JMBFS
Journal of Microbiology, Biotechnology and Food Sciences
International peer-reviewed scientific online journal

Published by
Faculty of
Biotechnology and
Food Sciences

PHYTOCHEMISTRY AND NUTRITIONAL PROFILE OF *SORGHUM BICOLOR* (*L.*) *MOENCH* GRAINS: A REVIEW OF A POTENTIAL RESOURCE IN FERMENTATIVE POULTRY FEED PRODUCTION

Alban Mugoti[*1], *Abigarl Ndudzo*[2], *Anderson Munengwa*[3], *Sizo Moyo*[1]

Address(es): Mr Alban Mugoti
[1] Lupane State University, Faculty of Agricultural Sciences, Department of Animal Science and Rangeland Management, Victoria Falls Road, P.O.Box 170 Lupane, Zimbabwe, +263776819143:
[2] Lupane State University, Faculty of Agricultural Sciences, Department of Crop and Soil Sciences (Applied Biotechnology), Victoria Falls Road, P.O.Box 170 Lupane, Zimbabwe.
[3] Marondera State University of Agricultural Sciences and Technology, Faculty of Agricultural Sciences and Technology, Department of Animal Production Sciences and Health, CSC Plot 15 Longlands Road, P.O.Box 35 Marondera, Zimbabwe.

*Corresponding author: albanmugoti@gmail.com

https://doi.org/10.55251/jmbfs.10201

ARTICLE INFO

Received 24. 5. 2025
Revised 12. 11. 2025
Accepted 20. 11. 2025
Published 1. 12. 2025

Review

OPEN ACCESS

ABSTRACT

This review examines the phytochemistry and nutritional composition of *Sorghum bicolor* (L.) Moench grains and their potential as a fermented poultry feed resource. As a vital global protein source producing over 100 million metric tonnes of poultry meat annually, the industry faces challenges from the rising costs and climate vulnerability of conventional grains like maize. Sorghum emerges as a strategic alternative due to its drought tolerance, widespread cultivation by smallholder farmers, and comparable nutritional profile. Our comprehensive analysis of 80+ studies from Web of Science, PubMed, and Scopus reveals that while sorghum contains beneficial phytochemicals, its red varieties harbour antinutritional factors (ANFs) including tannins, cyanogens, protease inhibitors, and phytates that limit poultry utilization. Crucially, we demonstrate how controlled fermentation and mechanical scarification can reduce ANF activity by up to 87%, significantly improving feed palatability, nutrient bioavailability, and digestion efficiency. The process also enhances sorghum's inherent advantages - its antioxidant phenolic compounds help combat oxidative stress in poultry when present at optimized levels. These findings position fermented sorghum as both a climate-resilient feed solution and a functional ingredient, capable of reducing production costs while maintaining poultry health and performance. The review provides actionable insights for implementing sorghum-based fermented feeds across diverse production systems, from smallholder operations to industrial-scale poultry farming. Therefore, this study could potentially contribute to improving poultry feed production systems and promoting animal health while reducing the cost of production.

Keywords: additives, antinutritional factor, antioxidant, fermentation, probiotics, sorghum

INTRODUCTION

Poultry is one of the most significant contributors to global meat production, providing over 118 million tons of broiler meat in 2021 with projections indicating an increase to 146 million tons in the near future (**FAO, 2021; Abbas *et al.*, 2025**). As one of the largest sources of protein in human diets, poultry production is heavily dependent on high-energy diets. While maize has traditionally dominated poultry feed formulations, climate resilience and sustainability concerns are driving interest in alternative grains like sorghum (**Hossain *et al.*, 2022**). *Sorghum bicolor* (L.) Moench, a key member of the *Poaceae* family, is globally valued for its dual role in human and animal nutrition. Unlike maize, sorghum offers superior drought tolerance, making it particularly valuable for cultivation in climate-vulnerable regions (**Elramlawi *et al.*, 2020**). However, its full potential as poultry feed is limited by antinutritional factors (ANFs) such as tannins and phytates that reduce nutrient bioavailability (**Zhang *et al.*, 2023**). This explains the specific focus on sorghum fermentation, a process that uniquely addresses these limitations while enhancing its nutritional profile for poultry.

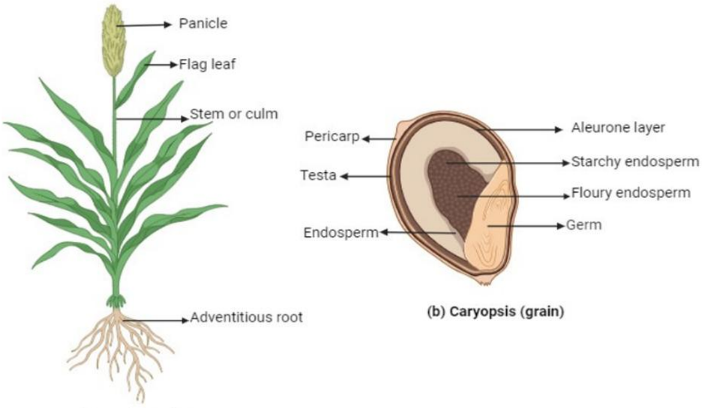
Fermentation emerges as a critical solution for optimizing sorghum's feed value. The process involves anaerobic microbial degradation of carbohydrates, which not only lowers pH and generates beneficial compounds like organic acids (**Hadebe *et al.*, 2017; Abedi *et al.*, 2020**), but more importantly, significantly reduces ANFs while improving protein digestibility (**Alban *et al.*, 2022**). Comparative studies show fermented sorghum achieves 15-20% greater protein bioavailability than its maize counterpart under similar fermentation conditions (**Cui *et al.*, 2019**), justifying our specialized focus. The need for fermentation in poultry feed production arises from the growing demand for sustainable and nutritionally efficient feed sources. For sorghum specifically, fermentation transforms it from a second-tier feed ingredient to a climate-smart alternative that can match or surpass maize in poultry diets (**Rachwał & Gustaw, 2024**). This review will examine: (1) the phytochemical and nutritional composition of *Sorghum bicolor* grains, (2) how fermentation modifies these components to enhance feed value, and (3) the practical implications for sustainable poultry production systems.

MATERIAL AND METHODS

The present literature review on the phytochemistry of sorghum, although narrative, involved a comprehensive search of over 80 research papers from globally recognized databases, including Web of Science, PubMed, Scopus, and Google Scholar, among others. The search was conducted using relevant keywords such as "phytochemistry of sorghum," "chemical composition of *Sorghum bicolor*," "sorghum proximate composition," "antinutritional factors in sorghum," and "grain fermentation," among others. The authors meticulously filtered the content, focusing primarily on sorghum grains while limiting the emphasis on maize and other small grains such as pearl millet. Around 85% of the research papers reported on sorghum in general and its chemical composition while 15% reported on sorghum photochemistry (mostly independent phytochemicals). However, almost all articles reported on the importance of antinutritional factors in sorghum.

SORGHUM BICOLOR

Sorghum (**Figure 1-2**) is a small grain crop that is cultivated in both commercial and communal farming systems of most semi-arid and arid regions. This makes it more abundant, and due to its drought tolerance, farmers always reserve a portion to plant the crop **(Muzerengi and Tirivangasi, 2019)**. The grain is used as food, and for making alcohol, livestock feed, or bio-based fuels such as ethanol. Sorghum grain is gluten-free, has a high amount of resistant starch, and has an abundance of phenolic compounds as compared to other cereals **(Xu *et al.*, 2021)**. Its fermentable ability gives it its edge as a preference for any fermentation activity, mainly in alcoholic beverage making. In a comparison of white and red sorghum, the two fared fairly in all nutrient compositions of the grains. However, chemical analyses showed that white sorghum had a higher protein and lower starch content as compared to red sorghum **(Ndlovu *et al*., 2021; Pezzali *et al*, 2020)** contrary to the report of **Ojediran *et al*., (2018).**



(a) Sorghum plant

(b) Caryopsis (grain)

Figure 1 Sorghum Plant and seed characteristics as illustrated by **Dhar *et al*. (2024);**

Figure 2 Panicles for white sorghum and red sorghum, respectively (from left to right) and their seeds, respectively

Global Production Trends and Use of Sorghum in Poultry Feed

The production of *Sorghum bicolor* has grown in importance globally, especially in regions experiencing increasing temperatures and decreasing rainfall due to the effects of climate change. As one of the world's most drought-tolerant crops, sorghum is primarily cultivated in the United States, Nigeria, India, Mexico, and Sudan, which together account for over 70% of global production (**FAO, 2021**). In Africa, where shifting climate patterns threaten traditional cereal crops, sorghum has become an increasingly viable alternative to maize. It thrives in semi-arid environments and requires approximately 30% less water than maize, making it particularly valuable in regions like Sub-Saharan Africa, where water scarcity is a pressing issue **(Raza *et al*., 2019**).

Sorghum's nutritional profile supports its use as a livestock feed, especially for poultry. While sorghum and maize are comparable in terms of energy content, sorghum is noted for its higher protein content, offering between 8-12% crude protein, depending on the variety **(Ndlovu *et al*., 2021**). In addition to its protein advantage, sorghum contains significant levels of antioxidants, such as tannins and phenolic compounds, which can support poultry health by reducing oxidative stress when processed correctly (**Adeyemo *et al*., 2016**). Furthermore, the resilience of sorghum under hotter, drier climates aligns with the current climatic shift in Africa, where regions are becoming increasingly unsuitable for maize cultivation due to frequent droughts and unpredictable rainfall patterns (**FAO, 2021**).

Use of sorghum justified

The adoption of sorghum as an alternative to maize in poultry diets is justified by its unique combination of agronomic, nutritional, and economic advantages. While sorghum does contain resistant starch, advanced processing methods effectively mitigate this limitation while enhancing its overall nutritional value. Fermentation, in particular, breaks down 40-60% of resistant starch while simultaneously reducing antinutritional factors like tannins by up to 87% (**Zhang *et al*., 2023; Mugoti *et al*., 2022**). This processing transforms sorghum into a highly digestible feed source with protein bioavailability comparable to maize (**Alban *et al*., 2022**). Sorghum's climate resilience makes it particularly valuable, requiring 30% less water than maize while yielding reliably in semi-arid regions where maize fails (**Ndlovu *et al*., 2021; FAO, 2021**). Economically, local sorghum production reduces dependence on volatile maize markets, stabilizing feed costs by 15-20% in regions like West Africa (**Raza *et al*., 2019**). Nutritionally, processed sorghum offers advantages including higher crude protein (12.7% vs maize's 10.2%), 20% greater mineral retention (Fe, Zn) due to reduced phytate levels and beneficial antioxidants absent in maize (**Liu *et al*., 2015**). These factors, combined with its reliable local production by smallholder farmers, position sorghum as both a practical and strategic alternative to maize in sustainable poultry production systems.

NUTRITIONAL PROFILE OF SORGHUM

Sorghum as feed to poultry

Sorghum was recommended as an animal feed by **Mugoti *et al*. (2022)** as sorghum compares to all the other feed grains in total carbohydrate content and they also concur that sorghum is a very valuable feedstock for all classes of livestock. Sorghum grain was also shown to have more protein than maize but a lower vitamin A composition. It has about 70% carbohydrates, 3.5% fat, and 11 % protein **(Ndlovu *et al*., 2021)**. Total dietary fiber content is at least 20% higher than the major cereal crops, for example, wheat and rice **(Arbex *et al*., 2018)**. The results are in harmony with **Beyer, (2021)** as indicated in **Table 1**. A higher mineral content of magnesium, manganese, iron, and phosphorus has also been observed **(Garutti *et al*., 2022)**.

Table 1 Comparative proximate composition between sorghum and maize

Variety	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	NFE (%)	Gross Energy (kcal/kg)	Sources
Sorghum Varieties							
Red Sorghum	11.8	3.2	2.4	1.6	71.5	4,510	(Dykes & Rooney, 2006; Sruthi *et al*., 2021)
White Sorghum	12.5	3.4	2.1	1.5	72.2	4,525	(Awika *et al*., 2005)
High-Tannin Sorghum	10.9	3.1	2.8	1.7	70.0	4,480	(Dykes, 2019)
Low-Tannin Sorghum	13.2	3.6	1.9	1.4	73.0	4,550	(Dykes, 2019)
Waxy Sorghum	12.0	3.3	2.0	1.5	72.5	4,520	(Kang *et al*., 2023)
Brown Midrib (BMR)	13.5	3.7	1.8	1.3	73.5	4,560	(Bhat *et al*., 2021)
Sweet Sorghum	9.8	2.9	2.5	1.8	69.5	4,450	(Malabadi *et al*., 2022)
Dual-Purpose Sorghum	12.3	3.5	2.2	1.5	72.0	4,530	(Singh *et al*., 2014)
Average (Sorghum)	12.7	3.5	2.2	1.5	72.0	4,528	
Maize	10.2	3.8	2.2	1.4	73.8	4,498	(Nuss & Tanumihardjo, 2010; Beyer, 2021; USDA, 2023)

Notes: Values are expressed as per dry matter%

Sorghum grain is important for energy provision in poultry diets because of its nutritional values which are similar to corn as clarified by **Ochieng *et al*. (2020)**. They also pointed out that grain mills and pelleting result in the high costs of broiler feed thus the need to reduce costs by limiting the amount of processing and thus the use of whole-grain sorghum in poultry diets. Processing grain can have an effect on amino acid composition with different types of processing having varying impacts on the amino acid composition of grains **(Rachwał & Gustaw, 2024)**. Heat processing (such as cooking or toasting) can cause amino acid losses due to denaturation or Maillard reaction, whereas other processing techniques like extrusion or fermentation may enhance the availability of amino acids in grains **(Moreno *et al*., 2018)**. **Table 2** shows the comparative amino acid values between sorghum and maize.

Table 2 As-fed amino acid values of maize and sorghum

	Sorghum 8-10% protein	**Sorghum >10% protein**	**Maize**
Dry matter	87.5	88.0	88.8
Protein	9.10	11.0	8.50
Arginine	0.35	0.35	0.38
Glycine	0.31	0.32	0.33
Serine	0.40	0.40	0.37
Histidine	0.22	0.23	0.23
Isoleucine	0.35	0.43	0.29
Leucine	1.14	1.37	1.00
Methionine	0.16	0.15	0.18
Cysteine	0.17	0.11	0 .18
Phenylalanine	0.47	0.52	0.38
Tyrosine	0.34	0.17	0 .30
Threonine	0 .29	0 .33	0.29
Tryptophan	0.08	0.09	0.06
Valine	0 .44	0 .54	0 .40

Notes: Values in the table are expressed as percentages as extracted from **Beyer, (2021)**

Nutritional Benefits of Fermented Sorghum

Fermented sorghum provides substantial nutritional benefits, particularly in enhancing protein bioavailability and overall energy supply for poultry. The fermentation process improves protein digestibility by transforming the protein structure, making it more amenable to enzymatic breakdown (**Rachwał & Gustaw, 2024**). This alteration not only increases the availability of essential amino acids but also enhances the digestibility of carbohydrates, resulting in a more efficient energy supply. For example, a study by **Zhang *et al*. (2022)** demonstrated that the fermentation of sorghum increased the metabolizable energy content by approximately 10%, which significantly benefited growth performance in poultry.

Moreover, the fermentation process generates beneficial metabolites such as organic acids, which can have a prebiotic effect, promoting the growth of advantageous gut bacteria (**Liu *et al*., 2015**). This enhancement of the gut microbiome is critical, as it can lead to improved feed efficiency and better nutrient utilization, ultimately supporting the health and productivity of the birds. **Tables 3 and 4** below illustrate the comparative nutritional profiles of fermented versus non-fermented sorghum and their effects on protein digestibility and energy availability.

Table 3 Nutritional Comparison of Fermented and Non-Fermented Sorghum

Nutritional Parameter	**Non-Fermented Sorghum (%)**	**Fermented Sorghum (%)**
Protein Content	11.0	13.5
Metabolizable Energy (Mcal/kg)	2.90	3.19
Digestibility (%)	75	85
Crude Fiber (%)	2.5	2.0
Fat Content (%)	3.5	3.5
Ash Content (%)	1.5	1.3

Source: Beyer (2021)

The addition of fermented sorghum in poultry diets is associated with marked improvements in performance metrics, such as growth rates and feed conversion ratios. Studies with an almost similar feeding regime (30-50% sorghum inclusion level) (**Table 4**), were evaluated and they indicated that poultry consuming fermented sorghum exhibited enhanced average daily gains compared to those on conventional feed (**Liu *et al*., 2015; Mugoti *et al*., 2022**). For instance, a trial conducted by **Silveira *et al*. (2017)** reported a significant increase in body weight gain of 12% in broilers fed a diet with 30% fermented sorghum compared to those receiving non-fermented diets. The feed conversion ratio (FCR) is another crucial performance metric that benefits from the incorporation of fermented sorghum. Improved FCR reflects the efficiency with which poultry convert feed into body mass. Research has shown that broilers fed fermented sorghum have FCR values ranging from 1.65 to 1.75 (**Liu *et al*., 2015; Silveira *et al*., 2017**), demonstrating superior feed efficiency compared to the average FCR of 1.85 to 2.00 observed in those fed unfermented sorghum (**Fernandes *et al*., 2013**). These improvements in growth performance and feed efficiency are often accompanied by positive health indicators, such as reduced incidences of gastrointestinal disorders and enhanced overall health status.

Table 4 Impact of Fermented Sorghum on Poultry Performance

Study	**Growth Rate (g/bird/day)**	**Feed Conversion Ratio (FCR)**	**Mortality Rate (%)**	**Average Body Weight (g)**
Ochieng *et al*. (2020)	45	1.75	2.0	1800
Fernandes *et al*. (2013)	50	1.68	1.5	1850
Silveira *et al*. (2017)	48	1.70	1.8	1825
Mugoti *et al*. (2022)	49	1.65	1.2	1900

Mineral requirements in feed

In poultry diets, minerals are essential for growth, bone development, metabolic function, and overall health. Key minerals like calcium, phosphorus, and magnesium play vital roles, especially in young and laying birds, as outlined in **Table 5**. However, the bioavailability of these minerals can be limited by the presence of antinutritional factors (ANFs) in grains like sorghum, including phytic acid and tannins, which bind minerals and prevent their absorption (**Adegunwa *et al*., 2012**). Fermentation of sorghum offers a solution by breaking down these ANFs, thereby improving the digestibility and bioavailability of essential minerals. For instance, studies show that lactic acid fermentation reduces phytic acid levels significantly, allowing minerals such as calcium, magnesium, and zinc to be more readily absorbed by poultry (**Martinez Rojas *et al*., 2018; Mugoti *et al*., 2022**).

The bioavailability of minerals or trace elements refers to the portion of the nutrients absorbed and utilized to enable normal physiological functions after ingestion, as defined by **Atuna *et al*. (2022)**. Physiological requirements for the varying inorganic nutrients can differ widely based on various factors, including age, sex, growth stage, pregnancy, and importantly lactation in different livestock. Mineral elements are crucial to the vital processes of the body, and they differ from other nutrients in that they are not destroyed, according to **Ross *et al*. (2020)**. However, appropriate processing methods such as cooking, germination, fermentation, and malting before consumption, as proposed by **Adegunwa *et al*. (2012)**, can enhance the bioavailability of minerals.

SORGHUM GRAIN PROCESSING AND ITS IMPACT

Fermentation

Fermentation is a process that significantly enhances the nutrient quality of feed by making previously inaccessible nutrients available for absorption and utilization in the body (**Kung *et al*., 2018**). Specifically, when fermenting sorghum grains, microorganisms such as lactic acid bacteria (LAB), including *Lactobacillus plantarum*, *Lactobacillus acidophilus*, and *Pediococcus pentosaceus*, are commonly used due to their efficiency in breaking down complex compounds and producing lactic acid, which lowers the pH and preserves the feed (**Day & Morawicki, 2018**; **Mugoti *et al*., 2022**). During fermentation, these LAB microorganisms proliferate under anaerobic conditions, typically maintained at temperatures between 20-30°C and a moisture content suitable for sorghum grain silage (approximately 60-70%) (**Kung *et al*., 2018**). This process produces organic acids, including lactic, acetic, and butyric acids, which not only preserve the grain but also enhance its palatability and digestibility **(Mugoti *et al*., 2022)**. For example, lactic acid production lowers the feed's pH, creating an environment that inhibits spoilage organisms and pathogens, thus extending the shelf life and improving the safety of the feed **(Mugoti *et al*., 2022)**.

Fermentation also helps reduce antinutritional factors (ANFs) like phytic acid and tannins, which interfere with mineral absorption. Fermentation with LAB can reduce tannin levels by up to 87% when combined with scarification, a process that further enhances seed permeability and nutrient availability (**Mugoti *et al*., 2022**). Beyond enhancing nutrient availability, fermentation promotes the production of antioxidant compounds, which contribute to the feed's health benefits by reducing oxidative stress in animals (**Shin *et al*., 2019**; **Zhang *et al*., 2023**). This optimized metabolic profile not only supports the efficient use of nutrients but also enhances the functional properties of the feed, making it more bioavailable and beneficial for livestock. Despite the well-documented improvements in tannin and phytic acid reduction, further research is needed to understand how fermentation impacts other ANFs in sorghum.

Table 5 Poultry mineral requirements

Mineral	Unit	Broilers (0-3 weeks)	Broilers (3-6 weeks)	Layers	Indigenous chickens
Calcium	%	0.9 - 1.10	0.70 - 0.9	3.25 - 4.25	1.0 - 1.1 (growth); 3.3 - 3.7 (laying)
Phosphorus	%	0.45 - 0.50	0.35 - 0.45	0.35 - 0.45	0.35 - 0.45
Magnesium	%	0.06	0.05	0.05	0.05 - 0.06
Potassium	%	0.20	0.20	0.25 - 0.30	0.20 - 0.30
Sodium	%	0.10 - 0.20	0.10- 0.20	0.15	0.10 - 0.15
Chlorine	%	0.25 - 0.40	0.25 - 0.40	0.30	0.25 - 0.30
Iron	ppm (mg/kg)	60 - 80	60 - 80	60 - 80	60 - 80
Copper	ppm (mg/kg)	6 - 10	5 - 10	6 - 10	6 - 10
Manganese	ppm (mg/kg)	60 - 120	50 - 100	80 - 120	60 - 120
Zinc	ppm (mg/kg)	40 - 60	30 - 60	40 - 60	40 - 60
Iodine	ppm (mg/kg)	0.60	0.60	0.60	0.60
Selenium	ppm (mg/kg)	0.10 - 0.20	0.1 - 0.20	0.15 - 0.20	0.15 - 0.20

Notes: Values followed by hyphen indicate ranges (such as 0.9-1.1). Values are approximate and may vary depending on factors such as birds age, breed, and sex as indicated by the **National Research Council (NRC), (1994)**, **Kingori *et al*, (2014), Alaru *et al*, (2024) and Ngaira *et al*, (2024).**

Reduction of anti-nutrients (mg/g) by LAB in Sorghum after Fermentation

A Gram-positive bacterial species known as lactic acid bacteria (LAB) is fastidious, acid-tolerant, catalase-negative, lacking in cytochrome, and non-respiring rod-shaped bacteria. They are also often non-sporulating. LAB is primarily involved in producing lactic acid as the sole product of the fermentation process as noted by **Durand *et al.* (2010)**. LABs are highly valued in the food industry for their numerous benefits in food processing and fermentation. The growth and action of LABs during the preparation of cultured foods, or following ingestion of these foods, may lead to several health benefits as highlighted in **Davis *et al.* (2012).** *Lactobacillus plantarum* (*L. plantarum*, **Table 6**) is an example of LAB that has been used to increase the shelf life of food products and provide desired aromas that enhance the flavor. It has been used for a long time in the preservation of human food **(Durand *et al.*, 2010).** It is therefore advisable to consider inoculation of fermentable material with LAB to ensure efficiency in the process. However, there are issues surrounding antimicrobial resistance (AMR) which need to be studied.

Table 6 Reduction of anti-nutrients (mg/g) by LAB in Sorghum after Fermentation

Anti-nutrient	Day 0	Day 3	Day 5	% Reduction
Tannin	0.738			
L. plantarum		0.425	0.207	72
L. brevis		0.592	0.325	56
Phytate				
L. Plantarum	6.962	3.945	2.785	60
L. Brevis		3.481	2.089	70
Trypsin				
L. Plantarum	0.366	0.334	0.115	69
L. brevis		0.226	0.155	58
Protease				
L. plantarum	1.750	1.431	1.225	30
L. brevis		1.303	1.050	40

Source **Adeyemo *et al.* (2016) and Mugoti *et al.* (2022)**

Impact of other Sorghum Grain Processing Methods on Poultry Performance and Nutrient Utilization

Grinding sorghum grain significantly influences feed characteristics, including digestibility, utilization, growth performance, and feeding costs **(Mahasukhonthachat *et al.*, 2010; Liu *et al.*, 2015).** Studies indicate that larger geometric mean particle sizes (GMPS) can enhance total weight gain and feed intake, thereby improving the feed conversion ratio (FCR) **(Nir *et al.*, 1990; Naderinejad *et al.*, 2016; Lyu *et al.*, 2020).** However, neither particle size nor physical form (e.g., whole vs. ground) affects carcass yield **(Seitz, 2019).** For instance**, Silveira *et al.* (2017)** observed no differences in growth performance or carcass yield in broilers (21–49 days) fed diets containing 15–45% whole or ground sorghum, suggesting that high inclusion levels of whole grain may be feasible without compromising productivity.

Further evidence supports that pelleted feeds containing ground or whole-grain sorghum yield similar weight gains in chickens, though whole grains promote gizzard development and increase gastrointestinal tract length **(Moss *et al.*, 2018).** Similarly, **Bennett *et al.* (2002)** reported that whole-grain wheat diets improved the gain-to-feed ratio and gizzard weight without altering carcass yield. These findings highlight that particle size primarily affects nutrient availability and gut morphology rather than slaughter metrics. Poultry species (turkeys, layers, broilers) exhibit feed selectivity based on particle size. Unlike mammals, birds rely on the gizzard, not oral mastication, to grind feed particles before intestinal absorption **(Moritz *et al.*, 2023).** This adaptation allows mature birds to digest whole grains efficiently, as demonstrated by **Fernandes *et al.* (2013),** who observed comparable growth in broilers fed whole sorghum. However, mechanical processing (e.g., grinding or scarification) remains critical to mitigate antinutritional factors (e.g., tannins, phytates), which otherwise impair amino acid availability and intake rates **(Mugoti *et al.*, 2022; Rachwał & Gustaw, 2024).** Thus, while whole grains support gizzard function, optimal processing balances nutrient release and ANF reduction.

PROBIOTICS AND ADDITIVES IN POULTRY FEED FERMENTATION

Probiotics and fermentation

Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits to the animal host, particularly by supporting gut health and nutrient absorption (**Ndudzo *et al.*, 2022**). In the context of fermented feed production, probiotics such as lactic acid bacteria (LAB), including strains like *Lactobacillus plantarum*, *Lactobacillus acidophilus*, and *Pediococcus pentosaceus*, are crucial for initiating and maintaining fermentation processes in sorghum. These LAB strains efficiently convert fermentable sugars in the sorghum grains into organic acids, such as lactic acid, which lowers the pH and preserves the nutritional quality of the feed (**Ndudzo *et al.*, 2022**). By using probiotics specifically selected for their fermentative and preservative properties, fermentation improves the safety, stability, and digestibility of sorghum-based feeds.

The application of probiotics in sorghum fermentation mimics the ensiling process traditionally used for forage plants but is adapted for grains. Under anaerobic conditions, LAB probiotics promote the production of lactic acid and, to a lesser extent, acetic and butyric acids. This leads to a rapid decrease in pH, which not only preserves the feed but also prevents spoilage by inhibiting unwanted microorganisms. Studies have shown that probiotic-fermented sorghum can enhance feed efficiency by reducing antinutritional factors and increasing nutrient bioavailability (**Barekatain *et al.*, 2013; Chen *et al.*, 2025**). However, careful management is required, as excess probiotic microorganisms may lead to nutrient loss in wet grains like sorghum due to over-fermentation, which can diminish feed quality. By leveraging probiotics tailored for fermentation, sorghum can be processed into a high-quality, stable feed suitable for long-term storage and efficient livestock nutrition.

Benefits of probiotics in silage making

In the fermentation of sorghum for livestock feed, lactic acid bacteria (LAB) act as effective probiotics that enhance feed quality and stability by increasing lactic acid and other organic acid production. These acids rapidly reduce the pH of the silage, creating an environment that inhibits spoilage microorganisms and preserves the nutritive value of sorghum. By lowering pH, LAB help to retain the sorghum's carbohydrate content while making proteins and other nutrients more accessible for digestion, ultimately improving digestibility and enhancing dry matter intake (DMI) in livestock (**Mugoti *et al.*, 2022**; **Ndudzo *et al.*, 2023**). Additionally, when LAB inoculants are used with sorghum, they produce a more stable silage that maintains its quality during extended storage, which is particularly beneficial in warm climates where sorghum is often grown. The use of LAB as probiotics in sorghum silage production thus supports efficient nutrient utilization in poultry and other livestock, making fermented sorghum a reliable, high-quality feed source (**Chen *et al.*, 2025**).

Use of probiotic strains in silages

Inoculation is a key practice in silage making, and it has proven effective in enhancing fermentation characteristics across a wide range of silages, including forage sorghum, alfalfa, wheat, and corn. Over 90% of silages inoculated with beneficial bacteria show improved fermentation profiles, higher lactic acid content, and better preservation, highlighting the value of inoculants in maintaining feed quality (**Mugoti *et al*., 2022, Masemula, 2022**). Recent research is now exploring the effects of probiotics in grain silages, and preliminary studies indicate promising results for sorghum silage. For example, probiotic strains can aid in fermenting sorghum-based chicken feed, enriching it with essential nutrients such as B vitamins and making the feed more palatable (**García-Chávez *et al*., 2018**). Effective forage preservation techniques, including probiotic inoculation, minimize spoilage and dry matter (DM) losses, which are crucial for retaining the energy content of the feed. Since the energy value of silage is directly related to the amount of DM preserved, inoculating sorghum silage not only helps in preserving nutritional quality but also supports efficient feed utilization, making fermented sorghum a valuable resource for poultry and other livestock (**Ndudzo *et al*., 2023**).

Additives in Silage and Fermentation

Additives can be natural or industrial products added to forage or grain during silage production **(Nkosi *et al*., 2012)**. The primary purpose of additives is to control the nutritive preservation process to ensure that the forage or grain retains as many nutrients as possible from the original fresh plant or grains. Additionally, additives help to promote the growth of lactic bacteria during the fermentation process, which subsequently leads to the production of lactic acid in sufficient quantities necessary for producing high-quality silage or feed, an interesting potential for sorghum **(Kung *et al*., 2018)**.

Importance of additives in fermented feed production

The use of additives in the fermentation of sorghum feed is crucial for optimizing feed quality and stability, particularly during the ensiling, storage, and feed-out stages. By controlling the fermentation process and minimizing nutrient losses, additives enhance the nutritive value and digestibility of sorghum, making it a more effective feed source for poultry. Additives such as molasses, enzymes, nutrients, and certain chemicals are commonly used to improve the anaerobic stability of fermented feeds, inhibit the growth of undesirable microorganisms (e.g., aerobic bacteria and fungi), and promote the dominance of lactic acid bacteria (LAB), which are essential for a successful fermentation process (**Nkosi *et al*., 2012**; **Yibarek & Tamir, 2014**).

Molasses

Molasses is a widely utilized additive in the ensiling of sorghum due to its high content of fermentable carbohydrates, which serve as a readily available energy source for LAB. By supporting LAB growth, molasses accelerates lactic acid production, which rapidly lowers the pH of the ensiled material, inhibiting spoilage organisms and preserving the nutritive value of sorghum (**Muck *et al*., 2018**). This is particularly valuable when ensiling lower-quality forages or when ensiling in warm-season climates where sorghum is often grown. Although molasses can be viscous and challenging to apply, diluting it with warm water can facilitate even distribution and prevent seepage, typically at 4-5% concentration when ensiling sorghum (**Yibarek & Tamir, 2014**).

Enzyme additives

Enzyme additives play a critical role in enhancing the digestibility of fermented sorghum feed by breaking down plant cell walls, particularly cellulose and hemicellulose, into fermentable sugars. These sugars not only support the growth of LAB but also lead to a higher production of lactic acid, reducing pH and improving silage stability (**Kung *et al*., 2018**). Enzyme-treated sorghum feed has demonstrated benefits in poultry nutrition, such as increased palatability, better nutrient absorption, and overall improvements in feed conversion ratios (**Yibarek & Tamir, 2014**). Combining enzyme additives with LAB further improves the lactic acid-to-acetic acid ratio, promoting stable and high-quality fermented sorghum feed.

Nutrient Additives

Ammonia and urea are the two main nutrient additions used in the production of sorghum silage. In the past, silage has often been produced using molasses and ammonia mixtures. The benefits of utilizing ammonia included an improved source of crude protein, silages with increased aerobic stability, reduced heating and molding during ensiling, and less protein breakdown in the silo **(Garca-López *et al*., 2021)**. Corn silage, small cereal grain silage, and high-moisture corn have all been successfully treated with ammonia **(Yibarek and Tamir 2014)**. Its application is particularly adaptable because ammonia can be injected at the blower, bagger, or bunker stages. Higher dry matter forages typically have urea added, which raises the crude protein level and aerobically stabilizes silage for feed-out **(Garca-López *et al*., 2021)**. Other additives used in the production of silage include calcium carbonate, ammonium sulfate, biuret with urea, and other sources of starch. A few minerals have also been added to silages, including calcium, phosphorus, magnesium, and sulfur. Instead of assisting in the fermentation process, these minerals function as buffers, resulting in increased pH **(Atuna *et al*., 2022)**. Minerals are also included because they improve the nutritional balance of the silage mixture **(Yibarek and Tamir, 2014)**.

Chemical Additives

The main purposes of chemical additives like acids are to lower the pH of silages or lengthen their bunk life. Formic acid and mineral acids can be supplied at rates of 15 kg per wet ton of raw material to reduce the fermentation losses of nutrients like proteins and carbohydrates. These acids include sulphuric acid and hydrochloric acid. **Yibarek and Tamir (2014)** found that when acids are introduced to plant material, the plant's respiration rate is stopped, which minimizes heat and nutrition loss. Gain silages, like sorghum, can become hazardous for the animals being fed if acid is applied more frequently, which can also result in excess effluent. Because they can damage equipment and animals, most acids are not used frequently. A study by **Franco *et al*. (2019)** demonstrated that the use of a chemical additive in wheat grain fermentation restricted bacterial activity but did not enhance aerobic stability, which could be an important consideration when applying similar additives in sorghum fermentation.

CHALLENGES AND LIMITATIONS

While sorghum is recognized for its nutritional benefits and adaptability in various agricultural contexts, its use in poultry feed presents several challenges and limitations. These include amongst the following:

Cost and Market Volatility

One of the primary limitations of using sorghum as a poultry feed ingredient is its higher cost compared to traditional grains like maize. The price of sorghum can fluctuate significantly due to market demand, availability, and production challenges, which can pose financial constraints for poultry producers, particularly smallholder farmers operating on tight margins (**Raza *et al*., 2019**). To mitigate this, blended feeding strategies (e.g., 50% sorghum + 50% maize) and government-supported price stabilization programs have shown promise in reducing costs while maintaining nutritional value (**FAO, 2021**).

Nutritional Limitations and Antinutritional Factors (ANFs)

The nutritional profile of sorghum may not always align perfectly with the dietary requirements of poultry, necessitating careful formulation of feed rations to ensure balanced nutrition. Several challenges associated with the use of sorghum in poultry feed can affect overall production efficiency. Notably, the presence of antinutritional factors (ANFs), such as phytates and tannins, can hinder nutrient absorption and negatively impact poultry health if not adequately managed (**Adeyemo *et al*., 2016**). Phytate, found primarily in the seed coat and germ of sorghum, forms complexes with cations, decreasing their bioavailability, while tannins are concentrated in the seed coat beneath the pericarp (**Kaufman *et al*., 2013**). These ANFs can lead to reduced feed efficiency and impaired growth rates in poultry if high levels of sorghum are included in their diets without proper processing. Fermentation has been proven to reduce tannins by 40–60% and phytates by 50%, while enzyme supplementation (e.g., phytase at 500–1,000 FTU/kg feed) can further improve mineral absorption (**Zhang *et al*., 2023**). Capacity-building programs for farmers on these techniques are essential to maximize sorghum's potential.

Toxicity Risks

Careful management practices are essential to avoid health hazards when feeding sorghum to poultry (**Etuk *et al*., 2012**). Sorghum can pose risks of nitrate and cyanide poisoning if fed in excessive amounts. Additionally, sorghum grown under high-temperature conditions can contain lethal levels of prussic acid, which can be fatal to livestock (**Etuk *et al*., 2012; Sanjana Reddy, 2017**). To counteract these risks, pre-feed testing using rapid cyanide test kits (<5 ppm safe threshold) and controlled feeding regimes (e.g., avoiding hungry birds overconsuming sorghum) are recommended (**APVMA, 2023**). In cases of poisoning, immediate veterinary intervention with sodium thiosulfate as an antidote can save livestock.

Fermentation Management

The use of preserved forages is a practice present in many properties to supply the lack of food in critical periods for ruminants, however, the fermentation process and the silage's quality are both impacted by several variables. **Muck *et al*. (2018)** claim that the primary issue of ensilage is to conserve nutrients through a fermentation process that produces high nutritional and microbially superior quality, limiting fermentative losses. Prolonged fermentation of grain (more than 7 days) may result in loss of carbohydrates through the use of microbes which ultimately results in the accumulation of lactic acids and lowered pH values (**Ahmed *et al*., 2023**). Optimizing fermentation duration (3–5 days) and using starter cultures (e.g., *Lactobacillus plantarum*) can enhance nutrient retention while preventing excessive acidification (**Olukomaiya *et al*., 2020**). The following factors affect seed fermentation;

a) Respiration

Seed respiration plays a key role in hindering the successful outcome of the conservation process. The seeds entering a silo will start respiration as conditions allow for germination. The presence of water, light, oxygen, and heat will accelerate the respiration process **(Maity *et al*., 2023)**. If a silo is filed slowly or imperfectly sealed, too much respiration occurrence may result in potential setbacks. Respiration causes loss of dry matter and this dry matter is lost rapidly by fermenting carbohydrates representing the loss of energy value of the crop as well as lactic acid formation **(da Silva *et al*., 2017)**. Also, prolonged respiration days on the onset of pH decline allow detrimental microbial activity to continue. Finally, respiration produces heat that may increase the formation of bad products including acid detergent insolubles.

b) Proteolytic activity

The activity of plant proteases in silage-making is affected by pH, time, dry matter content of the seed, and temperature. The effects of pH on plant proteases have been studied in legumes. Proteolytic activity decreases with a prolonged duration of fermentation in the silo. The decline in proteolysis rate with time is independent of dry matter thus measures to reduce proteolysis must be effective upon ensiling silage. Dry matter content is also a significant factor affecting protease occurrence, increasing temperatures over the range of 10ºC increases proteolyze rate as a result it affects the fermentation **(Nkosi *et al*., 2012)**.

c) Clostridial fermentation

Clostridial fermentation is a problem in silage-making. In high dry matter silages that have minimal moisture available, Osmo-tolerant LAB may become a limiting factor in the silage-making process. Seeds that contain dry matter (DM) above 50% are particularly difficult to ensile, as noted by **Wróbel *et al.* (2023)**. To combat this issue, additives that promote silage fermentation can be used to reduce clostridial spore counts. An effective fermentation stimulant for this purpose is molasses. Additionally, to prevent clostridial growth, additives based on ingredients such as formic acid, hexamethylene, and nitrite appear to be the most effective inhibitors. Mechanical scarification of seeds can also help avail water-soluble carbohydrates to the microbes thereby promoting excellent fermentation. It is clear that to inhibit aerobic spoilage, spoilage organisms, in particular, the causative organisms (yeasts and acetic acid bacteria) at the onset of deterioration in their activity and growth, and silage additives should be used to produce good silage **(Yibarek and Tamir, 2014)**.

d) Aerobic microbial activity

Air is an important factor affecting silage fermentation. Its presence exerts influence through the activities of aerobic microorganisms such as bacteria, aerobic fungi, and yeast **(Ahmed *et al*., 2023)**. These microorganisms utilize forage nutrition thereby lowering the nutritive value of silage by altering its physical and chemical characteristics **(Muck *et al*., 2018)**. Aerobic conditions are unsuitable for silage making because too much exposure to air at the start of fermentation prolongs the metabolism resulting in the unwanted microbes thriving which ultimately delays the growth of beneficial (probiotic) bacteria that produce lactic acid **(Muck *et al*., 2018)**. This obviously will lead to undesirable fermentations and a significant loss in feed nutritive value. Furthermore, the processing of sorghum for poultry feed can present difficulties. Techniques such as grinding and fermentation are essential for improving digestibility and reducing ANFs; however, these processes can increase production costs and require additional labor and equipment (**Liu *et al*., 2015**). Farmers must weigh the benefits of using sorghum against these processing challenges, especially in regions where resources are limited.

FUTURE RESEARCH DIRECTIONS

The potential of sorghum as a feed ingredient for poultry is substantial, however, addressing existing research gaps is essential for maximizing its benefits and ensuring sustainable agricultural practices. One significant area for future research is the optimization of fermentation processes for sorghum. While current studies have demonstrated the advantages of fermentation in improving digestibility and reducing antinutritional factors, there is a need for more comprehensive investigations into the specific conditions that maximize these benefits. This includes examining various fermentation durations, temperatures, and microbial strains to identify optimal combinations that enhance the nutritional profile of sorghum (**Hadebe *et al*., 2017; Silveira *et al*., 2017**). Additionally, research should explore the impact of different fermentation substrates, inclusion levels and methods on the production of beneficial metabolites, such as organic acids and probiotics, which can further support poultry health (**Adebo, 2020**).

Another critical research direction involves the exploration of new probiotics or additives that can be incorporated into sorghum-based diets to enhance feed value. While existing probiotics have shown promise in improving gut health and nutrient absorption, there is still a limited understanding of how specific probiotic strains interact with sorghum and its fermentation products. Upcoming studies should investigate the efficacy of various probiotic formulations and natural additives, such as enzymes and herbal supplements, in conjunction with fermented sorghum to determine their synergistic effects on poultry performance and health (**Ndudzo *et al*., 2023**). Furthermore, research should aim to evaluate the long-term impacts of feeding fermented sorghum on poultry health and productivity, including aspects such as immunity, disease resistance, and overall welfare.

CONCLUSION

The utilization of drought-resistant crops such as sorghum presents a promising alternative for enhancing energy provision in poultry diets. Its ability to offer high nutritional value and microbiological quality is crucial for promoting poultry health and growth. However, addressing the challenges posed by antinutritional factors (ANFs) is essential to maximize the benefits of sorghum as a feed ingredient. Fermentation has emerged as a highly effective practice for improving the digestibility and nutrient availability of sorghum, thereby enhancing its overall feed value. Additionally, the incorporation of specific additives during fermentation can further optimize these benefits, highlighting the importance of ongoing research in this area. Future studies should focus on the activity of ANFs and antioxidants in fermented sorghum, as there is currently limited information available on their impacts. Furthermore, investigating the effects of various additives and the optimal duration of grain storage on fermentation processes will be crucial for developing best practices in poultry nutrition.

Acknowledgements: The authors thank Lupane State University for affording resources and support for this review paper.

REFERENCES

Abbas, A. O., Nassar, F. S., & Al Ali, A. M. (2025). Challenges of Ensuring Sustainable Poultry Meat Production and Economic Resilience under Climate Change for Achieving Sustainable Food Security. *Research on World Agricultural Economy*, 159-171. https://doi.org/10.36956/rwae.v6i1.1441

Abedi, E., & Hashemi, S. M. B. (2020). Lactic acid production–producing microorganisms and substrates sources-state of art. *Heliyon*, *6*(10). https://doi.org/10.1016/j.heliyon.2020.e04974

Adebo, O. A. (2020). African sorghum-based fermented foods: past, current and future prospects. *Nutrients*, *12*(4), 1111. http://dx.doi.org/10.3390/nu12041111

Adegunwa, M. O., Adebowale, A. A., Solano, E. O. (2012). Effect of thermal processing on the biochemical composition, antinutritional factors, and functional properties of beniseeds (Sesamumindicum) flour. American Journal of Biochemistry and Molecular Biology, 2: 175–182. https://doi.org/10.3923/ajbmb.2012.175.182

Adeyemo, S. M., Onilude, A. A., & Olugbogi, D. O. (2016). Reduction of Anti-nutritional factors of sorghum by lactic acid bacteria isolated from Abacha-an African fermented staple. *Front Sci*, *6*(1), 25-30. http://article.sapub.org/10.5923.j.fs.20160601.03.html

Ahmad, R., Oli, A. N., Etando, A., Sharma, P., Sinha, S., Chowdhury, K., ... & Haque, M. (2023). Lactic acid bacteria fermented foods: Impact on immune system and consequences over type 2 diabetes mellitus. *Journal of Applied Pharmaceutical Science*, *13*(6), 018-056. https://doi.org/10.7324/JAPS.2023.142387

Alaru, P. A. O., Wangui, G., Ouko, V. O., Wachira, A., & Miano, D (2024)**.** Feeding Indigenous Chicken. KALRO-Naivasha, Kenya. https://agrificsapp.kalro.org/file_uploads/feeding%20Indigenous%20chicken.pdf

Alban, M., Nation, C., Anderson, M., & Lenin, D. (2022). Effects of lactic acid bacteria on phytate and the ensiling properties of Sorghum bicolor L. Moench. *Aceh Journal of Animal Science*, *7*(3), 111-115. https://doi.org/10.13170/ajas.7.3.25050

Allen, A. R., Booker, L., & Rockwood, G. A. (2015). Acute cyanide toxicity. *Toxicology of Cyanides and Cyanogens: Experimental, applied and clinical aspects*, 1-20. https://doi.org/10.1002/9781118628966.ch1

APVMA, Australian Pesticides and Veterinary Medicines Authority. (2023). Nitrate and cyanide poisoning in livestock. Accessed on April 8, 2023. Retrieved from https://apvma.gov.au/node/14871

Arbex, P. M., de Castro Moreira, M. E., Toledo, R. C. L., de Morais Cardoso, L., Pinheiro-Sant'ana, H. M., dos Anjos Benjamin, L., ... & Martino, H. S. D. (2018). Extruded sorghum flour (Sorghum bicolor L.) modulate adiposity and inflammation in high fat diet-induced obese rats. *Journal of functional foods*, *42*, 346-355.. https://doi.org/10.1016/j.jff.2018.01.010

Arsov, A., Tsigoriyna, L., Batovska, D., Armenova, N., Mu, W., Zhang, W., ... & Petrova, P. (2024). Bacterial Degradation of Antinutrients in Foods: The Genomic Insight. *Foods*, *13*(15), 2408. https://doi.org/10.3390/foods13152408

Atuna, R. A., Ametei, P. N., Bawa, A. A., & Amagloh, F. K. (2022). Traditional processing methods reduced phytate in cereal flour, improved nutritional, functional and rheological properties. *Scientific African*, *15*, e01063. https://doi.org/10.1016/j.sciaf.2021.e01063.

Awika, J. M., McDonough, C. M., & Rooney, L. W. (2005). Decorticating sorghum to concentrate healthy phytochemicals. *Journal of agricultural and food chemistry*, *53*(16), 6230-6234. https://doi.org/10.1021/jf0510384

Barbacariu, C. A., Dumitru, G., Rimbu, C. M., Horhogea, C. E., Dîrvariu, L., Todirașcu-Ciornea, E., ... & Burducea, M. (2024). Inclusion of Sorghum in Cyprinus carpio L. Diet: Effects on Growth, Flesh Quality, Microbiota, and Oxidative Status. *Animals*, *14*(11), 1549. https://doi.org/10.3390/ani14111549

Barekatain, M. R., Antipatis, C., Rodgers, N., Walkden-Brown, S. W., Iji, P. A., & Choct, M. (2013). Evaluation of high dietary inclusion of distillers dried grains with solubles and supplementation of protease and xylanase in the diets of broiler chickens under necrotic enteritis challenge. *Poultry Science*, *92*(6), 1579-1594. https://doi.org/10.3382/ps.2012-02786

Bennett, C. D., Classen, H. L., & Riddell, C. (2002). Feeding broiler chickens wheat and barley diets containing whole, ground and pelleted grain. *Poultry Science*, *81*(7), 995-1003. https://doi.org/10.1093/ps/81.7.995

Beyer, S. (2021). Feed Value Benefits of Sorghum for poultry. Kansas State University. Accessed on May 5, 2023. https://www.sorghumcheckoff.com/wpcontent/uploads/2021/11/2018_04_26_PoultryFeedingGuide_New-Logo.pdf

Bhat, B. V., Venkateswarlu, R., & Tonapi, V. A. (2021). Breeding sorghum for forage and feed: status and approaches. In *Sorghum in the 21st century: food–fodder–feed–fuel for a rapidly changing world* (pp. 393-420). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-15-8249-3_17

Butnariu, M. (2023). Plant genome engineering for improved flavonoids production. *Plants as Bioreactors for Industrial Molecules*, 215-240.

Cairns, J. R. K., & Esen, A. (2010). β-Glucosidases. *Cellular and molecular life sciences: CMLS*, *67*(20), 3389. https://doi.org/10.1007/s00018-010-0399-2

Cardoso, L. D. M. (2014). Sorghum: variability of nutrients and bioactive compounds and their heat processing stability. *Nutrition Science* http://www.locus.ufv.br/handle/123456789/7306

Carr, A. C., & Maggini, S. (2017). Vitamin C and immune function. *Nutrients*, 9(11), 1211. https://doi.org/10.3390/nu9111211

Cirkovic Velickovic, T. D., & Stanic-Vucinic, D. J. (2018). The role of dietary phenolic compounds in protein digestion and processing technologies to improve their antinutritive properties. *Comprehensive Reviews in Food Science and Food Safety*, *17*(1), 82-103. https://doi.org/10.1111/1541-4337.12320

da Silva, T. C., da Silva, L. D., Santos, E. M., Oliveira, J. S., & Perazzo, A. F. (2017). Importance of the fermentation to produce high-quality silage. *Fermentation processes*, *8*, 1-20. https://www.intechopen.com/chapters/52326

Davis, C. K., Webb, R. I., Sly, L. I., Denman, S. E., & McSweeney, C. S. (2012). Isolation and survey of novel fluoroacetate-degrading bacteria belonging to the phylum Synergistetes. *FEMS Microbiology Ecology*, *80*(3), 671-684. https://doi.org/10.1111/j.1574-6941.2012.01338.x

Day, C. N., & Morawicki, R. O. (2018). Effects of fermentation by yeast and amylolytic lactic acid bacteria on grain sorghum protein content and digestibility. *Journal of Food Quality*, *2018*(1), 3964392. https://doi.org/10.1155/2018/3964392

Dhar, A., Kumari, B., Kavithamani, D., Boopathi, N., Meenakshi, P. (2024). Understanding the advances in Sorghum grain quality improvement: An overview. Plant Science Today. 10.14719/pst.3527. https://doi.org/10.14719/pst.3527

Dicko, M. H., Gruppen, H., Traoré, A. S., Voragen, A. G., & van Berkel, W. J. (2006). Phenolic compounds and related enzymes as determinants of sorghum for food use. *Biotechnology and Molecular Biology Review*, *1*(1), 20-37. https://edepot.wur.nl/20650

Durand, J., Bodénès, C., Chancerel, E., Frigerio, J. M., Vendramin, G., Sebastiani, F. (2010). A fast and cost-effective approach to develop and map EST-SSR markers: oak as a case study. BMC Genomics, 11:570. https://doi.org/10.1186/1471-2164-11-570

Dykes, L. (2019). Tannin Analysis in Sorghum Grains. Methods in molecular biology (Clifton, N.J.), 1931, 109–120. https://doi.org/10.1007/978-1-4939-9039-9_8

Dykes, L., & Rooney, L. W. (2006). Sorghum and millet phenols and antioxidants. *Journal of cereal science*, *44*(3), 236-251. https://doi.org/10.1016/j.jcs.2006.06.007

Elango, D. (2018). *Genetic Diversity and Genome Wide Mapping of Stress Induced Secondary Metabolites in Sorghum (Sorghum bicolor (L.) Moench)*. The Pennsylvania State University. https://etda.libraries.psu.edu/files/final_submissions/17817

Elramlawi, H.R., Mohammed, H.I., Elamin, A.W., Abdallah, O.A., Taha, A.A.A.M. (2020). Adaptation of Sorghum (Sorghum bicolor L. Moench) Crop Yield to Climate Change in Eastern Dryland of Sudan. In: Leal Filho, W. (eds) Handbook of Climate Change Resilience. Springer, Cham. https://doi.org/10.1007/978-3-319-93336-8_157

Emendack, Y., Burke, J., Laza, H., Sanchez, J., Hayes, C., (2018). Abiotic stress effects on sorghum leaf dhurrin and soluble sugar contents throughout plant development. Crop Sci. 58, 1706–1716. https://doi.org/10.2135/cropsci2018.01.0059

Etuk, E. B., Okeudo, N. J., Esonu, B. O., & Udedibie, A. B. I. (2012). Antinutritional factors in sorghum: chemistry, mode of action and effects on livestock and poultry. https://www.ojafr.com/main/attachments/article/85/OJAFR,%20B23,%20113-119,%202012.pdf

FAO, (2021). The State of Food and Agriculture 2021. Making agri-food systems more resilient to shocks and stresses. *FAO.* https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1457191/

Fernandes, E. A., Pereira, W. J. S., Hackenhaar, L., Rodrigues, R. M., & Terra, R. (2013). The use of whole grain sorghum in broiler feeds. *Brazilian Journal of Poultry Science*, *15*, 217-222. https://doi.org/10.1590/S1516-635X2013000300008

Franco, M., Stefanski, T., Jalava, T., Kuoppala, K., Huuskonen, A., & Rinne, M. (2019). Fermentation quality and aerobic stability of low moisture-crimped wheat grains manipulated by organic acid-based additives. *The Journal of Agricultural Science*, *157*(3), 245-253. https://doi.org/10.1017/S0021859619000546

García-Chávez, I., Meraz-Romero, E., Castelán-Ortega, O., Zaragoza-Esparza, J., Osorio Avalos, J., Robles Jiménez, L. E., & González-Ronquillo, M. (2022). Corn silage, a systematic review of the quality and yield in different regions around the world. *Ciencia y Tecnología Agropecuaria*, *23*(3). https://doi.org/10.21930/rcta.vol23

Garutti, M., Nevola, G., Mazzeo, R., Cucciniello, L., Totaro, F., Bertuzzi, C. A., Caccialanza, R., Pedrazzoli, P., Puglisi, F. (2022). The Impact of Cereal Grain Composition on the Health and Disease Outcomes. Frontiers in nutrition, 9, 888974. https://doi.org/10.3389/fnut.2022.888974

Hadebe, S. T., Modi, A. T., & Mabhaudhi, T. (2017). Drought tolerance and water use of cereal crops: A focus on sorghum as a food security crop in sub‐Saharan Africa. *Journal of Agronomy and Crop Science*, *203*(3), 177-191. https://doi.org/10.1111/jac.12191

Hagerman, A. E., Riedl, K. M., Jones, G. A., Sovik, K. N., Ritchard, N. T., Hartzfeld, P. W., & Riechel, T. L. (1998). High molecular weight plant polyphenolics (tannins) as biological antioxidants. *Journal of agricultural and food chemistry*, *46*(5), 1887-1892. https://doi.org/10.1021/jf970975b

Hole, A.S., Rud, I., Grimmer, S., Sigl, S., Narvhus, J., Sahlstrom, S. (2012). Improved bioavailability of dietary phenolic acids in whole grain barley and oat groat following fermentation with probiotic Lactobacillus acidophilus, Lactobacillus johnsonii, and Lactobacillus reuteri. Journal of Agricultural and Food Chemistry, 60:6369-6375. https://doi.org/10.1021/jf300410h

Hossain, M. S., Islam, M. N., Rahman, M. M., Mostofa, M. G., & Khan, M. A. R. (2022). Sorghum: A prospective crop for climatic vulnerability, food and nutritional security. *Journal of Agriculture and Food Research*, *8*, 100300. https://doi.org/10.1016/j.jafr.2022.100300

Chen, D., Yang, D., Guo, T., & Zhang, Q. (2025). Effects of Lactic Acid Bacteria Inoculants on Fermentation Quality, Bacteria Communities and Antibiotic Resistance Genes in Whole-Crop Corn Silage. *Microorganisms*, *13*(9), 1977. https://doi.org/10.3390/microorganisms13091977

Juskiewicz, J., Jankowski, J., Zielinski, H., Zdunczyk, Z., Mikulski, D., Antoszkiewicz, Z., ... & Zdunczyk, P. (2017). The fatty acid profile and oxidative stability of meat from turkeys fed diets enriched with n-3 polyunsaturated fatty acids and dried fruit pomaces as a source of polyphenols. *PLoS One*, *12*(1), e0170074. https://doi.org/10.1371/journal.pone.0170074

Kang, X., Gao, W., Cheng, Y., Yu, B., Cui, B., & Abd El-Aty, A. M. (2023). Investigating structural and property modifications in starch from waxy, stick, and H37 sorghum varieties: Advancing starch structure understanding and applications. *Industrial Crops and Products*, *203*, 117239. https://doi.org/10.1016/j.indcrop.2023.117239

Kaufman, R. C., Herald, T. J., Bean, S. R., Wilson, J. D., & Tuinstra, M. R. (2013). Variability in tannin content, chemistry and activity in a diverse group of tannin containing sorghum cultivars. *Journal of the Science of Food and Agriculture*, *93*(5), 1233-1241.. https://doi.org/10.1002/jsfa.5890

Kieliszek, M., & Błażejak, S. (2016). Current knowledge on the importance of selenium in food for living organisms: a review. *Molecules*, *21*(5), 609. https://doi.org/10.3390/molecules21050609

Kingori, A. M., Wachira, A. M., & Tuitoek, J. K. (2014). Influence of energy intake on egg production and weight in indigenous chickens of Kenya. *International Journal of Poultry Science*, *13*(3), 151. www.cabidigitallibrary.org/doi/full/10.5555/20143240229

Kögel-Knabner, I., & Amelung, W. (2014). Dynamics, chemistry, and preservation of organic matter in soils. https://api.semanticscholar.org/CorpusID:101764175

Kung Jr, L., Shaver, R. D., Grant, R. J., & Schmidt, R. J. (2018). Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *Journal of dairy Science*, *101*(5), 4020-4033. https://doi.org/10.3168/jds.2017-13909

Leung, D., Abbenante, G., & Fairlie, D. P. (2000). Protease inhibitors: current status and future prospects. *Journal of medicinal chemistry*, *43*(3), 305-341. https://doi.org/10.1021/jm990412m

Liu, S. Y., Fox, G., Khoddami, A., Neilson, K. A., Truong, H. H., Moss, A. F., & Selle, P. H. (2015). Grain sorghum: a conundrum for chicken-meat production. *Agriculture*, *5*(4), 1224-1251. doi:10.3390/agriculture5041224. https://doi.org/10.3390/agriculture5041224

Lyu, F., Thomas, M., Hendriks, W. H., & Van der Poel, A. F. B. (2020). Size reduction in feed technology and methods for determining, expressing and predicting particle size: A review. *Animal Feed Science and Technology*, *261*, 114347. https://doi.org/10.1016/j.anifeedsci.2019.114347

Mahasukhonthachat, K., Sopade, P. A., & Gidley, M. J. (2010). Kinetics of starch digestion and functional properties of twin-screw extruded sorghum. *Journal of Cereal Science*, *51*(3), 392-401. https://doi.org/10.1016/j.jcs.2010.02.008

Maity, A., Paul, D., Lamichaney, A., Sarkar, A., Babbar, N., Mandal, N., ... & Chakrabarty Chakrabarty, S. K. (2023). Climate change impacts on seed production and quality: current knowledge, implications, and mitigation strategies. *Seed Science and Technology*, *51*(1), 7-38. https://doi.org/10.15258/sst.2023.51.1.07

Malabadi, R. B., Kolkar, K. P., & Chalannavar, R. (2022). Sweet Sorghum for Biofuel energy: grain sorghum for Food and Fodder-Phytochemistry and Health benefits. *International Journal of Innovation Scientific Research and Review*, *4*(9), 3305-3323. https://www.researchgate.net/publication/364149928

Manjunath, M., Lavanya, G., Sivajyothi, R., & Reddy, O. V. S. (2011). Antioxidant and radical scavenging activity of Actiniopteris radiata (Sw.) Link. *Asian J. Exp. Sci*, *25*(1), 73-80. http://ajesjournal.com/PDFs/2011-1/16_M.%20Manjunath.pdf

Martinez Rojas, I. Y., Ávila González, E., Arce Menocal, J., Dos Santos, T. T., Rubio Arguello, J., & López Coello, C. (2018). Assessment of a phytase included with lactic acid on productive parameters and on deposition of phosphorus, calcium, and zinc in laying hens fed with sorghum–soybean-meal-based diets. *Journal of Applied Animal Research*, *46*(1), 314-321. https://doi.org/10.1080/09712119.2017.1299740

Masemula, N. (2023). A study of indigenous sorghum agriculture in Southern Africa: combining isotope and indigenous knowledge systems approaches. http://hdl.handle.net/11427/39644

Mohamed, H. I., Fawzi, E. M., Basit, A., Lone, R., & Sofy, M. R. (2022). Sorghum: nutritional factors, bioactive compounds, pharmaceutical and application in food systems: a review. *Phyton*, *91*(7), 1303. https://doi.org/10.32604/phyton.2022.020642

Moraes, É. A., da Silva Marineli, R., Lenquiste, S. A., Steel, C. J., de Menezes, C. B., Queiroz, V. A. V., & Júnior, M. R. M. (2015). Sorghum flour fractions: Correlations among polysaccharides, phenolic compounds, antioxidant activity and glycemic index. *Food chemistry*, *180*, 116-123. https://doi.org/10.1016/j.foodchem.2015.02.023

Moreno, C. R., Fernández, P. C. R., Rodríguez, E. O. C., Carrillo, J. M., & Rochín, S. M. (2018). Changes in nutritional properties and bioactive compounds in cereals during extrusion cooking. *Extrusion of metals, polymers and food products*, 104-124. https://doi.org/10.5772/65577

Moritz, A. H., Lumpkins, B., Mathis, G. F., Bridges, W. C., Wilson, S., Blair, M. E., ... & Arguelles-Ramos, M. (2023). Comparative efficacy of tannin-free grain sorghum varieties for the control of necrotic enteritis caused by Clostridium perfringens in broiler chickens. *Poultry Science*, *102*(2), 102300. https://doi.org/10.1016/j.psj.2022.102300

Muck, R. E., Nadeau, E. M. G., McAllister, T. A., Contreras-Govea, F. E., Santos, M. C., & Kung Jr, L. (2018). Silage review: Recent advances and future uses of silage additives. *Journal of dairy science*, *101*(5), 3980-4000. https://doi.org/10.3168/jds.2017-13839

Mugoti, A., Nation, C., & Anderson, M. (2022). Response of broiler chickens Gallus gallus domesticus to dietary supplementation with LAB-treated sorghum seed. *Aceh Journal of Animal Science*, *7*(1), 1-6. https://doi.org/10.13170/ajas.7.1.18271

Muzerengi, T., & Tirivangasi, H. M. (2019). Small grain production as an adaptive strategy to climate change in Mangwe District, Matabeleland South in Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, *11*(1), 1-9. https://doi.org/10.4102/jamba.v11i1.652

Naderinejad, S., Zaefarian, F., Abdollahi, M. R., Hassanabadi, A., Kermanshahi, H., & Ravindran, V. (2016). Influence of feed form and particle size on performance, nutrient utilisation, and gastrointestinal tract development and morphometry in broiler starters fed maize-based diets. *Animal Feed Science and Technology*, *215*, 92-104. https://doi.org/10.1016/j.anifeedsci.2016.02.012

Ndlovu, E., Van Staden, J., & Maphosa, M. (2021). Morpho-physiological effects of moisture, heat and combined stresses on Sorghum bicolor [Moench (L.)] and its acclimation mechanisms. *Plant Stress*, *2*, 100018. https://doi.org/10.1016/j.stress.2021.100018

Ndudzo, A., Ndlovu, S., Nyathi, N., & Makuvise, A. S. (2022). Unlocking the potential of ghost probiotics in combating antimicrobial resistance. *The Global Antimicrobial Resistance Epidemic-Innovative Approaches and Cutting-Edge Solutions*. https://doi.org/10.5772/intechopen.104126

Ndudzo, A., Pullen, J., Magwaba, T., Ndlovu, S., Moyo, M., Sibanda, S., ... & Mugoti, A. (2023). Incorporation of functional feed ingredients to substitute antimicrobials in animal nutrition: Opportunities for livestock production in developing countries. *International Journal of Livestock Production,* 2, 44 – 57. https://doi.org/10.5897/IJLP2023.0820

NERI, H. (2024). *Purification and Characterization of Trypsin Inhibitor from germinating seeds of Leucaena leucocephala L* (Doctoral dissertation, Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY). https://krishikosh.egranth.ac.in/server/api/core/bitstreams/d145c688-44a0-4226-bd73-32277a91de27/content

Ngaira, V. M., Alaru, P. A. O., & Wachira, A. M. (2024). Feeding Indigenous Chicken. KALRO Non-Ruminant Research Institute. https://www.kalro.org/navcdp/docs/publications/FEEDING%20INDIGENOUS%20CHICKEN.pdf

Nir, I., Melcion, J. P., & Picard, M. (1990). Effect of particle size of sorghum grains on feed intake and performance of young broilers. *Poultry Science*, *69*(12), 2177-2184. https://doi.org/10.3382/ps.0692177

Nkosi, B. D., Vadlani, P. V., Brijwani, K., Nanjunda, A., & Meeske, R. (2012). Effects of bacterial inoculants and an enzyme on the fermentation quality and aerobic stability of ensiled whole-crop sweet sorghum. *South African Journal of Animal Science*, *42*(3), 232-240. https://doi.org/10.4314/sajas.v42i3.4

Novitasari, E., & Novita, D. D. (2022, May). Physical quality and tannin content of sorghum (Sorghum bicolor L.) at different temperature and soaking immersion. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1024, No. 1, p. 012068). IOP Publishing. https://iopscience.iop.org/article/10.1088/1755-1315/1024/1/012068

Nuss, E. T., & Tanumihardjo, S. A. (2010). Maize: a paramount staple crop in the context of global nutrition. *Comprehensive reviews in food science and food safety*, *9*(4), 417-436. https://doi.org/10.1111/j.1541-4337.2010.00117.x

Ochieng, B. A., Owino, W. O., Kinyuru, J. N., Mburu, J. N., & Gicheha, M. G. (2020). Effect of low tannin sorghum based feeds on broiler meat nutritional quality. *Journal of Agriculture and Food Research*, *2*, 100078. https://doi.org/10.1016/j.jafr.2020.100078.

Patra, A. K., & Saxena, J. (2011). Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. *Journal of the Science of Food and Agriculture*, *91*(1), 24-37. https://doi.org/10.1002/jsfa.4152

Pezzali, J. G., Suprabha-Raj, A., Siliveru, K., & Aldrich, C. G. (2020). Characterization of white and red sorghum flour and their potential use for production of extrudate crisps. *Plos one*, *15*(6), e0234940. https://doi.org/10.1371/journal.pone.0234940

Quintieri, L., Nitride, C., De Angelis, E., Lamonaca, A., Pilolli, R., Russo, F., & Monaci, L. (2023). Alternative protein sources and novel foods: benefits, food applications and safety issues. *Nutrients*, *15*(6), 1509. https://doi.org/10.3390/nu15061509

Rachwał, K., & Gustaw, K. (2024). Lactic Acid Bacteria in Sustainable Food Production. *Sustainability*, *16*(8), 3362. https://doi.org/10.3390/su16083362

Ram, S., Narwal, S., Gupta, O. P., Pandey, V., & Singh, G. P. (2020). Anti-nutritional factors and bioavailability: Approaches, challenges, and opportunities. *Wheat and barley grain biofortification*, 101-128. https://doi.org/10.1016/B978-0-12-818444-8.00004-3

Rather, M. A., Thakur, R., Hoque, M., Das, R. S., Miki, K. S. L., Teixeira-Costa, B. E., ... & Gupta, A. K. (2023). Sorghum (Sorghum bicolor). *Nutri-Cereals: Nutraceutical and Techno-Functional Potential*.

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, *8*(2), 34. https://doi.org/10.3390/plants8020034

Rhodes, D. (2014). *Diversity, genetics, and health benefits of sorghum grain*. University of South Carolina. https://scholarcommons.sc.edu/etd/3005

Rietjens, I. M., Martena, M. J., Boersma, M. G., Spiegelenberg, W., & Alink, G. M. (2005). Molecular mechanisms of toxicity of important food-borne phytotoxins. *Molecular nutrition & food research*, *49*(2), 131-158. https://doi.org/10.1002/mnfr.200400078

Ross, A. C., Caballero, B., Cousins, R. J., & Tucker, K. L. (2020). *Modern nutrition in health and disease*. Jones & Bartlett Learning. https://pure.psu.edu/en/publications/modern-nutrition-in-health-and-disease-eleventh-edition

Samardžija, M. (2017). Veterinary toxicology for Australia and New Zealand. *Veterinarska stanica*, *48*(5), 411-411. https://www.croris.hr/crosbi/publikacija/prilog-casopis/242929

Sanjana Reddy, P. (2017). Sorghum, sorghum bicolor (L.) Moench. *Millets and Sorghum: Biology and Genetic Improvement*, 1-48. https://doi.org/10.1002/9781119130765.ch1

Sawhney, A. P. S., Paudyal, S., Dhakal, I. P. (2019). Cyanide toxicity in poultry. Journal of livestock science and management, 6(1), 58-61.

Seitz, D. 2019. Will changes in sorghum processing improve broiler chick performance. Master of Science Thesis, Kansas State University, Manhattan, Kansas, US. https://krex.k-state.edu/server/api/core/bitstreams/5c83f026-af5e-468d-be08-ef20d5474532/content

Shi, L., Jin, X., Xu, Y., Xing, Y., Yan, S., Guo, Y., ... & Shi, B. (2022). Effects of total flavonoids of artemisia ordosica on growth performance, oxidative stress, and antioxidant status of lipopolysaccharide-challenged broilers. *Antioxidants*, *11*(10), 1985. https://doi.org/10.3390/antiox11101985

Shin, H. Y., Kim, S. M., Lee, J. H., & Lim, S. T. (2019). Solid-state fermentation of black rice bran with Aspergillus awamori and Aspergillus oryzae: Effects on phenolic acid composition and antioxidant activity of bran extracts. *Food chemistry*, *272*, 235-241. https://doi.org/10.1016/j.foodchem.2018.07.174

Silveira, M. M., Martins, J. M. S., Litz, F., Carvalho, C. M. C., Moraes, C. A., Silva, M. C. A., & Fernandes, E. A. (2017). Effect of sorghum based nutritional programs on performance, carcass yield and composition of breast in broilers. *Revista Brasileira de Ciência Avícola*, *19*(spe), 43-50. https://doi.org/10.1590/1806-9061-2016-0253

Singh, S., Shukla, G. P., & Joshi, D. C. (2014). Evaluation of dual-purpose sorghum hybrids for nutritional quality, energetic efficiency and methane emission. *Animal Nutrition and Feed Technology*, *14*(3), 535-548. http://dx.doi.org/10.5958/0974-181X.2014.01356.0

Sivadurga, K., Srivastava, R., & Swamy, C. T. (2025). Colored Pigments: Extraction, Identification, and Health Aspects. *Colored Cereals: Properties, Processing, Health Benefits, and Industrial Uses*, 119. https://doi.org/10.1201/9781003454922-6

Sruthi, N. U., Rao, P. S., & Rao, B. D. (2021). Decortication induced changes in the physico-chemical, anti-nutrient, and functional properties of sorghum. *Journal of Food Composition and Analysis*, *102*, 104031. https://doi.org/10.1016/j.jfca.2021.104031

Statista, (2022). Production of poultry meat world-wide. Accessed on May 1, 2023. https://www.statista.com/statistics/237637/production-of-poultry-meat-worldwide-since-1990/

Stefova, M., Stafilov, T., & Kulevanova, S. (2003). HPLC analysis of flavonoids. *Encyclopedia of chromatography*, 183-195. https://www.academia.edu/17638769/HPLC_analysis_of_flavonoids

Surai, P. F., Kochish, I. I., Fisinin, V. I., Juniper, D. T. (2019). Revisiting Oxidative Stress and the Use of Organic Selenium in Dairy Cow Nutrition. Animals: an open access journal from MDPI, 9(7), 462. https://doi.org/10.3390/ani9070462

Swathi, M., Lokya, V., Gujjarlapudi, M., Verma, S., Kisku, P., Kumar, N. S., & Padmasree, K. (2021). Proteinase inhibitors. *Molecular Approaches for Sustainable Insect Pest Management*, 209-252. https://doi.org/10.1007/978-981-16-3591-5_7

Traber, M. G. (2019). Vitamin E. In Modern Nutrition in Health and Disease (11th ed., pp. 295-305). Wolters Kluwer. https://doi.org/10.1016/j.bcab.2023.102869

USDA. (2023). National Nutrient Database for Standard Reference. U.S. Department of Agriculture. https://fdc.nal.usda.gov

Vuolo, M. M., Lima, V. S., & Junior, M. R. M. (2019). Phenolic compounds: Structure, classification, and antioxidant power. In *Bioactive compounds* (pp. 33-50). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-814774-0.00002-5

Wikipedia, (2024). Cyanogens. Accessed on 20 May 2024. https://en.wikipedia.org/wiki/Cyanogen

Wróbel, B., Nowak, J., Fabiszewska, A., Paszkiewicz-Jasińska, A., & Przystupa, W. (2023). Dry matter losses in silages resulting from epiphytic microbiota activity—A comprehensive study. *Agronomy*, *13*(2), 450. http://dx.doi.org/10.3390/agronomy13020450

Xu, J., Wang, W., & Zhao, Y. (2021). Phenolic Compounds in Whole Grain Sorghum and Their Health Benefits. Foods (Basel, Switzerland), 10(8), 1921. https://doi.org/10.3390/foods10081921

Yitbarek, M. B., & Tamir, B. (2014). Silage additives. *Open Journal of Applied Sciences*, *2014*. http://dx.doi.org/10.4236/ojapps.2014.45026

Zhang, A. R., Wei, M., Yan, L., Zhou, G. L., Li, Y., Wang, H. M., ... & Liang, Y. X. (2022). Effects of feeding solid-state fermented wheat bran on growth performance and nutrient digestibility in broiler chickens. *Poultry Science*, *101*(1), 101402. https://doi.org/10.1016/j.psj.2021.101402

Zhang, J., Liu, Y., Wang, Z., Bao, J., Zhao, M., Si, Q., ... & Jia, Y. (2023). Effects of different types of LAB on dynamic fermentation quality and Microbial Community of native grass silage during anaerobic fermentation and aerobic exposure. *Microorganisms*, *11*(2), 513. https://doi.org/10.3390/microorganisms11020513

Zheng, M., Liu, Y., Zhang, G., Yang, Z., Xu, W., & Chen, Q. (2024). The Antioxidant Properties, Metabolism, Application and Mechanism of Ferulic Acid in Medicine, Food, Cosmetics, Livestock and Poultry. *Antioxidants*, *13*(7), 853. https://doi.org/10.3390/antiox13070853