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A GLOBAL PERSPECTIVE ON THE INFLUENCE OF GRASS-FED CATTLE IN RELATION TO MEAT SAFETY AND QUALITY: A REVIEW

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ABSTRACT

Cattle grass feeding regimes for meat animals have come over centuries. Grass feeding is a practice where there are little or no human induced feeding growth interventions. Dependant on geographical location, vegetation in grass feeding pastures vary. The forage can be composed of perennial grass types in different geographical areas. Due to horticulture reproductive research, many grass types used in cattle feeding can now be found around the globe. In the past two decades, cattle grass feeding has gained popularity due to grass-fed beef products demand. Literature suggests that consumers prefer grass-fed beef due to better sensory attributes and perceived human health benefits. Grass-fed beef has been touted as having anti-cariogenic properties, leaner fat that promote the reduction of blood and heart conditions. While the driving factors of grass-fed beef demand are consumer related, grass feeding farmers and grass-fed meat serving cuisines have also seen economic gains. The compilation of this review aims to recapitulate the influence of cattle grass feeding and its role in meat quality and safety benefits. The review was derived from English written studies published between 2012 and 2023. Data was sourced from science web CINAHL, PsycINFO, Science Direct, Google Scholar and Android Research App to search for grass types, characters and the influence on meat safety and quality. For the period of this review, a total of 35 studies were accepted, where 31 % of the studies were elaborating on grass types, origins and influence in meat safety and quality; recommendations derived from grass-fed meat conferences, meetings resolutions were derived 26 % of the studies; and 43 % of studies were used to draw findings and conclusions by experimental studies on grass-fed meat. The conclusions of the review point to the direction that grass-fed meat has gained popularity as a result of consumer preferred quality attributes, health benefits and perceived environmentally friendly farming practices. To prevent consumer exploitation and the publicity of misleading grass-fed meat qualities, a concerted effort by governments and nongovernment formations are required to: 1) develop effective communication and distribution of grass-fed meat and farming protocols; 2) advance and expand grass-fed meat research; 3) Innovate grass-fed meat verifying and testing technology; 4) establish central grass-fed meat industry associations and lobby groups; and 5) promotion of educating of future veterinarians, meat animal health technicians, farmers, meat inspectors and consumer alike.

Key words: grass-fed, pastures, beef, grazing, quality, meat safety, meat quality

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INTRODUCTION

Global practice of cattle grass feeding regimes has come over centuries, estimated as predating civilisation [1]. It started with unguarded mix vegetation grazing and later reformed to monoculture cattle grazing on perennial grass [2]. Grass-fed Association of South African (GFASA) defined grass feeding as a situation where livestock are restricted to grass diet from weaning to culling [3]. Minimal restriction of livestock movement may also be applied as part of grass feeding and breeding practice [4]. Grass feeding may influence meat sensory attributes for different grazing patterns, vegetation types and climatic conditions of grasslands [5]. Cattle grazing in different grasslands may result in differing meat characteristics and other quality attributes [6]. Grass feeding is seen as a slow breeding and thus, not favoured by commercial cattle breeders for fear of low investment returns [7]. Globally, there has been a shift that created an astounding rise in grass-fed meat consumption in the past two decades [8]. This has led to the adoption of different grass feeding types and grazing methods in order to balance and maximize the length of grass grazing period, optimum slaughter outputs and grass-fed meat quality attributes [9]. The different grazing patterns for various grass feeding systems can be able to incorporate flexible grass grazing methods [10], where cattle movements are controlled and managed in various ways during the grass feeding and grazing period, depending on the vegetation used and the feeding outcome or expectations [11].

In developed countries such as the United States of America (USA) and Canada, grass-fed meat demand is estimated to increase from 25 - 30 %, with an expectation of further rise in the next five years [12]. Mathijs [13] estimated that grass-fed meat consumption demand in the United Kingdom (UK) was to increase from 29 - 35 % by 2023 and up to 40 % by 2050. The predicted driving factors of the demand are consumer perception of health benefits and quality traits of grass-fed meat [1]. Syrengelas *et al.* [14] highlighted that grass-fed meat consumption preferences are largely due to distinct meat flavours, tenderness and consumer health benefits perceptions. The access to digital platforms, such as the dominance of information sharing through social media, has largely influenced some consumers on the benefits of grass-fed meat [7]. Based on grass-fed beef lean subcutaneous fat, it is reported that continuous consumption of grass-fed beef has the ability to reduce occurrence of chronic health conditions [15]. Other considerations of grass-fed beef were that consumers have developed interest in aspects such as animal handling ethics, health, cultural and environmental breeding conditions of meat animals [16]. Where a number of studies reports that grass-fed breeding of meat animals is more humane compared [10,12]. Furthermore, there has been a considerable global evolution of formulations and

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manufacturing of grass-fed processed meats as influenced consumer demand patterns [16]. He *et al.* [17] detailed that the demand for grass-fed meat was mainly limited to raw sausages, ground meat, burger patties and a few varieties of dried products. Gwin *et al.* [18] concluded that grass-fed processed meat products were not so highly demanded; however, some growth in the demand has been noticed. This has already been observed in countries such as the United States of America (USA), Australia and the United Kingdom (UK) where cases of grass-fed meat fraudulent and misleading labelling are now on the increase [19]. Concerted efforts by health authorities and relevant agencies are required to manage and control grass-fed meat labelling [14].

MATERIALS AND METHODS

This review was derived from peer-reviewed English literature studies published between 2012 and 2023. Data was sourced from science web CINAHL, PsycINFO, ScienceDirect and Google Scholar. The methods of search followed a basic three pillars of articles on different types of grass characters used in meat animals grass feeding published articles reporting on grass feeding and grass-fed meat conferences and meeting from 2012 to 2023, and recommendations of experimental studies[1][20] of grass-fed meat deliberated upon at organised conferences and meetings. To aid the search, key words used include grass-fed meat OR grass-fed cattle OR grazing pastures AND grass feeding OR Africa OR Europe OR South America OR North America OR Asia pacific OR Australia. Organisations such as the Grass-fed Association of South Africa [3] and Atlas Big [21] were searched for unpublished materials on grass-fed meat, and meat production patterns from websites, conferences and meetings. This review was drawn out of a combination of 35 accepted searched papers published. After screening, 642 searches were returned for different reasons. The literature obtained was then compared in relation to significance, relevance, and similarities in the field of grass feeding and meat animal production.

INCLUSION AND EXCLUSION CRITERIA

The study focused on published work from 2012 to 2023 specifically on different types of grass characters used in grass feeding in meat animals. The criteria included studies that focused on grass feeding types, grass characters, experimental studies done in the period of review as well as studies reporting on grass-fed and grass feeding conferences convened during the period in review. Records with no specific reference to grass-fed, grass feeding for cattle intended to

[1] Experimental studies refer to studies whose outcomes are derived from data collected from a purposely applied technical treatment, procedure or program

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be used in grass-fed meat and studies in languages other than English were not included.

DATA ANALYSIS

The narrative and frequency review approaches were used for synthesizing the review data. Analysis of the data included a global perspective of different grass feeding pastures used for grass-fed cattle intended for human consumption, grass-fed experimental studies and conferences around the world as reported by scholars. Differences and conclusions of grass feeding regimes were tabulated and illustrated in diagrams. Subsequently, recommendations and conclusions were analysed and study conclusions formulated. Figure 1 depicts the literature review approach and the structure that was followed.

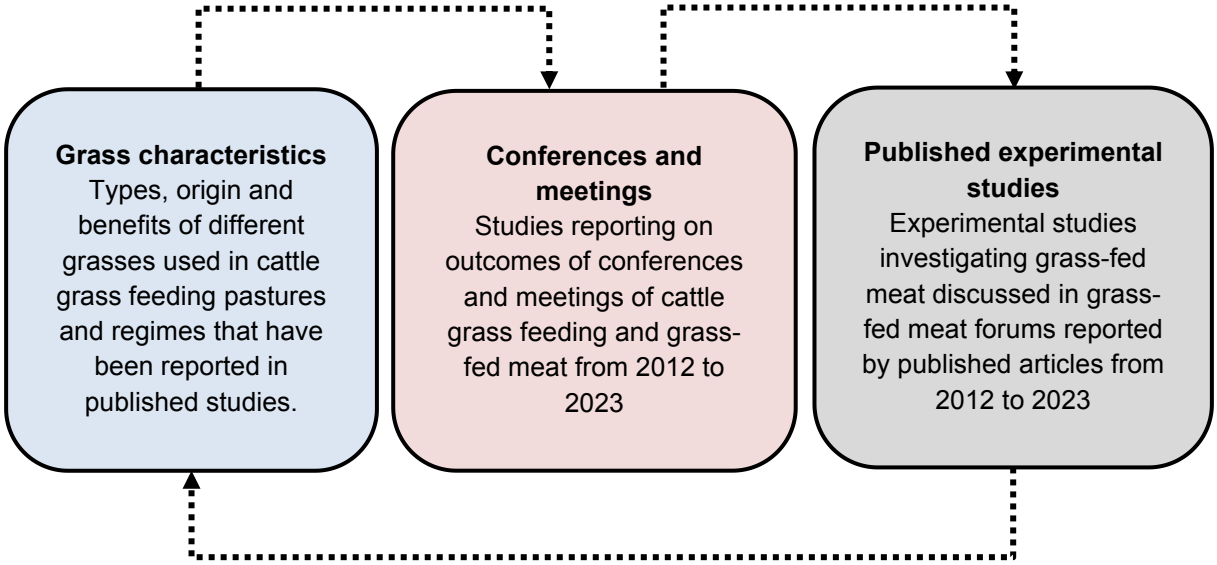

Figure 1: Literature review structure and flow diagram

For the review, figures, tables and art diagrams were created to illustrate a view of different studies reporting on grasses used in grass feeding pastures, grass-fed meat, grass feeding regimes, and outcomes of grass-fed meat conferences convened from 2012 to 2023 around the globe.

RESULTS AND DISCUSSION

Grass feeding of cattle has become a global phenomenon, and the demand for meat sourced from grass-fed animals has been on the rise in the past two decades. Developed countries such as the USA, UK and Australia have conducted studies on this aspect. The investigations depicted the type of grass, its origin and contributions to meat quality and safety traits. In addition, it is revealed that cattle grass feeding has been in existence for the longest time, with its modernisation

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emerging in the past two decades. Furthermore, the results of the customised search show that the demand for grass-fed meat was associated with perceived health benefits and better sensory characteristics. Table 1, shows a summary of types, origin and meat yields from common grasses predominantly used in cattle grass feeding and how they relate to meat quality and safety.

Table 1 (31 %) showed that grasses used in grass feeding regimes originated from sub-Saharan Africa (7), East Africa (2), Australia (3), Mediterranean region (2), Western Asia (1), South Asia (4), Europe (4), Middle East (1), North America (2), Central America (1) and South America (2). As depicted, the most commonly used grasses in cattle grass feeding regimes and pastures are Buffel grass, Klein grass, cowpea (black-eyed pea), Bahia grass, Guinea grass, Grass-pea, Weeping lovegrass, red pea grass, Leucaena grass, Smuts finger grass, Hairy vetch, Kikuyu grass, Alfalfa (Lucerne), Elephant grass, Bermuda grass, Rhodes grass and Ryegrass. From the studies, the grass-fed meat benefits varied from health (6) and quality related attributes (11). Table 2 (26 %) provides a summary of conferences and meetings convened between 2012 and 2023 that highlighted grass feeding and grass-fed meat. There were no other published studies that mentioned other geographical areas regarding grass-fed concepts or grass-fed meat conferences and meetings for the period of this review. Figure 2 (26 %) indicates the geographical distribution of grass-fed meat studies that were reported at meat conferences and meetings. Table 3 (43 %) summarizes objectives, findings and recommendations from experimental studies on grass-fed meat.

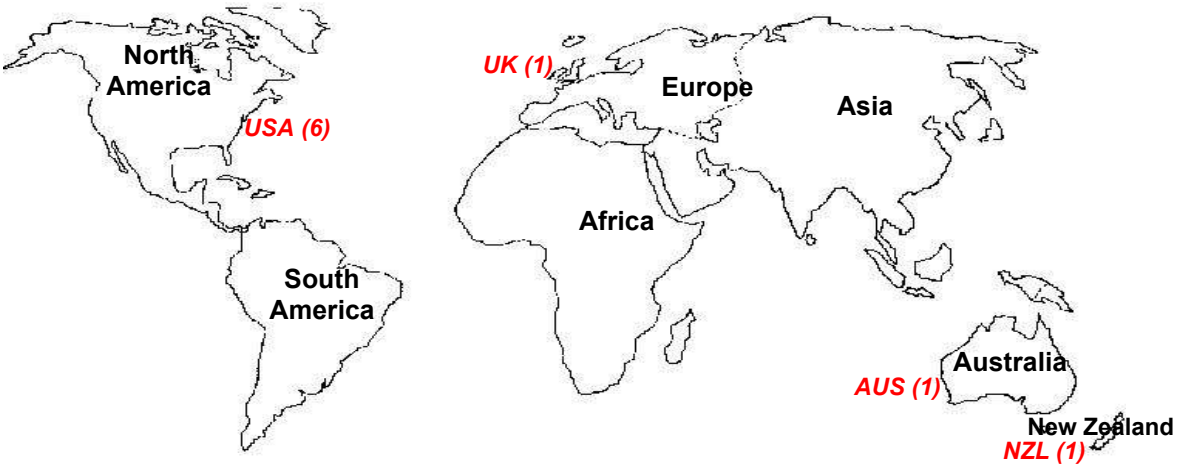

Figure 2: Geographical locations of conferences and meetings on grass-fed meat convened between 2012 and 2023 as reported by published studies (Google maps)

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Progressive scholars have undertaken experimental studies to evaluate consumers' rationale for grass-fed beef meat preferences. Table 3 indicates a summary of experiments conducted on grass-fed, the objectives of the experiments, their findings and recommendations proposed and published in the same review period. The results show that the majority of experimental studies related to grass-fed meat conducted were from the USA (5), followed by Australia (3), the UK (2), Ethiopia (1), Brazil (1), China (1), Korea (1), Argentina (1) and Italy (1). Surprisingly none of the studies came from countries that are also synonymous with high meat production, such as Germany, India, Russia and Spain. Furthermore, Ethiopia was the only country in Africa with an experimental study on grass-fed meat during the period under review. Of note, the majority (11) of the experimental studies investigated grass-fed meat quality attributes, followed by three that investigated physio-chemical composition, while one investigated nutritional value. Unexpectedly, there was only one study that investigated grass-fed meat related to human safety aspects.

From this review, the demand of grass-fed meat is linked to meat quality attributes and perceived consumer health benefits. This is in line with the conclusion by Carabante *et al.* [50] that grass-fed meat, "beef" in particular, is promoted largely due to its health benefits for this reason. While the preference of other consumers was associated with the manner of animal handling, the literature suggests that a large section of consumers and meat enthusiasts considered health reasons. As a result, health benefits publicity of grass-fed beef has recently increased that has caused the surge of grass-fed meat price [17]. Rudy [51] emphasized that grass-fed meat is targeted for high-earning consumers in big cities around the world and those considered as well-resourced. Generally, it can be accepted that health-conscious meat consumers and environmental activists are prepared to pay a premium price for grass-fed meat irrespective of its promotional status.

Grass types, origin and meat yields from common grasses used in cattle grass feeding pastures and how they relate to meat quality and safety

It was evident that there is a physiological link between the type of grass used in cattle feeding pastures and the meat. From the literature, studies of the period in review have shown that different grasslands can influence cattle meat sensory and quality characteristics. For instance, meat quality of beef from cattle continuously feeding on Buffel grass, Bahia grass, Hairy vetch and Napier grass pastures contain distinct pastoral flavour. Furthermore, grasslands with grass pea, red pea results in beef with improved reddish colour as a result of lipoprotein and beta carotenoids and antioxidants that results in better meat texture. Moreover, the safety of the beef from cattle grazing on grasslands with ryegrass, grass pea, Guinea and Klein grass beef has enhanced iron deposits and lower fatty acids that

can be beneficial to anaemic and high cholesterol individuals [24]. In addition, other human health benefit characteristics of grass-fed meat include anticarcinogen in Buffel grass and higher magnesium content in beef from cattle grazing on ryegrass. Notably, the majority of perennial grasses used in grass feeding are predominantly native to Africa. The literature shows that USA, Europe and Australia geographical areas are home to mostly the origin of grass commonly used for cut-and-carry forage. Globalisation and research have promoted the emergence and cross-growing of grasses in other geographical areas [29]. There are significant varieties of grass planted for livestock feeding in pan-tropical climatic conditions that are used in tropical pastures. Grela *et al.* [27] concluded that high protein grass types such as *Lathyrus sativus* are preferred for commercial farming. Grass-pea (*Lathyrus sativus*) originates around the Mediterranean, South Asia have also shown high protein content, possessing characteristics to yield lean fat meat with preferred meat quality attributes. Evidently, in cattle grazing grasslands yield meat differing human health benefits, nutritional content and quality related characteristics. Hwang and Joo [46] added that grass-fed grazing pastures yield meat with human health benefits and improved meat palatability.

Studies emanating from conferences and meetings on grass feeding and grass-fed meat from 2012 to 2023

A global perspective of the studies shows minimal conferences and meetings held centred on grass-fed meat and feeding patterns. There is generally a scarcity of public platforms for information relevant to premium meats such as grass-fed meat and related farming [52]. Aspects of grass-fed meat trade trends and possible violations can be shared in conference deliberations [53]. Likewise, Gillespie *et al.* [54] suggested that grass-fed meat and cattle farming information should be collated and discussed on multilateral platforms to guard the reputation of grass-fed meat. Such platforms can be supported by establishing collaborative grass-fed schemes or associations. For instance, in the US, for one to trade grass-fed meat, there is a need for one to be affiliated with a reputable body or authority [37]. Such associations are established by industries such as grass-fed cattle dairy-producing breeders [22]. The studies further recommend that grass-fed related conferences provided the insights of possible trade interventions that are to be adopted. Published conferences and meetings by scholars addressed recommended the control of grass-fed meat value chain by reliable data and information distribution. Stakeholders such as grass-fed animal farmers and state institutions establish collaborative efforts to manage grass-fed advertising and establish central global standards of grass-fed beef [7]. This was supported by Clonan *et al.* [33] that farmer education relating to grass-fed meat standard and trading is to be implemented to protect the industry and consumers. The results of the review

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further suggest that the conferences recommended the establishment of grass-fed meat standards, farm guidelines and strict policies to curb possible exploitation of grass-fed concepts. The promotion of the development of testing technology, grass-fed meat policies and protocol monitoring strategies were prominently recommended by the different gatherings around the world. Formation of lobby groups, central stakeholder associations and grass feeding statues cannot be overemphasized [32].

Outcomes from experimental studies investigating grass-fed meat published by scholars from 2012 to 2023

Extensive experimental research on grass-fed meat has been conducted in the past decade or so. However, most studies concluded on the rationale of consumer preference and selection of grass-fed meat as better sensory attributes and health benefits. This was often linked to other attributes such as meat tenderness, juiciness and colour. Berger *et al.* [40] elaborated that a common thread for grass-fed meat-related studies is dominated by the investigation of quality-related meat attributes and the impact of animal feed mixes. Similarly, Moholisa *et al.* [55] emphasised that a concerted effort is required to expand on studies related to grass-fed meat safety and its link to human health benefits. This investigation highlighted the fact that most experiments were conducted in developed countries such as the USA, UK and Australia. The majority of experimental studies concluded that grass-fed meat contains better nutritious value and better-quality attributes. It is a common development that grass feeding farming will be supported on the grounds of cleaner air emissions. In addition, grass-fed beef, in particular, is marketed as containing low fat, nutritiously loaded with omega-3 and omega-6 [8]. As such, the establishment of legislation measures for fair trading is long overdue. While other experimental studies emphasised the establishment of trade management levers such as surveillance, monitoring, testing technology to manage market claims. Failure to develop control measures for grass-fed meat trade such as legislation and policy, will lead to consumer exploitation and grass-fed meat and meat products adulteration. It is clear that grass-fed meat was fairly considered for human health benefits, while most studies are predominantly done on grass-fed meat quality benefits.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The conclusions of the studies point to the direction that grass-fed meat has consumer preferred sensory and health benefits characteristics. From the literature, it is evident that grass-fed beef possesses physiological composition that has preferred quality attributes and inherent properties with health benefits. Moreover, cattle grass feeding regimes are regarded as environmentally friendly and

perceived as more humane for flock breeding intended for meat. With the quality attributes and human health grass feeding provides an opportunity to produce high quality beef while promoting environmentally friendly farming practices. The driving factors of grass-fed meat demand are meat characteristics such as taste, colour, aroma, tenderness and juiciness. It can be accepted that there is global meat consumers' perception that grass-fed meat is regarded as a healthier meat alternative. On the basis of the literature of the period under review, it is evident that grass-fed meat consumption has inherent health and quality advantages. Thus, protection and limitations to the benefits are to be publicised for consumer benefits and the prevention of unfounded claims. On this basis, more research needs to be done to prove the perception or to support it so as to justify the costs linked to grass-fed meat. Thus, a concerted effort is required by health authorities and consumer associations to guard against faux claims and consumer exploitation. Furthermore, grass-fed meat consumer education should be encouraged to ensure informed decision making. The possibility of grass-fed meat trade abuse for financial gains necessitates efforts for efficient control measures at different levels of the food chain. Global interventions by governments and nongovernment formations should be inclusive of: 1) development and effective communication of grass-fed meat and farming legislations; 2) expand grass-fed meat research resources; 3) investment in grass-fed meat testing technology and innovations; 4) establish grass-fed meat industry associations and 5) promotion of educating of future veterinarians, meat animal health technicians, farmers, meat inspectors and consumer. As a result of the growing demand and exportation of grass-fed meat and meat products, inter-country grass-fed meat trade treaties must take such control interventions into consideration. Future research should focus on longitudinal studies that assess the long-term impacts of grass-feeding practices on beef safety and quality. The literature in the review period contained limited information on the role of key stakeholders involved in meat animal breeding and animal husbandry. The proficiency of the key stakeholders such as veterinarians and animal technicians will play a significant role in providing up-to-date insights into best practices in grass feeding and grass-fed beef. Additionally, investigating the economic viability and consumer acceptance of grass-fed beef can provide a more holistic understanding of its potential benefits and challenges. Therefore, the formation of grass feeding cattle associations must play a role in ensuring the novelty of grass-fed meat in meat and farming industries globally.

Ethics Statement

Ethics approval of the study was obtained from Tshwane University of Technology (TUT), Faculty of Science research for Animal Research Committee (AREC) (Ref. AREC202204002).

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Authors' contributions

E.J.M. conceptualized and conducted the research as part of a Doctoral degree in Environmental Health, synthesized and wrote the manuscript. I.M.M supervised the study, conceptualised and provided technical advisory of the manuscript. D.V.N supervised the study, supported with referencing software, conceptualised and reviewed the manuscript. J.L.B. was responsible for the review of the overall concept of the study, provided technical advice and conceptualised the structure of the manuscript. All authors have read the content and approve to publish the manuscript.

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Conflicts of interest

The authors declare that they have no competing interests.

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Table 1: Summary of types, origin and meat yields of common grass types for cattle grass feeding pastures and how they relate to meat quality and safety

Common grass used in grass feeding	Native, description and characteristics	Meat safety and quality yields	References
Buffel grass (Blue buffalo grass) (*Cenchrus ciliaris)*	– Tropical grass that thrives best in Central Africa, Australia and Southern Asia. – Commonly planted for permanent cattle pastures.	– Meat has anticarcinogen properties – Increase meat flavour, tenderness and juiciness due to better intramuscular fat presence.	Van Vliet *et al.* [22]
Klein grass (*Panicum coloratum)*	– Is a warm-season grass that is native to Southern Africa. – It is a fine stemmed, soft and leafy grass hay that is very palatable and nutritious for cattle.	– It has the ability to enhance palatability.	Schmidt *et al.* [23]
Cow pea (black-eyed pea) (*Vigna unguiculata)*	– One of the most popular legume seed forages in central and Southern Africa. – Also dubbed as "hungry season crop", because it is harvested first.	– Enhances iron deposit in beef meat that is beneficial to anaemic people. – Meat has improved taste and flavour	Geleti Agza *et al.* [24]

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Common grass used in grass feeding	Native, description and characteristics	Meat safety and quality yields	References
Bahia grass (*Paspalum notatum)*	– This grass is a long-lived, perennial in South America, mostly in Mexico. – Its best quality appears to be during summer and autumn.	– Low fat content profile and higher omega-3 fatty acids – Meat reduces chances of blood clots and cardiovascular disease (CVD). – Distinct aroma and taste.	Ferreira *et al.* [25]
Guinea grass (Tanganyika grass) *(Megathyrsus maximus)*	– It is a pantropical grass that originates in East African climate, – It is used in tropical pastures.	– Contains lean fat layer to reduce chances of cholesterol. – Improves meat colour and texture. – It improves tenderness in aged cattle meat.	Harmon Harmon [26]
Grass-pea (chickling pea) (*Lathyrus sativus)*	– It is crude protein rich (ca. >30%) legume that grows in dry areas of Europe, Balkan peninsula, South Asia and Mediterranean origin. – Grass pea is now available in many pastures globally.	– Meat has less cholesterol profile fatty acids with improved reddish colour. – Low profile of fatty acids that may cause cardiac illnesses.	Grela*et al.* [27]

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Common grass used in grass feeding	Native, description and characteristics	Meat safety and quality yields	References
Red pea (*Lathyrus cicero)*	— This legume was domesticated in south-western Europe by 3000 - 4000 B.C.	– Meat contains more beta carotenoids and antioxidants. – Results in better meat texture.	Grela *et al.* [27]
Smuts finger grass (*Digitaria eriantha)*	– It is used in green pastures in autumn and early winter months for cattle grass feeding. – It is regarded as adaptable grass suitable for pastures of South African climate.	– Result in distinct pastoral flavour as result of Conjugated linolenic acid (CLA).	Fukumoto *et al.* [28]
Hairy vetch (*Vicia villosa)*	– It is native to Europe, the Mediterranean and Western Asia – It improves meat taste due to its ability its high protein.	– Increased anti-oxidant activity in meat. – Meat has improved lipoprotein. – Distinct red meat colour.	Provenza *et al.* [29]

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Common grass used in grass feeding	Native, description and characteristics	Meat safety and quality yields	References
Elephant grass (Napier grass) (*Pennisetum purpureum)*	– Originates in sub-Saharan tropical Africa – Can be used in tropical and subtropical area pastures and as silage worldwide – It is largely used for cut-and-carry forage	– Common for production of lean meat yields. – Improved meat flavour.	Islam *et al.* [30]
Ryegrass (*Lolium multiflorum)*	– It is a perennial grass common in southern Europe, the Middle East, North Africa and Asia.	– Meat has lean fat properties. – Synonymous with higher magnesium levels. – Improved reddish meat colour	Montenegro *et al.* [2]

Table 2: Summary of studies reporting on developments of conferences and meetings of grass feeding and grass-fed meat from 2012 to 2023

Year of assembly	Country, State/City	Conference/meeting title or theme	Aims or objectives	Recommendations from the conferences / meetings	References

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Year of assembly	Country, State/City	Conference/meeting title or theme	Aims or objectives	Recommendations from the conferences / meetings	References
2012	USA, Texas	— Success and failures of animal nutrition and technologies in developing countries.	— To examine grass-fed livestock nutrition using technological advancement.	— Develop reliable nutritive data tracking technologies for grass-fed meat. — Identify relevant extension services for grass feeding pastures by partnering with scientists.	Owen *et al.* [31]
2015	USA, Michigan	— International grass-fed exchange conference.	— To bring the grass-fed beef producers together	— To establish clear international standards of grass-fed cattle production.	Klopatek *et al.* [7]
2016	USA, Washington DC	— A call on withdrawal of grass-fed marketing claims and standards.	— To restrict marketing claims on grass-fed beef meat.	— Establish guidelines of marketing of grass-fed meat. — Establish monitoring standards and protocols for breeders.	King *et al.* [32]

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Year of assembly	Country, State/City	Conference/meeting title or theme	Aims or objectives	Recommendations from the conferences / meetings	References
2016	UK, Sheffield	— The concerns and regarding the future of animal products in the human diet.	— To collaborate on the future of animal products in the human diet and environmental concerns emanating from grass feeding farms.	— Encourage consumers education strategy — Maintain traditional feeding regimes to have environment and health habits. — Establish legislations related to grass-fed meat labelling claims. — Control and management of grass-fed meat and trade marking.	Clonan *et al*. [33]
2017	USA, Alabama	— Beef care and farm practices: Analysis of US Grass-fed beef industry.	— Analysis of the U.S. grass-fed beef industry	— Policy development and establish reliable data for grass-fed beef meat for pasture raised beef meat.	Sitienei *et al.* [34]

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Year of assembly	Country, State/City	Conference/meeting title or theme	Aims or objectives	Recommendations from the conferences / meetings	References
2017	USA, Pennsylvania	— The future and potential opportunities and threats of grass-fed beef.	— Producer interest in standardisation of grass feeding regimes.	— Development of common practice to establish common ground on the claims related to grass-fed breeding.	Tichenor *et al.* [35]
2018	Australia, Queensland	— The international data portal for good grass-fed breeding practices.	— International conference on the role of *Leucaena* grass in grass feeding.	— A concerted effort on the understanding of the role of *Leucaena* in cattle grass feeding for beef meat production.	Shelton [36]
2018	USA, Nebraska	— Nebraska Grazing Conference	— To understand the transitional practices for effective grazing for meat animals	— Soil health must be regarded as a priority for animal health to ensure safe grass-fed meat. — Establish grass-fed meat associations.	Redfearn [37]
2021	New Zealand, Dunelin	— Plate to pasture farmer conference	— Developing sustainable and ethical values for grass-fed livestock production	— Develop standard guidelines of grass-fed meat — Developing	Horn and Isselstein [38]

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			intended for meat.	guidelines for grass-fed farming practices. – Promote grass feeding to promote a cleaner environment to combat climate change.	

Table 3: Summary of objectives, findings and recommendations from experimental studies investigating grass-fed meat published by scholars from 2012 to 2023

Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
Agza *et al.*[24]	· Ethiopia	· To evaluate the impact of cowpea varieties as a source of protein in grass-fed meat.	· Quality attributes	· Cow pea cattle grass feeding pastures have a direct impact on meat quality.	· Cow pea as part of protein source for grass-fed cattle, may be used to counter food security. · Human health related to the consumption of grass-fed meat should be studied further.

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Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
Apaoblaza *et al.* [39]	· Brazil	· To determine the cause of dark, firm and dry grass-fed beef meat.	· Quality attributes	· The lean fat content from grass-fed was as result of more oxidative metabolism. · Grass-fed meat may appear slightly darker.	· Grass-fed meat might have different meat chemical composition. · Advertise consumer education on grass-fed meat buying options. · Open grazing pasture management regimes influence meat quality.
Berger *et al.* [40]	· USA	· To investigate the effect of dry ageing of grass-fed beef on quality and its influence on microbial load.	· Quality attributes · Meat safety and spoilage attributes	· Dry ageing improves grass-fed meat quality attributes such as low fat and enhances intramuscular marbling.	· Dry ageing induced grass-fed meat flavour. · Salted and dried grass-fed meat contained lower microbial load.
Butler *et al.* [41]	· UK	· To determine the beneficiary of organic and inorganic acid formation in grass-fed meat derivatives.	· Organic chemical composition in grass-fed beef.	· Linoleic and linolenic acid composition were lower in grass-fed beef cuts.	· Access to grass-fed beef information for consumers. · Grass-fed meat is a higher source of omega-3 and omega-6.

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Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
Carrillo *et al.* [42]	· USA	· To examine physio-chemical composition of grass-fed beef meat.	· Quality attributes	· Grass-fed beef is enriched with anti-inflammatory properties and tenderness.	· Grass-fed meat consumption may reduce type 2 diabetes and liver inflammation. · Integrated and humane animal husbandry is required for optimum beef yield and reduction of stress in grass-fed cattle.
Frank *et al.* [43]	· Australia	· To investigate grilled meat sensory attributes and chemistry flavour from grass-fed Angus herd.	· Quality attributes	· The tenderness and juiciness of grilled grass-fed beef are closely correlated with muscle marbling.	· The amount of marbling in grass-fed meat increases the amount of unsaturated fatty acids that may be beneficial to human health.
Garmyn *et al.* [44]	· Australia	· To assess the enhanced, non-enhanced grass-fed beef and consumer acceptability.	· Quality attributes	· Consumers preferred the enhanced grass-fed meat.	· Consumer satisfaction was based on tenderness, juiciness, and flavour of the meat.
Holman *et al.* [45]	· China	· To compare colour and shelf-life of wet aged grass and grain-fed beef.	· Meat quality	· The ageing period of meat has a direct effect on vitamin E and colour margins.	· Grass-fed meat ageing may maintain acceptable microbial load without affecting its quality.

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Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
Hwang and Joo [46]	· Korea	· To determine the level of oleic acid intramuscular fat in grass-fed and grain fed meat cuts.	· Quality and chemical composition in beef.	· Grass fed meat contains lower intramuscular fat. · Grass-fed meat palatability was better than grain fed.	· Grass-fed meat claims should be verified before trade. · There is a difference between grass-fed and grain fed quality attributes and intramuscular fat.
Kurve *et al.* [47]	· USA	· To evaluate the effect of native grass feeding in carcass meat quality.	· Meat quality attributes	· Fat content from various grass-fed vegetation varied. · There were variations in moisture content from different grass-fed meat.	· Effective management of grazing grass may result in good quality attributes in beef carcasses.
Logan *et al.* [8]	· Australia	· To determine the premium measurement for maintaining high cost of grass and grain fed beef products.	· Meat quality attributes	· High levels of Omega 3 and polyunsaturated fatty acids were found in grass-fed meat.	· To establish reliable methods of grass-fed meat evaluation for reliable consumer information. · Establish multiple options for grass and grain fed classification test methods.

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Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
Moloney *et al.* [48]	· UK	· To determine the influence of grazing period and the influence to sensory attributes of grass-fed and concentrate-fed meat.	· Meat quality	· Grass-fed meat had less and yellowish fat while appearing darker. · Grass-fed meat was more tender after five months of feeding cycle compared to concentrate-fed cattle.	· It is difficult to physically see the difference between grass-fed and concentrate fed meat. · Control of market claims for grass meat is required.
Montenegro *et al.* [2]	· Argentina	· To investigate grass carp and ryegrass-fed meat quality attributes.	· Quality attributes	· Grass-fed meat contains high antioxidant and fat-soluble vitamins. · Improved nutritional value and lipid stability.	· Develop entrusted grass-fed feeding system pastures. · Establish surveillance and monitoring of grass feeding pastures and create data.
Pavan and Duckett [49]	· USA	· To evaluate grass-fed meat fatty acid profile and changes associated with beef meat cuts.	· Meat quality	· Grass beef meat contained varying fatty acids and moisture deposits in meat cuts.	· Develop management levers for saturated fatty acids from grass-fed meat cuts. · Saturated fatty acids from grass-fed beef have higher stearic acid. · Consumer education on grass-fed meat benefits.
Stanton *et al.* [5]	· Italy	· To investigate the health benefits of	· Meat quality	· Low cholesterol was detected on consistent	· Establish technology for detection of grass-fed meat

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Author(s)	Country	Study objective(s)	Grass-fed beef attributes investigated	Results and study findings	Conclusion and Recommendations
		grass-fed meat to human health.		consumers of grass-fed meat.	health related parameters. · Educating the consumers on the variables of grass-fed meat.

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