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Review

The Relationships among Microelement Composition of Reindeer Meat (*Rangifer tarandus*) and Adaptation: A Systematic Review and Meta-Analysis

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Abstract: This systematic review and meta-analysis based on PRISMA statements aimed to summarise the data on the chemical composition of reindeer meat depending on the region of the *Rangifer tarandus*. We searched SCOPUS, PubMed, Embase, CrossRef, Medline, Cochrane library, eLibrary, and CyberLeninka. A total of 3310 records published between January 1980 and December 2021 were screened. We identified 34 relevant studies conducted in Russia, Norway, the USA, Canada, and Finland for the synthesis. Overall, the consumption of reindeer meat reduces arterial hypertension and atherosclerosis due to many polyunsaturated fatty acids (linoleic, linolenic, arachidonic) and vitamin C, which balances lipid fractions. Venison is an effective means of preventing obesity and adapting to cold due to the content of a complete set of essential trace elements, amino acids, and even L-carnitine. The high content of vitamin C and microelements (iron, zinc, copper) in reindeer meat is likely to increase the body's antioxidant defence against free radicals and help prevent chronic non-infectious diseases. Thus, venison is an essential component of the adaptation mechanism for the Arctic population.

Keywords: systematic review; reindeer meat; macro- and microelement analysis; adaptation; Arctic population; meta-analysis

1. Introduction

The unique nutrition of the Arctic Indigenous Peoples is associated with their increased endurance, health, and adaptability to the harsh climate [1]. Reindeer meat, blood, and liver are the most critical elements of this traditional nutrition enriched with minerals [2,3]. Reindeer consumption is a crucial factor of successful adaptation to the cold stress, as well as a component of national culture, food, and economic security and sovereignty, affecting the well-being and health of the Indigenous population in the Arctic [4–9].

The reindeer (*Rangifer tarandus*) habitat covers territories in Eurasia and North America between 50- and 81-degrees north latitude [10] and includes continental and island territories, tundra, taiga, and mountainous areas close to them in vegetation composition and climatic conditions [11]. Reindeer live in Russia, the USA, Norway, Sweden, Finland, Denmark, Iceland, Canada, Mongolia, Great Britain, and China [10]. The largest populations of wild reindeer (*Rangifer tarandus caribou*) are in Russia (952.9 thousand; 2015) and Canada (1300 thousand; 2016) [11]. The world's largest livestock of domesticated reindeer is in Russia (1620.8 thousand reindeer in 2021) [12]. In Russia, the largest population of wild reindeer is in the Krasnoyarsky Krai, the Chukotka Autonomous Okrug, the Republic of Sakha (Yakutia), and domesticated reindeer are in the Yamal-Nenets Autonomous Okrug [13]. Such various reindeer habitats make pre-conditions for the different chemical compositions of reindeer products in different northern regions.

The macro- and microelement composition of reindeer meat is impacted by significant differences in the species and mineral composition of forages (plants and lichens), the duration of grazing seasons on winter and summer pastures, the proportion in the diet of green fodder, shrubs, lichens, mushrooms, eggs of birds, and rodents, the macro- and microelement composition of soil and water, pollution, availability of salty seawater, and the cutting of velvet antlers [14,15]. A specific feature of the northern reindeer is its seasonal migration to areas with different forage resources: Summer pastures with a predominance of herbaceous plants and shrubs and winter pastures rich in lichens [16].

The study of the macro- and microelement composition of reindeer meat started in the second half of the 20th century. In the 1970s, in Canada, O. Schaefer (1977) and K. Hoppner (1978) confirmed the high nutritional value of reindeer meat due to high protein and low fat content [17,18]. Two decades later, H.V. Kuhnlein (1992; 1996; 2000; 2002) conducted a study of micronutrient composition of reindeer products [19–22] and developed recommendations for the use of venison by patients with atherosclerosis, vitamin deficiency, diabetes mellitus, and for the prevention of heart, liver, and stomach diseases [23–25]. In the 1990s, in Alaska, the USA, the chemical composition of traditional products, including venison, was studied [26]. Currently, a national database includes the data on the complete quantitative and qualitative chemical composition of reindeer meat in Alaska [27]. In Russia, studies conducted in Yamal-Nenets Autonomous Okrug [28,29], Nenets Autonomous Okrug [30–32], Taimyr [33–35], the Republic of Yakutia [36], and on the Kola Peninsula [37–39] confirmed the nutritional and biological value of reindeer meat. Furthermore, they proved the need to include this product in a healthy diet.

Rangifer tarandus is highly adapted to Arctic conditions. The optimal work of enzymes that ensure adaptation to cold stress provides the accumulation of essential trace elements necessary for the practical work of enzymatic chains. The most crucial macronutrients are calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), and sodium (Na), among others, which activate enzymes, regulate the number of hormones, promote muscle and nervous activity, and therefore are essential components of the daily human diet [40–42]. Thus, the consumption of reindeer meat can increase adaptation to the Arctic conditions, reduce the risk of heart diseases, and improve metabolism [43–45].

Improving knowledge about the macro- and microelement composition of reindeer meat in different northern regions will contribute to the expansion of the use of reindeer products to prevent diseases and increase the adaptation of the Arctic population and shift workers in the circumpolar area, as well as develop effective medicinal and pharmaceutical products. Furthermore, studying the chemical composition of reindeer meat will also increase the value of exported reindeer meat, which is an important factor in promoting the economic sovereignty and well-being of the Indigenous Peoples in the Arctic.

Our systematic review and meta-analysis aim to summarise the data on the chemical composition of reindeer meat depending on the region of the *Rangifer tarandus* and analyse the effects of venison consumption on human health and adaptation in the Arctic.

2. Materials and Methods

In this research, a systematic review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, the PRISMA statement [46,47], was conducted. The PRISMA checklist is presented in Appendix A according to the model [48].

The research questions for this systematic review were: "Does the macro- and microelement composition of reindeer meat vary in different northern regions?".

2.1. Search Strategy

We searched the SCOPUS, PubMed, Embase, CrossRef, Medline, Cochrane library, eLibrary, and CyberLeninka electronic databases to identify relevant studies for the synthesis without language restrictions, using and updating them (from January 1980 to December 2020). In addition, the reference lists of all studies included and all the systematic reviews identified during the search process were checked.

The search strategy for all databases included terms of the Medical Subject Headings. Searches were made using the following keywords or their combination: "chemical composition of reindeer meat", "chemical composition of venison", combined with "sodium", "potassium", "calcium", "magnesium", "phosphorus", "iron", "zinc", "trace elements".

2.2. Inclusion Criteria

Eligible studies were required to meet the following criteria: (1) Evaluate the concentration of the minerals (sodium, potassium, calcium, magnesium, phosphorus, zinc, iron) in reindeer meat; (2) the results were received in the territories located in the High North; (3) experimental descriptive or retrospective studies. We also excluded study protocols, letters to the editor, editorials, and conference abstracts with no full text available. All citations were entered into a bibliographic reference manager, and duplicate studies were excluded, automatically or manually (EndNote®, v. X7, Tomson Reuters, Philadelphia, PA, USA).

The control group included data on the macro- and microelement composition in reindeer meat obtained from our data. The content of trace elements in reindeer meat was assessed in the testing laboratory centre of the Federal Research Center for Nutrition and Biotechnology (Moscow) (certificate No. ROSS RU.0001.21IP14 dated 22 August 2014). In addition, sampling of the studied objects was carried out following the national standard GOST R 51447–99 [49]. The following standard methods were used to determine the chemical composition: (1) Identification of the content of trace elements (potassium, calcium, sodium, magnesium, phosphorus) according to R 4.1.1672-2003 [50]; (2) determination of iron and zinc under the national standard GOST No. 30178-96 [51].

Laboratory studies to identify trace elements in food were conducted in the autumn–winter season. To determine the concentration of metals, during the analysis food products were subjected to mineralisation to remove organic impurities. The determination was made using a model-Z 5300 atomic absorption spectrophotometer by atomic absorption spectrometry. The determination of the content of trace elements (calcium, magnesium, phosphorus) was implemented on a liquid chromatograph (HPLC) (model "Agilent 1100" detector DAD) in the laboratory of vitamins and minerals.

2.3. Study Selection, Data Extraction and Assessment of Methodological Quality and Risk of Bias

According to the search strategy, the authors (SA, EB) screened titles and abstracts and independently assessed the full text of all potentially relevant studies for inclusion in this review. All disagreements were managed through discussion with a third author (AL). Then, following a standardised data collection form, the information was extracted from the included studies: (i) Study characteristics: Setting, study design, and countries; (ii) microelement composition of reindeer meat; and (iii) health impacts. We also evaluated the lists of references of the studied papers to identify other relevant articles to be included. Reasons for exclusion are reported in Figure 1.

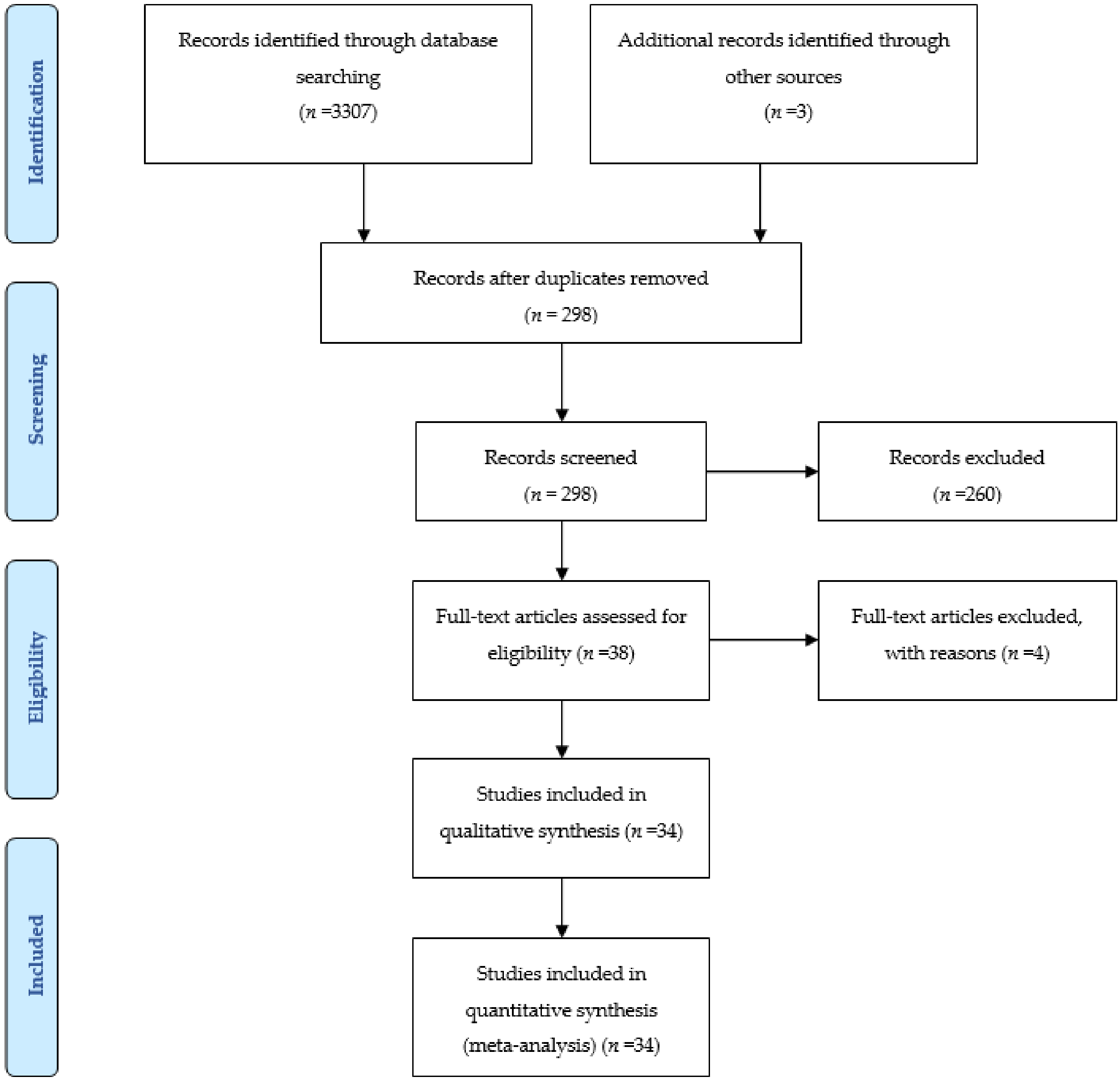

Figure 1. PRISMA flow chart of study selection.

To assess the methodological quality and risk of bias, the checklist of Esther F. Myers [52–54] was applied (Appendix B). After a detailed evaluation of the methods and results, the studies were analysed to verify the possibility of "skewed results", "confusions", and "random occurrence". Only studies with a low risk of bias were included.

2.4. Data Analysis and Synthesis

We applied Cochran's Q statistics and calculated I^2 [55] to assess the statistical heterogeneity across studies. The interpretation of the value of I^2 was: 0 to 40 = low; 30 to 60 = moderate and worthy of investigation; 50 to 90 = severe and worthy of understanding; 75 to 100 = aggregate with major caution [56], and a 95% confidence interval. A p-value < 0.05 was considered statistically significant. The interpretation threshold for the weighted effect values was 0.8 [57]. We generated the forest plots for each analysis. A comprehensive analysis of Egger's test and Funnel Plot Visual interpretation were implemented for the assessment of the publication bias [58–60]. The standardised difference in mean values (Hedge's g) and 95% confidence intervals were calculated using a random-effects model [58–61]. The Jamovi statistical software (version 1.6, Sydney, Australia) [62] and the MAJOR module [63] were used to generate figures and run the test. Jamovi uses the Graphical User Interface (GUI) version of the R module, and MAJOR uses the R package, Metafor [64]. We used sensitivity analysis to explore the influence of each study in the pooled meta-analysis or publication bias results. This analysis was adopted in the case of substantial or considerable (50 to 100%) heterogeneity or significant publication bias ($p < 0.05$) [65,66].

3. Results

3.1. General Characteristics

A total of 3310 records published between January 1980 and December 2021 were screened. First, the abstracts of the publications were analysed. We excluded duplicated, descriptive (e.g., [67]) articles and publications that did not have information about the content of trace elements in reindeer meat or contained data about other animals (3012) (e.g., [68–81]). In total, 260 studies were excluded due to the unavailability of the full text of the publication (e.g., [82]). Therefore, 38 sources included in the further analysis were assessed by two independent reviewers.

Quantitative synthesis used 34 studies (Figure 1) published in English (n = 25) and in Russian (n = 9). In addition, fourteen studies were conducted in Russia [3,38,83–94], seven in Norway [74,95–100], six in the USA [27,101–105], four in Canada [19,21,22,106], and three in Finland [107–109]. The details of the included studies are presented in Table 1.

Table 1. The data of the included studies.

Region	Sample of Animals, n	Macro- and Microelements, mg/100 g							Source
		K	P	Na	Mg	Ca	Fe	Zn	
Yamal-Nenets Autonomous Okrug (control group)	10	360.0 ± 18.0	250.0 ± 12.5	77.0 ± 4.5	28.0 ± 1.5	15.0 ± 0.8	5.0 ± 0.5	2.2 ± 0.4	[own data]
Murmansk region	10	225.0 ± 11.2	226.0 ± 11.3	121.0 ± 6.1	16.1 ± 0.8	9.6 ± 0.5	6.1 ± 0.3	3.0 ± 0.5	[38,83,86]
Komi Republic	10	333.0 ± 50.0	*	54.16 ± 9.2	31.03 ± 4.55	7.13 ± 1.78	5.55 ± 0.9	4.19 ± 0.7	[3]
Taimyr, Krasnoyarsk Territory	30	465.0 ± 10.2	71.0 ± 5.0	276.0 ± 11.0	120.0 ± 10.0	158.0 ± 40.0	18.2 ± 1.5	10.1 ± 0.8	[85]
Republic of Yakutia	10	316.6 ± 6.4	266.7 ± 6.5	137.2 ± 4.5	23.7 ± 0.5	14.9 ± 0.6	15.2 ± 1.6	3.0 ± 0.5	[84,87–92]
Far East	10	305.2 ± 15.0	194.4 ± 9.7	77.4 ± 3.9	24.5 ± 1.2	10.2 ± 0.5	2.9 ± 0.15	3.0 ± 0.5	[93,94]
Finland	30	318.0 ± 15.9	230.0 ± 11.5	95.0 ± 4.8	26.0 ± 1.3	8.1 ± 0.4	3.6 ± 0.2	3.0 ± 0.2	[107–109]
Norway	30	290.0 ± 14.5	189.0 ± 9.5	95.0 ± 4.8	33.0 ± 2.0	7.0 ± 1.3	2.9 ± 0.7	4.8 ± 1.6	[74,95–100]
Canada	158	451.8 ± 22.5	219.5 ± 11.0	49.7 ± 2.5	33.1 ± 1.7	5.0 ± 0.3	5.4 ± 0.3	3.5 ± 0.2	[19,21,22,106]
Alaska, the USA	30	320.0 ± 16.0	230.0 ± 11.5	52.0 ± 2.6	26.0 ± 1.3	5.0 ± 0.3	4.1 ± 0.2	2.1 ± 0.1	[27,101–105]

* No data.

The retrieved studies involved a total of 328 *Rangifer tarandus*, which were adult animals of both sexes with an average age of 2.0 ± 0.5 years. The sample sizes ranged from 10 to 158. The mean value (mg/100 g) of macro- and microelements varied: Potassium—from 225.0 ± 11.2 to 465.0 ± 10.2; sodium—from 49.7 ± 2.5 to 276.0 ± 11.0; phosphorus—from 71.0 ± 5.0 to 266.7 ± 6.5; calcium—from 5.0 ± 0.3 to 158.0 ± 40.0; magnesium—from 16.1 ± 0.8 to 120.0 ± 10.0; iron—from 2.9 ± 0.15 to 18.2 ± 1.5; and zinc—from 2.1 ± 0.1 to 10.1 ± 0.8 (Table 1).

Separate meta-analyses were conducted for different macro- and microelements (magnesium, iron, zinc, calcium, potassium, sodium, and phosphorus).

3.2. Macro- and Microelement Composition in Reindeer Meat: Heterogeneity Analysis

3.2.1. Magnesium

The iron content in reindeer meat was available in 11 studies. The standardised mean differences ranged from 2.9107 to 11.0987; most ratings were positive (100%). The estimated standardised mean difference based on a random-effects model was 5.3972 (95% CI: 3.7340–7.0604). Thus, the mean value was significantly different from zero (z = 6.3602, $p < 0.0001$) (Table 2, Figure 2).

Table 2. The content of macro- and microelements in reindeer (*Rangifer tarandus*) meat: Heterogeneity analysis.

Macro- and Microelements	Random-Effects Model, k	Estimate *	se	Z	*p*	CI Lower	CI Upper
Magnesium	9	5.40	0.849	6.36	<0.001	3.734	7.060
Iron	9	5.83	1.31	4.43	<0.001	3.250	8.404
Zinc	9	0.51	0.149	3.45	<0.001	0.22	0.804
Calcium	9	−2.12	2.45	−0.867	0.386	−6.918	2.674
Potassium	10	24.3	25.4	0.96	0.34	−25.45	73.99
Sodium	9	24.1	23.7	1.02	0.31	−22.31	70.5
Phosphorus	9	14.5	19.0	0.76	0.45	−22.7	51.7
Heterogeneity Statistics							
Macro- and Microelements	**Tau**	**Tau^2**	**I^2**	**H^2**	**df**	**Q**	***p***
Magnesium	2.419	5.8524 (SE = 3.259)	92.17%	12.776	8.000	66.719	<0.001
Iron	3.832	14.686 (SE = 7.81)	97.04%	33.77	8.000	269.34	<0.001
Zinc	0.44	0.194 (SE = 0.0995)	97.67%	42.98	8.000	429.42	<0.001
Calcium	7.292	53.1782 (SE = 26.9478)	99.3%	142.905	8.000	488.351	<0.001
Potassium	79.87	6378.95 (SE = 3034.51)	99.44%	178.16	9.000	1970.58	<0.001
Sodium	71.00	5041.41 (SE = 2522.57)	99.94%	1779.06	8.000	8955.84	<0.001
Phosphorus	56.8	3227.16 (SE = 1621.7)	99.54%	216.18	8.000	2146.4	<0.001

* Note. Tau^2 Estimator: Hedges.

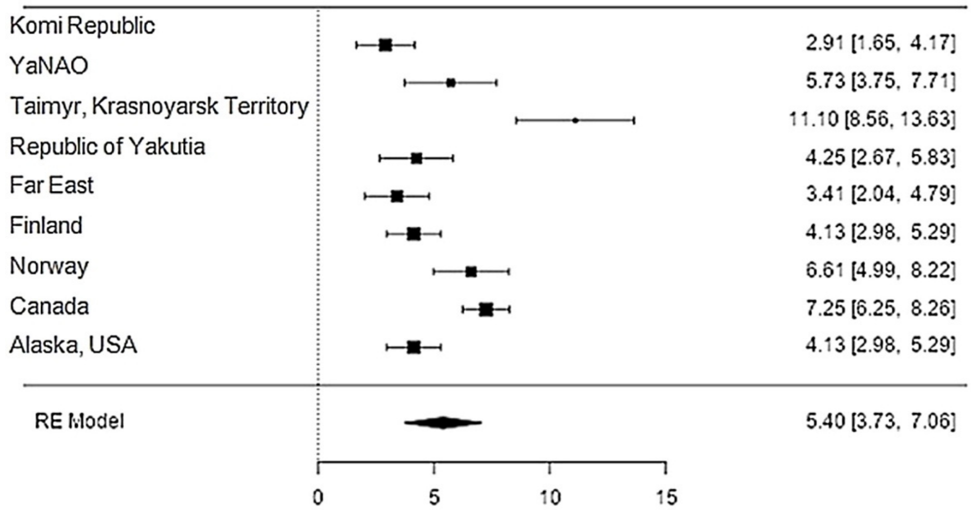

Figure 2. Forest plot of the comparison of the content of magnesium in reindeer (*Rangifer tarandus*) meat by geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of magnesium in reindeer (*Rangifer tarandus*) meat (Q(8) = 66.72, $p < 0.0001$, $tau^2 = 5.85$, $I^2 = 92.17\%$). The 95% interval was from 0.37 to 10.42. Publication bias was explored with a visual inspection of the funnel plot (Figure 3), where the regression test showed asymmetry in the funnel plot ($p = 0.026$), but not the rank correlation test ($p = 0.3429$) (Table 3).

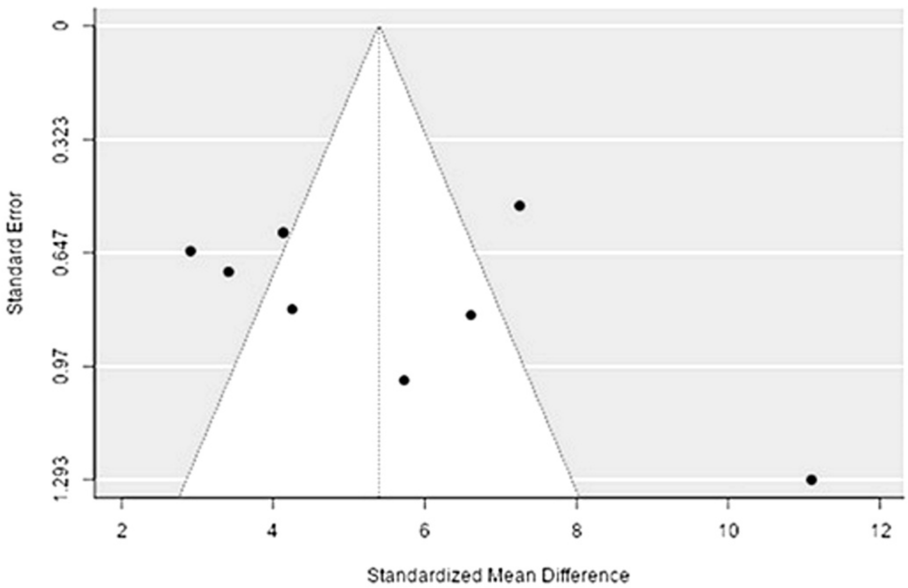

Figure 3. Funnel plot for publication bias evaluation of magnesium content in reindeer (*Rangifer tarandus*) meat by geographical regions.

Table 3. The statistical analysis of publication bias of the included sources with the data on macro- and microelements content in reindeer (*Rangifer tarandus*) meat *.

Macro- and Microelements	Test			
	Fail-Safe N		Egger's Regression	
	Value	*p*	Value	*p*
Magnesium	1559.000	<0 .001	2.221	0.026
Iron	1284.000	<0 .001	3.33	0.001
Zinc	1689.000	<0 .001	−0.099	0.921
Calcium	226.0	<0 .001	−0.14	0.89
Potassium	735.0	<0 .001	−0.14	0.89
Sodium	735.0	<0 .001	−0.14	0.89
Phosphorus	225.0	<0 .001	1.3	0.19

* Fault-tolerant calculation of N using Rosenthal's approach.

3.2.2. Iron

The iron content in reindeer meat was available in 11 studies. The standardised mean differences ranged from 0.32 to 11.56, and most ratings were positive (100%). The estimated standardised mean difference was 5.83 (95% CI: 3.25–8.4) based on a random-effects model. Thus, the mean value was significantly different from zero (z = 4.43, $p < 0.0001$) (Table 2, Figure 4).

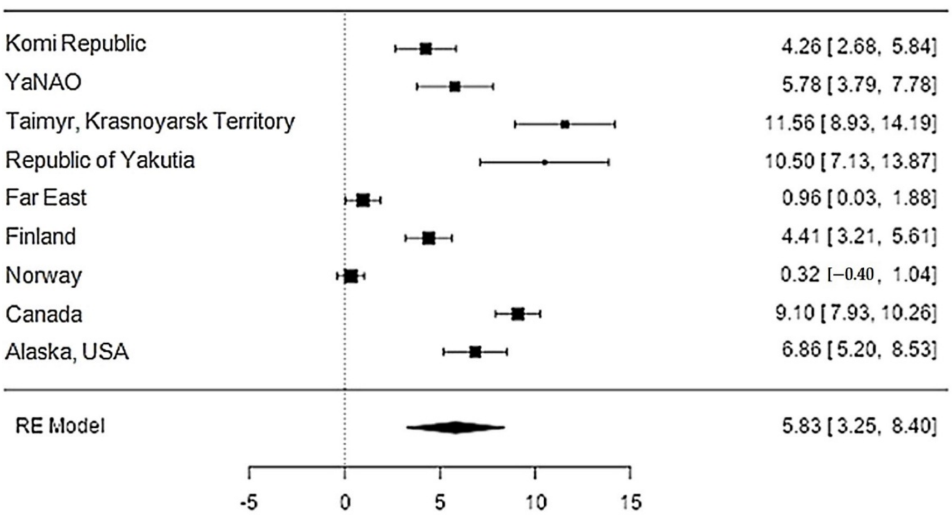

Figure 4. Forest plot of the sources, including the data on the iron content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of iron in reindeer (*Rangifer tarandus*) meat (Q(8) = 269.34, $p < 0.0001$, $tau^2 = 14.69$, $I^2 = 97.04\%$). The 95% interval was from −2.11 to 13.77. Publication bias was explored with a visual inspection of the funnel plot (Figure 5), where the regression test showed asymmetry in the funnel plot ($p = 0.0009$), but not the rank correlation test ($p = 0.12$) (Table 3).

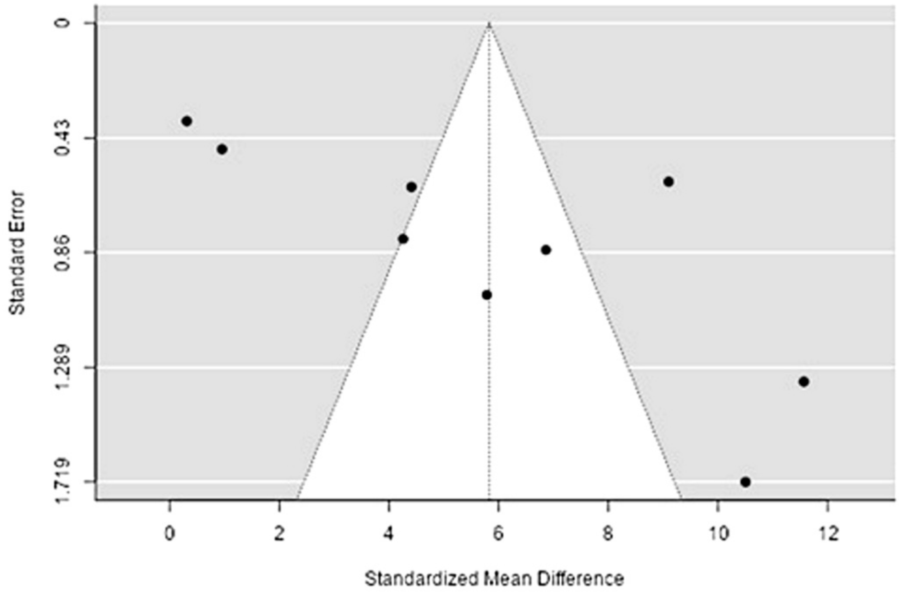

Figure 5. Funnel plot of the sources, including the data on the content of iron in reindeer (*Rangifer tarandus*) meat in different geographical regions.

3.2.3. Zinc

Data on the content of zinc in reindeer meat were available in 11 studies. The standardised mean differences ranged from −0.05 to 1.52, with most ratings being positive (89%). The estimated standardised mean difference based on a random-effects model was 0.51 (95% CI: 0.22–0.80). Thus, the mean value was significantly different from zero (z = 3.45, $p < 0.0006$) (Table 2, Figure 6).

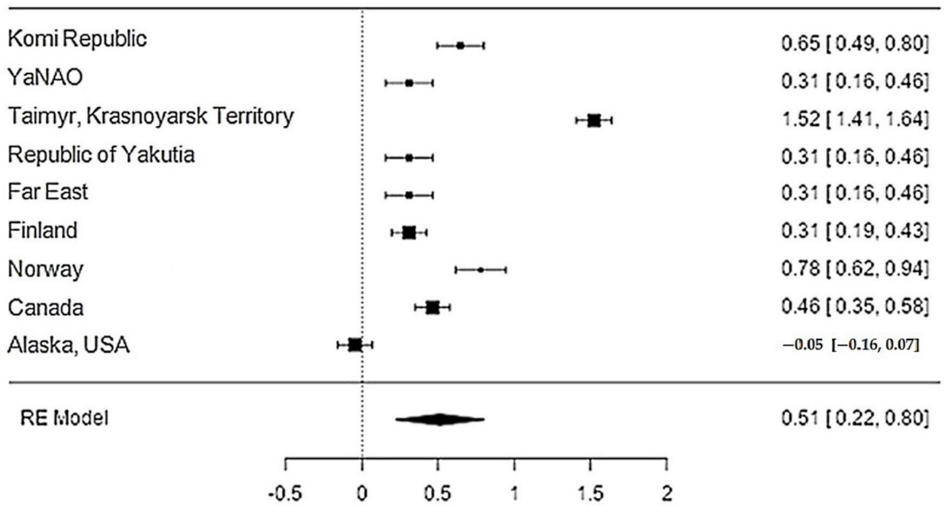

Figure 6. Forest plot of the sources, including the data on the content of zinc in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of zinc in reindeer (*Rangifer tarandus*) meat (Q(8) = 429.42, $p < 0.0001$, $tau^2 = 0.194$, $I^2 = 97.67\%$). The 95% interval was from −0.399 to 1.42. Publication bias was explored with a visual inspection of the funnel plot (Figure 7), where the rank correlation and regression tests were $p = 0.45$ and $p = 0.92$, respectively (Table 3).

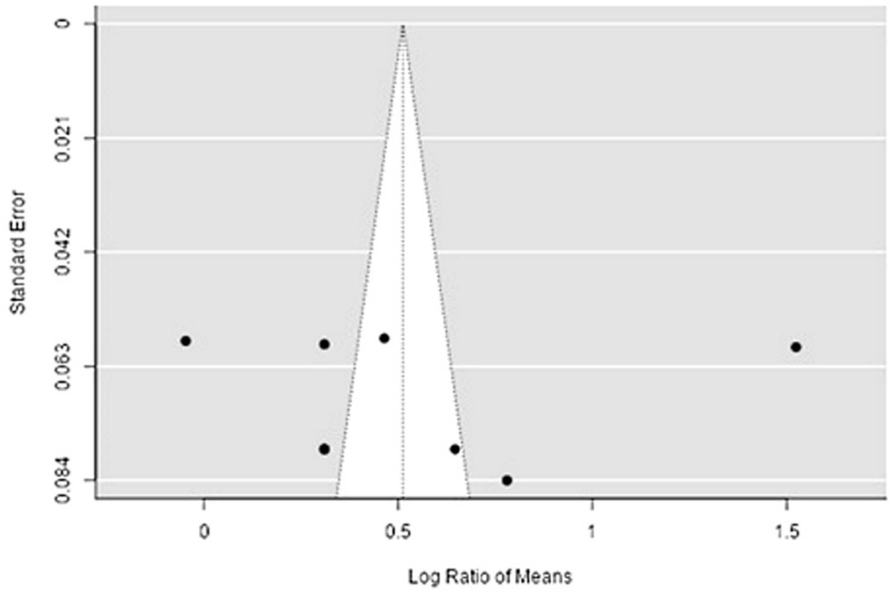

Figure 7. Funnel plot of the sources, including the data on the content of zinc in reindeer (*Rangifer tarandus*) meat in different geographical regions.

3.2.4. Calcium

Data on calcium content in reindeer meat were available in 11 studies. The standardised mean differences ranged from −14.9 to 7.2, with most ratings being negative (56%). The estimated standardised mean difference was −2.1 (95% CI: −6.92–2.67) based on a random-effects model. Thus, the mean value was significantly different from zero (z = −0.87, p = 0.39) (Table 2, Figure 8).

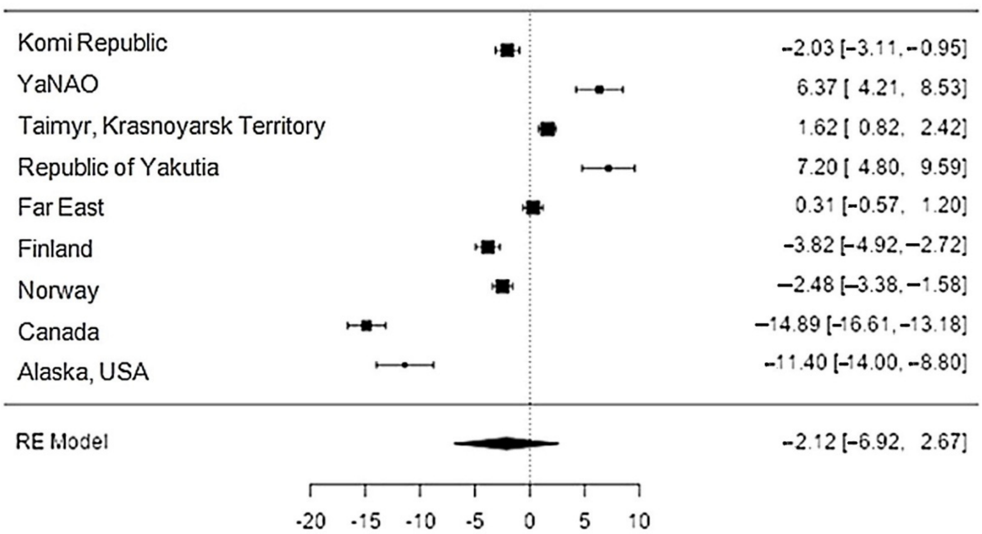

Figure 8. The forest plot of the sources includes the data on the calcium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of calcium in reindeer (*Rangifer tarandus*) meat (Q(8) = 488.35, $p < 0.0001$, $tau^2 = 53.18$, $I^2 = 99.3\%$). The 95% interval was from −17.2 to 12.96. Publication bias was explored with a visual inspection of the funnel plot (Figure 9), where the rank correlation and regression test did not reveal any asymmetry in the funnel plot (p = 0.26 and p = 0.89, respectively) (Table 3).

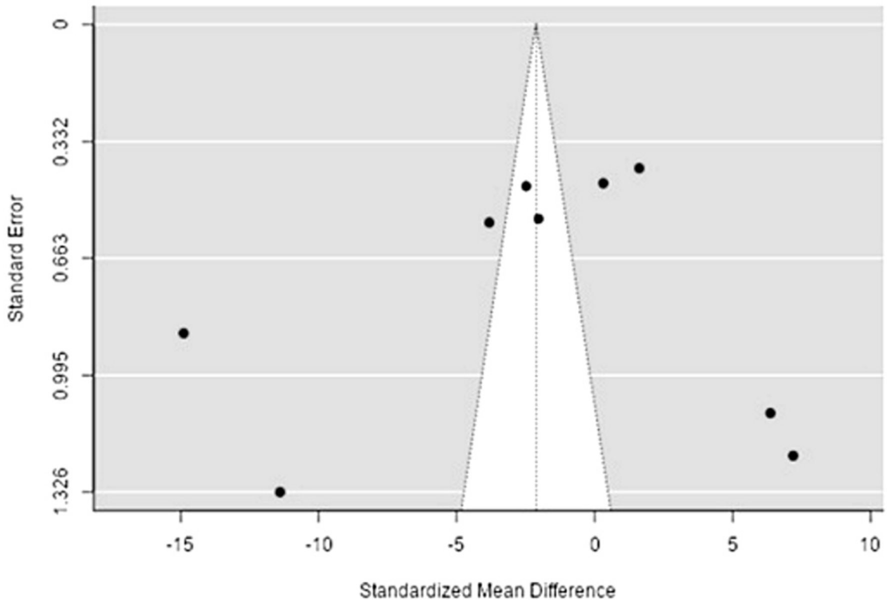

Figure 9. The funnel plot of the sources includes the data on the calcium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

3.2.5. Potassium

Data on potassium content in reindeer meat were available in 11 studies. The standardised mean differences ranged from −25.45 to 73.99, with most ratings being negative (70%). The estimated standardised mean difference was 24.3 (95% CI: −25.45–73.99) based on a random-effects model. Thus, the mean value was significantly different from zero (z = 0.96, p = 0.34) (Table 2, Figure 10).

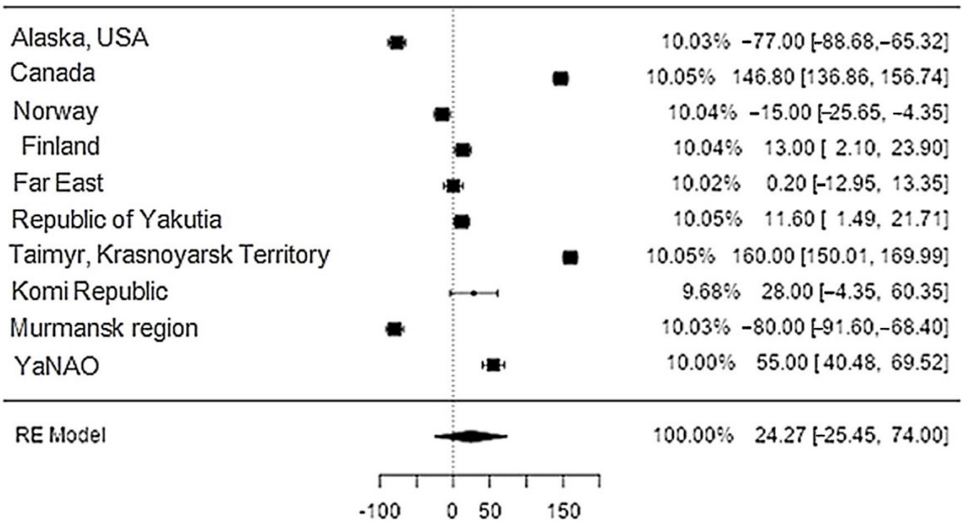

Figure 10. Forest plot of the sources, including the data on potassium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of potassium in reindeer (*Rangifer tarandus*) meat (Q(9) = 1970.58, $p < 0.0001$, $tau^2 = 6378.65$, $I^2 = 99.44\%$). The 95% interval was from −164.4 to 161.95. Publication bias was explored with a visual inspection of the funnel plot (Figure 11), where the rank correlation and regression tests were p = 0.48 and p = 0.88, respectively (Table 3).

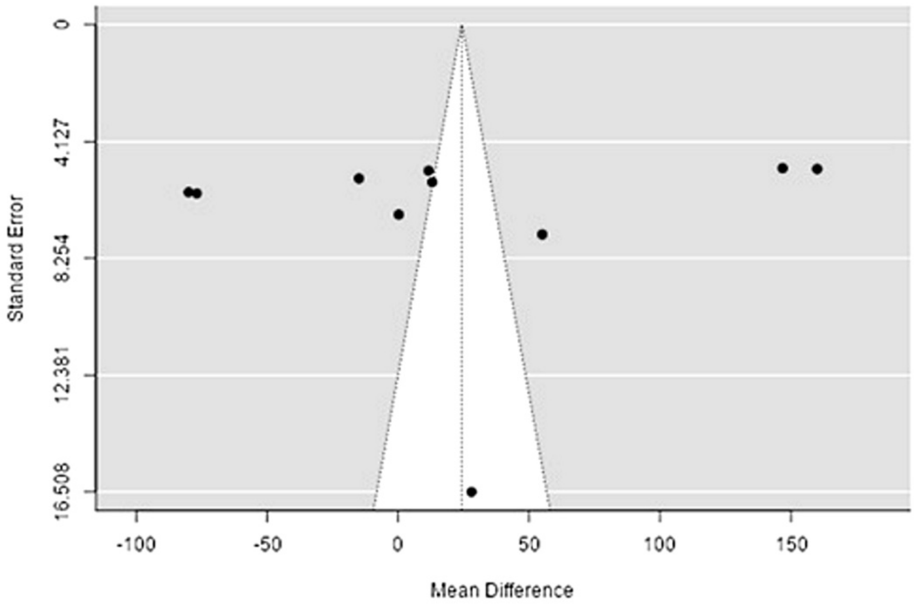

Figure 11. Funnel plot of the sources, including the data on potassium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

3.2.6. Sodium

Data on the content of sodium in reindeer meat were available in 11 studies. The standardised mean differences ranged from −27.7 to 198.6, with most ratings being negative (44%). The estimated standardised mean difference was 24.1 (95% CI: 22.31–70.5) based on a random-effects model. Thus, the mean value was significantly different from zero ($z = 1.02$, $p = 0.31$) (Table 2, Figure 12).

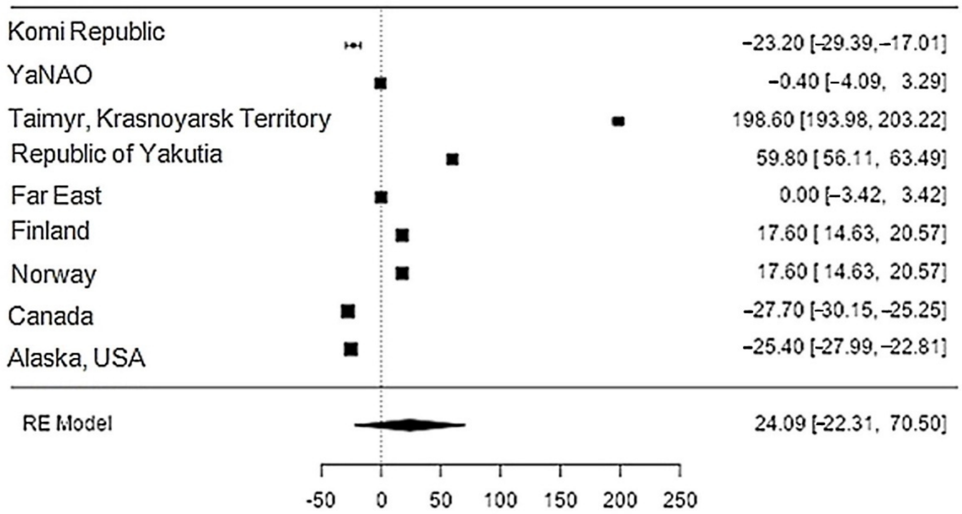

Figure 12. Forest plot of the sources, including the data on sodium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of sodium in reindeer (*Rangifer tarandus*) meat ($Q(8) = 8955.85$, $p < 0.0001$, $tau^2 = 5041.41$, $I^2 = 99.94\%$). The 95% interval was from −122.6 to 170.8. Publication bias was explored with a visual inspection of the funnel plot (Figure 13), where the rank correlation and regression tests were $p = 0.14$ and $p = 0.46$, respectively (Table 3).

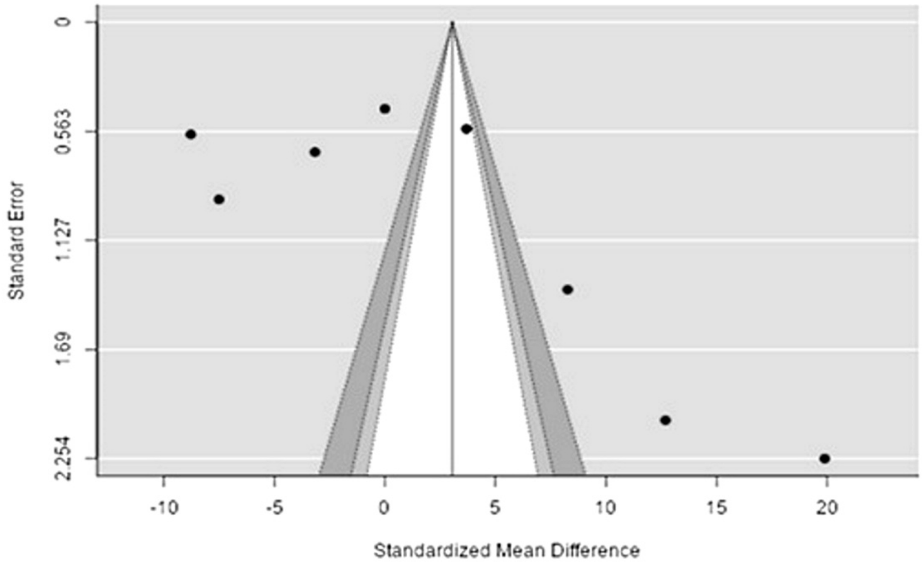

Figure 13. Funnel plot of the sources, including the data on sodium content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

3.2.7. Phosphorus

The data on phosphorus content in reindeer meat was available in 11 studies. The standardised mean differences ranged from −27.7 to 198.6, with most ratings being positive (78%). The estimated standardised mean difference was 14.5 (95% CI: −22.7 to 51.7) based on a random-effects model. Thus, the mean value was significantly different from zero ($z = 0.763$, $p = 0.45$) (Table 2, Figure 14).

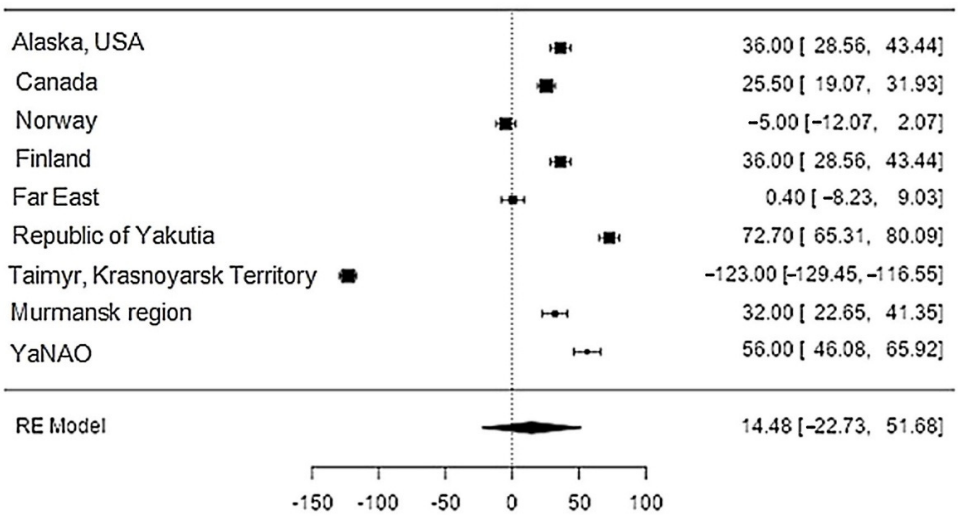

Figure 14. Forest plot of the sources, including the data on phosphorus content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

The *Q*-test confirmed the heterogeneity of the sources, including the data on the content of phosphorus in reindeer (*Rangifer tarandus*) meat ($Q(8) = 2146.4$, $p < 0.0001$, $tau^2 = 3227.16$, $I^2 = 99.54\%$). The 95% interval was from −102.9 to 131.9. Publication bias was explored with a visual inspection of the funnel plot (Figure 15), which did not present significant asymmetry: The rank correlation and regression tests were $p = 0.34$ and $p = 0.19$, respectively (Table 3).

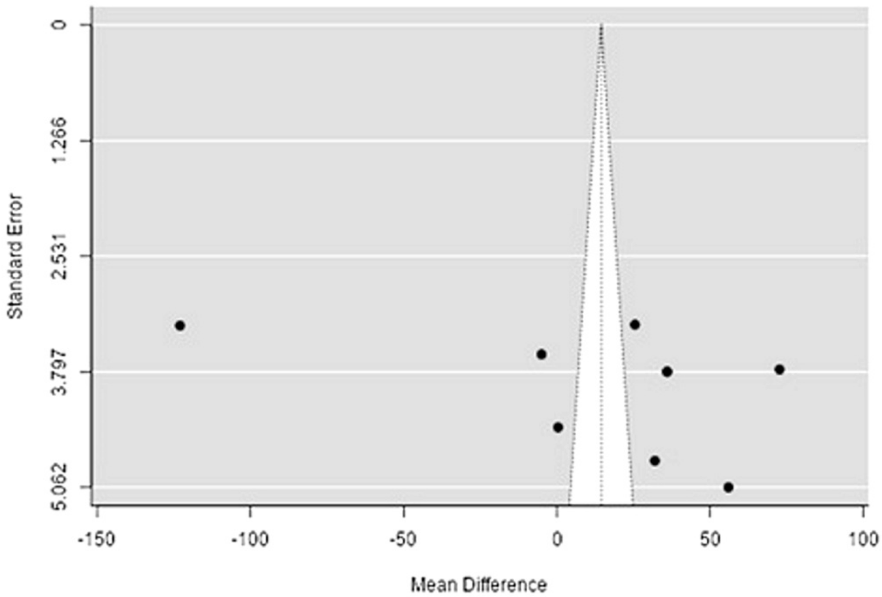

Figure 15. Funnel plot of the sources, including the data on phosphorus content in reindeer (*Rangifer tarandus*) meat in different geographical regions.

4. Discussion

This meta-analysis has expanded the knowledge of the composition of reindeer meat in different Arctic regions. The main findings of our research showed that the highest concentration of macro- and microelements is present in reindeer meat of the following Arctic regions: Magnesium—in Taimyr, Yamal-Nenets Autonomous Okrug, Canada; iron—in Taimyr, Republic of Yakutia, Canada; zinc—in Taimyr, Komi Republic, Norway; calcium—in Yamal-Nenets Autonomous Okrug, Republic of Yakutia, Taimyr; potassium—in Canada, Taimyr, Yamal-Nenets Autonomous Okrug; sodium—in Taimyr, Republic of Yakutia; phosphorus—in Republic of Yakutia, Alaska, Finland. Different proportions of macro- and microelements in reindeer meat can be a pre-condition for discussing the possible correlation between the value (nutritious and biological) and price of reindeer meat in different Arctic regions.

Different content of the macro- and microelements in the Arctic regions can be explained by ecosystems and anthropogenic (economic and industrial differentiation) factors. For example, a higher concentration of magnesium, calcium, potassium, and sodium in the Arctic regions with a harsh climate can be the outcome of a longer period of eating lichens and rags of vascular plants as a result of a long snow season. This is probably due to the higher concentration of trace elements in lichens and scrubs than green plants [110]. Higher concentrations of iron in Taimyr, the Republic of Yakutia, and Canada are probably associated with the regional features of iron accumulation in acidified soils and the high content of this trace element in the surface waters of these Arctic regions [111]. The high zinc content in Taimyr, Komi Republic, and Norway is possibly due to anthropogenic pollution caused by mining and processing polymetallic ores containing zinc [112]. However, the increased zinc content may also be of natural origin [113]. The phosphate content is probably related to the geochemical features of the soils [114]. In comparison, the soils of the Alaska and Finland regions contain more phosphates available for plants [115]. However, the primary source of the macro- and microelements in reindeer meat is their nutrition.

The supply of metals largely depends on their content in the surface layer of the soil [116]. Plants accumulate chemical compounds from the surface layer of the soil, which is typical for most of the territory of the Kola Peninsula, the Arkhangelsk Region, and the Nenets Autonomous Okrug and, to a lesser extent, with a decreasing trend in metal concentrations in the Yamal-Nenets Autonomous Okrug and the Republic of Yakutia [117]. Zinc belongs to the elements of strong biological accumulation [118,119], so the increase in the concentration of this element in soils is strongly associated with the processes of accumulation in plants (e.g., in Western Siberia [120,121]). Consequently, zinc entry with plant litter into the soil is very intensive.

Reindeers' diet consists of lichens, mosses, and vascular plants, accumulating significant amounts of metals and metalloids [79,122,123]. Therefore, the considerable variation of reindeers' habitat causes significant differences in the reindeer's diet. For example, the macro- and microelement composition of venison is influenced by the species composition of plants and lichens and the content of trace elements in them, the duration of grazing seasons on summer pastures, the proportion of green fodder, shrubs, lichens, mushrooms, eggs of birds, and rodents, the macro- and microelement composition of soil and water, the presence of pollution, the availability of salty seawater, cutting antlers, etc. The rich diet of *Reindeer tarandus* is also explained by specific seasonal migration to areas with different forage resources. Summer pastures are rich with herbaceous plants and shrubs. In contrast, winter pastures have many lichens.

The reindeer consumes 44 shrub willows and birches, 94 species of sedges, 52 species of cereals, 24 species of legumes, and 170 species of other plants [121]. Lichens are an essential and rich part of the reindeer's diet, especially in wet and frosty seasons (mainly in winter). So, on the territories located in the Arctic tundra zone (i.e., the northern part of the Yamal-Nenets Autonomous Okrug), as the significant part of the reindeer's ratio, lichens dominate most of the year [124–126]. In venison, it results in a high concentration of iron and zinc (important elements of antioxidant systems and cytochromes of the respiratory cell chain). The concentration of many trace elements in lichens is generally higher than in bryophytes, ferns, conifers, shrubs, and grasses [110]: Lichens accumulate more Co, Ni, Mo, Au, Mg, Ca, Zn, Cd, Sn, and Pb compared with other plants in the Arctic region [127]. Due to the lack of a root system and obtaining most minerals with precipitation (snow, rains), the concentration of trace elements in lichens highly depends on the transboundary transfer of trace elements and the amount of precipitation [128]. So, in more southern and western regions of Eurasia, less magnesium and calcium are accumulated in lichens than in the eastern and northern areas due to a large amount of precipitation during the snowless period [127]. The accumulation of trace elements by lichen also depends on its type and geographical location [129], i.e., woody lichens accumulate less zinc than bushy lichens (e.g., Cetraria, Cladonia) [130].

Moss, quickly accumulating metals, is the dominant form of vegetation in Arctic tundra ecosystems [122,131]. Sea aerosol is an additional source of elements including sodium, lead, mercury, and caesium [123,132]. Some of the elements are accumulated efficiently in mosses (e.g., Cd, Co, Cr, Cu, Fe, Mn, and Zn) [122], the Zn-Cd-Cu-Mn and Mo element correlation may be explained by their dietary intake from moss tundra. Compared to other Arctic regions and Canada, the values of most trace elements in the soils of the Yamal-Nenets Autonomous Okrug is higher (except Pb, Fe, and Mn) [133]. It can impact their transition to venison and increase the nutritious value of the reindeer meat in this Arctic region.

While mosses, lichens, and shrubs mostly accumulate cationogenic elements, herbaceous plants do it with anionic ones [111]. In the northern subarctic tundras, Zn, Nb, P, Mn, and Cu are actively accumulated [134]; in the middle and southern tundras, there are Zn, P, and Mn, and in the low northern subarctic tundras close to the coastal areas, the spectrum of elements is much more comprehensive than on the uplands of the continent [111].

Sedges and grasses and cereals (e.g., arctophile, bluegrass, arctagrostis, reed grass) dominate in the reindeer's diet (over 50% in early autumn; over 40% in early autumn) during the snowless period [135], and they actively accumulate Cu, Zn, and Pb [111]. In winter, especially with a lack of lichen forage, the rags of these plants can make up even more than 60% of the reindeer's diet.

The source of zinc, silver, lead, manganese, and barium for a reindeer is vaginal fluffy (Erióphorum vaginátum), a valuable nutritious food in winter and spring [136,137]. The accumulation of these trace elements depends not only on the composition of the substrate but also on the acidity of the soil [138]. Variegated and reed horsetails included in the reindeer's diet in early spring and autumn, as well as field horsetail, marsh horsetail, marsh horsetail, and meadow horsetail all year round [135], also contribute to enriching reindeer meat with manganese, silicon, and iron [111].

The high content of zinc and copper in reindeer meat can also result from consuming leaves of willows (gray willow, filiform willow, spear-shaped willow, ferruginous willow, Lapland willow, beautiful willow) and low and white birch. In early summer, the leaves of shrubs can provide up to 30% of the reindeer's diet (over 90% of them are willow leaves) [135]. Yernik and willow have the maximum accumulation of zinc [120].

Upon consuming blueberries, lingonberries, cloudberries, bearberries, crows, and rowan berries, a reindeer accumulates zinc, iron, and magnesium [134]. Likewise, mushrooms bring zinc, selenium, lead, copper, strontium, and mercury in a reindeer's diet [139]. While grazing, a reindeer can also eat birds' eggs, lemmings and voles, rodent nests, and frozen fish, covering the deficiency of such trace elements as calcium, potassium, phosphorus, sodium and zinc [140].

The knowledge of the macro- and microelement content of reindeer meat can help develop dietary programmes to manage the health risks of Arctic residents. The concentration of valuable trace elements necessary for adaptation in the Arctic is much higher in venison than other meat types. In north-eastern Canada, Kuhnlein H.V. et al. (1996) proved that consuming traditional food (venison) results in receiving more phosphorus, iron, zinc, and magnesium compared with imported products [20]. According to Bogdan E.G. and Turshuk E.G. (2016), S.V. Andronov, and A.A. Lobanov et al. (2017), venison is rich in macro- and microelements, has high nutritional and biological value [37,141].

Some researchers recommend widely using reindeer products to increase human resistance to unfavourable environmental factors in the diet [41,141–144] because reindeer meat is especially rich in calcium, phosphorus, potassium, sodium, magnesium, iron, and zinc. The high phosphorus, magnesium, potassium, and iron content in venison provides its high efficiency for increasing adaptation to cold stress and geomagnetic activity in the Arctic [145,146]. A diet enriched with reindeer products significantly increases the antiatherogenic fraction of blood lipids, prevents overweight, atherosclerosis, and heart disease [37,144], and improves microcirculation, tissue fluid exchange, and the body's antioxidant defence against free radicals [6]. A sufficiently large amount of trace elements (iron, zinc) contained in venison can help to prevent acute infectious diseases and provide antioxidant protection of the human body from free radicals [91,102]. This explains the high efficiency of adaptation to cold stress, as well as increased prophylactic activity during hypothermia [7,8].

The important contribution of reindeer meat and its macro-nutrients towards adaptation was acknowledged in Nordic countries. According to the Nordic nutrition recommendations, reindeer meat as game meat does not present the epidemiological evidence shown with high consumption of processed or red meat increasing the risk of colorectal cancer, type-2 diabetes, obesity, and coronary heart disease [147,148].

Our study had some limitations. First, the reindeer habitat in the Arctic is huge, therefore we had to present a less-detailed analysis for some regions. Second, a number of published studies included in the analysis are characterised by heterogeneity. In our meta-analysis, we used random effects models; so, a high level of heterogeneity (>80.0%) could impact the reliability. Third, there were a number of variations in the studies that were analysed: The quality, research methods, observation period, etc. Finally, selection bias is possible because observational studies were used in this meta-analysis.

The strengths of our study are associated with the implementation of a complex approach to systematising information on the mineral composition of reindeer meat in different Arctic regions. The meta-analysis has wide geographical coverage. A comprehensive and robust search strategy was designed to avoid the loss of relevant research. Moreover, there were no studies excluded for linguistic reasons to avoid linguistic bias. In addition, routine tests and visual inspection of the funnel plot plots did not reveal any evidence of a risk of publication bias.

5. Conclusions

The meta-analysis revealed that the indicators of the content of trace elements in reindeer meat had a high variability depending on the geographical region. The ecosystems and anthropogenic factors strongly impacted the macro- and microelements composition of reindeer meat in different Arctic regions. In the Russian Arctic regions with the most severe climatic conditions (especially, Taimyr, Yamal-Nenets Autonomous Okrug, and the Republic of Yakutia) and Canada, venison has the highest mineral saturation, and therefore, higher nutritious and biological value due to enriched biodiversity and the rich fodder base for reindeer. This makes reindeer meat an effective means of preventing obesity and adapting to cold due to the content of a complete set of essential trace elements and amino acids. The high content of iron and zinc in reindeer meat increases the body's antioxidant defence against free radicals and helps to prevent chronic non-infectious diseases. Ultimately, future research could compare the differences in the content of macro- and microelements in venison and other types of meat in the Arctic to prove its higher biological value.

A unique macro- and microelement composition of reindeer meat also proves its economic value and will be important for nutritional policy makers in the Arctic regions. This is a good pre-condition for the negotiation of fair prices for reindeer meat exported from this region based on the balance of the nutritious/biological value and price. It contributes to increasing the profitability of reindeer herding in the Arctic regions and maintaining this significant traditional livelihood of the Indigenous Peoples.

Author Contributions: Conceptualisation, A.L. and I.K.; methodology, A.L.; software, S.A.; validation, E.B. and A.Y.; formal analysis, S.A. and E.B.; investigation, A.L.; resources, S.A.; data curation, A.P.; writing—original draft preparation, E.B., S.A. and A.L.; writing—review and editing, A.Y.; revising, D.R. and O.S.; visualisation, S.A.; supervision, A.L.; project administration, E.B.; funding acquisition, E.B. and O.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. PRISMA Checklist *.

Section/Topic	#	Checklist Item	Reported on Page #
		TITLE	
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
		ABSTRACT	
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
		INTRODUCTION	
Rationale	3	Describe the rationale for the review in the context of what is already known.	1–3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	2–3
		METHODS	
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	N/A
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	3–4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3–4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	3-4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	3–4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4–5
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4–5
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	5
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5, Appendix B
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A

Table A1. *Cont.*

Section/Topic	#	Checklist Item	Reported on Page #
		RESULTS	
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5–6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	5–14
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	6–14
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	6–14
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	6–14
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	6–14
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
		DISCUSSION	
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	14–17
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16–17
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	17
		FUNDING	
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	17

* According to [46].

Appendix B

Table A2. Quality Criteria Checklist *.

Quality Criteria checklists	[3]	[85]	[88]	[89]	[84]	[90]	[91]	[92]	[39]
Year	2019	2019	2010	2011	2014	2016	2017	2019	2019
Relevance questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Validity Questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quality Rating (+,0,−)	+	+	+	+	+	+	+	+	+
Quality Criteria checklists	[19]	[21]	[22]	[98]	[95]	[96]	[74]	[97]	
Year	1992	2000	2002	2002	2012	2012	2012	2013	
Relevance questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Validity Questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Quality Rating (+,0,−)	+	+	+	+	+	+	+	+	

Table A2. *Cont.*

Quality Criteria checklists	[107]	[108]	[109]	[102]	[103]	[104]	[105]	[106]	
Year	1995	1997	2007	2010	2011	2014	2020	2021	
Relevance questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Validity Questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Quality Rating (+,0,−)	+	+	+	+	+	+	+	+	
Quality Criteria checklists	[83]	[100]	[27]	[87]	[38]	[101]	[99]	[93]	[94]
Year	1999	2006	2009	2009	2018	2019	2019	2020	2013
Relevance questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Validity Questions									
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes
2	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	Yes
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quality Rating (+,0,−)	+	+	+	+	+	+	+	+	+

* According to [54].

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