. (FLP2) 2017				15.7% of FLP	Agro-industrial by-product	1.322		
12	[33]	-	Sheep (Comisana)	Multi-parous	Component feeding; PMR [3] of *ad libitum* chopped lucerne hay with 100 g of rolled barley, and 800 g/animal daily	0% of olive crude phenolic concentrates (OCPC)	-	-	21/14	2
		Cappucci et al. (L0.6) (2018)				0.6% of OCPC	Agro-industrial by-product	0.064		
		Cappucci et al. (L0.8) (2018)				0.8% of OCPC	Agro-industrial by-product	0.083		
		Cappucci et al. (L1.2) (2018)				1.2% of OCPC	Agro-industrial by-product	0.118		

Table 1. *Cont.*

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
13	[34]	-	Cows (Holstein -Friesian)	Multi-parous	Component feeding; PMR [3] of grass hay, corn silage, and Extrulin 135 (contain 60% of extruded linseed oil and 40% of wheat bran) Experimental dietary variation generated by offering AL/SF/BT in amounts representing approximately 20% of the basal diet	Pelleted alfalfa (AL) (*Medicago sativa L. 'Sanditi'*)	Forages	0.97	21/7	2
		Grosse Brinkhaus et al. (SF) 2016				Pelleted sainfoin (SF) (*Onobrychis viciifolia L. 'Perly'*)	Forages	3.241		
		Grosse Brinkhaus et al. (BT) 2016				Pelleted birdsfoot trefoil (BT) (*Lotus corniculatus L. 'Polom'*)	Forages	1.633		
14	[35]	-	Goat (Alpine × Beetal)	n/a	TMR [2]; 50:50 (F:C) [1] berseem hay and concentrate	0% of cumin seed extract (CSE)	-	-	28/2	2
		Heidarian Miri et al. (C1) 2013				1.27% CSE	Seed/grain	3.89		
		Heidarian Miri et al. (C2) 2013				2.53% CSE	Seed/grain	7.77		
15	[36]	-	Cow (Holstein)	n/a	TMR [2]	diet without soybean oil (SO0) and dried citrus pulp (DCP)	-	0.25	21/7	2
		-				SO0 + 8.65% of DCP	Agro-industrial by-product	0.71		
		Karimi et al. (SO0 + DCP2) 2022				SO0 + 17.3% of DCP	Agro-industrial by-product	1.17		
		Karimi et al. (SO1 + DCP1) 2022				17.3 g of soybean oil + 8.65% of DCP	Agro-industrial by-product	0.71		
		Karimi et al. (SO1 + DCP2) 2022				17.3 g of soybean oil + 17.3% of DCP	Agro-industrial by-product	1.17		

Table 1. *Cont.*

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
16	[37]	-	Cow (Holstein)	Multi-parous	PMR [10] *Acacia mearnsii* bark (694 g per kg DM of total tannin) as tannin source	Morning grazing + afternoon PMR meal with 9.0 g of tannins/kg of PMR DM	-	-	14/8	2
		Pozo et al. (AM-PM) 2022				Morning PMR with 9.0 g of tannins/kg of PMR DM + afternoon grazing meal	-	-		
		Pozo et al. (PM-TAN) 2022				Morning grazing + afternoon PMR with 15.0 g of tannins/kg of PMR DM	Agro-industrial by-product	6.885		
17	[38]	-	Cannulated cow (Holstein)	n/a	60:40 (F:C) [1] corn silage as forage and concentrate of soybean meal, ground corn grain, wheat bran, urea and mineral supplements	Control (basal diet)	Forages	0.345	14/7	2
		Santos et al. (FO) 2016				Diet with flaxseed oil (FO)	Seed/grain	0.392		
		Santos et al. (PBP) 2016				Diet with FO + propolis-based Product (PBP)	Agro-industrial by-product	2.827		
		Santos et al. (PBP-E) 2016				Diet with FO + PBP + vit E	Agro-industrial by-product	2.923		
18	[39]	-	Cows (Holstein -Friesian)	Multi-parous	PMR of 76:24 (F:C) [1]	Control	Forages	-	21/5	2
		Huang et al. 2022				6% of paulownia leaves silage diet replacing alfalfa silage	Forages	0.36		
19	[40]	-	Cows (Holstein -Friesian)	n/a	Component feeding; partial mixed ration (PMR) [3] of *ad libitum* forage with 2 kg of concentrates daily	Buckwheat diet	Forages	0.85	9/6	2
		Kälber et al. (BC-fm) 2012				Chicory diet	Forages	0.71		
		Kälber et al. (BR-fm) 2012				Ryegrass diet	Forages	0.82		

Table 1. *Cont.*

No. Exp	References	ID	Species	Parity Status	Basal Feed	Polyphenol Sources	Type of Polyphenol Sources	Total Phenolic Content, % of DM	Adaptation Period/Long Treatment (day)	Milking (time/day)
20	[41]	-	Goats (crossbred Saanen)	n/a	TMR [2]; 60:40 (F:C) [1]	0% whole mango meal (WMM) as control	-	-	14/5	2
		Silva et al. (WMM33) 2016				33% WMM	Agro-industrial by-product	3.96		
		Silva et al. (WMM66) 2016				66% WMM	Agro-industrial by-product	7.91		
		Silva et al. (WMM100) 2016				100% WMM	Agro-industrial by-product	11.9		
21	[42]	-	Goat (cross-bred)	n/a	Component feeding; 50:50 (F:C) [1]	Control	-	-	14/30	2
		Tsiplakou et al. 2017				1% of *Chlorella pyrenoidosa*	Marine microalgae	0.5		

[1] Forage to concentrate ratio. [2] Total mixed ration. [3] Partial mixed ration.

3.1. Effect of Polyphenol Supplementation on Milk Fat Content

As depicted in Figure 2, the pooled SMD showed did cross the line of no effect, and thus it can be concluded that the overall effect is not significant statistically when supplemented with polyphenols in the diet ($p > 0.05$). Meanwhile, significant heterogeneity was observed for this outcome measure ($p < 0.05$) ($I^2 = 93\%$). Sub-group analysis was conducted to evaluate different sources of polyphenol supplementation (grain, forages, or agro-industrial by-products) effects on milk fat content. The analysis showed there are no significant differences ($p > 0.05$) in milk fat content between different sources of polyphenol supplementations with significantly lower heterogeneity ($I^2 = 15.6\%$).

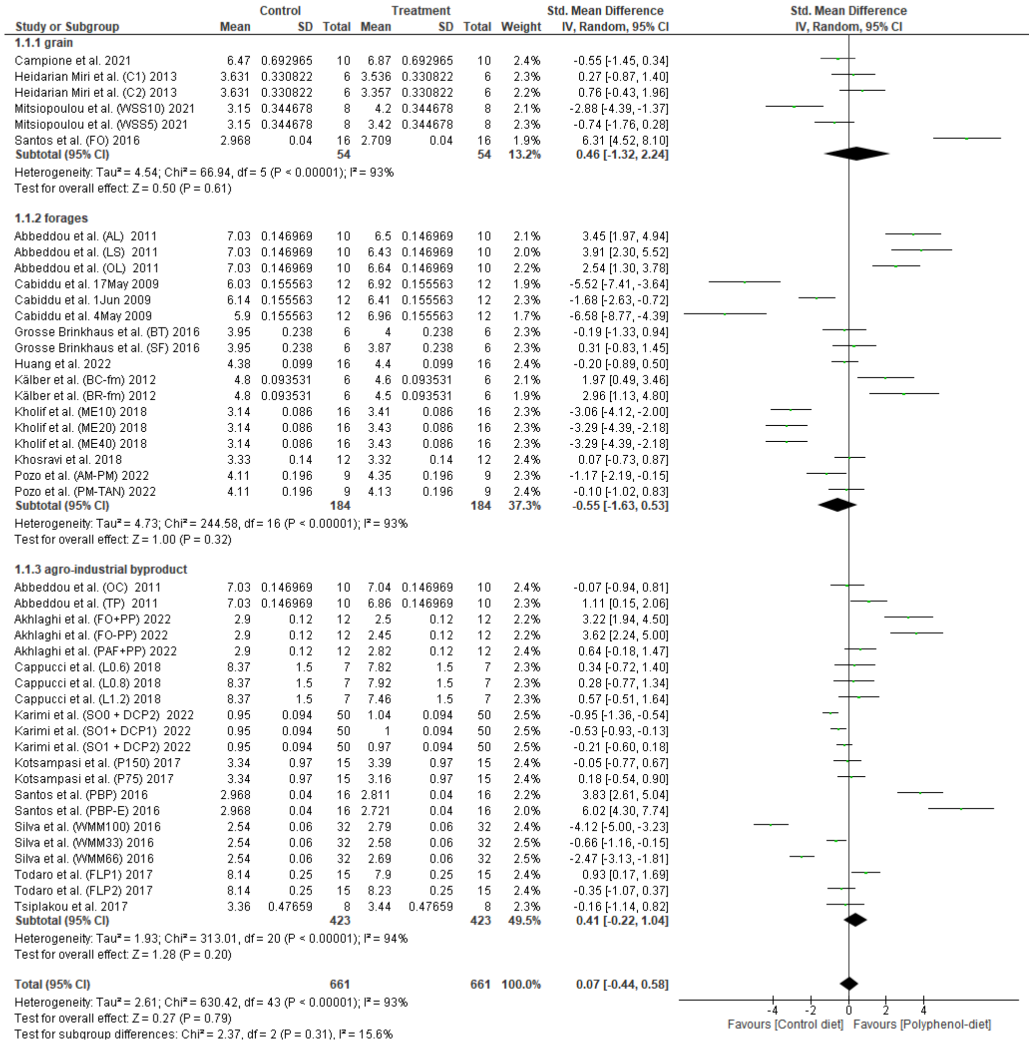

Figure 2. Forest plots for the links between milk fat content and polyphenol.

It is clearly shown in the forest plot of the grain group that the 95% confidence intervals of four studies crossed the line of no effect. These studies, individually were not significant however the 95% confidence intervals of two studies by Mitsiopoulou et al. (WSS10) (2021) and Santos et al. (FO) (2016) did not cross the line of no effect, which means that the results from these individual studies were significant. Meanwhile, 95% confidence intervals of five studies crossed the line of no effect and twelve other studies did not cross the line of no effect as shown in the forest plot of the forages group. Among these twelve studies, the studies by Abbeddou et al. (LS) (2011) showed the highest SMD and 95% confidence interval [3.91 (2.30, 5.52)] and the study by Cabiddu et al. 4 May (2009) showed the lowest SMD and 95% confidence intervals [−6.58 (−8.77, −4.39)] in the forages group, which signaled these are the possible outliers for this group. Whereas, in the agro-industrial by-product group, 95% confidence interval of ten studies crossed the line of no effect and eleven studies did not. The possible outliers for this group are shown by studies of Santos et al. (PBP-E) (2016), where it is at the highest value of SMD and 95% confident interval [6.02 (4.3,7.74)] and the lowest value of SMD and 95% confident interval is depicted by Silva et al. (WMM100) (2016) in his study with −4.12 (−5, −3.23).

3.2. Effect of Polyphenol Supplementation on Milk Protein Content

Figure 3 shows the forest plot of the effect of three different sources of polyphenol on protein content in milk. The pooled SMD shown above did cross the line of no effect, which concludes that the overall effect is statistically insignificant when supplemented with polyphenols in the diet ($p > 0.05$). However, it was observed that the heterogeneity for this overall outcome measure was significant ($p < 0.0001$) where $I^2 = 88\%$. When the analysis was done to evaluate different sources of polyphenol supplementation (grain, forages, or agro-industrial by-products) effects on milk protein content, the results showed that there are no significant differences ($p = 0.18$) in milk protein content between different sources of polyphenol supplementations with considerably low heterogeneity, $I^2 = 42\%$.

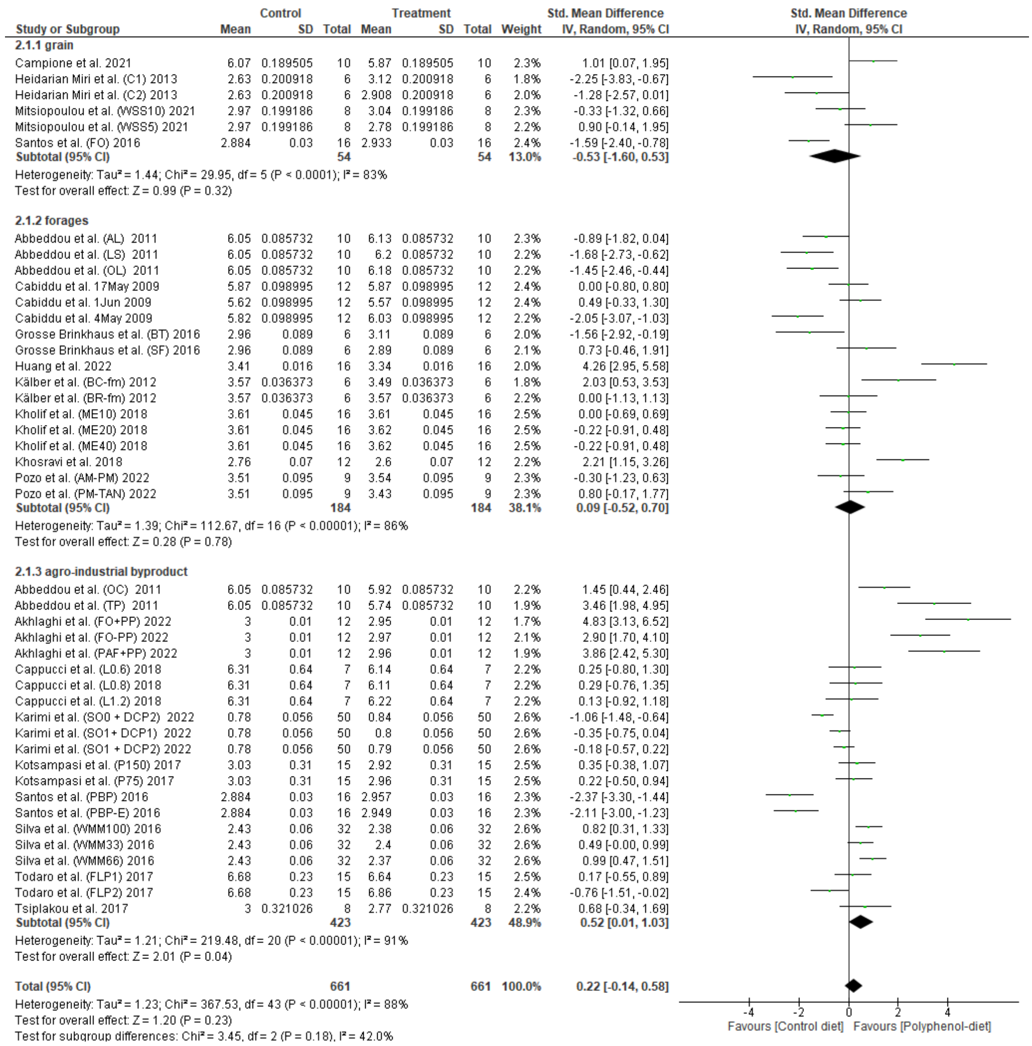

Figure 3. Forest plots for the links between milk protein content and polyphenol.

In the forest plot of the grain group, 95% confidence intervals of three studies crossed the line of no effect while the other three did not cross the line of no effect. Since all of the confidence intervals of these studies falls within the range of pooled results of 95% confidence interval of this group (−1.60, 0.53), there are no outliers identified in the grain group of polyphenol sources. As for the forages group of polyphenol sources, 95% confidence intervals of ten studies crossed the line of no effect and seven other studies did not cross the line of no effect as shown the forest plot. Among these seven studies, Huang et al. [39] showed the highest SMD [4.26 (2.95, 5.58)] and the lowest value of SMD [−2.05 (−3.07, −1.03)] was by the study of Cabiddu et al. 4 May (2009), and thus also represent the potential outliers under forages group. Meanwhile, the forest plot of the agro-industrial by-product group showed 95% confidence interval of ten studies crossed the line of no effect and eleven studies did not cross the line of no effect. However, the result for polyphenols from agro-industrial by-products showed significant differences ($p = 0.04$) with significant heterogeneity at $I^2 = 91\%$ ($p < 0.00001$). As for this group, Akhlaghi et al. (FO + PP) (2022) showed the highest value of SMD at [4.83 (3.13, 6.52)] and the lowest value of SMD is by the study of Santos et al. (PBP) (2016) at [−2.37 (−3.3, −1.44)], in which also represented as possible outliers for this group.

3.3. Effect of Polyphenol Supplementation on Milk Lactose Content

Forest plots of the effect of three different sources of polyphenol on lactose content in milk are shown in Figure 4. From the plot, it was observed that the pooled SMD for overall effect did cross the line of no effect, which concurs that the supplementation of polyphenol in the diet insignificantly affects lactose content in milk ($p > 0.05$). However, it was noted that the heterogeneity for this overall outcome measure was significant ($p < 0.0001$) where $I^2 = 86\%$. There are significant differences ($p < 0.05$) found when assessing different sources of polyphenol supplementation (grain, forages, or agro-industrial by-products) effects on milk lactose content. Results showed that there are significant differences ($p = 0.02$) in milk lactose content from grain source of polyphenol supplemented in the diet, with considerably moderate heterogeneity, $I^2 = 43\%$.

In the grain group, the forest plot shown in Figure 4 shows 95% confidence intervals of four studies crossed the line of no effect while the other two did not cross the line of no effect. However, there were no outliers detected since the 95% confidence intervals of all the studies included in the grain group overlap with the pooled SMD of the grain group. Concurrently, 95% confidence intervals of eleven studies crossed the line of no effect while three other studies did not cross the line of no effect as shown in the forest plot of the forages group. These three studies were the outliers for the forages group since it does not overlap with the pooled standard mean difference of the forages group. The highest value of the study standard mean difference and 95% confidence interval is from the studies of Khosravi et al. (2018) [2.25 (1.19, 3.31)] and the lowest value of the study standard mean difference and 95% confidence intervals are from the studies of Abeddou et al. (LS) (2011) with −2.84 (−4.16, −1.53) and Abeddou et al. (OL) (2011) with −6.22 (−8.54, −3.9). As for the agro-industrial by-product group, the forest plot showed 95% confidence interval of ten studies crossed the line of no effect and seven studies did not cross the line of no effect. Among the individually significant studies, the highest value of standard mean difference and 95% confidence interval was found in the study of Akhlagi et al. (FO + PP) (2022) with 3.86 (2.42, 5.3), and the lowest value was shared with the study of Abeddou et al. (OC) (2011) and Abeddou et al. (TP) (2011) with −4.62 (−6.44, −2.4).

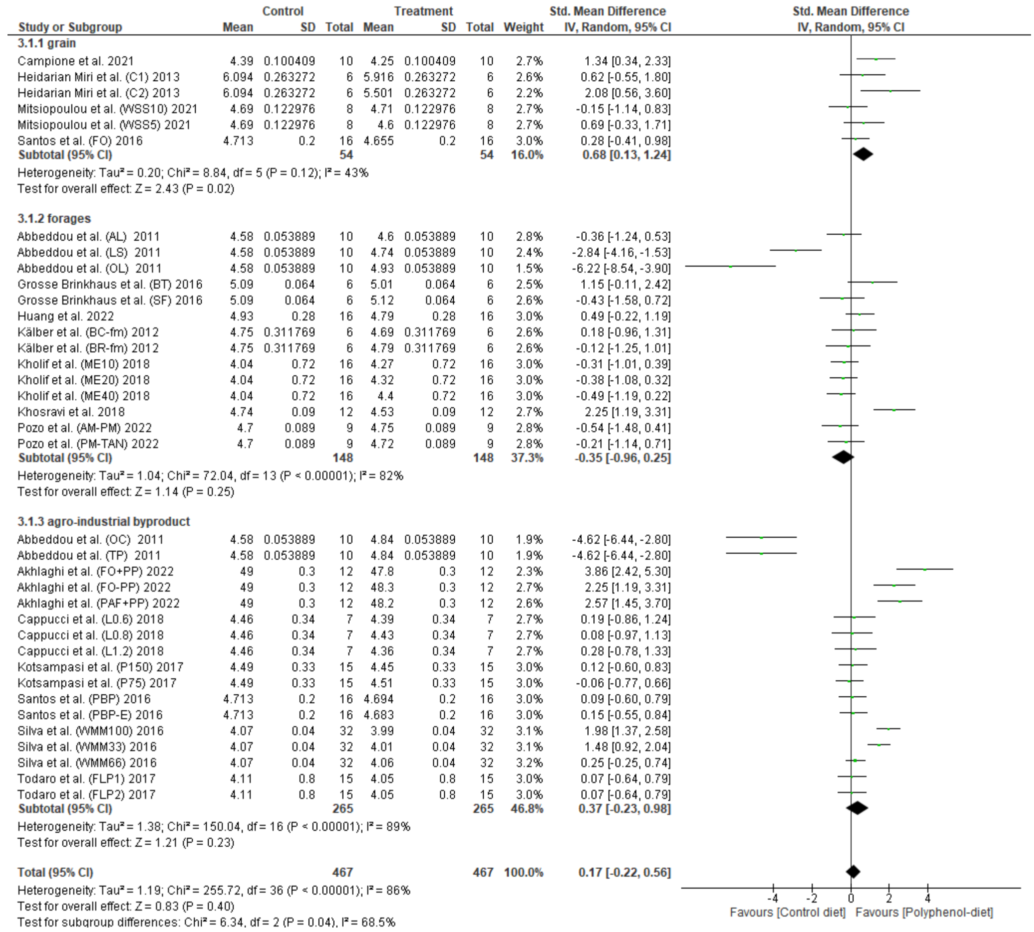

Figure 4. Forest plots for the links between milk lactose content and polyphenol.

3.4. Effect of Polyphenol Supplementation on Milk SFA Content

Figure 5 depicts the forest plots of the effect of three different sources of polyphenol on SFA content in milk. It was found that polyphenol supplementation significantly affects ($p < 0.05$) the saturated fatty acid content in milk with significantly high heterogeneity ($p < 0.05$) at I^2 = 96%. In the analysis to evaluate different sources of polyphenol supplementations, it was also found that different polyphenol sources (grain, forages, or agro-industrial by-products) significantly affect ($p < 0.05$) the content of saturated fatty acid in milk with high heterogeneity at I^2 = 75.7%. Results showed that there are significant differences ($p < 0.05$), with a heterogeneity of I^2 = 89% in milk SFA content from grain source of polyphenol supplemented in the diet, and significant differences ($p < 0.05$) with a heterogeneity of I^2 = 91% in milk SFA content from forages source of polyphenol supplemented diet. The polyphenol from agro-industrial by-product sources also showed a significant difference ($p < 0.05$) in milk SFA content at high heterogeneity of I^2 = 97%.

In the grain group of polyphenol sources, only one study showed the 95% confidence interval that crossed the line of no effect (Figure 5) while the other five did not cross the line of no effect. The study that crossed the line of no effect also showed the lowest value of standard mean difference and 95% confidence interval at 0.51 (−0.38, 1.41) which is a study by Campione et al. [28]. Meanwhile, the study that recorded the highest value of standard mean difference and 95% confidence interval was by Santos et al. (FO) (2016) with 7.05 (5.08, 9.02). In the forages group of polyphenol sources, the number of studies in this group was evenly split with the 95% confidence interval of seven studies crossed the line of no effect while the other seven did not cross the line of no effect. The highest value of SMD and 95% confident interval was recorded by the study of Kholif et al. (ME40) (2018) with

7.22 (5.21, 9.23) and the lowest value of SMD and 95% confident interval was found by Kalber et al. (BC-fm) (2012) with −0.49 (−1.65, 0.66). The forest plot of the agro-industrial by-product group showed the 95% confidence interval of all studies in the group did not cross the line of no effect and thus showed all studies in the group were significant, individually. Among the results, Abbeddou et al. (TP) (2011) showed the highest value of standard mean difference and 95% confidence interval with 13.07 (8.47, 17.67) whereas Todaro et al. (FLP2) (2017) recorded the lowest value of standard mean difference and 95% confident interval with −3.22 (−4.35, −2.09) in this analysis.

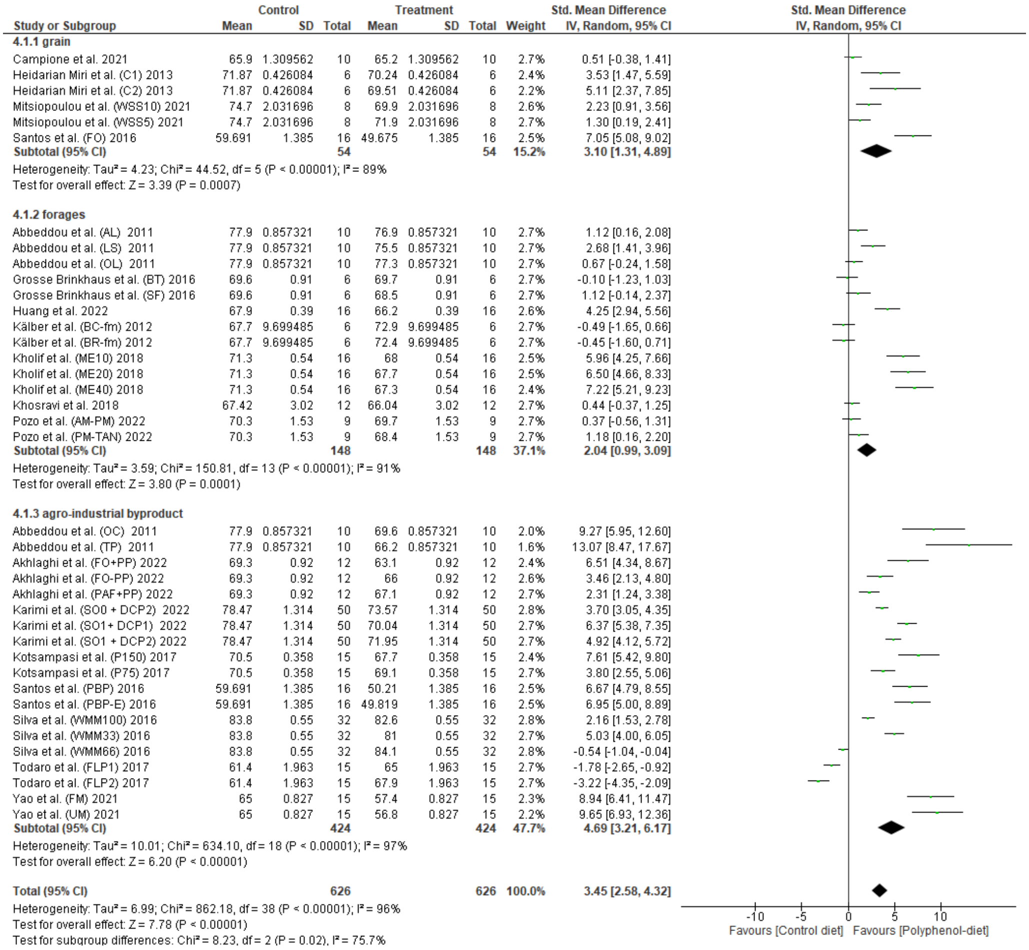

Figure 5. Forest plots for the links between saturated fatty acid content in milk and polyphenol.

3.5. Effect of Polyphenol Supplementation on Milk MCFA Content

The forest plot on the effect of polyphenol supplementation on MCFA content in milk is depicted in Figure 6. The pooled SMD shown in the above figure recorded significant differences ($p < 0.05$) with the heterogeneity of $I^2 = 96\%$ which concurred that polyphenol supplementation significantly affects the MCFA content in milk. It was worth noting that different polyphenol sources (grain, forages, or agro-industrial by-products) significantly affect ($p < 0.05$) the content of MCFA in milk with high heterogeneity at $I^2 = 87.7\%$. Results from the analyses show significant differences were noted in grain and agro-industrial by-product ($p < 0.05$) polyphenol sources with the heterogeneity of $I^2 = 87\%$ and $I^2 = 97\%$, respectively.

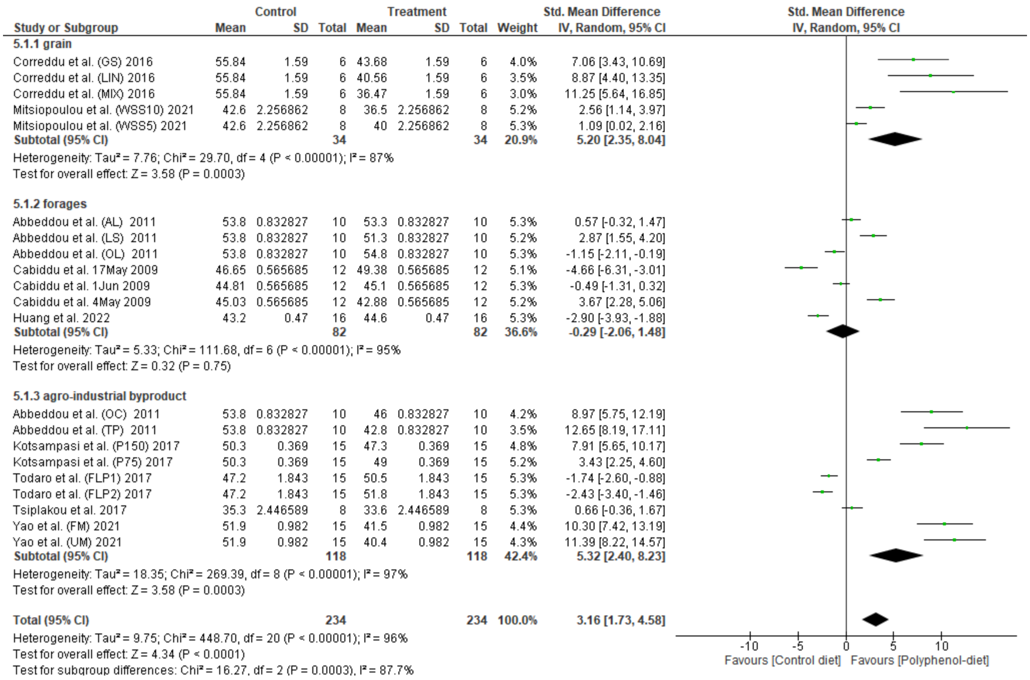

Figure 6. Forest plots for the links between MCFA in milk and polyphenol.

It was shown in the forest plot of grain group (Figure 6) that 95% confidence intervals of all studies did not cross the line of no effect which indicates that the studies were individually significant where the highest value of standard mean difference, and 95% confident interval was recorded by Coreddu et al. (MIX) (2016) with 11.25 (5.64, 16.85) and the lowest value of standard mean difference and 95% confident interval was by Mitsiopoulou et al. (WSS5) (2021) with 1.09 (0.02, 2.16). The outlier among the studies in this group was also by Mitsiopoulou et al. (WSS5) (2021) since the 95% confidence interval of this study does not overlap with the group pooled SMD. Meanwhile, the forest plot of the forages group (Figure 6) showed that 95% confidence intervals of two studies crossed the line of no effect while five other studies did not cross the line of no effect. There were no outliers detected in this group (Figure 6) since all 95% confidence intervals fall within the range of the pooled standard mean difference of this group. The highest value of standard mean difference and 95% confidence interval was found by Cabiddu et al. 4 May (2009) with 3.67 (2.28, 5.06) whereas Cabiddu et al. 17 May (2009) recorded the lowest value of standard mean difference and 95% confidence interval with −4.66 (−6.31, −3.01). As for the agro-industrial by-product group, the forest plot showed 95% confidence interval of two studies crossed the line of no effect while ten other studies did not cross the line of no effect. It was observed that the highest value of standard mean difference and 95% confidence interval was by Abbeddou et al. (TP) (2011) with 12.65 (8.19, 17.11) while Todaro et al. FLP2 (2017) recorded the lowest value of standard mean difference and 95% confidence interval with −2.43 (−3.40, −1.46). Both studies were also among the outliers since their 95% confidence intervals did not overlap with the pooled SMD of this group.

4. Discussion

Generally, plant polyphenol has been given to dairy animals to improve health and productivity. Dairy animal health and productivity can be enhanced through feeding feeds that contain plant components that have attractive biological properties such as antioxidant, anti-inflammatory and anti-microbial, etc. [43]. In this study, the effects of plant polyphenols in dairy feeds on milk compositions and fatty acid content in milk were explored.

In the present analysis, no clear difference was observed in milk fat content of animals fed with a polyphenol-supplemented diet compared with feed without polyphenol supplementation. Among the dietary supplementation throughout the reviewed study, the highest value of standard mean difference was found in the study of Santos et al. [38] where flaxseed oil was included in the diet of dairy cows with total phenolic content of 0.392% in DM whereas the lowest value of standard mean difference is showed in the study of Cabiddu et al. [26] where polyethylene glycol was orally fed to the ewes during grazing the flowering-stages of pastures on 4 May with total phenolic content of 3.21% in DM. From the observations in this study, the number of studies which favour the control diet is 13 while the number of studies which favour the polyphenol diet is 12, where it can be concluded that the milk fat content is not affected significantly by the supplementation of polyphenols in the diet, despite having it from different sources. It is interesting to note that the pooled effect estimates for the forages favour the control diet but the pooled effect estimates for grain and agro-industrial by-products favour the polyphenol diet.

The same observations can be seen in the evaluation of milk protein content when supplemented with polyphenols in the diet where there are no significant effects were found on the overall effect of polyphenol supplementation in the diet. It is also found true when tested against different polyphenol sources, where there is no significant difference was found which suggests that milk protein content was similar throughout different polyphenol sources. Throughout the reviewed studies, Akhlaghi et al. [30] in its treatment of fish oil and pomegranate peel (FO + PP) showed the highest value of standard mean difference with total phenolic content of 0.357% of DM, and Santos et al. [38], with its treatment of propolis-based product (PBP) showed the lowest value of standard mean difference with total phenolic content of 2.83% of DM. Polyphenol-diet significantly affects milk protein content in the study of Abbeddou et al. [27] (sheep feeding trial with TMR of high concentrates, Akhlaghi et al. [30] (heifer feeding trial with TMR of high concentrates) and Silva et al. [20] (goat feeding trial with TMR of high forages diet). The changes might be due to rumen microbial diversity especially bacterias as Xue et al. [44] suggested that as rumen microbiota contributes to milk protein yield in dairy cows as rumen bacterial abundances differed in high and low milk protein yield heifers. According to the forest plot, the total number of studies that milk protein content favours the control diet is 10 while the total number of studies that milk protein content favours the polyphenol diet is 11. These findings lead to the insignificant results of this overall outcome effect, and only polyphenol source from agro-industrial by-product is found significant in this study. It is worth highlighting that the pooled effect estimates for the grain group favours the control diet but the pooled effect estimates for forages and agro-industrial by-products group favour the polyphenol diet and the overall pooled effect estimates favour the polyphenol diets with 0.22 value of the standard mean difference, although it was insignificant. Present study results agreed with the observation by Butler and Stergiadis [45] where milk protein composition has stronger genetic control than diet and hence the insignificant results of the current study.

In the evaluation of milk lactose content changes when supplemented with polyphenol diets, an insignificant result was reported in the overall effect estimates, on the other hand, a significant difference was found only in the grain group of polyphenol sources diet. Throughout the dietary supplementation in the reviewed studies, Akhlaghi et al. [30] in its treatment of fish oil and pomegranate peel (FO + PP), again showed the highest value of the standard mean difference in this outcome with total phenolic content of 0.357% of DM and the lowest value of the standard mean difference in this outcome was by Abbeddou et al. [27] in its treatment of olive leaves, with total phenolic content of 2.25% of DM. The current study demonstrates that the polyphenol-diet has a substantial impact on the milk lactose content in the study of Campione et al. [7] (sheep feeding trial with 11.7% of cocoa bean shell and ad-libitum hay) and Heidarian Miri et al. [14] (goat feeding trial with equal ratio of F:C as basal diet and 2.53% cumin seed extract). This occurrence is potentially due to the increase in milk yield as milk lactose content is positively correlated with milk yield (r = 0.10) [46]. Present study observed the number of studies that milk lactose content favours the control diet amounts to four, and the number of studies that milk lactose content favours the polyphenol diet amounts to eight. Meanwhile, it is worth mentioning that the milk lactose content of the studies in the grain groups favours the polyphenol diet compared with the control diet while the rest, although insignificant, milk lactose content of the studies in the forages group mostly favours the control diet and the agro-industrial by-product group favours polyphenol diet. This is in line with the reported study by Modaresi et al. [47] where milk lactose content increased with pomegranate seed pulp supplementation, an agro-industrial by-product, in the feed and similarly, an increase in milk lactose content in the study by Caroprese et al. [48] when lactating ewes were supplemented with flaxseed (grain group) as fat supplement under high temperature-humidity index value averaging 77 during daytime.

In the effect of polyphenol supplementation in the diet on milk SFA content, significant differences were observed in this study, in the overall pooled estimate effect as well as all three different polyphenol sources (grain, forages and agro-industrial by-product). Milk fatty acid profile may be affected by bio-actives compound in polyphenol-diet through rumen biohydrogenation of monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) and as well as the transfer of these FA and its biohydrogenation intermediates into milk fat [49]. This supported by an observation by Di Meo et al. [50], where a substantial decrease in milk SFA of polyphenol-supplemented diet was found in favor of milk MUFA and PUFA concentration in all parity classes. Additionally, other studies also demonstrated the changes in the ratio of SFA/MUFA with the polyphenol supplementations in the diet of other livestock such as sheep [51] and buffalo [52]. Among the reviewed studies, dietary supplementation of tomato pomace by Abbeddou et al. [27] showed the highest amount of the SMD with total phenolic content of 0.6% of DM while the lowest value of the SMD was by Todaro et al. [32] in its treatment of 15.7% fresh lemon pulp with total phenolic content of 1.322% of DM. Interestingly, the total number of studies that milk SFA content favours the polyphenol diet is 28 while the total number of studies that milk SFA content favours the control diet is only three which concludes most result from individual studies in this outcome favours the polyphenol diets compared to control diet. The differences from the three studies mentioned previously might lies in its diet where they use fruit wastes such as pulp, peel, and seed; in this cases mango and lemon to replace part of concentrates portion of the diet. The common content of phytochemical in these fruits are p-coumaric acid and ferulic acid [53,54], meanwhile lycopene is the potential phytochemical commonly found in tomato [55].

The changes in MCFA content in the milk-fed with polyphenol supplementation in the diet showed similar outcomes as observed for milk SFA content, previously but not in forages group. Among the dietary supplementation in this study, the highest value of the SMD comes from the agro-industrial by-product group which is Abbeddou et al. [27], where lipid-rich tomato pomace, which contains 0.6% of DM in phenolic content were included in the ewe's diet. On contrary, the lowest value of SMD in this study comes from the forages group, where Cabiddu et al. [26] in its study of polyethylene glycol oral supplementation to the ewes prior to grazing the flowering stages of Sulla pastures on 17 May, in which the phenolic content of the pasture was 3.55% of DM. What stands out in this study was the total number of studies that favour the polyphenol diet was more than the total number of studies that favour the control diet, which is thirteen and five studies, respectively. The five studies that favour the control diets are considered outliers since it does not fall within the 95% of the confidence interval of overall effect estimates. Among the five studies were, both Todaro et al. [32] study as previously mentioned in milk SFA content, Cabiddu et al. [26] 17 May study, Abbeddou et al. [27], where polyphenol-rich olive leaves, which contains 2.25% of DM in phenolic content were included in the ewes' diet, and the study by Huang et al. [39] where paulownia leaves silage was used as alfalfa silage replacement in dairy cows' diet which contains 0.36% of DM in phenolic content. The most dominant phenolic acid in paulownia leaves silages as addressed by Huang et al. [39], was phenylpropanoid glycosides meanwhile the most dominant phenolic acid in olives leaves are secoiridoids, oleuropein specifically, as secoiridoids is a family compound that is characteristic of Oleaceae plant [56].

Nevertheless, these reviews showed the potential of using polyphenol supplementation in animal feed to further improved production in dairy farm, especially in milk fatty acid profile. The polyphenols contained in these three main categories of polyphenol sources exhibits beneficial biological properties such as anti-oxidant and anti-microbial activities that may contribute to the extension of milk shelf-life must not be disregard. The enrichment of milk with polyphenol with anti-oxidant capacity would preserve milk fatty acid from oxidative stress, as well as milk enriched with anti-microbial capacity would preserve it from microbial deterioration that leads to an easily spoilt milk. Hence, the usage of polyphenol as supplemental feed may serve as a valuable tool to improved milk quality produced and must be exploited especially for the betterment of the animal well-being.

Overall, this review has demonstrated the different categories a polyphenol supplementation may segregate into showed the impact polyphenol supplementation has made, which is in in fatty acid content of milk. However, the current study contained potential limitation such as the amount of study involved in milk MCFA is not as substantial as the other four parameters (milk fat content, milk protein content, milk lactose content and milk SFA content). Hence, the recommendation for future review is to incorporate more study and may probably add other group of fatty acid should the need arise.

5. Conclusions

The current study shows milk fat, protein, and lactose content were unaffected by polyphenol supplementation, overall. However, when polyphenol supplementation was categorized into different sources (grain, forage, and agro-industrial by-product), the milk protein content of the agro-industrial by-product group as well as the milk lactose content of the grain group was significantly affected. Both SFA and MCFA content in milk, show a significant difference in all three groups but not in the forage group of milk MCFA where it is insignificant. In conclusion, milk protein content was affected by agro-industrial by-product-sources polyphenols, milk lactose content was influenced by grain-sources polyphenols, and both sources were impactful towards milk MCFA content. On the other hand, milk SFA was affected by all three polyphenol sources, significantly.

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Abbreviations

The following abbreviations are used in this manuscript:

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SFA	Saturated Fatty Acid
MCFA	Medium-Chain Fatty Acid
SMD	Standard Mean Difference
CI	Confidence Intervals
F:C	Forage to Concentrate Ratio
TMR	Total Mixed Ration
PMR	Partial Mixed Ration
UM	Unfermented
FM	Fermented
ME10	10 mL *M. oleifera* leaves extract
ME20	20 mL *M. oleifera* leaves extract
ME40	40 mL *M. oleifera* leaves extract
WSS5	5% of whole sesame seed
WSS10	10% of whole sesame seed
LS	Lentil straw
AL	Atriplex leaves
OL	Olive leaves
OC	Olive cake
TP	Tomato pomace
GS	Grape seed
LIN	Extruded linseed
MIXED	Mixed of grape seed and extruded linseed
FO + PP	1.5% Ca salts of Fish Oil with 8.7% Pomegranate Peel
PAF-PP	1.5% of Palmitic Acid-enriched Fat without Pomegranate Peel
FO-PP	1.5% Ca salts of Fish Oil without Pomegranate Peel
PPS	Pomegranate pulp silage
P75	7.5% of Pomegranate pulp silage
P150	15% of Pomegranate pulp silage
FLP	Fresh lemon pulp
FLP1	9.01% of Fresh lemon pulp
FLP2	15.7% of Fresh lemon pulp
OCPC	Olive Crude Phenolic Concentrates
L0.6	0.6% of Olive Crude Phenolic Concentrates
L0.8	0.8% of Olive Crude Phenolic Concentrates
L1.2	1.2% of Olive Crude Phenolic Concentrates
AL	Alfalfa
SF	Sainfoin
BT	Birdsfoot Trefoil
CSE	Cumin Seed Extract
C1	1.27% Cumin Seed Extract
C2	2.53% Cumin Seed Extract
SO0	Without Soybean Oil
DCP	Dried Citrus Pulp
SO0 + DCP2	SO0 + 17.3% of DCP
SO1 + DCP1	17.3 g of soybean oil + 8.65% of DCP
SO1 + DCP2	17.3 g of soybean oil + 17.3% of DCP
DM	Dry matter
AM	Morning

PM	Afternoon
TAN	Tannin
FO	Flaxseed Oil
PBP	Propolis-BasedProduct
PBP-E	Propolis-BasedProduct and Vitamin E
BC-fm	Chicory diet
BR-fm	Ryegrass diet
WMM	Whole Mango Meal
WMM33	33% Whole Mango Meal
WMM66	66% Whole Mango Meal
WMM100	100% Whole Mango Meal
MUFA	Monounsaturated fatty acid
PUFA	Polyunsaturated fatty acid

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