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Review

Camel meat composition by species, breeds, publication year, age, and breeding system: A global systematic review and meta-analysis

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ABSTRACT

Camel meat is increasingly being recognized as a sustainable and nutritious red meat source, particularly in arid and semi-arid areas where camels are thriving. However, its chemical composition and sensory attributes vary significantly owing to genetic, management, and environmental factors. This study conducted a systematic review and a meta-analysis to quantify the nutritional and sensory properties of camel meat and identify the key factors influencing these characteristics. A systematic review of peer-reviewed studies was conducted using Springer, PubMed/MEDLINE, Scopus, and ScienceDirect databases. This review comprised 57 papers published in English from 12 countries, covering the period between January 1991 and August 2024, including 377 analyses focusing on camel species, breeds, and breeding systems. Statistical analyses were performed to determine the effect sizes, heterogeneity, and impact of the moderating factors. The findings from our meta-regression and subgroup analyses revealed that variations in camel meat profiles are influenced by multiple factors, including breeding system, camel species, breeds, and age, but not by sex. Subgroup analysis revealed that higher final body weight (FBW) was reported for meat from *Camelus bactrianus* camels raised under the extensive system. Camels slaughtered at ≤6 years of age were characterized by higher dry matter, ash, and fat contents, but lower sarcomere length, lightness, redness, and cobalt content. The Najdi, Baladi Saudi, and Pakistani breeds were characterized as tender meat breeds. This study emphasizes the need for improved breeding strategies, meat processing techniques, and market awareness to enhance the appeal of camel meat. These findings provide valuable insights for livestock producers, policymakers, and the food industry, supporting the promotion of camel meat as a viable substitute for traditional red meat in regions affected by climate change and food insecurity.

1. Introduction

Camels, usually called the "ships of the desert," perform a sustaining role in pastoralist societies within arid and semi-arid environments (Sazmand & Nourian, 2023). Currently, there are 42 million camels worldwide (FAOSTAT, 2022). Large camelids include the one-humped dromedary camel (*Camelus dromedarius*) from arid countries of the Middle East, Africa, and South Asia, and the double-humped Bactrian camel (*Camelus bactrianus*) from Central Asia (Faye, 2020). Owing to their anatomical and physiological adaptations, camels are unique in their ability to thrive under adverse harsh conditions, such as dry environments with low rainfall, high ambient temperatures, and feed scarcity (Al Jassim, 2024; Goumi et al., 1993). Under very hot conditions, camels lose up to 30 % of their entire body weight through dehydration, as they may drink only every eight–ten days (Bekele et al., 2013). They are also good milk producers compared to other species (Ait El Alia et al., 2025a; Ait El Alia et al., 2025b; Ait El Alia et al., 2023; Boukrouh et al., 2023a). Moreover, camels are produced much more economically than cattle. Therefore, camels are considered potential meat producers, especially in regions where extreme weather conditions

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impact the overall reproduction rates of other animal species (Al-Jassim & Sejian, 2015; Boukrouh et al., 2025c). Although camel meat accounted for only 0.62 % of the global red meat market in 2013 (FAOSTAT, 2022), its production and consumption are increasing at a faster rate than those of beef and sheep meat (Faye, 2020), particularly in countries with arid climates. Camel meat production reached 0.6 million tons in 2022 (FAOSTAT, 2022). In 2022, Africa produced 61.9 % of world camel meat, followed by Asia at 38.1 % (FAOSTAT, 2022).

Camel meat is recognized as healthy and rich in nutrients owing to its higher vitamin, mineral, and amino acid contents; lower total fat, especially cholesterol content, and quality of fat, which lowers the risk of cardiovascular diseases (Hamed et al., 2019); and similar protein content (Baba et al., 2021) compared to meat from other farm animals (lamb, goat, beef, and chicken). Camel meat also has a higher iron content (Hamed et al., 2019; Maqsood et al., 2015), primarily in the form of heme iron, characterized by superior bioavailability, making it an ideal choice for anemic patients, as it helps increase the hemoglobin concentration in the blood, thereby compensating for the deficiency of this mineral in the body (Abdelrahman et al., 2023). Camel meat is also used to treat diseases such as hypertension, hyperacidity, and respiratory diseases (Abrhaley & Leta, 2018). Owing to these health considerations, the demand for camel meat as a nutritious red meat alternative is increasing, particularly in Asia and the Middle East, with consumption rates exceeding 2 kg/inhabitant/year in Somalia, Mauritania, Morocco, Oman, Emirates, and Mongolia (Boukrouh et al., 2025b; Faye & Bonnet, 2012).

Although camel meat is often perceived as healthy, it is commonly viewed as watery, tough, coarse, and somewhat sweet compared to other meats. This perception can be partly attributed to the fact that camel meat typically comes from a traditional meat production system. In these traditional systems, meat is usually obtained from older animals that are no longer useful for their primary roles, such as providing milk, serving as transportation, or being used for breeding. As a result, the quality of the meat may not be representative of its true potential. Although studies on camel meat are fewer than those on other animal species, its physicochemical parameters, other than tenderness, have been studied in the literature, but the results were inconsistent. Some studies have reported differences in camel species (Ebadi, 2015), age (Dawood, 1995; Gheisari et al., 2009), sex (Abdelhadi et al., 2017; Gheisari et al., 2009), season (Hamad et al., 2018), breed (Al-Owaimer et al., 2014), muscle type (Dawood, 1995; Ebadi, 2015), and region (Abdelrahman et al., 2023).

Some review articles have investigated the performance and meat quality of camels (Baba et al., 2021). However, these reviews did not quantify the variation in these parameters or the factors affecting them. Moreover, narrative reviews can result in biased conclusions owing to the absence of a structured methodology, leading to subjective interpretations by the authors (Sauvant et al., 2008). Conversely, meta-analysis is a statistical method that enables the quantification of data from multiple studies (Littell et al., 2008). Furthermore, Meta-analysis enables the exploration of sources of heterogeneity among diverse studies, providing additional information into the factors driving variability in observed outcomes (Sutton & Higgins, 2008). Thus, this study aimed to quantify, for the first time, the chemical and sensory qualities of camel meat using a systematic review and meta-analysis approach. The aim was also to explore, using meta-regression, the heterogeneity of responses, with the purpose of identifying factors contributing to variability in the response variables.

2. Methodology

2.1. Searching strategy

The search approach for the systematic review was based on PICO: Population, Intervention, Comparator, and Outcome (Schiavenato & Chu, 2021). The search was conducted using four different databases and bibliographic repositories, namely Springer, PubMed/MEDLINE, ScienceDirect, Scopus, and Web of Science, for studies published between January 1991 and August 2024.

The searching keywords were population "Camel" Or "C*amelus*," OR "*Camelus dromedarius*" OR "*Camelus bactrianus*"; AND "meat" OR "meat composition" OR "meat analysis" OR "meat chemical composition." Finally, to ensure that all relevant papers were included, the reference lists of the obtained studies were examined for further review. An additional search method was implemented using manual exploration of specific journals, including *Meat Science*, *Journal of Animal Science*, *Livestock Science*, *Food Chemistry*, *Journal of Food Quality*, *Journal of Camel Practice and Research*, *Animal Production Science*, *Animal Feed Science and Technology*, *Journal of Food Quality*, *Food Research International*, *Emirates Journal of Food and Agriculture*, *Journal of Camelid Science*, *Journal of Food Science and Technology*, *Journal of Food Processing and Preservation*, *International Journal of Food Science & Technology*, *Food Control*, and *LWT - Food Science and Technology,* following the method described by Alhaj et al. (2022). Communication was established through the ResearchGate platform and email to obtain missing data from the corresponding authors of the included studies.

2.2. Eligibility inclusion and exclusion criteria

The basic quality standard included the exclusion of articles published before 1991, abstracts in proceedings, book chapters, letters to the editor, systematic reviews or meta-analyses, articles with incomplete or absent primary information, and grey literature in general. Consequently, the information sources were chosen based on the following inclusion criteria: (i) original and short communication papers published in English in or after 1991. The included camel species were *Camelus dromedarius*, *Camelus bactrianus*, and crossbreeds. Studies reporting distinct species, breeds, ages, and breeding systems were considered independent studies.

Papers published after 1991 were selected due to the unavailability of earlier publications. Furthermore, although standard analytical methods for meat analysis were proposed before 1991, papers on camel meat quality were not published until 1991, possibly because of the increased interest in camel meat and the recognition of its nutritional benefits as a dietary protein source (Baba et al., 2021). Furthermore, studies reporting data on ruminants, including lambs, goats, cows, and other mammals, were excluded.

2.3. Study outcomes

Following the application of the inclusion and exclusion criteria, the final database comprised 57 peer-reviewed publications: (Abdelhadi et al., 2013; Abdelwhab, 2019; Ahmed et al., 2023; Al-Sheddy, Al-Dagal, & Bazaraa, 1999; Al-Sultan et al., 2023; Bahwan et al., 2023; Brima et al., 2019; Darwish, Tharwat, Elkady, & Fakhry, 2023; Djenane, Aboudaou, Djenane, García-Gonzalo, & Pagán, 2020; Dunlop et al., 2022; El Alia et al., 2023; El Badawi, El Naggar, Abedo, Hassan, & Yacout, 2024; El-Faer, Rawdah, Attar, & Dawson, 1991; El-Ghareeb, Darwish, & Meligy, 2019; Eskandari, Majlesi, Gheisari, Farahnaky, & Khaksar, 2013; Hamad, Hadef, Bellabidi, & Aggad, 2023; Hassanien, El-Khateib, Hassan, & Abd-El-Malek, 2022; Hussein et al., 2022; Ibrahim, Nour, Al-Maqbali, & Kadim, 2017b; Ibrahim, Nour, & Kadim, 2015; Kadim, 2014; Kadim et al., 2011; Kurtu, 2004; Maqsood, Abushelaibi, Manheem, & Kadim, 2015; Maqsood, Al Haddad, & Mudgil, 2016; Mohammed et al., 2020; Morshdy, El Bayomi, Abd El Galil, & Mahmoud, 2018; Rahmani & Khama, 2024; Raiymbek et al., 2018; Raiymbek, Faye, Serikbayeva, Konuspayeva, & Kadim, 2013; Rawdah, El-Faer, & Koreish, 1994; Seid, Kurtu, & Urge, 2017, 2018; Shehata, 2005; Suliman, Al-Owaimer, Hussein, Abuelfatah, & Othman, 2019; Suliman, Al-Owaimer, Hussein, Qaid, & Ahmed, 2021; Suliman, Hussein, & Al-Owaimer, 2013; Yarmand, Nikmaram, Djomeh, & Homayouni, 2013) (Supplementary Table 1). Data were extracted for variables reported in a minimum of three distinct studies, including the average, sample size, and standard deviation (SD). In cases where SD was not provided, it was computed by multiplying the standard error of the mean (SEM) by the square root of the sample size in each group.

From the selected articles that were included in the research, the extraction of information was feasible for the following parameters: final body weight (FBW) before slaughter, followed by meat chemical composition, including pH, moisture, dry matter, protein, intramuscular fat, and ash. Physical parameters included shear force, cooking loss, expressed juice, sarcomere length, myofibrillar fragmentation color index, and meat color (lightness (*L), redness (*a**), and yellowness (*b**)). Data on mineral composition were collected (phosphorus, iron, copper, zinc, calcium, sodium, cobalt, and chromium).

The following meta-analysis reported the results of the parameters present in at least three studies. The secondary outcome comprised moderators that were identified as crucial contributors to variation in camel meat composition, such as camel species (*C. dromedarius, C. bactrianus,* or crossbreed), breeding system (extensive, semi-intensive, and intensive), breed, year, age (<2, 2–6, and > 6 years old), and sex (male or female).

2.4. Data analysis and data visualization

In this meta-analysis, we employed various statistical methods to analyze and synthesize data. The untransformed means were combined using inverse variance weighting, whereas the REML estimator calculated the tau-squared (τ^2). The Jackson method was utilized to determine the 95 % confidence interval (95 % CI). Assuming that the true effects differed across studies, a random-effects meta-analysis was conducted to integrate the data. The findings are presented in a forest plot that visually depicts the estimated results from the individual studies and the overall pooled outcomes. R software for statistical analyses (version 4.4.1) was used to perform visualization and data analyses using the packages "metafor" and "meta."

The I^2 statistic was used to measure study heterogeneity, with values <25 % indicating low heterogeneity, I^2 values ranging between 25 % and 50 % indicating moderate heterogeneity, and I^2 values >50 % indicating high heterogeneity. Further assessment of heterogeneity among the studies was conducted using Cochran's Q statistics for tau-squared (τ^2) and tau (τ).

Egger's regression and Beggs's rank-order correlation tests were used to evaluate publication bias. Publication bias was assessed graphically using funnel plots. In cases where these two parameters were significant, Rosenberg's fail-safe number (NF) was applied as a third test. When these two parameters were significant, a third evaluation using Rosenberg's fail-safe number (NF) was conducted. NFs are typically considered robust when they surpass 5 × Ne + 10, with Ne denoting the number of papers in each treatment category (Rosenberg et al., 1997).

Meta-regression was conducted to detect moderators (species, breed, breeding systems, age of animals, their sex, and year of publication), that account for variability between studies. For the moderators that presented significant or marginal values ($P \leq 0.10$), a subgroup analysis was conducted for each. The proportion of between-study variance explained by the variables was determined using the adjusted R^2.

3. Results

3.1. Descriptive statistics of the included studies

This meta-analysis incorporated 1315 samples derived from 57 studies (K = 57) conducted across 12 countries, covering the period between January 1991 and August 2024. These studies reported 377 subgroups consisting of 2 camel species, 19 breeds, 3 breeding systems, 12 countries, and 3 age groups (Fig. 2). The number of studies and percentages of the included camel species were as follows: Dromedary, (78.6 %); Bactrian, (7.1 %); and crossbreed, (3.6 %). The percentages of studies according to the countries included were as follows (Fig. 1): Saudi Arabia (26.8 %), Egypt (16.1 %), Iran (8.9 %), Oman (8.9 %), Sudan (8.9 %), Algeria (7.1 %), the United Arab Emirates (7.1 %), Ethiopia (5.4 %), Kazakhstan (3.6 %), China (3.6 %), and Australia (1.8 %). The number of studies and percentages of the included breeding systems were as follows: extensive, 6 (10.9 %); semi-intensive, 3 (5 %); and intensive, 11 (20 %). Animals were from different age categories: <2 years old, 12 (21.8 %), 2–6 year old, 25 (45.5 %); >6 years old, 11 (20 %); Regarding sex, there were 30 males (54.5 %) and 10 females (18.2 %). The majority of the included studies (86.8 %) were published in 2011 or later, while a smaller portion (13.2 %) were published prior to 2011.

3.2. Camel meat composition and physicochemical characteristics

The overall pooled estimates for camel meat composition showed a mean pH of 5.78, dry matter content of 32.52 %, protein at 20.38 %, fat at 4.88 %, and ash at 1.40 %. Cooking loss averaged 34.50 %, expressed juice 36.09 %, and shear force 7.75 kg/cm^2, indicating moderate to high water retention and varying tenderness levels. Meat color analysis yielded mean values for lightness (*L**) of 34.15, redness (*a**) of 13.92, and yellowness (*b**) of 7.25. Myofibrillar fragmentation index averaged 65.29, with a sarcomere length of 1.59 μm.

3.3. Sensory attributes

Sensory quality analysis reported average tenderness, flavor, and juiciness scores of 4.33, 4.30, and 4.29, respectively, on a scale of 1–5. Cohesiveness and springiness scored lower (0.58 and 0.64, respectively), suggesting variability in textural characteristics.

3.4. Mineral composition

Camel meat demonstrated a high micronutrient profile. The pooled concentrations (mg/100 g) were: phosphorus (371.64), iron (51.45), copper (1.13), calcium (45.82), sodium (200.91), cobalt (0.51), and chromium (0.06). Notably, iron and phosphorus levels were among the highest, reflecting camel meat's potential to address nutritional deficiencies.

3.5. Heterogeneity and publication bias

As observed in Table 1, high between-study heterogeneity was observed for most parameters ($I^2 > 95$ %), justifying the use of random-effects modeling. Following the Egger et al. (1997) test and funnel plots (Supplementary Figs. 1–27), publication bias was significant ($P < 0.05$) for fat, ash, expressed juice, shear force, sarcomere length, tenderness, flavor, juiciness, cohesiveness, and cobalt. However, according to Begg and Mazumdar (1994), no significant bias ($P > 0.05$) was reported for shear force or cobalt. For the rest of the variables where Egger et al.'s, Begg and Madzumar's, and Rosenberg et al.'s NFs tests were significant ($P < 0.05$), its values were 274,446 (Fat), 288725 (Ash), 22041 (Tenderness), 26897 (Flavor), 24212 (Juiciness), 707 and (Cohesiveness) were higher than the Rosenthal NFs of 145 (5 × 27 + 10), 140 (5 × 26 + 10), 30 (5 × 4 + 10), 30 (5 × 4 + 10), 30 (5 × 4 + 10), and 30 (5 × 4 + 10) needed to declare the mean effect size significant, despite the possibility of publication bias for these parameters.

3.6. Subgroup and Meta-regression analyses

Subgroup and meta-regression analyses revealed significant effects of covariates, including species, age, breeds, year, and breeding system, on camel meat composition and quality parameters. The *P*-values are reported in Table 2 and Supplementary Tables 2–28. Species differences were particularly notable: *Camelus bactrianus* exhibited higher FBW and sodium content in meat, whereas *Camelus dromedarius* had higher meat

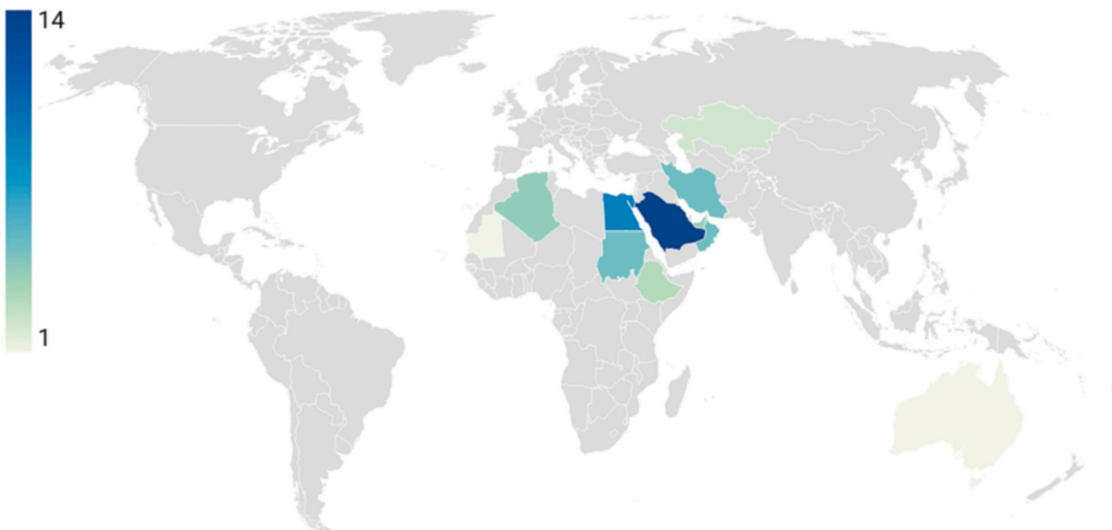

Fig. 1. Geographic distribution of the included studies is illustrated on a map with generated latitude and longitude. Shaded areas indicate the frequency of studies on a global scale.

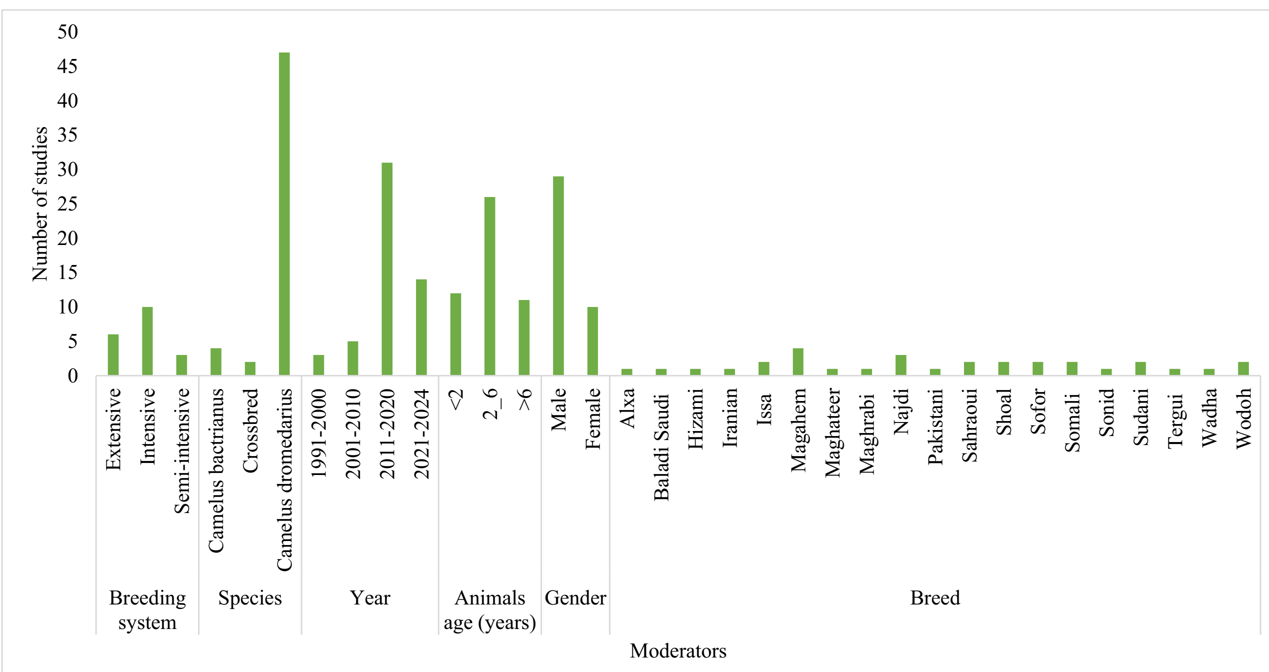

Fig. 2. Bar chart illustrating the frequency of explanatory predictor variables employed in the meta-analysis.

calcium content. The crossbreed presented notably higher meat protein, ash, fat, cooking loss, phosphorus, iron, and zinc.

In terms of breeding system, camels raised under the extensive system were characterized by higher final body weight and tenderness, whereas camels raised under the semi-intensive system had higher meat redness, yellowness, and cohesiveness scores. Camels under the intensive system were characterized by higher meat lightness.

Age was a significant determinant of camel carcass and meat quality. Camels slaughtered at ≤6 years of age were characterized by higher final body weight, dry matter, ash, and fat, but lower sarcomere length, lightness, redness, and cobalt content. Young camels (<2 years old) had higher meat protein, expressed juice, and chromium levels, and lower meat sarcomere length, yellowness, cohesiveness, phosphorus, copper, calcium, and sodium levels. Medium-aged camels (2–6 years old) were characterized by lower meat dry matter, protein, ash, fat, shear force, chromium, and higher sarcomere length, lightness, redness, yellowness, cohesiveness, phosphorus, copper, calcium, sodium, and cobalt.

Regarding camel breeds, Sonid and Alxa exhibited the highest final body weights ($P < 0.001$), making them ideal for meat yield and commercial slaughter. Maghrabi, Sofor, Shoal, Wodoh, and Magahem breeds were characterized by higher intramuscular fat, rich flavor profiles, lower cooking losses, and tougher texture with high shear force values. Other breeds, such as Sudani and Sahraoui, stand out for their exceptional levels of essential minerals, such as copper, zinc, calcium, and sodium, making them nutritionally dense. The Najdi, Baladi Saudi, and Pakistani breeds could be characterized as tender meat breeds because they were characterized by lower shear force values. Another group of breeds, Sahraoui, Hizami, and Issa, has distinct meat color

Table 1
A meta-analysis of camel meat composition analysis.

Parameters	K	N	Random effect model		Heterogeneity				Publication bias		
			Pooled results [95 % CI]	I^2 (%)	Tau [95 % CI]	Tau^2 [95 % CI]	H[95 % CI]	Cochran Q *p*-Value	Egger's test	Rank's test	NFs number
Final live weight (kg)	44	405	381.16 [316.33; 445.98]	99.8	218.91 [145.72; 240.81]	47,923 [21,235; 57,991]	26.26 [25.56; 26.99]	<0.001	0.490	0.003	5,293,618
Chemical composition											
pH	148	1315	5.78 [5.76; 5.82]	98.7	0.16 [0.15; 0.22]	0.03 [0.02; 0.05]	8.39 [8.11; 8.67]	<0.001	0.063	<0.001	2,518,798
Dry matter (%)	30	352	32.52 [30.29; 34.74]	97.6	5.87 [2.22; 7.47]	34.46 [4.91; 55.81]	6.47 [5.92; 7.06]	<0.001	0.503	0.165	–
Protein (%)	119	998	20.38 [20.12; 20.65]	99.8	1.35 [0.62; 1.86]	1.81 [0.39; 3.45]	24.90	<0.001	0.587	0.348	29,480,778
Fat (%)	124	956	4.88 [4.20; 5.57]	100	3.74 [1.70; 4.91]	13.97 [2.89; 24.15]	84.71	<0.001	0.034	<0.001	2,690,810
Ash (%)	119	998	1.40 [1.28; 1.52]	100	0.64 [0.76; 2.23]	0.41 [0.58; 4.99]	256.79	<0.001	0.004	<0.001	315,125
Physical properties											
Expressed juice (%)	42	396	36.09 [34.42; 37.75]	96.8	5.08 [3.77; 6.76]	25.84 [14.21; 45.65]	5.61 [5.17; 6.08]	<0.001	0.034	<0.001	235,022
Cooking loss (%)	126	1083	34.50 [33.06; 35.94]	99.5	8.19 [7.29; 9.75]	67.08 [53.07; 95.03]	14.02	<0.001	0.659	0.076	3,722,269
Shear force (N)	110	900	76.16 [68.62; 83.70]	99.8	40.25 [16.90; 31.73]	1620.2 [285.70; 1007.0];	59.65	<0.001	<0.001	0.216	–
Sarcomere length (μm)	57	412	1.59 [1.53; 1.64]	99.5	0.20 [0.20; 0.36]	0.04 [0.04; 0.13]	13.98 [13.46; 14.52]	<0.001	<0.001	<0.001	26,342
Myofibrillar fragmentation index Color	68	636	65.29 [61.21; 69.37]	98.4	14.63 [6.83; 12.03]	213.98 [46.62; 144.72]	7.91 [7.52; 8.32]	<0.001	0.812	0.093	1,260,336
Meat color											
Lightness (L^*)	110	843	34.15 [32.91; 35.40]	100	6.59 [3.39; 8.28]	43.48 [11.50; 68.53]	62.83	<0.001	0.174	0.260	4,364,956
Redness (a^*)	110	843	13.92 [13.37; 14.48]	100	2.88 [3.92; 8.67]	8.30 [15.33; 75.23]	61.53	<0.001	0.741	0.058	925,780
Yellowness (b^*)	110	843	7.25 [6.50; 8.01]	99.9	3.98 [3.30; 5.71]	15.82 [10.86; 32.54]	43.96	<0.001	0.538	0.387	372,491
Sensory properties (1–5)											
Tenderness	29	474	4.33 [3.93; 4.72]	99.7	1.08 [0.91; 1.67]	1.17 [0.82; 2.79]	17.32 [16.54; 18.13]	<0.001	<0.001	<0.001	22,041
Flavor	29	474	4.30 [3.93; 4.66]	99.8	1.00 [0.84; 1.50]	0.99 [0.70; 2.25]	20.64 [19.83; 21.49]	<0.001	<0.001	0.005	26,897
Juiciness	29	474	4.29 [3.86; 4.71]	99.8	1.16 [1.00; 1.77]	1.34 [1.00; 3.13]	21.13	<0.001	<0.001	<0.001	24,212
Cohesiveness	14	119	0.58 [0.52; 0.63]	98.5	0.10 [0.06; 0.15]	0.01 [0.004; 0.02]	8.22 [7.35; 9.20]	<0.001	0.002	0.041	707
Springiness	14	119	0.64 [0.62; 0.66]	95.1	0.04 [0.03; 0.07]	0.00 [0.00; 0.01]	4.52 [3.84; 5.32]	<0.001	0.320	0.042	1142
Minerals (mg/100 g)											
Phosphorus	85	864	371.64 [331.03; 412.24]	100	187.86 [101.37; 258.74]	35,290 [10,276; 66,948]	87.93	<0.001	0.936	<0.001	6,542,894
Iron	89	1241	51.45 [37.93; 64.96]	99.8	64.97 [9.26; 28.89]	4221.10 [85.79; 834.89]	20.05 [19.59; 20.52]	<0.001	0.276	<0.001	633,304
Copper	58	816	1.13 [0.73; 1.54]	99.8	1.51 [0.17; 0.47]	2.29 [0.03; 0.22]	20.02 [19.44; 20.60]	<0.001	0.123	<0.001	–
Calcium	85	864	45.82 [35.84; 55.80]	100	44.56 [0.00; 11.14]	1985.33 [0.00; 123.98]	93.8	<0.001	0.067	<0.001	214,812
Sodium	85	864	200.91 [146.58; 255.24]	99.9	254.70 [60.62; 158.82]	64,874 [3675; 25,223]	38.04	<0.001	0.807	0.004	1,807,919

(*continued on next page*)

Table 1 (*continued*)

Parameters	K	N	Random effect model		Heterogeneity				Publication bias		
			Pooled results [95 % CI]	I^2 (%)	Tau [95 % CI]	Tau^2 [95 % CI]	H[95 % CI]	Cochran Q *p*-Value	Egger's test	Rank's test	NFs number
Zinc	92	1233	25.56 [20.03; 31.09]	100	27.00 [2.08; 6.42]	729.23 [4.31; 41.15]	284.34	<0.001	0.295	<0.001	351,604
Heavy metals (mg/100 g)											
Cobalt	26	221	0.51 [0.21; 0.8230]	93.6	0.79 [0.06; 0.16]	0.62 [0.00; 0.03]	3.95 [3.48; 4.50]	<0.001	<0.001	0.090	–
Chromium	12	114	0.06 [0.03; 0.10]	94.1	0.06 [0.02; 0.10]	0.00 [0.00; 0.01]	4.12 [3.41; 4.97]	<0.001	0.930	0.164	–

K: Number of comparisons; N: number of samples.

Table 2
Meta-regression of covariate effect on camel meat composition.

Parameters	Coefficient of moderators	Species	Year	Breeding system	Age	Breed	Adjusted R^2
Final live weight (kg)	254.1 (<0.001)	693.85 (<0.001)	280.33 (<0.001)	693.85 (<0.001)	233.02 (<0.001)	682.67 (0.05)	83.92
Chemical composition (%)							
pH	5.41 (0.18)	5.82 (0.36)	5.75 (0.33)	–	5.77 (0.79)	5.74 (0.43)	10.26
Dry matter	36.08 (<0.001)	22.58 (0.004)	31.31 (0.45)	–	33.80 (<0.001)	–	74.64
Protein	21.68 (0.001)	19.34 (0.002)	19.54 (<0.001)	–	20.95 (<0.001)	21.16 (0.53)	55.67
Ash	0.64 (<0.001)	1.08 (<0.001)	1.09 (<0.001)	–	1.13 (<0.001)	1.19 (<0.001)	95.17
Fat	0.88 (0.02)	3.37 (<0.001)	1.67 (0.009)	3.44 (0.44)	4.25 (<0.001)	3.02 (0.03)	43.06
Physical composition							
Expressed juice (%)	28.41 (<0.001)	–	24.88 (<0.001)	–	39.52 (<0.001)	–	73.53
Cooking loss (%)	15.27 (<0.001)	31.68 (<0.001)	33.22 (0.14)	–	30.28 (0.32)	27.71 (<0.001)	70.11
Shear force (N)	22.80 (0.008)	–	63.46 (0.63)	72.73 (0.41)	86.52 (0.009)	104.10 (<0.001)	35.26
Myofibrillair color fragmentation index	41.79 (0.002)	–	74.17 (0.50)	–	67.10 (0.25)	41.79 (<0.001)	76.41
Meat color							
Lightness (*L**)	31.71 (<0.001)	–	33.74 (0.99)	31.60 (0.02)	33.91 (0.04)	37.13 (<0.001)	88.30
Redness (*a**)	13.05 (<0.001)	–	14.92 (0.05)	13.82 (0.007)	13.22 (0.006)	18.76 (<0.001)	65.07
Yellowness (*b**)	4.48 (<0.001)	–	6.93 (0.21)	8.40 (<0.001)	4.20 (<0.001)	9.17 (<0.001)	76.05
Sensory properties (1–5)							
Tenderness	6.04 (<0.001)	–	3.39 (0.004)	5.83 (<0.001)	3.98 (0.66)	–	91.11
Flavor	1.47 (<0.001)	–	3.52 (0.02)	–	–	3.65 (0.50)	94.99
Juiciness	1.19 (<0.001)	–	3.35 (0.009)	–	–	3.75 (0.58)	92.52
Cohesiveness	0.51 (0.36)	–	0.54 (<0.001)	0.5 (<0.001)	0.51 (0.004)	0.51 (0.36)	66.69
Springiness	0.66 (0.43)	–	0.64 (0.80)	0.66 (0.10)	0.66 (0.32)	–	1.41
Mineral composition (mg/100 g)							
Phosphorus	175.69 (<0.001)	417.6 (0.10)	189.12 (0.05)	–	6.77 (<0.001)	219.62 (<0.001)	99.8
Iron	1.31 (0.003)	6.74 (0.002)	1.28 (0.06)	1.74 (0.05)	0.85 (0.55)	–	38.31
Copper	0.09 (<0.001)	1.35 (0.92)	0.08 (0.01)	–	0.33 (0.07)	0.11 (<0.001)	99.97
Zinc	2.91 (<0.001)	3.98 (<0.001)	3.81 (0.001)	–	0.01 (0.34)	2.86 (<0.001)	99.98
Calcium	4.52 (<0.001)	9.13 (<0.001)	5.20 (<0.001)	–	0.07 (0.006)	4.52 (<0.001)	99.95
Sodium	50.10 (<0.001)	373.02 (0.01)	77.72 (0.40)	–	6.26 (0.009)	51.47 (<0.001)	99.96
Cobalt	0.65 (<0.001)	0.65 (<0.001)	0.0.01 (<0.001)	–	0.02 (0.10)	–	80.41
Chromium	0.04 (0.05)	–	0.01 (0.05)	–	0.20 (0.05)	–	77.34

characteristics, particularly high redness (*a**) and yellowness (*b**) values, which affect market appeal.

The publication period also had a significant impact on camel meat parameters. The mean protein levels rose from 19.6 % in studies before 2000 to 21.0 % in those published after 2020. Older studies (pre-2000) reported lower fat content (~1.7 %), whereas more recent studies (post-2020) reported lower levels (~4 %). Sensory properties, including tenderness, flavor, and juiciness, have improved over the years.

4. Discussion

Camel meat is a crucial source of macro- and micronutrients for human consumption in arid and urban areas. Over the past decades, researchers have extensively examined the composition of camel meat and the factors influencing its profile. The literature on camel species has revealed significant variations in camel meat composition, which are primarily attributed to the numerous factors mentioned in the Introduction section, including camel species (Ebadi & Sarhaddi, 2019), breed (Al-Owaimer et al., 2014; Shehata et al., 2011; Suliman et al., 2019), age (Ibrahim et al., 2017a), season (Hamad et al., 2018), and sex (Abdelhadi et al., 2017; Ebadi & Sarhaddi, 2019; Gheisari et al., 2009). Studies have shown that fat content plays a crucial role in determining meat quality and market value. Subgroup analysis highlighted the superiority of crossbreeds in fat content, followed by *Camelus dromedarius* and *Camelus bactrianus,* demonstrating the genetic improvement efforts to enhance meat quality. Although carcasses of crossbreed camels exhibited the highest fat percentage (8.8 %), these values were lower than those of other species, underscoring the nutritional superiority of this meat source (Yu et al., 2024). The reduced fat content of camel meat compared to other animal-derived meats presents substantial health advantages for human consumption. Compared to the closer genus *Lama*, *Camelus* has a higher fat content (Mamani-Linares & Gallo, 2014). Similarly, crossbreed meat was characterized by higher protein and ash contents. Generally, higher protein levels in camel meat are similar to those in other ruminant species (Al Rharad et al., 2024; Boukrouh et al., 2024c; Nogoy et al., 2022), making it a suitable source of high-quality protein in arid and semiarid regions. The higher ash content was mainly represented by higher phosphorus and calcium content. The difference from other breeds could be attributed to differences in grazed vegetation (Boukrouh et al., 2024a), and foraging behavior compared to dromedaries and Bactrians. Different results were reported by Ebadi (2015), who found no differences in mineral composition between *C. dromedarius* and crossbreeds. However, despite the higher nutritive value of the crossbreeds, cooking loss was higher, which shows that efforts are still needed to improve the overall quality of camel meat. Overall, Hamed et al. (2019) suggested that camel meat has higher moisture, vitamin, mineral, and amino acid contents than other meats, including mutton, beef, and chicken. Regarding mineral composition, Bactrian camels tend to have slightly higher calcium levels than dromedaries, possibly because of differences in skeletal structure and physiological adaptations to colder climates.

Breeding production systems have also been reported to play a crucial role in determining camel meat quality (Boudalia et al., 2023). Kadim et al. (2008) report the limitation of meat production in traditional camel rearing (extensive systems) due to poor nutritional levels and older slaughter ages. The present meta-analysis demonstrated that extensive grazing systems outperformed intensive systems in achieving higher body weights, indicating the benefits of traditional grazing systems for meat production. The general consumer view is that camel meat is unacceptably tough, but comparing extensive to intensive systems, camel meat from the extensive systems despite non significant differences regarding shear force values, resulted in higher sensory tenderness. However, to achieve tender meat with a lower shear force, semi-intensive processing is the most adequate. Meat color is considered one of the most important attributes, with appearance playing a significant role in the perception of product quality and consumers' purchase decisions (Su et al., 2024). In the present meta-analysis, meat color also varied according to the breeding system. The higher lightness of meat from the intensive and semi-intensive systems could be due to lower exercise compared to pastures. Under these two systems, camels are confined, which reduces muscular activity and oxygen demand, and consequently lowers myoglobin concentration, the pigment primarily responsible for the dark red color in meat. Similar results have been reported for lambs (Ekiz et al., 2012). Similar to intensive systems, animals in semi-intensive systems are often supplemented with concentrated feeds and crop residues rich in pigments, such as carotenoids, which are deposited in muscle tissues, enhancing meat yellowness (b^*) (Boukrouh et al., 2025c; Boukrouh et al., 2024c). In lamb carcasses, intramuscular fat is positively associated with yellowness (b^*) (Calnan et al., 2017). The results could also be due to the higher fat content, as meat from intensive and semi-intensive systems had a tendency to be higher than that from the extensive system. Regarding meat color, redness (a^*) has been reported to be correlated with high myoglobin and iron content (Pujol et al., 2023). The reason for the higher redness in meat from the semi-intensive system could be the additional impact of higher iron supplementation in the concentrate and the presence of volatile compounds in some pastoral plants, which prevents the oxidation of myoglobin, thus improving meat redness (a^*) (Su et al., 2024; Boukrouh et al., 2023b; Boukrouh et al., 2023c; Boukrouh, 2023; Boukrouh et al., 2024b; Boukrouh et al., 2024c; Boukrouh et al., 2022; Boukrouh et al., 2021; Echegaray et al., 2021). Red meat, especially that with high myoglobin content, is an important source of essential nutrients in the human diet (Juárez et al., 2021).

The results regarding the age of animals generally showed distinct advantages in slaughtering camels at an early age. Despite the lower weight of younger animals and higher expressed juice compared to older animals, protein content was higher in younger animals (<2 years) with lower sarcomere length, whereas ash, fat, and dry matter contents were higher in older animals (>6 years). Similar results were reported by Kadim et al. (2006), who reported a maximum fat content of 10.5 % for camels between 5 and 8 years old and 4.4 % for 1–3 year-old camels. Camel age also affected meat color, with older animals showing the lowest lightness (L^*). Older camels typically have denser and darker muscle fibers owing to increased connective tissue, leading to lower lightness (L^*). Similar results were reported by Kadim et al. (2006). Several studies have reported a positive correlation between fat and yellowness (b^*), which could explain the higher yellowness in older animals (>2 years old). Regarding meat tenderness, subsequent subgroup analysis reported that the shear force of meat was higher for older animals (>6 years). Traditionally, camel meat comes mostly from old males and females at the end of their productive life (transportation, racing, and milk rather than meat production, >10 years old). This suggests that the increase in the shear force of older camels may be due to connective tissue (Qihe et al., 2006). Differences due to age may be related to variations in muscle structure and composition as animals grow older, particularly in terms of the quantity and nature of myofibrillar proteins in the connective tissue (Kadim et al., 2013). Sarcomere length is another parameter related to tenderness, and the lowest tenderness for older animals could be related to longer sarcomeres. Indeed, research by Weaver et al. (2008) demonstrated that muscle samples with elongated sarcomeres (2.57 μm) exhibited reduced shear force measurements compared to those with contracted sarcomeres (1.43 μm), suggesting enhanced tenderness. Macro-minerals (P, Ca, and Na) increased in animals aged 2–6 years, and decreased after 6 years of age. Similar results were reported by Si et al. (2022), who found that the mineral content of camel meat ceased to increase after 6 to 7 years of age.

Genetic material has been reported to exert a substantial influence on chemical composition and meat quality characteristics. Indeed, Sonid camels are among the high-quality camel breeds in China and are listed on China's excellent livestock and poultry breed resource list (Lyu et al., 2024). They have a gentle temperament and are characterized by exceptional resilience against diseases and illnesses. This could explain their higher FBW compared to other breeds. Although Magahem, Wodoh, Shoal, and Sofor were raised in an intensive system, they showed lower weights than the other breeds, which confirms our results regarding superiority of the extensive system concerning FBW. However, they had high-quality meat with higher protein and ash contents. The Wodoh breed has been reported to have a white coat, medium to large size, and good milking ability (Al-Owaimer et al., 2014). This breed was interesting even in terms of meat quality, as it showed high protein content. Generally, these breeds showed contrasting results regarding meat quality, such as the lowest redness (a^*) and yellowness (b^*), which could indicate the oxidation of metmyoglobin (Manheem et al., 2023). However, they showed the lowest cooking loss, which is reported to result in juicier and more tender meat, thus enhancing consumer acceptance and eating experience (Xu & Falsafi, 2024). Despite being characterized by the lowest meat fat, the Najdi breed was characterized by higher flavor and juiciness, probably because of the adaptation to the traditional extensive systems and poor levels of nutrition where they are managed (Suliman et al., 2011).

Subgroup meta-analysis by publication year revealed a statistically significant difference in FBW, protein, fat, flavor, and juiciness for1991–2000, 2001–2010, 2011–2020, and 2021–2024 periods, whereas a statistically insignificant difference was found for pH, cooking loss, shear force, myofibrillar color fragmentation index, lightness, yellowness, and sodium. The oldest data could be considered with caution, and recent studies tend to highlight higher protein content, possibly due to improved feeding strategies, breeding selection, or updated analytical techniques. Older studies (pre-2000) reported a lower fat content (∼1.7 %), whereas more recent studies (post-2020) reported higher levels (∼4.2 %), despite the changing consumer demand for leaner meat and improved animal management. Regarding sensory properties, earlier studies have often described camel meat as tough with high cooking loss, whereas newer studies have explored processing methods to enhance tenderness and juiciness (Abdel-Naeem & Mohamed, 2016).

5. Conclusion

This meta-analysis highlights camel meat as a nutritious and sustainable protein source that is influenced by the breeding system, age, year of publication, species, and breed. Younger camels produce tender and juicier meat, whereas older animals produce tough meat, impacting consumer acceptance. Addressing processing techniques, breeding strategies, and market awareness can enhance their appeal. Further research on postharvest handling and value-added processing is required to improve quality. With better production systems and consumer education, camel meat can become a viable alternative for global food security, particularly in climate-vulnerable regions. Understanding the role of breed in shaping camel meat characteristics will provide valuable insights into the camel meat industry. Selective breeding programs targeting desirable traits coupled with optimized feeding strategies can enhance meat quality and cater to consumer preferences. Moreover, the identification of superior breeds for specific physicochemical and sensory attributes can facilitate the development of niche markets, promoting camel meat as a high-value product in global markets. Future research should focus on exploring genetic markers associated with meat quality traits and conducting controlled trials to further elucidate breed-specific influences on camel meat properties.

CRediT authorship contribution statement

Soumaya Boukrouh: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Asma Al Rharad:** Writing – original draft, Methodology, Investigation. **Omar Ait El Alia:** Writing – original draft, Methodology, Investigation, Formal analysis. **Jean-Luc Hornick:** Writing – review & editing, Validation, Supervision. **Bernard Faye:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.meatsci.2025.109947.

Data availability

No data was used for the research described in the article.

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