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Meta-analysis of the efficacy of camel milk consumption for improving autism symptoms in children in randomized clinical trials

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ABSTRACT

Background: Camel milk has emerged as a potential complementary therapy for autism spectrum disorder (ASD).

Aim: This study aimed to gather evidence from randomized controlled trials (RCTs) on the effectiveness of camel milk consumption in improving symptoms and associated measures in children with ASD.

Methods: Comprehensive searches of multiple databases were conducted up to March 14, 2024, for RCTs that evaluated whether camel milk consumption by children with ASD was more beneficial than the consumption of a control substance. Quality and bias analyses and meta-anlaysis data were synthesized and analyzed.

Results: Of 136 records identified, 5 RCTs (n = 299 children) were selected. The mean difference in scores on the childhood autism rating scale (CARS) for the group given camel milk and the control groups was a mean deviation (MD) –0.75, 95% CI–1.97 to 0.47, p = 0.23. The mean difference in CARS scores in the subgroup analyses for raw camel milk was MD–0.95, 95% CI–2.33 to 0.44, p = 0.18 and boiled camel milk MD –0.50, 95% CI–1.93 to 0.93, p = 0.49. A qualitative synthesis found that raw camel milk intake led to improvements in various social behaviors in children with ASD. Camel milk consumption resulted in increased levels of anti-inflammatory, antioxidant, and immunomodulatory biomarkers, with some differences observed between patients given raw camel milk and boiled camel milk.

Conclusion: Camel milk shows promise in improving social behaviors and certain biochemical markers in children with ASD, although the current meta-analysis did not document a significant statistical difference in CARS scores for the children studied. Future studies should focus on rigorous RCTs and larger sample sizes to substantiate these preliminary findings.

Keywords: Autism spectrum disorder, Camel milk, Meta-analysis, Therapeutic intervention, Childhood autism rating scale.

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder affecting the social interactions and communication of children (Sharma *et al.*, 2018). The incidence of ASD in the USA as reported by the Centers for Disease Control and Prevention indicates that in 2000, ASD was estimated to affect 1 in 150 children but that by 2020, this estimate had risen to 1 in 36 children, a notable increase in identified cases over two decades (CDC, 2024). The precise causes of ASD remain unclear, though it is thought to result from genetic and environmental influences (Hertz-Picciotto *et al.*, 2018; Bai *et al.*, 2019; Rylaarsdam and Guemez-Gamboa, 2019; CDC, 2024). Although a cure for ASD has not been discovered, early intervention and supportive therapies can enhance the health and quality of life of those affected by it (Bai *et al.*, 2019; Ribeiro *et al.*, 2022).

Behavioral therapies are regarded as the primary approaches for treating ASD, but in recent years, promising therapies have emerged that could target the underlying neurophysiology of ASD (Aishworiya *et al.*, 2022). These therapies hold the promise of eventually becoming integral to treating ASD's core symptoms. The future development of these targeted treatments is expected to take into account the etiological diversity of ASD, with the disorder's genetic factors likely becoming the initial focus of treatments, including gene therapy. Medications such as trofinetide, metformin, lovastatin, arbaclofen, cannabidiol, and bumetanide and dietary supplements such as sulforaphane and

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N-acetylcysteine were evaluated in ASD patients (Aishworiya *et al.*, 2022). Several medications used for the disorder's comorbid conditions, such as alpha-2 agonists, serotoninergic agents, and atypical antipsychotics, were also assessed (Zafeiriou *et al.*, 2009; Ghanizadeh *et al.*, 2019; Sahnoun *et al.*, 2024).

Treatments for ASD extend beyond conventional medical interventions to include various complementary and alternative medicine options. These alternative approaches are an array of non-traditional therapies such as music therapy, massage therapy, the application of natural products and herbal remedies, and specific dietary plans (Levy and Hyman, 2008; Saral *et al.*, 2023). One such alternative approach that has garnered increasing attention is the use of camel milk (Adams, 2013; Bakry *et al.*, 2021; Swelum *et al.*, 2021; Alkattan *et al.*, 2023; Gahlot and Adams, 2023; Muthukumaran *et al.*, 2023).

Camel milk has shown promise as a potential therapeutic option for various diseases and conditions other than ASD. Its anti-inflammatory, antimicrobial, antioxidant, and immunomodulatory properties have led researchers to investigate its use for conditions such as diabetes, cancer, and hepatic disorders (Shakeel *et al.*, 2022; Shaban *et al.*, 2023). Camel milk and its components have also had beneficial effects on cardiovascular health, wound healing, and nutrition and growth in children (Muleta *et al.*, 2021; Flis *et al.*, 2023).

While several preclinical and clinical studies have explored the potential benefits of camel milk in ASD, the findings have been inconsistent, and its overall efficacy remains unclear. Previous reviews have been narrative in nature or focused on specific aspects such as the biochemical composition of camel milk or its effects on animal studies (Konuspayeva *et al.*, 2009; Alhaj *et al.*, 2022). To date, no comprehensive systematic review and meta-analysis have been conducted to evaluate the collective evidence from randomized controlled trials (RCTs) on the efficacy of camel milk consumption in improving autism symptoms and associated measures in children with ASD.

This study aimed to synthesize the available evidence from RCTs to assess the effectiveness of camel milk consumption in ameliorating autism symptoms and related outcomes in children diagnosed with ASD.

Materials and Methods

Study documentation and registration

This study was carried out in alignment with regulatory instructions (Cumpston *et al.*, 2019) and PRISMA standards (Liberati *et al.*, 2009) (Supplementary Table 1). The study design and strategy were registered in the PROSPERO repository with accession no. CRD42024525278.

Search strategy

A standard search strategy for systematic reviews is a planned process aimed at identifying all relevant studies on a particular research question, ensuring comprehensiveness and minimizing bias. The first step was to define clear, specific research questions. This helped in setting the scope and boundaries for the search. Following this, a comprehensive search of multiple databases was conducted. Keywords and controlled vocabulary terms [e.g., Medical Subject Headings (MeSHs)] relevant to the research question were used in various combinations to capture all possible studies. Boolean operators (AND, OR, and NOT) were employed to refine the search results further, ensuring that all potentially relevant studies were included and irrelevant ones excluded.

The search included the Web of Science, PubMed, Scopus, and the Cochrane Library, covering publications up to March 14, 2024. The search strategy incorporated a blend of pertinent keywords and MeSH terms focused on "camel milk" and "ASD". There were no limitations imposed on the language of the study or the publication date. Comprehensive details of the search strategy are available in Supplementary Table 2.

In addition to database searches, a robust search strategy included checking the references of included studies and systematic reviews to identify any additional relevant studies that may have been missed. Grey literature sources such as conference proceedings, theses, and government reports were also searched to capture unpublished or non-peer-reviewed studies. Citation Manager software was used to organize and deduplicate the search results. The search strategy was documented in detail in a listing of the databases searched, the search terms used, and the number of results obtained from each source. Finally, the identified studies were screened against pre-defined inclusion and exclusion criteria so that the most relevant studies could be selected for the review.

Inclusion and exclusion criteria

The inclusion criteria were designed to ensure the selection of high-quality studies that would provide robust evidence on the effects of camel milk consumption in children with ASD. Only RCTs were included, as they are considered the gold standard in clinical research due to their ability to minimize bias and establish causality. The studies had to involve children diagnosed with ASD to ensure the findings were relevant to the target population. The intervention of interest was camel milk consumption, and its effects were compared with the effects of a control substance, which was a placebo, another type of milk, or a standard treatment. This comparison was necessary to assess the specific effects of camel milk on autism-related outcomes. The studies also had to report outcomes directly related to autism symptoms, such as behavioral assessments, cognitive functions, social interactions, and communication skills, to ensure that the review focused on clinically meaningful improvements.

Studies were excluded if they did not adhere to these rigorous criteria. Non-randomized trials, observational

studies, case reports, and reviews were not considered, as they do not provide the same level of evidence as RCTs. Additionally, studies without a control group were excluded because the hope was to ensure that the effects of camel milk would be accurately compared with a baseline or alternative intervention. By setting these stringent inclusion and exclusion criteria, the study aimed to synthesize the most reliable and relevant evidence on the impact of camel milk consumption in children with ASD, thereby providing clear and actionable insights for clinicians, researchers, and families.

Study selection and data extraction

The study selection and data extraction were performed as previously described (Alkattan *et al.*, 2023; Alsaleem *et al.*, 2024). The study selection process started with a thorough search of several databases, followed by the removal of duplicates. Then, titles and abstracts of the remaining studies were screened against pre-defined criteria so that at least two independent reviewers could make decisions about inclusion or exclusion. Studies that met the initial screening criteria were subjected to a full-text review, and the same inclusion and exclusion criteria were applied more rigorously. Any disagreements between the reviewers during this process were resolved through discussion or by asking an additional reviewer to assess the findings, so that a thorough and unbiased selection of studies would be ensured for the review.

A standardized data extraction form is typically used to ensure consistency and comprehensiveness. This form includes key information such as the study design, participant characteristics, intervention details, comparison groups, outcome measures, and results. The data extraction process is usually performed by at least two independent reviewers to reduce errors and enhance accuracy. Critical appraisal tools may also be employed to assess the quality and risk of bias of the included studies. The primary scale used for our study was the childhood autism rating scale (CARS), which assesses the severity of ASD symptoms in children (Schopler *et al.*, 1980).

Quality assessment

The potential bias in the included RCTs was assessed using the RoB 2 tool (Sterne *et al.*, 2019). It is specifically designed to evaluate the risk of bias in RCTs, ensuring that the results of the study are based on high-quality and reliable evidence. The assessment is conducted across several domains. Each domain is judged based on a series of signaling questions, which guide the reviewer to determine the level of risk as "low", of "some concern", or "high".

This thorough assessment was carried out by two independent reviewers to ensure objectivity and reduce the potential for bias in the evaluation process. Any disagreements between reviewers were resolved through discussion or by consulting a third reviewer if necessary. The outcomes of the RoB 2 assessment were then summarized and merged for analysis. By using the RoB 2 tool, systematic reviews can provide a detailed and transparent assessment of the risk of bias in the included studies, which is crucial for interpreting the results and drawing valid conclusions.

Data analysis

Meta-analyses were performed using RevMan 5.4 software. A fixed-effect model was used to pool the data. Subgroup analyses were conducted based on the nature of the camel milk (either raw or boiled) consumed. For outcomes that could not be meta-analyzed, a qualitative synthesis was provided.

Data analysis involves synthesizing the findings from studies to deliver comprehensive conclusions about a specific research question. Key information such as the study design, participant characteristics, and other details were extracted and tabulated. These structured data formed the basis for both the qualitative and quantitative analyses. Qualitative synthesis involved summarizing and interpreting the findings in a narrative format, highlighting patterns, differences, and key insights across the studies.

Heterogeneity was assessed using the I^2 statistic. Forest plots were generated to visually represent the effect sizes and confidence intervals (CIs) of the studies and the overall pooled estimate. Sensitivity analyses and subgroup analyses were also performed to explore the robustness of the findings and the impact of specific study characteristics.

Ethical approval

Not needed for this study.

Results

Characteristics of included studies

We found a total of 136 records through our thorough search, out of which 43 were duplicates and therefore removed. Following the screening of titles and abstracts, 6 studies met the eligibility criteria. After a full-text review, 4 RCTs were included (Al-Ayadhi and Elamin, 2013; Bashir and Al-Ayadhi, 2014; Al-Ayadhi *et al.*, 2015 and 2022). Additionally, one RCT was identified through a reference screening of the included studies (Mostafa *et al.*, 2021). Ultimately, our systematic review and meta-analysis contained 5 RCTs (Al-Ayadhi and Elamin, 2013; Bashir and Al-Ayadhi, 2014; Al-Ayadhi *et al.*, 2015; Mostafa *et al.*, 2021; Al-Ayadhi *et al.*, 2022) (Fig. 1).

All 5 RCTs were conducted in Saudi Arabia and included children diagnosed with ASD according to the diagnostic and statistical manual of mental disorders (DSM-IV) (Al-Ayadhi and Elamin, 2013; Al-Ayadhi *et al.*, 2015; Mostafa *et al.*, 2021) or Social Responsiveness Scale (SRS) (Al-Ayadhi *et al.*, 2022). The children's ages were between 2 and 12 years in 4 RCTs and between 3 and 12 years in the study by Mostafa *et al.* (2021). The daily amount of camel milk consumed was 500 ml and the length of the study was 2 weeks in all the RCTs, and the common outcome was

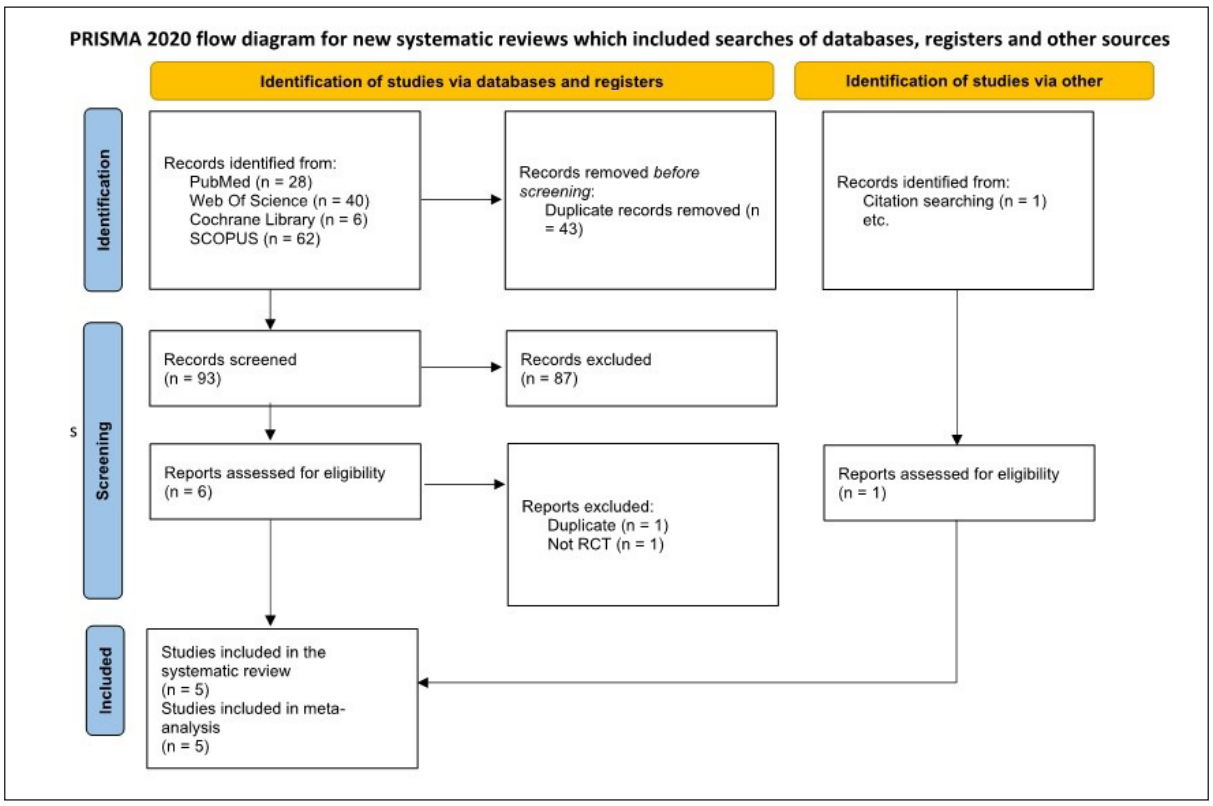

Fig. 1. PRISMA 2020 flow diagram illustrating the process of literature selection. The flow chart is divided into four main stages: identification, screening, eligibility, and inclusion.

recorded as a change in the CARS. Further details are shown in Table 1.

Quality assessment

The study by Bashir and Al-Ayadhi (2014) was considered to have a low risk of bias because all of the domains assessed by the RoB 2 were found to have a low score (Bashir and Al-Ayadhi, 2014). However, the other four RCTs were considered to be of some concern. Although these studies demonstrated a low bias in most domains, the randomization process was not clearly described, leading to an overall classification of some concern (Figs. 2 and 3).

Meta-analysis

Change in CARS

The pooled analysis of the five RCTs, with a total sample of 299 children, showed no significant differences between the camel milk group and control group mean deviation (MD = –0.75, 95% CI –1.97 to 0.47, $p = 0.23$), and the data showed moderate heterogeneity ($p = 0.16$, $I^2 = 39\%$) (Fig. 4).

Subgroup analysis

The subgroup analysis based on the nature of the camel milk as raw or boiled showed no significant differences between the groups (MD = –0.95, 95% CI –2.33 to 0.44, $p = 0.18$) and (MD = –0.50, 95% CI –1.93 to 0.93, $p = .49$), respectively. The data were homogeneous at $p = 0.33$, $I^2 = 14\%$ and $p = 0.16$, $I^2 = 39\%$, respectively (Fig. 5).

Qualitative synthesis

Social behavior in autism

Raw camel milk intake resulted in significant improvements in various aspects of social behavior among children with ASD, including social cognition, communication, and awareness. Boiled camel milk resulted in significant changes primarily in social cognition, so it may have potential benefits for social functioning (Al-Ayadhi *et al.*, 2015).

Anti-inflammatory, antioxidant, and immunomodulatory markers

Camel milk, whether raw or boiled, led to significant increases in plasma levels of myeloperoxidase (MPO) and glutathione (GSH) in the children studied. Additionally, boiled camel milk significantly affected superoxide dismutase (SOD) levels compared with a placebo (Al-Ayadhi and Elamin, 2013). Camel milk consumption was associated with significantly lower plasma levels of tumor necrosis factor-alpha (TNF-α) and improvements in autism-related symptoms and gastrointestinal symptoms among children with autism. These effects were not observed in the placebo group (Al-Ayadhi *et al.*, 2022). Both types of camel milk (raw and boiled) led to significant decreases in serum

Table 1. Summary of included studies.

Study ID	Site	Sex	Inclusion criteria	Study groups and sample	Daily consumed camel milk	Study outcomes	Follow-up	Conclusion
Al-Ayadhi and Elamin (2013)	Saudi Arabia	-	* Age range: 2–12 years * Diagnosis: ASD * Specific focus: Individuals with known allergies or food intolerances * Diagnostic criteria: According to the DSM-IV	* Group I (n = 24): Received raw camel milk. * Group II (n = 25): Received boiled camel milk. * Group III (n = 11): Received cow milk as a placebo.	500 ml for 2 weeks	Changes in levels of plasma levels of GSH, SOD, MPO, and CARS	2 weeks	Camel milk was found to potentially play a crucial role in reducing oxidative stress by altering levels of antioxidant enzymes and nonenzymatic antioxidant molecules. Furthermore, it demonstrated improvement in autistic behavior, as indicated by enhancements in the CARS.
Al-Ayadhi *et al.* (2015)	Saudi Arabia	Boys = 60, Girls = 5	* Age range: 2–12 years * Diagnosis: ASD * Diagnostic criteria: According to the DSM-IV	* Group I (n = 25): Received pasteurized camel milk. * Group II (n = 25): Received unpasteurized camel milk. * Group III (n = 11): Received cow milk as a placebo.	500 ml for 2 weeks	Changes in CARS, SRS, and ATEC	2 weeks	Camel milk showed promising potential as a therapeutic intervention for ASD. Further large-scale studies were strongly recommended.
Al-Ayadhi *et al.* (2022)	Saudi Arabia	-	* Age range: 2–12 years * Diagnosis: ASD * Diagnostic criteria: According to the SRS.	* Group I (n = 23): Received raw camel milk. * Group II (n = 27): Received boiled camel milk. * Group III (n = 14): Received cow milk as a placebo.	500 ml for 2 weeks	Changes in TNF-α and CARS.	2 weeks	The study provided evidence of the beneficial effects of both raw and boiled camel milk in alleviating neuroinflammation among patients with ASD.
Bashir and Al-Ayadhi (2014)	Saudi Arabia	Boys = 40, Girls = 5	* Age range: 2–12 years * Diagnosis: ASD * Diagnostic criteria: According to the DSM-IV	* Group I (n = 15): Received raw camel milk. * Group II (n = 15): Received boiled camel milk. * Group III (n = 15): Received cow milk as a placebo.	500 ml for 2 weeks	Changes in TARC serum levels and CARS	2 weeks	Administered for a duration of 2 weeks, camel milk significantly enhanced clinical assessments of autism severity and reduced serum levels of TARC in children with autism.
Mostafa *et al.* (2021)	Saudi Arabia	Boys = 48, Girls = 17	* Age range: 3–12 years * Diagnosis: ASD * Diagnostic criteria: According to the DSM-IV	* Group I (n = 24): Received raw camel milk. * Group II (n = 23): Received boiled camel milk. * Group III (n = 18): Received cow milk as a placebo.	500 ml for 2 weeks	Changes in VIP levels and CARS	2 weeks	Camel milk did not demonstrate significant results in decreasing CARS scores or increasing VIP levels.

ASD: Autism Spectrum Disorder, DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, CARS: Childhood Autism Rating Scale, SRS: Social Responsiveness Scale, ATEC: Autism Treatment Evaluation Checklist, TNF-α: Tumor Necrosis Factor Alpha, TARC: Thymus and Activation-Regulated Chemokine, VIP: Vasoactive Intestinal Peptide.

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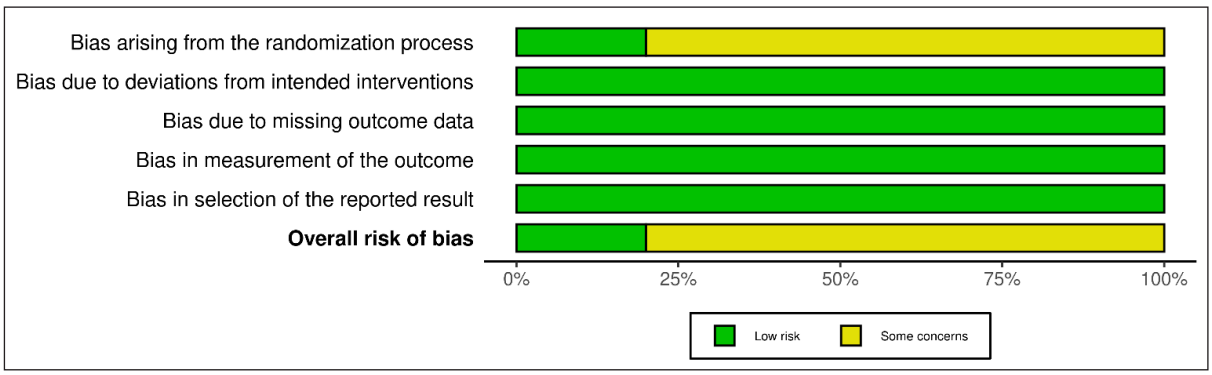

Fig. 2. Risk of bias assessment for studies included in a meta-analysis represented as a bar graph. Five different potential sources of bias are evaluated. Each type of bias is assessed as "Low risk" (green) or "Some concerns" (yellow), with the proportion of each risk level shown horizontally. The overall risk of bias summarizes the combined risk across all categories. The *X*-axis represents the percentage of studies with each level of risk, ranging from 0% to 100%.

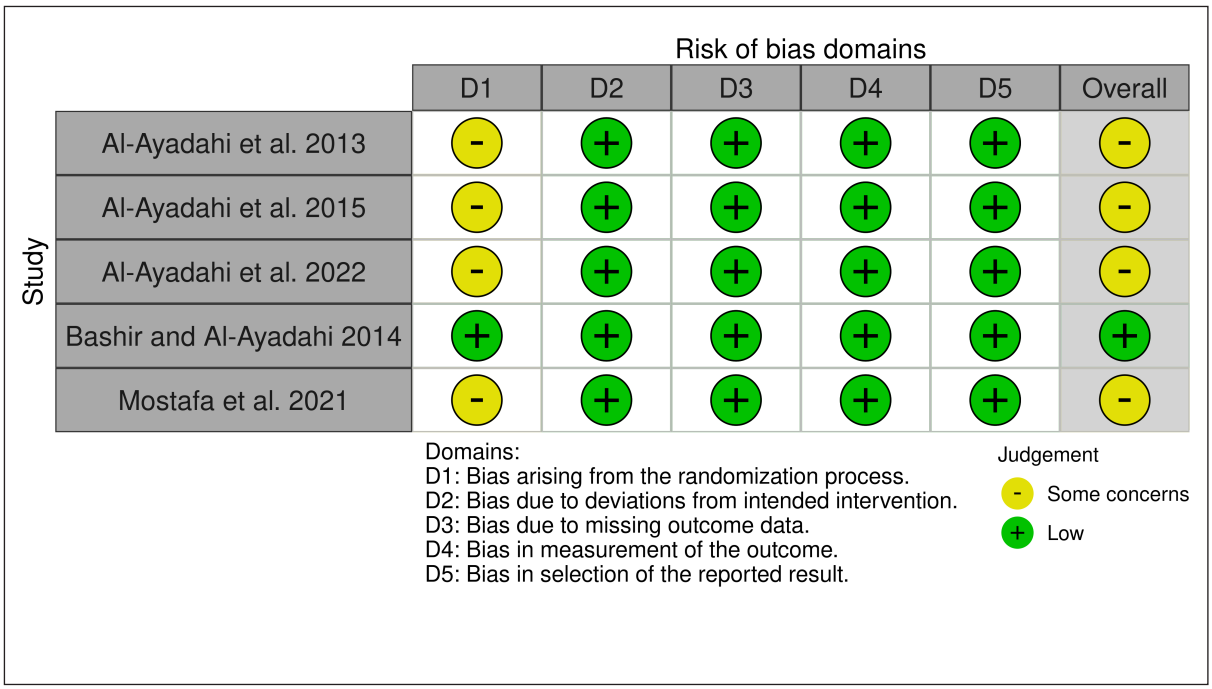

Fig. 3. Summary of risk of bias assessment across five domains for studies included in a meta-analysis. Some concerns are given plus mark while minus yellow mark indicates some concerns.

levels of thymus- and activation-related chemokine (TARC) (Bashir and Al-Ayadhi, 2014). In patients who consumed raw or boiled camel milk, serum vasoactive intestinal peptide (VIP) levels rose, but there was no statistically significant rise in these values (Mostafa *et al.*, 2021).

Discussion

The findings from the five included RCTs that studied 299 children with ASD did not demonstrate a significant difference in CARS scores for those given camel milk or a control substance. The subgroup analyses based on the nature of the camel milk as raw or boiled did not reveal any significant improvements in the patients given the milk or those given a control substance.

Despite the lack of significant effects on the primary outcomes, the qualitative synthesis revealed some potential benefits of camel milk consumption. Several studies reported improvements in antioxidant levels, social behavior, inflammatory markers, and serum chemokine levels among children with ASD who consumed camel milk. These findings aligned with the

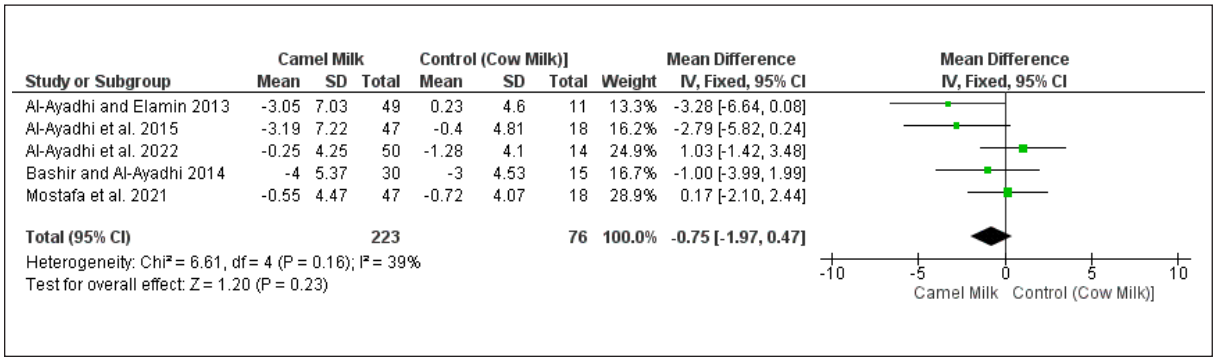

Fig. 4. Forest plot. The right side of the plot illustrates the overall mean difference with a black diamond, where the width represents the 95% CI. A vertical line through zero indicates no effect.

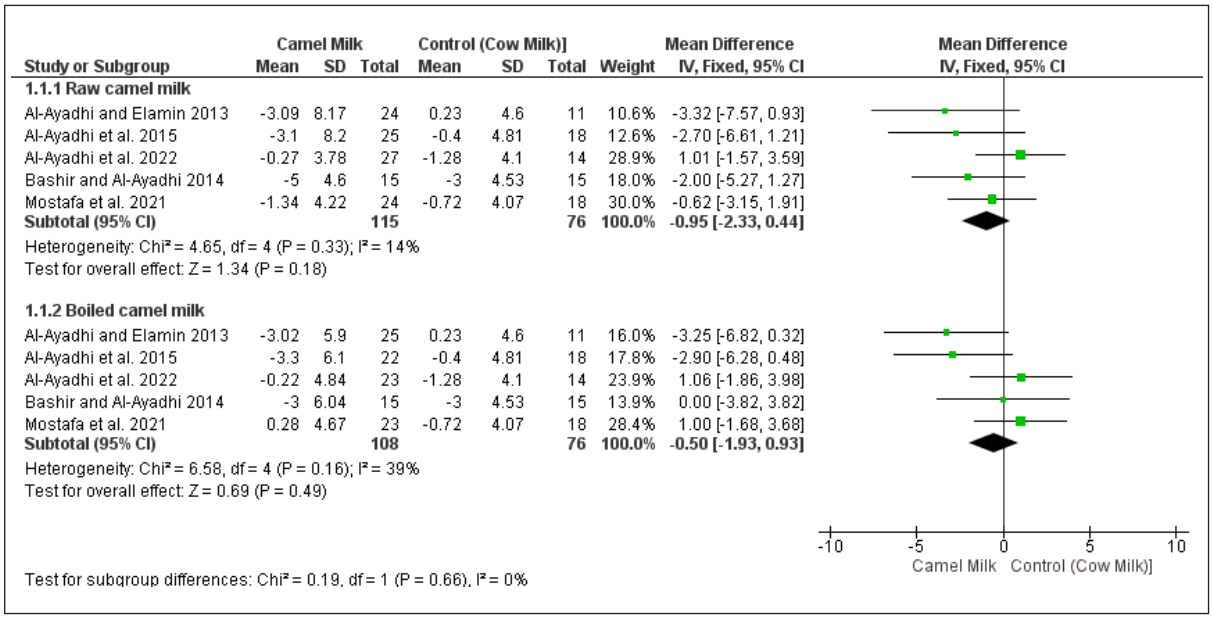

Fig. 5. Subgroup analysis forest plot. The weighted mean difference and 95% CIs are visually represented, with square markers indicating study-specific effects and horizontal lines depicting the CIs. The area of each square reflects the study's statistical weight. Black diamonds represent the pooled effect size for each subgroup, and the width of these diamonds indicates the corresponding 95% CI. The vertical line represents the point of no effect.

proposed mechanisms of action for camel milk in ASD, which include its anti-inflammatory, antioxidant, and immunomodulatory properties (Behrouz *et al.*, 2022). The potential therapeutic effects underlying the consumption of camel milk in ASD are multifaceted and involve various bioactive components (Swelum *et al.*, 2021; Shakeel *et al.*, 2022; Shaban *et al.*, 2023). Camel milk is rich in protective proteins and enzymes that exhibit anti-inflammatory, antimicrobial, and immunomodulatory activities and that are used in the treatment of human diseases (Khan *et al.*, 2021). These components may help alleviate the chronic inflammation and dysregulated immune responses observed in individuals with ASD. Additionally, camel milk contains high levels of antioxidants, including vitamins C and E, and compounds with antioxidant properties such as lactoperoxidase (Khan *et al.*, 2021). These antioxidants may counteract the oxidative stress implicated in the pathogenesis of ASD (Liu *et al.*, 2022).

Furthermore, camel milk is a natural source of bioactive lipids, including long-chain fatty acids and sphingolipids, which play crucial roles in brain development, neuronal function, and cognitive processes (Lagutin *et al.*, 2022). These lipids may contribute to the potential benefits of camel milk in improving social behavior and cognitive functioning in children with ASD. Moreover, camel milk is a rich

source of various micronutrients and trace elements, such as zinc, iron, and copper, which are essential for proper neurological development and function (Al-Juboori *et al.*, 2013).

The discrepancy between the quantitative meta-analysis results and the qualitative findings could be attributed to several factors. First, the CARS may not be sensitive enough to capture the specific domains of improvement observed in the included studies, such as social cognition, communication, and awareness. Second, the short duration of the camel milk intervention (2 weeks) in the included RCTs may not have been sufficient to elicit measurable changes in the overall severity of ASD symptoms as assessed by the CARS. In this context, in a case study, camel milk was found to improve cognition and social interactions (Adams, 2013).

Additionally, the small sample sizes and the potential risk of bias in some studies may have limited the ability to detect significant effects. Moreover, all the included studies were conducted in Saudi Arabia, which may have limited the generalizability of the findings to other populations and settings. Cultural factors and camel milk accessibility could influence adherence, as parents may face challenges in consistently providing camel milk to their children over the intervention period. The lack of adherence data in the included RCTs makes it difficult to assess whether suboptimal adherence could have affected the outcomes.

Camel milk has garnered attention for its potential therapeutic benefits, including its possible effects on ASD. Research suggests that camel milk may help alleviate some symptoms of autism due to its unique nutritional composition, which includes a high concentration of immunoglobulins, lactoferrin, and antioxidants. These components are known for their anti-inflammatory and immune-boosting properties, which might contribute to improved gut health and reduced oxidative stress in individuals with autism. Additionally, camel milk contains lower levels of beta-casein and beta-lactoglobulin than cow's milk, making it easier to digest and less likely to trigger allergic reactions or digestive issues that are commonly observed in autistic individuals (Swelum *et al.*, 2021; Alkattan *et al.*, 2023; Alsaleem and Kandeel 2023).

Clinical studies have provided some promising results regarding the consumption of camel milk by children with autism. For instance, a study conducted in 2013 indicated significant improvements in behavior, including reductions in hyperactivity, lethargy, and irritability among children who consumed camel milk. These findings were supported by anecdotal evidence from parents who reported noticeable positive changes in their children's behavior and cognitive functions (Adams, 2013).

The potential mechanisms by which camel milk exerts its effects on ASD symptoms include its rich composition of bioactive components, such as immunoglobulins, lactoferrin, antioxidants, and anti-inflammatory agents. These components may reduce neuroinflammation and oxidative stress, which are elevated in individuals with ASD, through the modulation of immune markers and the increase of antioxidant levels, as evidenced by the data showing significant changes in TNF-α, TARC, GSH, and SOD. Additionally, the neuroprotective lipids in camel milk, such as long-chain fatty acids and sphingolipids, support brain development and function, potentially improving social behavior and cognitive functions. The influence on the gut–brain axis through enhanced gut health and immune balance further supports these mechanisms in contributing to the observed improvements in ASD symptoms. These mechanistic insights align with the quantitative findings, linking camel milk's biochemical properties with clinical outcomes.

However, while the preliminary data are encouraging, more comprehensive and rigorous research is needed to fully understand the scope and mechanisms of camel milk's effects on autism. Large-scale, placebo-controlled clinical trials are necessary to confirm these findings and establish standardized guidelines for its use as a complementary therapy. Additionally, it is crucial to consider individual variations in response to camel milk and to approach its consumption as part of a broader, integrative approach to managing autism. Health practitioners should be consulted before incorporating camel milk into the diet of individuals with autism to ensure it is safe and appropriate for patients' specific health needs.

Notwithstanding these limitations, the results of this investigation add to the increasing amount of data about camel milk's possible therapeutic value for ASD. The qualitative synthesis suggests that camel milk consumption may confer benefits in specific domains, such as antioxidant status, social behavior, inflammation, and chemokine levels, which are important factors in the pathophysiology of ASD.

Further research is warranted to explore the long-term effects of camel milk consumption, optimal dosing regimens, and potential mechanisms of action. Future studies should consider using standardized diagnostic criteria and validated outcome measures specific to the domains of interest, such as social communication, repetitive behaviors, and adaptive functioning. Additionally, larger sample sizes and longer intervention periods may increase the ability to detect clinically meaningful changes in ASD symptoms.

Conclusion

In this meta-analysis, we evaluated the effects of camel milk consumption on children with ASD across five RCTs. While the pooled analysis did not show significant improvements in the scores of the CARS, the qualitative synthesis highlighted several potential benefits, including enhancements in antioxidant levels, social behavior, inflammatory markers, and serum

chemokine levels. These effects were likely due to camel milk's rich bioactive proteins, antioxidants, and essential micronutrients, which may mitigate the chronic inflammation, oxidative stress, and immune dysregulation associated with ASD. Despite the quantitative results, the qualitative improvements suggested that camel milk could offer supplementary therapeutic benefits in managing ASD, emphasizing the need for further research with larger sample sizes, longer intervention periods, and more sensitive outcome measures to validate these findings.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Authors' contributions

Conceptualization, M.K. and M.A.M.; methodology, M.K.; software, M.K.; validation, M.K., K.M.A. and S.A.; formal analysis, M.K.; investigation, K.M.A. and S.A.; resources, M.K.; data curation, M.K., K.M.A. and S.A.; writing—original draft preparation, M.K.; writing—review and editing, M.A.M., K.M.A. and S.A.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

Data availability

Data are in the manuscript and supplementary materials. Further details can be requested from the corresponding author.

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Supplementary Table 1. From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097.

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
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons,outcomes, and study design (PICOS).	2
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.	2
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.	2
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.	2
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	2
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
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processesfor obtaining and confirming data from investigators.	3
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	3
Risk of bias in individualstudies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this wasdone at the study or outcome level), and how this information is to be used in any data synthesis.	3
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	3
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency(e.g., I2) for each meta-analysis.	3
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).	3
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicatingwhich were pre-specified.	3
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions ateach stage, ideally with a flow diagram.	3

Continued...

Section/topic	#	Checklist item	Reported on page #
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow -up period) andprovide the citations.	3
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).	4
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 CIs, ideally with a forest plot.	4
Synthesis of results	21	Present results of each meta-analysis done, including CIs and measures of consistency.	4
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	5
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	6
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance tokey groups (e.g., healthcare providers, users, and policy makers).	7
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).	8
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	8
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for thesystematic review.	8

Supplementary Table 2.

Database and Date of search	Search strategy	Results
PubMed 14-3-2024	(“Disorder*, Autistic” OR “Kanner* Syndrome” OR “Kanner* Syndrome” OR Autism OR “ASD *” OR “Autistic Spectrum Disorder” OR “Disorder, Autistic Spectrum” OR ASD OR Parkinson OR Parkinsonism OR “Paralysis Agitan*”) AND (“camel milk” OR camel)	28
SCOPUS 14-3-2024	TITLE-ABS-KEY (“Disorder*, Autistic” OR “Kanner* Syndrome” OR Autism OR “ ASD *” OR “Autistic Spectrum Disorder” OR “Disorder, Autistic Spectrum” OR ASD OR Parkinson OR Parkinsonism OR “Paralysis Agitan*”) AND TITLE-ABS-KEY (“camel milk” OR camel)	62
Web Of Science 14-3-2024	TS=(“Disorder*, Autistic” OR “Kanner* Syndrome” OR Autism OR “ ASD *” OR “Autistic Spectrum Disorder” OR “Disorder, Autistic Spectrum” OR ASD OR Parkinson OR Parkinsonism OR “Paralysis Agitan*”) AND TS=(“camel milk” OR camel)	40
Cochrane Library 14-3-2024	(“Disorder*, Autistic” OR “Kanner* Syndrome” OR Autism OR “ ASD *” OR “Autistic Spectrum Disorder” OR “Disorder, Autistic Spectrum” OR ASD OR Parkinson OR Parkinsonism OR “Paralysis Agitan*”) AND (“camel milk” OR camel)	6