



Enhancing the feed value of cassava tuber meal using different treatment methods for Jumbo quail hens

A GAZI



orcid.org/0000-0001-5750-2405

Dissertation accepted in fulfilment of the requirements for the
degree Master in Animal Sciences at the North-West University

Supervisor: Prof CM Mnisi

Graduation: July 2024

DECLARATION

I, Athenkosi Gazi, hereby declare that this dissertation submitted to the North-West University for the degree of Master of Science in Animal Science is an outcome of my own investigation under the supervision of Prof C.M. Mnisi and has not been previously submitted to any other university or institution. All contributions to the production of this work and the sources used are fully acknowledged.

Student: A. Gazi

Signed:... 

Date:... 21/03/2024....

Supervisor: Prof C.M. Mnisi

Signed:...  ...

Date:...22/03/2024.....

GENERAL ABSTRACT

Globally, the human population is expected to grow by 2 billion over the next 30 years. To cater for this population growth, the current supply of poultry products as major protein sources must be diversified and increased. Diversification would imply the expansion of quail (*Coturnix* sp.) farming in mainstream poultry production. However, the continuous use of expensive energy sources such as maize (*Zea mays*) in conventional poultry diets poses socio-economic and environmental sustainability challenges. This necessitates the identification and exploration of alternative feed sources. Cassava (*Manihot esculenta*) is a non-conventional energy source that has potential to completely replace maize in poultry diets. However, its efficient utilisation may be restricted by the presence of secondary metabolites such as hydrogen cyanides (HCN). This study was, therefore, designed to examine the effect of different heat treatment methods (autoclaving, boiling, and oven-drying) of cassava tuber meal (CTM) as a complete replacement of maize on productive performance, egg quality and shelf-life parameters, haemato-biochemistry, welfare indicators, visceral morphometry, carcass characteristics and breast meat quality of Jumbo quail hens. A total of 240, five-week-old Jumbo quail hens ($191\text{g} \pm 16.60$ live-weights) were randomly allocated into 60 cages (4 hens/cage) based on body weight to produce 12 replicates per dietary treatment. The diets were formulated to be isonitrogenous and isocaloric as follows: a conventional maize-based layer diet without CTM (CON), and CON in which 100% maize was replaced with raw (CTMR), boiled (CTMB), autoclaved (CTMA), and oven-dried CTM (CTMO). The experiment lasted from 6 - 14 weeks of age during which layer performance traits (e.g., feed intake (FI), feed conversion ratio (FCR), rate of lay (ROL), egg weight (EWT), and internal and external egg quality attributes) were determined. At 12 weeks of age, a total of 180 eggs (3 eggs/ cage) were used to determine shelf-life indicators (e.g., egg weight, albumen height, pH and Haugh unit (HU)) at days 1, 5, and 10 of storage under room temperature (20 - 25°C). At 14 weeks of age,

all quail were slaughtered at local abattoir, while bleeding, about 4 mL of blood was randomly drawn from two randomly selected birds and immediately placed in sterilized test tubes for haemato-biochemical analysis. Thereafter, the carcasses were eviscerated and used to measure carcass characteristics, internal organ sizes and breast meat quality. All measured parameters were subjected to procedure of general linear models (PROC GLM) in SAS, while the welfare data was subjected to Kruskal-Wallis test. The raw or thermally-treated CTM samples showed variations on essential amino acids (AA; i.e., methionine, lysine, threonine, etc.), however, oven-dried CTM tended to have negative effects on AAs. Diet CON promoted higher ($P < 0.05$) overall FI than diet CTMB. Furthermore, birds on diet CTMB had lower ($P < 0.05$) overall BWG than birds on the CON diet. However, the CON group had the highest ($P < 0.05$) final body weight (FBW), followed by those on diet CTMR and the lowest ($P < 0.05$) FBW was from those on diet CTMB. There were no ($P > 0.05$) dietary influences on overall FCR and mortality. Fourteen-week-old birds fed the CON diet had higher ($P < 0.05$) ROL than diet CTMR. In weeks 10, 12 and 14, eggs from CON group had higher ($P < 0.05$) egg colour values compared to CTMB, which promoted lower egg colour values. Furthermore, birds reared on diet CON had the least ($P < 0.05$) shape index than those on diet CTMO. Fourteen-week-old birds fed diets CTMB and CTMO had smaller ($P < 0.05$) egg diameter compared to those fed with diet CON. Moreover, diet CTMA resulted in heavier ($P < 0.05$) shell weight than diet CTMR. Diet CON resulted in the lowest ($P < 0.05$) yolk index whereas diets CTMA and CTMR resulted in the highest. At day 5 of shelf-life, eggs from the CON group had the highest ($P < 0.05$) egg breaking strength while the lowest strength was from the CTMR group. At day 10, eggs from the CTMA group had the lowest ($P < 0.05$) albumen pH, whereas the highest albumen pH was from the CON group. Quail hens fed with CON diet had heavier ($P < 0.05$) carcass weights than those fed with diets CTMR and CTMB. Diets CTMO and CTMB resulted in heavier ($P < 0.05$) wing weights than diets CON and CTMA. Diet CON caused lower (P

<0.05) meat pH after 24 hours of slaughter than diet CTMB. The Kruskal-Wallis H test showed that there was a significant treatment effect on the latency-to-lie test [$X^2(2) = 10.18$; $P = 0.0375$] and not on gait and feather scores. Although the maize-based diet showed the best performance, the autoclaved and oven-dried cassava treatments performed better than the boiled cassava treatment in terms of productive performance, egg quality parameters, and indices of carcass quality. This study showed that boiling of CTM has no benefit for layer quail production therefore, it should not be considered when you want to maximize the production.

Keywords: Blood parameters, Cassava, Egg quality, Jumbo quail, Performance, Welfare

ACKNOWLEDGEMENTS

Foremost, I acknowledge Heavenly Father for giving me enormous strength to complete this degree. My sincere gratitude goes to my supervisor, Prof C.M. Mnisi, for his constant support, guidance and encouragement throughout the study. It would have never been possible for me to finish this work without his contribution.

I would also like to sincerely acknowledge the North-West University (NWU) Masters bursary and Faculty of Natural and Agricultural Science (FNAS) bursary for financial support.

To my fellow colleagues (“idiots”), especially Mr Mveleli Marareni, Mr Jones Tsibishi Moloto and other students in the School of Agriculture in NWU, I am very much grateful for your assistance from the beginning of the trial to the end; without your help I would not be here. Special thanks to Mr Simtembile Mpako (Ndab’omhle) for his constant support, helping me with data capturing and for sacrificing his sleep and time just to help me.

I am also grateful to my family for the love and support they gave to me throughout my academic journey.

DEDICATION

I dedicate this dissertation entirely to my family especially my lovely daughter, parents, and sister.

TABLE OF CONTENTS

DECLARATION	i
GENERAL ABSTRACT	ii
ACKNOWLEDGEMENTS	v
DEDICATION	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF ABBREVIATIONS	xi
1 CHAPTER ONE – GENERAL INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Justification	4
1.4 Aim and Objectives	5
1.5 Hypothesis	6
1.6 References	7
2 CHAPTER TWO - LITERATURE REVIEW	13
2.1 Introduction	13
2.2 Quail farming and nutrient requirements	14
2.3 Jumbo quail hens' performance metrics	16
2.3.1 Growth performance	16
2.3.2 Egg production	17
2.3.3 Egg quality	17
2.4 Overview of quail welfare	18
2.4.1 Welfare and its importance in poultry farming	18
2.4.2 Key welfare principles for Jumbo quail hens	19
2.4.3 Relationship between nutrition and quail welfare	20
2.5 Common dietary energy sources	21
2.5.1 Maize	22
2.5.2 Millet	23
2.5.3 Sorghum	24
2.6 Cassava as an alternative energy source	25
2.6.1 Socio-economic relevance of cassava meal	26
2.6.2 Nutritional composition of cassava	27
2.6.3 Bioactive compounds	27
2.6.4 Antinutritional factors in cassava tuber meal	28
2.7 Feeding value of cassava meal	29

2.7.1	Effect of cassava meal on poultry growth and egg performance	29
2.7.2	Effect of cassava meal on poultry health	30
2.7.3	Effect of cassava meal on poultry meat quality and carcass traits	31
2.8	Treatment methods to improve dietary cassava meal	32
2.8.1	Chemical treatment methods	32
2.8.2	Physical treatment methods	33
2.9	Summary	35
2.10	References	37
3	CHAPTER THREE – EFFECT OF RAW OR THERMALLY-TREATED CASSAVA TUBER MEAL ON PRODUCTIVE PERFORMANCE, EGG QUALITY PARAMETERS IN JUMBO QUAIL HENS	57
	Abstract	57
3.1	Introduction	59
3.2	Materials and methods	61
3.2.1	Ethics statement	61
3.2.2	Study site	61
3.2.3	Cassava procurement and processing	61
3.2.4	Laboratory analyses	62
3.2.5	Diet formulation and analysis	64
3.2.6	Feeding management and experimental design	66
3.2.7	Productive performance	66
3.2.8	Egg quality parameters	67
3.2.9	Statistical analysis	68
3.3	Results	69
3.3.1	Chemical components and essential amino acids of substrates and diets	69
3.3.2	Productive performance	73
3.3.3	Rate of lay	75
3.3.4	External and internal egg quality parameters	77
3.4	Discussion	82
3.5	Conclusion	86
3.6	References	88
4	CHAPTER FOUR - EFFECT OF RAW OR THERMALLY-TREATED CASSAVA TUBER MEAL ON EGG SHELF LIFE, WELFARE INDICATORS, BLOOD PARAMETERS, VISCERAL ORGANS, AND CARCASS INDICES IN JUMBO QUAIL HENS	94
	Abstract	94
4.1	Introduction	96

4.2	<u>Materials and methods</u>	98
4.2.1	<u>Study site, analysis, diet formulation and experimental design</u>	98
4.2.2	<u>Shelf-life measurements</u>	98
4.2.3	<u>Welfare indicators</u>	98
4.2.4	<u>Slaughter and collection of blood</u>	99
4.2.5	<u>Haemato-biochemical analyses</u>	99
4.2.6	<u>Internal organs and carcass traits</u>	100
4.2.7	<u>Meat quality traits</u>	100
4.2.8	<u>Statistical analysis</u>	101
4.3	<u>Results</u>	102
4.3.1	<u>Shelf-life indices</u>	102
4.3.2	<u>Welfare indicators</u>	104
4.3.3	<u>Haemato-biochemical analyses</u>	106
4.3.4	<u>Internal organs and carcass characteristics</u>	108
4.3.5	<u>Breast meat quality parameters</u>	112
4.4	<u>Discussion</u>	114
4.5	<u>Conclusion</u>	119
4.6	<u>References</u>	120
5	<u>CHAPTER FIVE - GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATION</u>	125
5.1	<u>General discussion</u>	125
5.2	<u>Conclusion</u>	127
5.3	<u>Recommendations and future prospects</u>	127
5.4	<u>References</u>	129
6	<u>LIST OF APPENDINCES</u>	130
6.1	<u>Ethics Certificate of the study</u>	130
6.2	<u>Language Editing Certificate</u>	132
6.3	<u>Turnitin Report</u>	133

LIST OF TABLES

<u>Table 3.1.</u> Ingredient composition (g/kg as fed basis) of diets containing pre-treated cassava tuber meal and calculated values.	65
<u>Table 3.2.</u> Proximate constituents (g/kg DM, unless stated otherwise) and essential amino acids (g /100 g DM) of raw or thermally-treated cassava tuber meal samples	70
<u>Table 3.3.</u> Proximate composition (g/kg DM, unless stated otherwise) and essential amino acids (g /100 g DM) of dietary treatments.	72
<u>Table 3.4.</u> Effect of completely replacing maize with raw or thermally-treated cassava tuber meal on productive performance traits (means $\pm$ standard error; g/bird, unless indicated otherwise) of Jumbo quail hens.	74
<u>Table 3.5.</u> Effect of completely replacing maize with raw or thermally-treated cassava tuber meal on rate of lay (means $\pm$ standard error; 7 – 14 weeks) and egg weight (9 – 14 weeks)..	76
<u>Table 3.6.</u> Effect of completely replacing maize with raw or thermally-treated cassava tuber meal on external egg quality parameters (mean $\pm$ standard error) of Jumbo quail hens from 9 - 14 weeks.....	78
<u>Table 3.7.</u> Effect of diets containing raw or thermally-treated cassava tuber meal on internal egg quality parameters (means $\pm$ standard error) of Jumbo quail hens from weeks 9 - 14.	80
<u>Table 4.1.</u> Effects of raw or thermally-treated cassava tuber meal on egg shelf-life attributes (means $\pm$ standard error) of Jumbo quail hens over a storage period of ten days.....	103
<u>Table 4.2.</u> The effect of total replacement of maize with raw or thermally-treated cassava tuber meal on medians of welfare indicators of Jumbo quail hens	105
<u>Table 4.3.</u> Effects of total replacement of maize with raw or thermally-treated cassava tuber meal on blood parameters (means $\pm$ standard error) of 14-week-old Jumbo quail hens	107
<u>Table 4.4.</u> Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on internal organ sizes (means $\pm$ standard error) of 14-week-old Jumbo quail hens....	109
<u>Table 4.5.</u> Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on carcass characteristics of Jumbo quail hens	111
<u>Table 4.6.</u> Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on breast meat quality attributes in Jumbo quail hens	113

LIST OF ABBREVIATIONS

AA	:	Amino acids
ADF	:	Acid detergent fibre
AWFI	:	Average weekly feed intake
AWG	:	Average weight gain
ANF	:	Anti-nutritional factors
AOAC	:	Association of Official Agricultural Chemist
CCW	:	Cold carcass weight
CF	:	Crude fibre
CP	:	Crude protein
CTM	:	Cassava tuber meal
EE	:	Ether extract
FCR	:	Feed conversion ratio
HCN	:	Hydrocyanic acid
HCW	:	Hot carcass weight
NDF	:	Neutral detergent fibre
ROL	:	Rate of lay

1 CHAPTER ONE – GENERAL INTRODUCTION

1.1 Background

Poultry production is the biggest segment of animal agriculture in South Africa (18 % of the total agricultural gross value stemmed from poultry production) (SAPA, 2020), which continues to expand and develop with the addition of new bird species such as the quail (*Coturnix sp.*) (Mnisi *et al.*, 2023). Quail are novel bird species that are currently gaining worldwide popularity as a source of animal protein in the form of meat and eggs (Marareni & Mnisi, 2020). Quail products have high-quality protein and essential amino acids that can improve food and nutrition security, especially in resource-poor communities of developing countries (Talukdar *et al.*, 2020). Quail birds are suitable for commercial production because they have fast growth rates, early sexual maturity, short generation intervals, and strong resilience to a variety of avian diseases (Egbeyale *et al.*, 2013). They are known for their efficient feed utilization, meaning they require less feed to produce a unit weight compared to other non-conventional poultry birds (Khalil, 2015). Due to their smaller size and space requirements, they can also be kept in a smaller area than chickens (El-Shafei *et al.*, 2012). However, the space ratio for quail is determined by a number of variables including breed type, age and production systems. For example, quail only require 0.1 square meters per bird, while chickens require 0.2 to 0.3 square meters (Adom & Lambert, 2023). Quail production can also be used to complement chicken, turkey, duck and ostrich farming as a source of animal protein (Mulaudzi *et al.*, 2019).

The layer subsector plays a crucial role in providing eggs for human consumption and eggs are renowned as a versatile food product (Vetrivel & Chandrakumarmangalam, 2013). Quail eggs play an important role in human nutrition and the cosmetic sector, which is important in reducing the over-reliance on chicken eggs (Redoy *et al.*, 2017). Quail eggs are significantly

more nutritious than chicken eggs, even though they are 5 – 6 times smaller (Savanna, 2020). They are known for their high content of proteins, vitamins and minerals, which can be beneficial as a source of nutrient-dense foods (Nasar *et al.*, 2016). The eggs have medicinal values and do not induce diabetes or any allergies (Savanna, 2020). However, a nutritious diet that is high in energy, protein and micronutrients (including minerals) must be provided daily to meet the quail's nutritional requirements and maximize productivity (Mulaudzi *et al.*, 2019). The availability of feed and the price of dietary ingredients used in feed formulations can be barriers to large-scale quail intensification and pose sustainability issues (Mnisi *et al.*, 2023). It is known that feed manufacturers use maize as the main source of energy when formulating diets for poultry (Ravindran, 2013), which is also used by humans for consumption. Therefore, it is important to look for alternative that has low competition between humans and animals for maize. Several energy-supplying ingredients have been investigated as an alternative to maize as an expensive energy source in poultry diets (Babatunde *et al.*, 2021). One of these substitutes include cassava (*Manihot esculenta*) products that are readily available in South Africa (Malik *et al.*, 2018). Cassava is a tropical starchy root crop with a global yield of 278 million tonnes per year (Tesfaye *et al.*, 2013) and a multipurpose plant that thrives well in tropical regions where it is considered an excellent energy source (Wanapat & Kang, 2015). This plant possesses desirable traits such as strong adaptability, drought resistance, and tolerance to poor quality soils. The roots or tubers can be processed as dried chip or pellet and are rich in soluble carbohydrates (75 - 85%), but low in crude protein (2 - 3%) (Uchechukwu-Agua *et al.*, 2015).

1.2 Problem Statement

A primary challenge facing poultry producers is high feed costs (Hagan, 2020). Indeed, large-scale quail intensification can be limited by feed availability and high market prices, which present sustainability challenges (Mnisi *et al.*, 2023). The poultry industry faces a complex web

of social, environmental and economic sustainability challenges that have negative impacts on operations and long-term viability (Kleyn & Ciacciariello, 2021). Maize is the major energy ingredient that is used by feed producers to formulate poultry diets (Ravindran, 2013). Moreover, maize is a staple food for humans in South Africa, where an average of 10.5 million tons per year is used, with an average yield of 5 t/ha (Blaker, 2021). This results in high competition between humans and animals for maize. The high feed-food competitions due to the high demand makes maize an unsustainable ingredient for use in quail production systems (Mnisi *et al.*, 2022). Furthermore, maize yield is mainly dependent on arable land, high rainfalls or large volumes of water for irrigation, good soil fertility and the application of fertilizers containing nitrogen, potassium, and phosphorus (Cullis *et al.*, 2019). Maize cultivation also leaves the soil compacted, damaged and exposed to erosion due to deforestation, use of heavy machinery, and heavy rainfall-water runoff (Zuazo & Pleguezuelo, 2009). Consequently, these activities result in the pollution of water bodies with pesticides and nutrients (eutrophication), which destabilize the aquatic ecosystem. However, this is not a cause for concern in cassava production because it requires less input but produces large quantities per unit area of land that is not suitable for maize growth (Nassar & Ortiz, 2007; Amelework *et al.*, 2021). Thus, the use of cassava tuber meal (CTM) as an alternative energy source in Jumbo quail can meet their energy requirements (Odegard & van der Voet, 2014), and therefore, promote sustainable intensification. However, the utilization of CTM has been limited by the extreme perishability of fresh roots during storage (Onyenwoke & Simonyan, 2014). This is because cassava tubers have a high moisture content, which ranges from 65 to 70% (Omosuli *et al.*, 2017). Another restriction on the use of the tuber is its toxicity due to the naturally occurring cyanogenic glycosides, which produces hydrocyanic acid that is harmful to animals in high concentrations (Omosuli *et al.*, 2017). Cyanogenic glycosides are a group of naturally occurring compounds found in many plants, including cassava (Yulvianti & Zidorn, 2021). They are non-toxic on

their own, but the glycosides react with linamarase upon damage to plant tissue which act as a defence mechanism, releasing the extremely toxic chemical called hydrogen cyanide (HCN) (McMahon *et al.*, 2022). Cyanide can further exacerbate nutritional deficiencies by interfering with the body's ability to absorb vital minerals like iron and zinc (Bayata, 2019). The amount of these toxins varies according to the type of cassava, with a bitter variety having a significantly higher concentration than sweet varieties (Panghal *et al.*, 2019). High levels of HCN in poultry feed can cause toxicity, respiratory problems, paralysis, and even death (Ramteke *et al.*, 2019). This suggests a need to valorise CTM with various physical treatment strategies including thermal methods to enhance its utility in diets of Jumbo quail hens.

1.3 Justification

The use of alternative energy sources with little food value for South Africans could help deliver sustainable quail intensification and mitigate food and nutrition insecurity risks in the country (Ijaiya & Eko, 2009). However, it is imperative that these alternative energy sources are locally available, readily accessible and inexpensive (Masenya *et al.*, 2021). Omoikhoje *et al.* (2008) stated that cassava by-products are readily utilized as a cheaper substitute for maize in the diet of monogastric animals. Cassava tuber meal has a high metabolizable energy value (12.6 MJ/kg) (Ojediran *et al.*, 2023), making it a suitable alternative to maize. However, the utility of CTM in quail diets could be limited by the high levels of hydrocyanic acid (HCN) (Tesfaye *et al.*, 2013). Thus, the use of thermal methods such as oven-drying, boiling, and autoclaving (Olusegun *et al.*, 2017) can reduce the negative effects of HCN and thereby improve its utilisation by the quail. These treatment strategies usually result in a significant reduction in cyanide but can also alter nutritional and physicochemical qualities (Udoro *et al.*, 2021). Boiling, autoclaving, and oven-drying have been reported to reduce anti-nutrients such as tannins and ultimately boost the nutritive value of plants including cassava products

(Oladunjoye *et al.*, 2008; Catteau *et al.*, 2013). Abbas & Ahmad (2018) reported that autoclaving cassava tubers at 121°C for 30 minutes improves nutrient bioavailability, texture, and palatability by reducing the availability of anti-nutrients. Boiling treatment also improves the availability and utilization of the energy stored in cassava, making it more palatable. Boiling also preserves the relative stability of water-soluble vitamins such as vitamin C and some B vitamins, making them more available for absorption. However, it can also cause nutrient loss through denaturation. Okonkwo *et al.* (2019) showed that oven-drying of cassava tubers at 60°C into cassava chips resulted in an acceptable level of cyanide contents. At drying temperatures above 55°C, linamarase activity is inhibited and, therefore, linamarin starts to accumulate in dried cassava chips (Okeke *et al.*, 2023). Linamarin is a cyanogenic glycoside, meaning it releases cyanide when broken down by enzymes (Mensah, 2022). This acts as a natural defence mechanism against herbivores and insects, deterring them from feeding on the cassava plant (Riis *et al.*, 2003). Furthermore, cassava stores nitrogen in the form of linamarin, which is a more efficient way to store it compared to other nitrogenous compounds (McMahon *et al.*, 2022). Hence, linamarase action (cyanogen degradation/cyanide content reduction) is optimal at temperatures below 55°C. However, to the best of our knowledge, no study has attempted to enhance the utility of CTM as a substitute to maize in Jumbo quail diets. Thus, this study is the first of its kind to employ different thermal methods to pre-treat CTM prior to inclusion in a diet of laying Jumbo quail hens.

1.4 Aim and Objectives

The aim of the study was to improve the feed value of CTM as an alternative energy source for Jumbo quail laying hens using thermal treatments. The following specific objectives were used to guide the study:

- a. To determine the effect of different thermal pre-treatment methods (autoclaving, boiling and oven-drying) of CTM on productive performance and external and internal egg quality parameters in laying Jumbo quail hens.
- b. To determine the effect of raw or boiled, autoclaved and oven-dried CTM in place of maize meal on egg shelf-life, welfare indicators, blood parameters, internal organs, carcass traits and breast meat quality of laying Jumbo quail hens.

1.5 Hypothesis

- a. The study tested the hypothesis that autoclaving, boiling and oven-drying of CTM would promote similar productive performance and external and internal egg quality traits as the maize-based control diet in Jumbo quail hens.
- b. The study also tested the hypothesis that autoclaving, boiling and oven-drying of CTM in place of maize meal would not alter egg shelf-life and welfare indicators, physiological responses, carcass traits and breast meat quality in Jumbo quail hens.

1.6 References

- Abbas, Y. & Ahmad, A., 2018. Impact of processing on nutritional and antinutritional factors of legumes: A review. *Ann. Food Sci. Technol.* 19(2), 199-215.
- Adom, E., Bir, C. & Lambert, L.H., 2023. A financial comparison of small-scale quail and laying hen farm enterprises. *Poult. Sci.* 102(4), 102507.
- Amelework, A.B., Bairu, M.W., Maema, O., Venter, S.L. & Laing, M., 2021. Adoption and promotion of resilient crops for climate risk mitigation and import substitution: A case analysis of cassava for South African agriculture. *Front. Sustain. Food Syst.* 5, 617783.
- Babatunde, O.O., Park, C.S. & Adeola, O., 2021. Nutritional potentials of atypical feed ingredients for broiler chickens and pigs. *Animals*, 11(5), 1196.
- Bayata, A., 2019. Review on nutritional value of cassava for use as a staple food. *Sci J Anal Chem.* 7(4), 83-91.
- Blaker, T.N., 2021. Farm-level barriers to the adoption of precision agriculture technologies in the South African maize industry: variable rate application, section control, and guidance (Doctoral dissertation, Stellenbosch: Stellenbosch University).
- Catteau, L., Lautié, E., Koné, O., Coppée, M., Hell, K., Pomalegni, C.B. & Quetin-Leclercq, J., 2013. Degradation of rotenone in yam bean seeds (*Pachyrhizus sp.*) through food processing. *J. Agric. Food Chem.* 61(46), 11173-11179.
- Cullis, C., Lawlor, D.W., Chimwamurombe, P., Bbebe, N., Kunert, K. & Vorster, J., 2019. Development of marama bean, an orphan legume, as a crop. *Food Energy Secur.* 8(3), 00164.
- Egbeyale, L.T., Fatoki, H.O. & Adeyemi, O.A., 2013. Effect of egg weight and ovi-position time on hatchability and post hatch performance of Japanese quail (*Coturnix coturnix japonica*) Niger. *J. Anim. Prod.* 40, 102-110.

- El-Shafei, A.A., Abdel-Azeem, A.F. & Abdullaha, E.A., 2012. Stocking density effects on performance and physiological changes of laying Japanese quail. *J. Anim. Poult. Prod.* 3(8), 379-398.
- Hagan, M.A.S., 2020. Challenges of poultry farmers at Ejisu municipality, Ghana. *Asian J. Agric. Ext. Economics Sociol.* 38(1), 63-77.
- Ijaiya, A.T. & Eko, E.O., 2009. Effect of replacing dietary fish meal with silkworm (*Anaphe infracta*) caterpillar meal on performance, carcass characteristics and haematological parameters of finishing broiler chicken. *Pak. J. Nutr.* 8, 850–855.
- Khalil, M., 2015. Use of enzymes to improve feed conversion efficiency in Japanese quail fed a lupin-based diet (Doctoral dissertation, University of Western Australia).
- Kleyn, F.J. & Ciacciariello, M., 2021. Future demands of the poultry industry: will we meet our commitments sustainably in developed and developing economies?. *Worlds Poult. Sci. J.* 77(2), 267-278.
- Malik, A.A., Aremu, A.T. & Akinwale, A., 2018. Growth response, carcass characteristics and egg laying performance of Japanese quail (*Coturnix coturnix japonica*) fed diets containing varying levels of fermented cassava (*Manihot esculenta*) peel meal. *Niger. J. Anim. Prod.* 45(2), 492.
- Marareni, M. & Mnisi, C.M., 2020. Growth performance, serum biochemistry and meat quality traits of Jumbo quails fed with mopane worm (*Imbrasia belina*) meal-containing diets. *Vet. Anim. Sci.* 10, 100141.
- Masenya, T.I., Mlambo, V. & Mnisi, C.M., 2021. Complete replacement of maize grain with sorghum and pearl millet grains in Jumbo quail diets: Feed intake, physiological parameters, and meat quality traits. *PLoS One.* 16(3), 0249371.
- McMahon, J., Sayre, R. & Zidenga, T., 2022. Cyanogenesis in cassava and its molecular manipulation for crop improvement. *J. Exp. Bot.* 73(7), 1853-1867.

- Mensah, M.A., 2022. Cyanogenic Glycosides as Food Toxins. Analysis of Naturally Occurring Food Toxins of Plant Origin, 25-52.
- Mnisi, C.M., Oyeagu, C.E. & Ruzvidzo, O., 2022. Mopane worm (*Gonimbrasia belina* Westwood) meal as a potential protein source for sustainable quail production: A review. Sustainability, 14(9), 5511.
- Mnisi, C.M., Oyeagu, C.E., Akuru, E.A., Ruzvidzo, O. & Lewu, F.B., 2023. Sorghum, millet and cassava as alternative dietary energy sources for sustainable quail production—A review. Front. Anim. 4, 1066388.
- Mulaudzi, A., Mnisi, C.M. & Mlambo, V., 2019. Dietary *Moringa oleifera* leaf meal improves growth performance but not haemo-biochemical and meat quality parameters in female Japanese quails. Pak. J. Nutr. 18(10), 953–960.
- Nassar, N.M.A. & Ortiz, R., 2007. Cassava improvement: challenges and impacts. J. Agric. Sci. 145(2), 163-171.
- Nasar, A., Rahman, A., Hoque, N., Talukder, A.K. & Das, Z.C., 2016. A survey of Japanese quail (*Coturnix coturnix japonica*) farming in selected areas of Bangladesh. Vet. World, 9(9), 940.
- Odegard, I.Y.R. & van der Voet, I., 2014. The future of food—Scenarios and the effect on natural resource use in agriculture in 2050. Ecol. Econ. 97, 51-59.
- Ojediran, T., Busari, O., Olagoke, O. & Emiola, A., 2023. Multi-processed cassava root meal: A suitable replacement for maize in Japanese quail diet. Emerg. Anim. Species, 9, 100035.
- Okeke, C.L., Onokwai, A.O., Okokpujie, I.P., Okonkwo, U.C., Nnochiri, E.S., Oladimeji, M. & Ogundele, R.I., 2023. Evaluation of drying behaviour of cassava chips under open sun and oven drying technologies. Int. J. Des. Nat. Ecodyn. 18(3), 547-556.

- Okonkwo, U., Onokwai, A., Okeke, C., Osueke, C., Ezugwu, C., Diarah, R. & Aremu, C., 2019. Investigation of the effect of temperature on the rate of drying moisture and cyanide contents of cassava chips using oven drying process. *J. Mech. Eng. Technol.* 10(1), 1507–1520.
- Oladunjoye, I.O., Ojebiyi, O.O. & Odunsi, A.A., 2008. Performance characteristics and egg quality of laying chicken fed lye treated cassava peel meal. *Proceedings of the 13 Annual Conference of the Animal Science Association of Nigeria (ASAN)*, Ahmadu Bello University, Zaria, Nigeria, 12 - 19 September, 2008, 355-357.
- Olusegun, O.A., Francis, K.P. & Ainamensa, G., 2017. Effect of selected processing and modification methods on quality of cassava and its starch. *Asian J. Agric. Res.* 11(3), 48–56.
- Omoikhoje, S.O., Bamgbose, A.M. & Aruna, M.B., 2008. Replacement value of unpeeled cassava root meal (UCRM) for maize in weaner rabbit diets. *Niger. J. Anim. Prod.* 35, 63-68.
- Omosuli, S.V., Ikujenlola, A.V. & Abisuwa, A.T., 2017. Quality assessment of stored fresh cassava roots and ‘fufu’ flour produced from stored roots. *J. Food Sci. Nutr. Therapy.* 3(1), 9-13.
- Onyenwoke, C.A. & Simonyan, K.J., 2014. Cassava post-harvest processing and storage in Nigeria: A review. *Afr. J. Agric. Res.* 9(53), 3853-3863.
- Panghal, A., Munezero, C., Sharma, P. & Chhikara, N., 2019. Cassava toxicity, detoxification and its food applications: a review. *Toxin Rev.* 40(1), 1-16.
- Ramteke, R., Doneria, R. & Gendley, M.K., 2019. Antinutritional factors in feed and fodder used for livestock and poultry feeding. *Act. Sci. Nutr. Health*, 3(5), 39-48.
- Ravindran, V., 2013. Main ingredients used in poultry feed formulations. *Poultry development review* (ed.) FAO, 67-69.

- Redoy, M.R.A., Shuvo, A.A.S. & Al-Mamun, M., 2017. A review on present status, problems and prospects of quail farming in Bangladesh. *Bangladesh J. Anim. Sci.* 46(2), 109-120.
- Riis, L., Bellotti, A.C., Bonierbale, M. & O'brien, G.M., 2003. Cyanogenic potential in cassava and its influence on a generalist insect herbivore *Cyrtomenus bergi* (Hemiptera: Cydnidae). *J. Econ. Entomol.* 96(6), 1905-1914.
- South African Poultry Association, 2020. South African Poultry Association 2020 Industry Profile. Available at: <https://www.sapoultry.co.za/wp-content/uploads/2022/03/SAPA-INDUSTRY-PROFILE-2020.pdf>.
- Savanna, S., 2020. Quail eggs: Nutrition, benefits and precautions. Available at: <https://www.healthline.com/nutrition/quail-eggs-benefits> (Accessed 5 August 2022).
- Talukdar, A., Kalita, K.P., Saikia, R. & Choudhury, D., 2020. Effect of using Moringa oleifera leaf meal on quality and sensory parameters of Japanese quail eggs. *Pharma Innov. J.* 9, 219-221.
- Tesfaye, E., Animut, G., Urge, M. & Dessie, T., 2013. Cassava root chips as an alternative energy feed ingredient in broiler ration. *Int. J. Poult. Sci.* 12(5), 298-306.
- Uchechukwu-Agua, A.D., Caleb, O.J. & Opara, U.L., 2015. Postharvest handling and storage of fresh cassava root and products: a review. *Food Bioproc. Tech.*, 8, 729-748.
- Udoro, E.O., Anyasi, T.A. & Jideani, A.I.O., 2021. Process-induced modifications on quality attributes of cassava (*Manihot esculenta Crantz*) flour. *Processes*. 9, 1891.
- Vetrivel, S.C. & Chandrakumarmangalam, S., 2013. The role of poultry industry in Indian economy. *Braz. J. Poult. Sci.* 15, 287-293.
- Wanapat, M. & Kang, S., 2015. Cassava chip (*Manihot esculenta Crantz*) as an energy source for ruminant feeding. *Anim. Nutr.* 1(4), 266-270.

Yulvianti, M. & Zidorn, C., 2021. Chemical diversity of plant cyanogenic glycosides: an overview of reported natural products. *Molecules*, 26(3), 719.

Zuazo, V.H.D. & Pleguezuelo, C.R.R., 2009. Soil-erosion and runoff prevention by plant covers: a review. *Sustain. Agric.* 785-811.

2 CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

The poultry industry is a leading subsector in animal agriculture throughout the world. This is because of its ability to supply animal protein and micronutrients to people at a relatively affordable cost (Mottet & Tempio, 2017). Poultry is a broad term that encompasses various types of domesticated birds, including chickens, ducks, turkey and quail (Istiak & Khaliduzzaman, 2022). Over the past decades, quail farming has successfully emerged in several nations because of the birds' ability to offer a variety of productive and economic benefits over other poultry species (Minvielle, 2009). Quail are primarily raised for their meat, which is considered a delicacy in many countries (Mohammed & Ejiofor, 2015). Quail eggs are highly valued for their rich flavour and nutritional value (Gunathilaka *et al.*, 2021). They are also valuable in genetic studies because of their rapid growth rates, sexual maturity, and short incubation periods (Dauda *et al.*, 2014). Quail meat is high in protein and low in fat, making it a popular choice for health-conscious consumers (Nasar *et al.*, 2016). Currently, the typical energy and protein sources utilized in commercial poultry diets are maize and soybean, creating a significant challenge to quail production (Mnisi *et al.*, 2021). This is due to high market prices of these ingredients, which are caused by the high demand by other industries to produce beverages, biofuels, commercial starch, and human food (Marareni & Mnisi, 2020; Masenya *et al.*, 2021).

Maize production is unsustainable from an environmental and economic standpoint since it incurs high input costs and heavily rely on the use of technology and chemical fertilizers (Arrieta *et al.*, 2018; Castanheira & Freire, 2013). Adverse meteorological conditions such as irregular rainfall patterns and droughts have also been reported to reduce maize yield (Newkirk, 2010). In this regard, current research efforts are aimed towards the use of locally available and

easily accessible alternative energy sources as a strategy to meet sustainable quail farming objectives (Khattab *et al.*, 2009).

Cassava is a potential candidate that can be used in place of maize because it is rich in soluble carbohydrates (80 - 90%), its energy value is comparable to maize meal, and it also contains essential vitamins and minerals, making it a valuable food crop for animals (Montagnac *et al.*, 2009). In recent years, cassava has gained attention as an alternative feed source for poultry due to its high nutritional value, low cost, and availability in many parts of the world (Okereke, 2012). Indeed, one main advantage of using cassava as a poultry feed is its high energy value, which is comparable to that of corn (Diarra *et al.*, 2014). In addition to its nutritional value, cassava is also a low-cost feed ingredient. Unlike maize, cassava is often grown by small-holder farmers in developing countries, and it is readily available in local markets at a lower cost (Halloran *et al.*, 2018). Using cassava as a poultry feed can, therefore, help reduce the cost of production for small-scale poultry farmers and increase profitability (Aladejebi *et al.*, 2019). However, cassava has some limitations as a poultry feed, which is due to the presence of cyanogenic glycosides that release toxic cyanide when consumed by animals. It is, thus, imperative to process cassava by peeling, chopping, and heating before including it into poultry feeds (Ngiki *et al.*, 2014). These processes help to reduce the cyanide content of cassava, making it safer for poultry consumption.

2.2 Quail farming and nutrient requirements

Quail birds are the smallest poultry species used for production of table eggs and meat. They are members of the *Phasianidae* family of the order *Galliformes* (Al-Nasser *et al.*, 2007). Quail farming is a lucrative business due to abundant egg and meat production, low initial investment, less labour requirement, high productivity, and quick financial returns (Priti & Satish, 2014). Quail production is already well-established in countries like Japan and China; however, it is

still in its early stages in South Africa (El Sabry *et al.*, 2022). Quail breeds that are currently used to produce meat and/or eggs include, but not limited to, Japanese quail (*Coturnix japonica*), bobwhite quail (*Colinus virginianus*), European quail (*Coturnix coturnix*), and California quail (*Lophortyx californica*) (Chege, 2016). Quail eggs are significantly higher in protein, phosphorus, iron, vitamin A, and vitamins B₁ and B₂ compared to other poultry eggs (Talukdar, 2020).

An adult Jumbo quail weighs between 250 and 300 g and the hens can produce more than 300 eggs every year (Genchev & Mihaylov, 2008). The hens begin laying eggs at 6 to 7 weeks of age, with a single egg weighing from 7 to 15 grams (g). Quail ability to produce eggs is enhanced by light, hence they typically lay in the afternoon, and they take roughly 17-18 days to hatch. A quail chick weighs between 6 and 7 g and due to their small size, quail require only minimal space (Cheng *et al.*, 2010). Like other poultry, quail birds have high requirements for energy. Energy is an essential component of poultry nutrition and must be supplied in sufficient amounts to meet the bird's requirements for maintenance, optimal growth, egg production, and reproduction (Ravindran, 2013). The energy requirements of quail birds vary according to their age, reproductive conditions, and ambient temperature. In tropical environments, young growing quail have a metabolic energy demand of 2800 ME kcal/kg (Altine *et al.*, 2016). Growing quail birds have an energy requirement of 2600 to 3000 ME kcal/kg, but there is an increase in weight gain when dietary energy levels are increased from 2600 to 2800 ME kcal/kg (Toppo *et al.*, 2004). The provision of quail with a balanced diet on a regular basis ensures a good health status, fast growth rate, and great productivity in terms of muscle development and egg production.

2.3 Jumbo quail hens' performance metrics

2.3.1 Growth performance

A key determinant of the health, development, and production of Jumbo quail hens is growth performance. Feed intake, body weight and feed conversion ratio (FCR) are essential measures for assessing growth performance (Marcu *et al.*, 2013). A measurement of how feed is effectively converted into body or egg mass is called FCR (Rodde *et al.*, 2020). Body weight gain is a crucial factor to consider when assessing the quail hens' potential for growth. It describes weight gain over a predetermined time-frame that is often expressed in grams or kilograms (Lonergan *et al.*, 2018). The effectiveness of feed utilization and the overall health status of the birds can both be determined by the rate of body weight gain. Jumbo quail hens are sought-after for commercial production due to their quick growth rate when compared to other quail varieties (Mondry, 2016). The Jumbo quail can gain significant weight under optimal management techniques, which increase the economic viability of a quail farm (Kinyua, 2022). Monitoring body weight gain throughout their growth stages provides valuable insights into their overall development (Grieser *et al.*, 2018). Consistent and acceptable weight increase is facilitated by effective feeding techniques, such as balanced diet provision and appropriate nutrient utilization. When the FCR is low, feed is used effectively, increasing productivity while lowering feed expenditures (Willems *et al.*, 2013). Jumbo quail hens are known for their relatively efficient feed conversion. Due to their genetic potential and proper nutrition, they can convert feed into body weight at a relatively rapid rate (Varkoohi *et al.*, 2011). This trait makes them economically valuable for quail farmers, as it allows for reduced feed costs and increased profitability.

2.3.2 Egg production

An important performance indicator for assessing the commercial feasibility of quail farming is egg production (Indrayani *et al.*, 2019). Egg production is greatly influenced by a number of factors including genetics, lighting, management methods and nutrition (Geng *et al.*, 2018). Genetics play a crucial role in determining the egg production potential of quail hens (Abou Khadiga *et al.*, 2017). Selective breeding programs focus on improving the genetic traits associated with high egg production (Underwood *et al.*, 2021). Breeders can identify genes responsible for higher egg production and improved performance in subsequent generations by selecting birds with superior laying abilities as parents (Cheng, 2010). Another important aspect that affects the number of eggs produced by Jumbo quail hens is their diet. It is crucial to provide birds with a balanced diet that meets their specific nutritional requirements (Nagy, 1987). Adequate amounts of protein, energy, vitamins and minerals are crucial for maintaining optimal egg production (Zaheer, 2015). Optimizing egg production potential also requires proper feeding management, which includes providing fresh water and monitoring feeding schedules. To increase egg production in quail farming, light management is crucial (Molino *et al.*, 2015). The reproductive behaviour of quail, particularly their laying pattern, can be influenced by regulating the length and intensity of light exposure (Demirbas & Kubanc, 2018). Farmers can encourage regular and consistent egg production by providing appropriate lighting conditions, such as a consistent photoperiod.

2.3.3 Egg quality

Egg quality is an essential parameter for assessing the marketability and consumer appeal of eggs (Hester, 2016). This is due to the fact that low-quality eggs have a negative impact on hatchability, amount and quality of processed eggs and egg products, as well as the value, production, and consumer acceptance of eggs (Abdelqader *et al.*, 2013). Egg quality is significantly influenced by nutrition, particularly the quality and hatchability of

fertilized eggs, and growth and survival rates of hatched chicks (Iqbal *et al.*, 2016). Several factors, including egg weight, shell thickness, and yolk colour, contribute to the overall quality of quail eggs (Sari *et al.*, 2012). Jumbo quail hens typically produce larger eggs (18g) compared to other quail breeds, which is advantageous for commercial egg production (Tavaniello, 2014). Larger eggs often have a higher perceived value and are preferred by consumers.

Shell thickness is a critical indicator of egg quality, as it affects the egg's protection and shelf life (Grashorn *et al.*, 2016). Jumbo quail hens produce eggs with thicker shells to minimize the risk of breakage during handling and transportation. Proper nutrition, particularly the availability of calcium, is essential for producing eggs with optimal shell thickness (Stefanello *et al.*, 2014). Yolk colour is an important attribute that influences consumer perception and preference (Beardsworth & Hernandez, 2004). A vibrant, deep-yellow yolk is generally associated with high-quality eggs and is preferred by many consumers (Rondoni *et al.*, 2020). The yolk colour is influenced by the quail's diet, particularly the inclusion of natural pigments such as xanthophylls (Moura *et al.*, 2016). Thus, appropriate inclusion of natural pigments can help ensure desirable yolk colour in Jumbo quail eggs.

2.4 Overview of quail welfare

2.4.1 Welfare and its importance in poultry farming

Animal welfare is a crucial aspect of poultry farming and is particularly vital when rearing quail. Quail are small game-birds farmed for their meat and eggs (Bessei, 2018). Ensuring good welfare practices in quail farming includes providing appropriate housing, nutrition and care that meets the birds' biological and behavioural needs (Peng & Broom, 2021). Farmers can improve the overall health, welfare and productivity of quail by prioritizing animal welfare (El Sabry *et al.*, 2022). An important part of quail welfare is adequate housing. Quail require adequate space, ventilation and comfortable nesting areas. Overcrowding can lead to stress,

aggressiveness and a higher risk of disease transmission (Peng & Broom, 2021). Therefore, providing quail with adequate space to move, sit and behave naturally is crucial for their well-being (Mohammed *et al.*, 2017). Additionally, appropriate bedding (sawdust in floor or plastic in cages) and nesting sites allow quail to exhibit their instinctive behaviours such as dust bathing and nesting, which contributes to their overall well-being (Riber, 2020). Another significant factor of quail welfare is nutrition (El Sabry *et al.*, 2022). Quail requires a highly nutritious diet to grow, reproduce and stay healthy (Minvielle, 2004). A balanced diet that consists of energy, proteins, vitamins and minerals is essential to meet their nutritional needs. Optimal nutrition ensures good growth, healthy feathers and a robust immune system (Bryden *et al.*, 2021). In addition, it promotes fertility and reproductive performance, such as egg production and high hatchability. Thus, meeting the nutritional requirements of quail contributes to improved health by preventing malnutrition, skeletal problems and other ailments (Jeke *et al.*, 2018). Quail welfare also includes good health and management techniques such as regular health examinations, disease prevention techniques (dosing and vaccination), and appropriate veterinary care (Raber *et al.*, 2017). To minimize stress on birds and prevent the spread of disease, it is important to implement biosecurity measures, vaccination programs, and rapid disease detection and treatment (Collett *et al.*, 2020). In addition, effective management practices that minimize stress factors, such as gentle handling and healthy environment contribute to the general well-being of quail (Jones & Manteca, 2009).

2.4.2 Key welfare principles for Jumbo quail hens

Several key welfare principles must be considered when raising Jumbo quail hens. Providing adequate space, proper ventilation, and appropriate housing systems are vital for ensuring the physical comfort and welfare of Jumbo quail hens (Peng & Broom, 2021). Sufficient space allows for natural behaviours, such as perching, dust bathing, and social interactions (Riber, 2020). Furthermore, meeting the nutritional requirements of the hens is essential for their

overall welfare (El Sabry *et al.*, 2022). Proper diet formulations, including adequate protein, energy, vitamins, and minerals, contribute to optimal growth, reproductive performance, and immune function. Imbalances or deficiencies in the diet can lead to health problems and reduced welfare (Whitehead, 2002). Some of the birds' main welfare concerns are related to leg problems, ascites, footpad dermatitis, and sudden death syndrome (Bradshaw *et al.*, 2002). These concerns are related to genetic selection for rapid growth and more efficient production (Hartcher & Lum, 2020). Skeletal problems affect mainly the locomotor system in quail and lead to lameness (Szafraniec *et al.*, 2022). The causes can be infectious (femoral head necrosis, synovitis, infectious stunting), developmental (bone deformity such as valgus-varus, dyschondroplasia, rickets, weak bones) or degenerative (EFSA Panel on Animal Health & Welfare, 2010). Restricted movements are thought to cause a higher incidence of bone deformity (Shields & Greger, 2013). Effective health management practices, including vaccination programs, biosecurity measures, and regular veterinary care, are crucial for safeguarding the well-being of quail (Hafez & Attia, 2020). Preventing and controlling diseases reduce stress, minimize the need for interventions, and enhance welfare outcomes. Enriching the birds' environment with perches and nesting areas promotes natural behaviours, mental stimulation, and overall welfare (Hemsworth & Edwards, 2020). Environmental enrichment enhances the quail hens' quality of life, social cohesion, and encourages exercise (Jones, 2002).

2.4.3 Relationship between nutrition and quail welfare

Nutrition plays an important role in ensuring that quail birds receive essential nutrients to support growth, development and physical activity, and overall health (Alagawany *et al.*, 2021). Optimal nutrition is essential for quail to develop and live a healthy life through the supply of energy, protein, vitamins, minerals and other important elements (Harper & Skinner, 1998). The provision of nutritionally complete diet has a positive effect on growth, immunity, reproductive abilities and overall disease resistance. An important consideration in quail

nutrition is to meet their energy and protein needs. Quail need an adequate supply of energy to perform their daily activities, maintain body temperature, and support growth (Zancanela *et al.*, 2015). This energy can be derived from a variety of dietary sources, including grains, oilseeds, and root crops like cassava. Ensuring energy balance in their diet could prevent cases of malnutrition, stunted growth, and weakened immune systems, all of which can have detrimental effects on their welfare (Hafez & Attia, 2020).

Additionally, quail require a range of vitamins and minerals to maintain their well-being. These micronutrients are involved in various physiological processes and are essential for normal growth, metabolism, and overall health (Alagawany *et al.*, 2021). For instance, deficiencies in vitamins A, D, E, or B-complex can lead to developmental abnormalities, impaired immune function, or reproductive disorders (Maggini *et al.*, 2018). Similarly, inadequate intake of minerals such as calcium, phosphorus, or selenium can result in skeletal problems, poor eggshell quality, or compromised immune responses (Godswill *et al.*, 2020). Therefore, providing quail birds with a nutritionally balanced diet is necessary to ensure their welfare (Alagawany *et al.*, 2021). Furthermore, the quality and safety of feed given to the birds are crucial for their welfare. Contaminated or poor-quality feed can lead to various health issues, which can negatively impact their overall well-being. Thus, it is essential to ensure that the feed is free from toxins, pesticides, and harmful substances and is stored in dry and draft-free conditions to maintain its nutritional quality (Kabak *et al.*, 2006).

2.5 Common dietary energy sources

Maize, millet, and sorghum are frequently used as sources of energy in animal feed due to their carbohydrate content (Jocelyne *et al.*, 2020). Poultry species can efficiently convert the energy in these grains into meat and eggs (Wilkinson, 2011). These crops indirectly contribute to the production of animal-based energy sources by providing energy to animals.

2.5.1 Maize

Maize is a great source of readily available energy for poultry because of its renowned high starch content (Salim *et al.*, 2010). In 2021/2022, the production of maize was approximately 15.3 million metric tons in South Africa. This represents a drop of around 10 percent from previous years (Statista, 2022). The high energy content of this grain enables the birds to perform their metabolic activities, muscular growth, and produce eggs (Musigwa *et al.*, 2021). The vital amino acids, vitamins, and minerals in maize also help in the overall nutritional balance required for optimal growth and health in poultry (Alagawany *et al.*, 2021). The balanced profile of carbohydrates and fats in maize makes it an ideal energy source that supports the diverse energy needs of poultry at different life stages (Murdia *et al.*, 2016). A greater portion of feed is converted into body weight gain or egg production when using maize because of its high energy content, which helps birds attain efficient feed conversion ratios. Poultry fed with maize-based diets tend to exhibit improved growth rates and enhanced feed efficiency, leading to reduced energy wastage and better overall performance (Abdollahi *et al.*, 2013). However, the use of maize (*Zea mays L.*) grain as an energy source in poultry feeds poses unsustainability challenges due to competing demands and suboptimal growing conditions for the crop. Maize cultivation contributes to soil erosion, deforestation, and water depletion because it requires rich soil, high water usage and intensive agricultural practices (Bashir *et al.*, 2017). It is vulnerable to the effects of climate change because it is prone to pest infestations, heat stress, and drought (Chávez-Arias *et al.*, 2021). The primary energy source in commercial quail diets is still primarily maize (*Zea mays L.*) grain, which presents a significant challenge to quail farmers (Morne, 2017). This is due to the fact that maize grain is highly valued on the market since it is a staple food for people in Africa (Mnisi & Mlambo, 2018). In addition to being a staple grain for farmed animals, maize is used to make a variety of drinks, biofuels, commercial starches, and

human food (Tenenbaum, 2008). The search for sustainable and efficient energy sources for poultry farming has received significant attention. Due to the increasing demand for poultry products, it is important to find alternative energy sources that are not only environmentally friendly, but also economically viable (Mottet & Tempio, 2017). Therefore, it is necessary to explore other energy sources that are more cost-effective and more readily available.

2.5.2 Millet

Millet, a small-seeded grain, offers several nutritional benefits and versatility, making it an ideal energy source for poultry production (Hassan *et al.*, 2021). In East and Southern Africa (ESA), the production of millets has risen from 1.3 to 1.8 million tons between 2016 and 2018 (Orr, 2020). Millet is a valuable energy source due to its high metabolizable energy (2900 kcal/kg ME), which can be compared favourably to maize (3330 kcal/kg ME) (Farahat *et al.*, 2020). It contains many carbohydrates and provides the birds with a source of energy for growth, metabolism and reproduction (Hassan *et al.*, 2021). Millets contain up to 40% more lysine and methionine than maize (Liu *et al.*, 2021). Due to its ability to withstand heat and drought, millet is a highly nutritious alternative to maize in quail diets and it can also be easily cultivated in tropical climates (Mnisi *et al.*, 2023). By adding millet to poultry nutrition, farmers can provide a balanced and nutrient-dense source that supports optimal performance. Millet exhibits excellent digestion in poultry, which allows efficient use of its energy content (Aderibigbe *et al.*, 2022). The complete replacement of maize with millet in quail and broiler diets enhanced growth and the health status of birds (Bala *et al.*, 2017; Masenya *et al.*, 2021). The high digestibility of millet allows the birds to obtain maximum energy from the feed, which improves feed utilisation efficiency. Although millet is a nutritious grain, its nutritional profile may not provide a complete balance of essential nutrients required for optimal health and growth in poultry (Qaisrani *et al.*, 2019). Though it contains carbohydrates for energy, it may lack sufficient levels of essential amino acids, vitamins,

minerals and other nutrients required for poultry nutrition (Saleh *et al.*, 2013). Millet has low glycaemic index (GI), its slow-releasing carbohydrates in millet may help control blood sugar levels, which may be advantageous for the health of birds and the quality of their eggs (Rai, 2008). Furthermore, it is gluten-free making it suitable for making gluten-free eggs (Sibanda *et al.*, 2023). It is also rich in phenolic compounds, which are powerful antioxidants that may strengthen the birds' immune systems and enhance the quality of their eggs (Kalinová, 2007). Millet offers unique and desirable attributes as quail feed, especially with its low GI and gluten-free nature.

2.5.3 Sorghum

Sorghum (*Sorghum bicolor* Moench L.) is a highly nutritious grain with a balanced carbohydrate, and fat profile. It contains a significant amount of starch, which is an excellent source of energy for poultry (Etuk *et al.*, 2012). Sorghum cultivation is typically very low and it is mostly consumed locally, primarily in the areas where it is cultivated (Mundia *et al.*, 2019). In East and Southern Africa (ESA), the production of sorghum has doubled between 1980–82 and 2016–18 to reach 8 million tons (t), (Orr, 2020). The use of old sorghum varieties in quail diets is severely limited because they contain significant amounts of anti-nutrients like tannins. These tannins inhibit the actions of fibrolytic and proteolytic enzymes, which lowers the digestibility of nutrients (Yanza *et al.*, 2021). Concurrently, the development of a low-tannin hybrid sorghum cultivar has been assessed in diets of pigs and poultry. It has been noted that in some poultry diets, low-tannin sorghum grain can be a good substitute for maize grain (Manyelo *et al.*, 2019). However, the use of sorghum grain as an energy source is restricted by the presence of kafirin, endosperm cell wall, ferulic acid, tannins, and phytate (Liu *et al.*, 2015). This could be the reason why discordant results have been reported when sorghum grain has been used in place of maize grain in poultry diets. Its amino acid profile complements the amino acid requirements for optimal growth and production in poultry (Applegate & Angel,

2008). Incorporating sorghum into poultry feed could provide poultry with valuable sources of energy, and thus promote healthy growth and development (Etuk *et al.*, 2012). The energy efficiency of sorghum in poultry production is an important advantage. Improved feed efficiency reduces total energy consumption in poultry farming and contributes to lower production costs (Elahi *et al.*, 2022). Poultry may not utilize sorghum-based diets as readily, resulting in reduced feed intake and possibly slower growth rate (Liu *et al.*, 2015).

2.6 Cassava as an alternative energy source

Cassava is a popular food crop mostly grown in West Africa but originates from South America, where it is known as Manihot (Parmar *et al.*, 2017). It is widely cultivated throughout the tropics because of its starchy and tuberous roots. Its by-product obtained from the processing of cassava roots into various food products such as cassava flour, *tapioca*, and *garri* (Quaye *et al.*, 2009) have been used as feed ingredients for various livestock including poultry due to its high nutritional value (Kanyinji & Moonga, 2014). Africa is currently the world's top cassava producer, with a 40 million metric ton capacity (Bolade *et al.*, 2019). Around 70 percent of Africa's cassava output is harvested in Nigeria, the Congo and Tanzania (Amelework *et al.*, 2021). In South Africa, cassava is produced mostly by small-holder farmers in <5,000 hectares of land including small-fragmented areas, with limited technologies and under low input farming system (Amelework *et al.*, 2021). Animal producers are becoming dependent on cassava products, which have been successfully used as an alternative energy source in the diets of pigs and fowl worldwide (Morgan & Choct, 2016). Cassava by-products including leaves, peels, and pulp, have the potential to be used as feed components in poultry feeds. Only 2% of cassava consumption in Africa involves its use in animal feed (Anaeto & Adighibe, 2011). The nutritional composition of cassava varies depending on the variety, maturity stage, and the employed processing methods. Cassava peels and pulps have been included in diets as

alternative to conventional energy sources because they have a moderate to high energy content (Diarra & Devi, 2015). Adio (2020) stated that molasses flavoured sun-dried cassava peel meal can completely replace maize in the diets of growing and laying Japanese quail without any adverse effects on growth, egg production and egg quality of birds. Limited research exists on the complete replacement of maize with cassava tuber meal quail diets to balance nutrient intake, growth performance, and egg production. Bridging these research gaps can unlock the socio-economic potential of cassava meal in the quail industry such as replacing expensive maize with cassava meal which can significantly reduce feed costs for quail farmers, especially in regions where cassava is readily available and cheaper (Ukachukwu, 2005).

2.6.1 Socio-economic relevance of cassava meal

Cassava occupies a special position in the international food economy, especially given that it succeeds when other crops fail (Parmar *et al.*, 2017). The utilization of cassava meal, derived from the processing of cassava roots, has a profound impact on food security, income generation, and agricultural diversification (Reincke *et al.*, 2018). Cassava meal plays a crucial role in ensuring food security, especially in regions where it serves as a staple food (Parmar *et al.*, 2017). Cassava is known for its resilience to challenging environmental conditions and ability to thrive in marginal lands (Jiang *et al.*, 2019). This makes it a reliable source of carbohydrates, providing a stable food supply even in areas with poor soil fertility or limited access to other staple grains. Cassava cultivation and processing offer valuable economic opportunities for farmers and entrepreneurs (Taiwo, 2006). Small-scale farmers often grow cassava as a cash crop, selling it to processors or local markets (Chipeta & Bokosi, 2013). This provides a source of income and employment for people in rural communities, lifting them out of poverty and improving livelihoods. Additionally, the processing of cassava into meal or flour creates job opportunities in the agro-processing sector, supporting local economies and stimulating economic activity (Nuwamanya *et al.*, 2016). Cassava is frequently grown by

resource-constrained communal farmers, many of whom are subsistence farmers. Currently, industrial applications and non-traditional uses such as animal feed (cassava hay, chips, pellets, and feed-grade single-cell protein) need to be more widely exploited (feedstock; sweeteners, alcohol, plywood, textiles, paper) (Anyanwu *et al.*, 2015).

2.6.2 Nutritional composition of cassava

The nutritional composition of CTM can vary depending on factors such as cassava variety, growth or harvesting sites, processing methods, among others (Chauynarong *et al.*, 2009). Gross energy value of unpeeled CTM was reported to be 15.46 MJ/kg, which is comparable to 16.46 MJ/kg of maize, but its carbohydrate (starch) content was found to be higher than that of maize (Mora *et al.*, 2014). The carbohydrate content can range from 80 to 90% and contains a significant amount of fibre that also varies from 3 to 15%, depending on the used processing method (Montagnac *et al.*, 2009). Its protein content (1 to 5%) is lower than that of maize (9 - 10%) (Chauynarong *et al.*, 2009; Oimage *et al.*, 2009) and lacks most essential amino acids (Salvador *et al.*, 2014). It is generally low in fat (0.2 to 2%), but it is a good source of minerals, including potassium, calcium, phosphorus, magnesium (Li *et al.*, 2017) and vitamin C (Salvador *et al.*, 2014). According to Chauynarong *et al.* (2009), CTM has high amounts of vitamin C but low levels of vitamins A, B₁, B₂, and niacin, which are also influenced by processing.

2.6.3 Bioactive compounds

Cassava tubers contain several bioactive compounds that can provide health benefits to quail when included in their diets. These bioactive compounds include cyanogenic glycosides, phenolic compounds, and tannins (Mutha *et al.*, 2021). Cyanogenic glycosides are present in cassava tubers and are converted to hydrogen cyanide (HCN) in an animal body, which can be toxic in high doses (Cressey & Reeve, 2019). However, at lower doses, it can stimulate the

growth of beneficial gut microbiota, which can boost the immune system against infections (Sugiharto & Ranjitkar, 2019). If the concentration of cyanogenic glycosides in CTM is high, this can be reduced during processing. Phenolic compounds such as flavonoids and tannins in CTM can act as natural antioxidants, preventing oxidative stress and improving the overall health of quail (Jumadin *et al.*, 2022). Overall, CTM is a rich source of bioactive compounds that can improve the health and performance of quail when used in combination with other feed ingredients in balanced proportions.

2.6.4 Antinutritional factors in cassava tuber meal

Although cassava is a unique staple crop that is mostly used in sub-Saharan Africa, it contains antinutrients such as cyanogen (Kasankala *et al.*, 2019). Moreover, cassava meal contains cyanogenic glycosides, which are toxic in high concentrations (Montagnac *et al.*, 2019). The cyanogenic glycosides found in cassava bind cyanogen to sugar molecules providing defence against herbivory (Montagnac *et al.*, 2009). The cyanide levels in cassava range from 75 to 1,000 mg/kg (Ngiki *et al.*, 2014) and the cyanogenic glycosides can be categorised into two types: linamarin (93%) and either lotaustralin or ethyl linamarin (7%) (Szabo *et al.*, 2010). Cyanogenic glycosides found in cassava serve as suppliers of aspartic acid, glutamic acids, and glutamine, which can be beneficial to the quail (Adio, 2020). These amino acids are essential for protein synthesis and other important metabolic processes. Although it is conjugated to cyanide ions, linamarin shares molecular similarities with glucose. Depending on the cultivar, fresh tuber contains 2 to 395 mg /100 g of linamarin (Chauynarong *et al.*, 2009). Valine is used to generate linamarin, whereas isoleucine is used to synthesize lotaustralin. During the crushing or slicing of cassava roots, linamarin and lotaustralin are converted to hydrocyanic acid by linamarase enzymes found in the root (Nambisan, 2011). The concentration of cyanogenic glycosides in the leaves is six times higher than in the roots, but reduces as the leaf ages (Ngiki *et al.*, 2014). The hydrocyanic acid is further released in the bird using enzymes such β -

glucosidase produced by the intestinal microbes, glucosidases produced by the liver and other organs, and acid hydrolysis in the gut (Morgan & Choct, 2016). Glucosidases produced by the liver can also contribute to HCN release from ingested glycosides (Rocha-e-Silva *et al.*, 2010). The HCN is a highly toxic compound that can disrupt cellular respiration and lead to death.

2.7 Feeding value of cassava meal

2.7.1 Effect of cassava meal on poultry growth and egg performance

Poultry performance is the most crucial factor to consider when looking for alternative feed ingredients (Thirumalaisamy *et al.*, 2016). Tesfaye *et al.* (2013) reported that total replacement of maize with cassava roots reduced feed intake in broiler chickens. Cassava meal has limitations, but it can be a valuable ingredient in poultry feeds where it can be used to replace maize in regions where maize is costly (Hossain *et al.*, 2013). Cassava meal can replace up to 50% of maize in poultry diets without affecting growth performance (Boonsinchai *et al.*, 2016). Agunbiade *et al.* (2002) reported better feed conversion ratios and weight gains in broiler chickens fed diets that included 50% cassava meal than when the birds were fed a diet based primarily on maize. Hossain *et al.* (2013) discovered that broiler chickens fed diets containing 50% cassava meal showed lower feed conversion ratios and higher weight gains compared to birds on a maize-based diet. According to Garcia & Dale (1999), cassava meal can also be included to 25% or less in layer diets to prevent any detrimental impacts on egg production. Studies have indicated that if cassava meal is included to layer diets in large quantities without being treated, it may have an adverse effect on hatchability, egg weight, and eggshell thickness. Indeed, Sapatattananan *et al.* (2005) conducted a study that revealed that laying hens on a diet containing 50% cassava meal produced fewer eggs and their weight was lower than that of birds fed a diet based on maize. The authors attributed the reduction in egg production to low protein content in the cassava meal treatment. A decline in quail weight was discovered by

Kyawt *et al.* (2015) in meals containing more than 60% cassava products with high hydrocyanic concentrations. Feeding quail with cassava meal in place of maize meal reduces the overall cost of feed for each bird (Edache *et al.*, 2007). This suggests that substituting maize with cassava meal in broiler diets is more economical. Although cassava-based diet may have some negative impacts on growth performance, pre-processing may improve its utility resulting in higher net profits (Zanu *et al.*, 2017).

2.7.2 Effect of cassava meal on poultry health

In poultry diets, cassava meal is a starchy feed ingredient that can be an alternative to maize (Chauynarong *et al.*, 2009). It is deficient in amino acids and proteins but is an excellent source of carbohydrates and energy (Salvador *et al.*, 2014). The anti-inflammatory and antioxidant properties of cassava meal can boost poultry immune system and give protection from diseases (Aza *et al.*, 2022). However, it lacks vital amino acids and proteins, which can lead to nutritional deficiencies in poultry (Salvador *et al.*, 2014). It also contains cyanogenic glycosides, which can be potentially toxic in excessive amounts (Montagnac *et al.*, 2019). Other anti-nutritional elements contained in cassava meal, such as tannins and saponins, can reduce the absorption of nutrients and impair poultry health (Zekarias *et al.*, 2019). Some studies have shown that replacing up to 250 g/kg of maize in poultry diets with cassava meal has no negative health effects (Ngiki *et al.*, 2014). Haematological analysis of the birds showed that adding cassava meal to the diet had no effect on the birds' health. Likewise, the addition of 400 g/kg cassava meal to quail diet had no adverse effects on haematological parameters (Khan *et al.*, 2021). Additionally, raw cassava meal may cause a variety of detrimental effects on poultry health including weakened immunity and nutrient deficiencies (Ngiki *et al.*, 2014). Still, studies suggest that pre-processing methods such as autoclaving, boiling, or oven drying can minimize the toxicity of cassava meal (Okoth *et al.*, 2022). These processing techniques

can reduce the amounts of cyanogenic glycosides and other nutritionally inhibiting components (Nambisan, 2011).

2.7.3 Effect of cassava meal on poultry meat quality and carcass traits

Carcass traits and meat quality play crucial roles in the overall value and consumer acceptance of meat products (Baéza *et al.*, 2022). Carcass characteristics provide crucial information about the overall shape and conformation of the carcass, as well as the amount and distribution of the edible meat, fat, and bones (Tavaniello, 2014). Carcass traits are important for both producers and consumers as they impact the economic value and utilization of meat animals (Santhi & Kalaikannan, 2017). A crucial trait is carcass weight as it has a direct impact on how much meat is available for consumption. In general, higher carcass weights result in higher meat yields, which can increase profitability of the producer (Polkinghorne & Thompson, 2010). The characteristics that affect the taste, appearance and nutritional value of meat are also called meat quality (Mir *et al.*, 2017), which influences consumer's satisfaction and purchasing decisions. Meat quality refers to the total qualities of meat, including its physio-chemical, morphological, biochemical, sensory, technological, hygienic, culinary, and nutritional qualities (Mir *et al.*, 2017). Tamburawa *et al.* (2019) found that feeding broiler chickens with 60% cassava root containing diets had no effect on the relative weights of liver, crop, lung, spleen, pancreases and heart. Moreover, feeding a diet containing cassava flour at 100% reduced carcass weights and dressing percentages in broiler chickens, but the weight of the intestines with digesta increased (Zanu *et al.*, 2017). The delay in the digestion of cassava flour in the birds' gastro-intestinal tract may be a contributing factor to the increased weight of the intestine with digesta. With or without digesta, crop weight decreased in birds fed with diets including cassava flour. However, Tamburawa *et al.* (2019) found that when chicks were fed with diets supplemented with cassava meal, their crop weight increased.

2.8 Treatment methods to improve dietary cassava meal

Cassava contains antinutrients like cyanogenic glycosides, linamarin, tannin, phytate, oxalate, and lotaustralin (Etsuyankpa *et al.*, 2015). Following tissue damage, they are hydrolysed to the appropriate cyanohydrins by linamarase. The chronic toxicity linked to improperly prepared cassava products is caused by further hydrolysis to hydrogen cyanide (Teles, 2002). Therefore, the antinutrients mentioned above in cassava must be reduced prior to its incorporation in quail diets. Quite successfully, antinutrients have been reduced using various processing techniques.

2.8.1 Chemical treatment methods

2.8.1.1 Detoxification of cyanogenic compounds

Cassava naturally contains cyanogenic glycosides, which can release toxic hydrogen cyanide upon consumption (Mensah, 2022). Chemical treatments such as soaking in water with additives such as sodium hydroxide or calcium hydroxide (limewater) can help reduce cyanide levels (Panghal *et al.*, 2019) in cassava. These alkaline solutions break down the cyanogenic chemicals and release fewer toxic by-products. This process is called hydrolysis of cyanogenic glycosides or detoxification of cyanides (Kuliahsari *et al.*, 2021).

2.8.1.2 Acid treatment

Acid treatment of cassava involves soaking the roots or grated cassava in dilute acid solutions, such as citric acid or acetic acid (Wang *et al.*, 2022). The activity of enzymes that lead to the deterioration of the quality of the cassava flour is reduced by the acid treatment (Udoro *et al.*, 2021). It can also improve the texture, reduce the bitter taste, and increase the nutritional value of cassava meal by enhancing the bioavailability of certain nutrients.

2.8.1.3 Antioxidant treatment

Oxidative degradation leads to the formation of off-flavours and loss of nutritional quality in cassava (Zainuddin *et al.*, 2018). To prevent oxidation and maintain the quality of cassava

flour, the crop can be treated with antioxidants such as sulphur dioxide or ascorbic acid (vitamin C) (Márquez Cardozo *et al.*, 2015). Antioxidant treatment can improve the shelf life and sensory properties of cassava products (Rodríguez *et al.*, 2020).

It is important to note that the use of chemical treatments should comply with appropriate guidelines and regulations to ensure safety and prevent any potential adverse effects. Chemical treatments should also be used in conjunction with other processing techniques such as thorough washing to ensure that any remaining chemicals are removed, and the nutritional value of cassava is preserved. In contrast to chemical treatment methods, physical treatment methods are more manageable and cost-effective.

2.8.2 Physical treatment methods

2.8.2.1 Boiling

Generally, boiling reduces anti-nutritional factors such as HCN, cyanide, tannins, among others. Boiling makes cassava tubers safer to consume by increasing digestibility, promoting palatability, improving keeping quality, and ultimately lowering the anti-nutrients to a level that is safe to consume (Deshpande, 2000). Similar to soaking, boiling quickly depletes the free cyanide in cassava chips. Boiling eliminates about 90% of the free cyanide within 15 minutes compared to 55% of bound cyanide after 25 minutes (Ngiki *et al.*, 2014). However, prolonged heating, which destroys the linamarase enzyme at $> 72^{\circ}\text{C}$, preserves the glycoside(s) and HCN. Typically, around 72°C and more, the linamarase enzyme is destroyed during boiling, leaving considerable portion of the glycoside intact (Panghal *et al.*, 2019). Linamarase is a heat-sensitive enzyme, which when cassava is boiled at high temperatures, its protein structure unfolds and lose its function (Urugo & Tringo, 2023). This inactivates the linamarase, preventing it from breaking down cyanogenic glycosides into potentially harmful cyanide.

Essentially, boiling acts like sterilization, eliminating the enzyme's ability to convert the precursor compound to toxic cyanide (Nyirenda, 2020).

2.8.2.2 Autoclaving

Autoclaving is essentially a high-intensity thermal process of boiling in a closed pressure chamber called an autoclave to exceed the normal boiling point of water (Sarfraz & Khan, 2021). Autoclaving reduces the content of antinutrients, resulting in products with readily available nutrients (Udensi *et al.*, 2005). Autoclaves work on the principle of moist heat sterilization, which uses steam under pressure to sterilize the materials present in the chamber. Higher pressure raises the boiling point of water, helping to achieve higher temperatures for sterilization (Dion & Parker, 2013). Water normally boils at 100 °C under atmospheric pressure (14.7 psi). However, increasing the pressure raises the boiling point of water. Similarly, high pressure promotes rapid penetration of heat into deeper parts of the material, and moisture present in the steam causes coagulation of proteins, leading to irreversible loss of microbial function and activity, used in autoclaves where water boils at 121°C at a pressure of 15 psi (McDonnell & Russell, 1999). Autoclaving works by exposing the desired product to pressurized saturated steam at approximately 121°C for 7 minutes to 1 hour, depending on the amount and type of legumes (Drulyte & Orlie, 2019). Cassava release cyanide upon hydrolysis, which interferes with the absorption of essential minerals like iron and zinc, further contributing to nutritional deficiencies (Zekarias *et al.*, 2019). However, autoclaving is highly effective in reducing cyanogenic glycosides, often by over 90% (Mensah, 2022). The highest temperature (>121°C) and pressure in an autoclave denature the enzymes that are responsible for hydrolysis, preventing cyanide release.

2.8.2.3 Drying

Drying is the removal of moisture from feedstuffs with the aim of reducing microbial activity and product spoilage, while extending shelf life (Zahra *et al.*, 2021). It is the simplest processing method that can reduce both moisture and cyanide levels in cassava roots (Lambri *et al.*, 2013). This treatment method is mainly used for varieties with low cyanide content and in areas where the water supply is limited. Drying can be through the sun or by placing root pieces over a fire (Balagopalan, 2001). The former is more common because it is easy and does not require firewood. Andama & Oloya (2017) showed that rapid air-drying reduced the total cyanide content of peeled cassava root chips by only 10 - 30%. However, slow drying in the sun resulted in greater loss of cyanide. Hahn (1989) reported that sun-drying of peeled and cut root pieces gave an HCN concentration of less than 10 mg/100 g, however, oven-drying was less effective. According to Kareem (2022), the level of the coumarin compound scopoletin (7-hydroxy-6-methoxychromen-2-one) in cassava increased significantly after peeling, slicing (flaking) and drying for six days. The mean content in fresh roots of four cultivars ranged between 4.1 and 11.1 mg/kg, while after six days the content increased to 242 mg/kg for the cultivar with the highest increase (Brimer, 2015).

2.9 Summary

Quail farming is a growing industry that could help meet the increasing demand for animal protein. Jumbo quail hens are known for their high egg production and relatively fast growth rates. For their sustainable intensification, a high energy diet is necessary to ensure optimal performance. However, the constant reliance on conventional energy sources, mainly maize, could restrict the economic sustainability of layer quail hens. Cassava is a potential alternative energy source that can be used due to its high availability, energy value and low cost. However,

it contains anti-nutritional factors that can reduce its utilisation in layer quail. Thus, treatment methods including chemical and physical methods can be employed to improve the nutritional quality of cassava meal and make it safe and suitable for use in poultry diets. The physical processing methods include drying, autoclaving, grinding, boiling, sun-drying, roasting and fermentation; However, this study focused on drying, autoclaving and boiling because they are less-time consuming, require less labour and have been proven to reduce anti-nutrients such as hydrogen cyanide. The following chapters, therefore, evaluated the effects of including raw or autoclaved, oven-dried and boiled cassava tuber meal in place of maize in a diet of Jumbo quail hens on metrics such as productive performance, egg quality and shelf life, haematology, serum biochemistry, welfare, internal organ development and some meat quality characteristics.

2.10 References

- Abdelqader A., Al-Fataftah A. R., & Das G., 2013. Effect of dietary *Bacillus subtilis* supplementation on performance, eggshell quality, intestinal morphology and microflora composition of laying hens in the later phase of production. *Anim. Feed Sci. Technol.* 179, 103–111.
- Abdollahi, M.R., Ravindran, V. & Svihus, B., 2013. Pelleting of broiler diets: An overview with emphasis on pellet quality and nutritional value. *Anim. Feed Sci. Technol.* 179 (1-4), 1-23.
- Abou Khadiga, G., Mahmoud, B.Y., Farahat, G.S., Emam, A.M. & El-Full, E.A., 2017. Genetic analysis of partial egg production records in Japanese quail using random regression models. *Poult. Sci.* 96(8), 2569-2575.
- Aderibigbe, O.R., Ezekiel, O.O., Owolade, S.O., Korese, J.K., Sturm, B. & Hensel, O., 2022. Exploring the potentials of underutilized grain amaranth (*Amaranthus spp.*) along the value chain for food and nutrition security: A review. *Crit. Rev. Food Sci. Nutr.* 62(3), 656-669.
- Adio, S., 2020. Growth performance and egg production of Japanese quails fed diets containing varying levels of molasses flavoured sun-dried cassava peel meal (Doctoral dissertation).
- Agunbiade, J.A., Adeyemi, O.A., Adepoju, O.A. & Lawal, O.A., 2002. The use of whole cassava meal and leaf meal in broiler diets. *Niger. J. Animal Sci.* 5(1), 161-173.
- Aladejebi, O.J., Fakayode, S.B., Oronti, O.O. & Sani, T.P., 2019. Post economic recession and agricultural production in Nigeria: A case study of small-scale poultry egg farming. In the 2019 6th International Conference of the African Association of Agricultural Economists (AAAE), Abuja, Nigeria, 23-26 September 2019, 1-16.

- Alagawany, M., Elnesr, S.S., Farag, M.R., Tiwari, R., Yatoo, M.I., Karthik, K., Michalak, I. & Dhama, K., 2021. Nutritional significance of amino acids, vitamins and minerals as nutraceuticals in poultry production and health—a comprehensive review. *Vet. Q.*41(1), 1-29.
- Al-Nasser, A., Al-Khalaifa, H., Al-Saffar, A., Khalil, F., Albahouh, M., Ragheb, G., Al-Haddad, A. & Mashaly, M., 2007. Overview of chicken taxonomy and domestication. *World Poult. Sci. J.* 63(2), 285-300.
- Altine, S., Sabo, M.N., Muhammad, N., Abubakar, A. & Saulawa, L.A., 2016. Basic nutrient requirements of the domestic quails under tropical conditions: A review. *World Sci. News.* 2(49), 223-235.
- Amelework, A.B., Bairu, M.W., Maema, O., Venter, S.L. & Laing, M., 2021. Adoption and promotion of resilient crops for climate risk mitigation and import substitution: A case analysis of cassava for South African agriculture. *Front. Sustain. Food Syst.* 5, 617783.
- Anaeto, M. & Adighibe, L.C., 2011. Cassava root meal as substitute for maize in layers ration. *Braz. J. Poult. Sci.* 13, 153-156.
- Andama, M. & Oloya, B., 2017. Effectiveness of traditional processing techniques in reducing cyanide levels in selected cassava varieties in Zombo District, Uganda. *Int. J. Biotechnol. Food Sci.* 2(4), 121-125.
- Ande, K.O., Oso, A.O., Oluwatosin, O.O., Sanni, L.O. & Adebayo, K., 2021. Effect of white and yellow cassava root meal diets supplemented with different additives on performance of layers and the quality of eggs laid. *Trop. Anim. Health Prod.* 53(2), 1-12.
- Anyanwu, C.N., Ibeto, C.N., Ezeoha, S.L. & Ogbuagu, N.J., 2015. Sustainability of cassava (*Manihot esculenta crantz*) as industrial feedstock, energy and food crop in Nigeria. *Renew. Energy.* 81, 745-752.

- Applegate, T.J. & Angel, R., 2008. Protein and amino acid requirements for poultry. *Anim Sci.*
- Arrieta, E.M., Cuchietti, A., Cabrol, D. & González, A.D., 2018. Greenhouse gas emissions and energy efficiencies for soybeans and maize cultivated in different agronomic zones: A case study of Argentina. *Sci. Total Environ.* 625, 199–208.
- Bala, S., Sharma, R.K., Khan, N., Rastogi, A. & Haq, Z., 2017. Performance of broiler chicken as affected by replacement of maize with pearl millet and broken rice mixture in the diet. *Indian J. Anim. Nutr.* 34(4), 437-446.
- Balagopalan, C., 2001. Cassava utilization in food, feed and industry. In *Cassava: Biology, production and utilization*. CABI, Wallingford, UK. 301-318.
- Bashir, S., Javed, A., Bibi, I. & Ahmad, N., 2017. Soil and water conservation. Pakistan, University of Agriculture, Faisalabad, 263-286.
- Beardsworth, P.M. & Hernandez, J.M., 2004. Yolk colour—an important egg quality attribute. *Int. Poult. Prod.* 12(5), 17-18.
- Baéza, E., Guillier, L. & Petracci, M., 2022. Production factors affecting poultry carcass and meat quality attributes. *Anim.* 16, 100331.
- Bessei, W., 2018. Impact of animal welfare on worldwide poultry production. *Worlds Poult. Sci. J.* 74(2), 211-224.
- Bolade, D.O., Ana, G.R.E.E., Lateef, S.A. & Soka-Adeaga, A.A., 2019. Exploration of the bioethanol yield of single and multi-substrate biomass from cassava processing wastes. *J. Solid Waste Technol. Manag.* 45(3), 305-314.
- Boonsinchai, N., Potchanakorn, M & Kijparkorn, S., 2016. Effects of protein reduction and substitution of cassava for corn in broiler diets on growth performance, ileal protein digestibility and nitrogen excretion in feces. *Anim. Feed Sci. Technol.* 216, 185-196.

- Bradshaw, R.H., Kirkden, R.D. & Broom, D.M., 2002. A review of the aetiology and pathology of leg weakness in broilers in relation to welfare. *Poult. Avian Biol. Rev.* 13(2), 45-104.
- Brimer, L., 2015. Cassava production and processing and impact on biological compounds. In *Processing and Impact on Active Components in Food*. Academic Press, 81-87.
- Bryden, W.L., Li, X., Ruhnke, I., Zhang, D. & Shini, S., 2021. Nutrition, feeding and laying hen welfare. *Anim. Prod. Sci.* 61(10), 893-914.
- Castanheira, É.G. & Freire, F., 2013. Greenhouse gas assessment of soybean production: Implications of land use change and different cultivation systems. *J. Clean. Prod.* 54, 49-60.
- Chauynarong, N., Elangovan, A.V. & Iji, P.A., 2009. The potential of cassava products in diets for poultry. *World Poult. Sci. J.* 65(1), 23-36.
- Chávez-Arias, C.C., Ligarreto-Moreno, G.A., Ramírez-Godoy, A. & Restrepo-Díaz, H., 2021. Maize responses challenged by drought, elevated daytime temperature and arthropod herbivory stresses: A physiological, biochemical and molecular view. *Front. Plant Sci.* 12, 702841.
- Chege, S.M., 2016. Opportunistic infections of avians. *The Rasputin effect: When commensals and symbionts become parasitic*. Springer, Cham. 221-260. doi:10.1007/978-3-319-28170-4.
- Cheng, H.W., 2010. Breeding of tomorrow's chickens to improve well-being. *Poult. Sci.* 89(4), 805-813.
- Cheng, K.M., Bennett, D.C. & Mills, A.D., 2010. The Japanese quail. *The UFAW handbook on the care and management of laboratory and other research animals: eighth edition*. 8th ed. Oxford: Wiley-Blackwell, 655-673.

- Chipeta, M.M. & Bokosi, J.M., 2013. Status of cassava (*Manihot esculenta*) Production and Utilization in Malawi. *Int. J. Agron. Plant Prod.* 4, 3637-3644.
- Collett, S.R., Smith, J.A., Boulianne, M., Owen, R.L., Gingerich, E., Singer, R.S., Johnson, T.J., Hofacre, C.L., Berghaus, R.D. & Stewart-Brown, B., 2020. Principles of disease prevention, diagnosis, and control. *Dis. Poult.* 1-78.
- Cressey, P. & Reeve, J., 2019. Metabolism of cyanogenic glycosides: A review. *Food Chem. Toxicol.* 125, pp.225-232.
- Dauda, G., Momoh, O.M., Dim, N.I. & Ogah, D.M., 2014. Growth, production and reproductive performance of Japanese quails (*Coturnix coturnix japonica*) in humid environment. *Egypt. Poult. Sci.* 34(2), pp.381-395.
- Demirbas, G.İ.D. & Kubanc, C., 2018. Effects of Light on Egg Performance and Behaviour in Japanese quails (*Coturnix coturnix japonica*). *Eurasia Proc. Sci. Technol. Eng. Math.* (2), 201-208.
- Deshpande, S.S., 2000. Fermented grain legumes, seeds and nuts: A global perspective. *Food & Agriculture Org. (Vol. 142)*.
- Devi, A. & Diarra, S.S., 2021. Factors affecting the utilisation of cassava products for poultry feeding. *Egypt J. Vet. Sci.* 52(3), 387-403.
- Diarra, S.S. & Devi, A., 2015. Feeding value of some cassava by-products meal for poultry: A review. *Pak J. Nutr.* 14(10), 735-741.
- Diarra, S.S., Sandakabatu, D., Perera, D., Tabuaciri, P. & Mohammed, U., 2014. Growth performance, carcass measurements and organs weight of broiler chickens fed cassava-copra meal based or commercial finisher diets in Samoa. *Asian J. Poult. Sci.* 8(1), 16-22.
- Dion, M. & Parker, W., 2013. Steam sterilization principles. *Pharm. Eng.* 33(6), 1-8.

- Drulyte, D. & Orlie, V., 2019. The effect of processing on digestion of legume proteins. J. Food Process. Preserv. 8(6), 224.
- Edache, J.A., Musa, U., Karsin, P.D., Esilonu, J.O., Yisa, A., Okpala, E.J. & Zwandor, N.J., 2007. The feeding value of cassava meal diets for growing Japanese quail (*Coturnix coturnix japonica*). Niger. J. Anim. Prod. 34(1), 77-82.
- EFSA Panel on Animal Health & Welfare, 2010. Scientific opinion on the influence of genetic parameters on the welfare and the resistance to stress of commercial broilers. EFSA J. 8(7), 1666.
- Elahi, E., Zhang, Z., Khalid, Z. & Xu, H., 2022. Application of an artificial neural network to optimise energy inputs: An energy-and cost-saving strategy for commercial poultry farms. Energy, 244, 123169.
- El Sabry, M.I., Hassan, S.S., Zaki, M.M. & Stino, F.K., 2022. Stocking density: a clue for improving social behavior, welfare, health indices along with productivity performances of quail (*Coturnix coturnix*)—a review. Trop. Anim. Health Prod. 54(1), 83.
- Etsuyankpa, M.B., Gimba, C.E., Agbaji, E.B., Omoniyi, K.I., Ndamitso, M.M. & Mathew, J.T., 2015. Assessment of the effects of microbial fermentation on selected anti-nutrients in the products of four local cassava varieties from Niger state, Nigeria. Am. J. Food Technol. 3(3), 89-96.
- Etuk, E.B., Ifeduba, A.V., Okata, U.E., Chiaka, I., Okoli, I.C., Okeudo, N.J., Esonu, B.O., Udedibie, A.B.I. & Moreki, J.C., 2012. Nutrient composition and feeding value of sorghum for livestock and poultry: a review. J. Anim. Sci. Adv. 2(6), 510-524.
- Farahat, M., Badawi, M. A., & Hussein, A. G., 2020. Effect of replacing dietary corn by sorghum on the growth performance, shank skin pigmentation, carcass traits, caecal microflora and nutrient digestibility of broiler chickens. Int. J. Poult. Sci. 19, 424–431.

- Garcia, M. & Dale, N., 1999. Cassava root meal for poultry. J. Appl. Poult. Res. 8(1), 132-137.
- Genchev, A. & Mihaylov, R., 2008. Slaughter analysis protocol in experiments using Japanese quails (*Coturnix japonica*). Trakia J. Sci. 6(4), 66-71.
- Geng, A.L., Zhang, Y., Zhang, J., Wang, H.H., Chu, Q. & Liu, H.G., 2018. Effects of lighting pattern and photoperiod on egg production and egg quality of a native chicken under free-range condition. Poult. Sci. 97(7), 2378-2384.
- Godswill, A.G., Somtochukwu, I.V., Ikechukwu, A.O. & Kate, E.C., 2020. Health benefits of micronutrients (vitamins and minerals) and their associated deficiency diseases: A systematic review. Int. J. Food Sci. 3(1), 1-32.
- Grashorn, M., Juergens, A. & Bessei, W., 2016. Effects of storage conditions on egg quality. Lohmann Inf. 50(1), 26-27.
- Grieser, D.D.O., Marcato, S.M., Furlan, A.C., Zancanela, V., Vesco, A.P.D., Batista, E., Ton, A.P.S. & Perine, T.P., 2018. Estimation of growth parameters of body weight and body nutrient deposition in males and females of meat-and laying-type quail using the Gompertz model. Rev. Bras. de Zootec. 47.
- Gunathilaka, M.G.N.W.W., Prabashwari, T.I.G., Cyril, H.W. & Himali, S.M.C., 2021. Assessment of different pickling solutions on quality characteristics of pickled quail (*Coturnix coturnix japonica*) eggs. Journal of Agriculture and Value Addition, 4(2).
- Hafez, H.M. & Attia, Y.A., 2020. Challenges to the poultry industry: Current perspectives and strategic future after the COVID-19 outbreak. Front. Vet. Sci. 7, 516.
- Hahn, S.K., 1989. An overview of African traditional cassava processing and utilization. Outlook Agric. 18(3), 110-118.
- Halloran, A., Megido, R.C., Oloo, J., Weigel, T., Nsevolo, P. & Francis, F., 2018. Comparative aspects of cricket farming in Thailand, Cambodia, Lao People's Democratic Republic, Democratic Republic of the Congo and Kenya. J. Insects Food Feed. 4(2), 101-114.

- Harper, E.J. & Skinner, N.D., 1998, July. Clinical nutrition of small psittacines and passerines. *Semin. Avian Exot. Pet Med.* 7(3), 116-127. WB Saunders.
- Hartcher, K.M. & Lum, H.K., 2020. Genetic selection of broilers and welfare consequences: a review. *Worlds Poult. Sci. J.* 76(1), 154-167.
- Hassan, Z.M., Sebola, N.A. & Mabelebele, M., 2021. The nutritional use of millet grain for food and feed: a review. *Agric. Food Secur.* 10, 1-14.
- Hemsworth, P.H. & Edwards, L.E., 2020. Natural behaviours, their drivers and their implications for laying hen welfare. *Anim. Prod. Sci.* 61(10), 915-930.
- Hester, P. ed., 2016. Egg innovations and strategies for improvements. Academic press.
- Hossain, M.A., Amin, J.R. & Hossain, M.E., 2013. Feasibility study of cassava meal in broiler diets by partial replacing energy source (corn) in regard to gross response and carcass traits. *Int. J. Agric. Res. Innov. Technol.* 3(2355-2020-1543), 59-65.
- Idowu, O.M.O., Oduweso, A. & Daisy, E., 2005. Performance and hypo-cholesterolemic response of laying hens fed cassava root sievate-based diets. *Niger. J. Anim. Prod.* 32(2), 215-223.
- Indrayani, I., Wati, R. & Rias, M.I., 2019, July. Analysis of the determining factor in profit efficiency of quail farming in Payakumbuh Sub-District, Lima Puluh Kota Regency. In *IOP Conf. Ser.: Earth Environ. Sci.* 287(1), 012035. IOP Publishing.
- Iqbal, J., Khan, S.H., Mukhtar, N., Ahmed, T. & Pasha, R.A., 2016. Effects of egg size (weight) and age on hatching performance and chick quality of broiler breeder. *J. Appl. Anim. Res.* 44(1), 54-64.
- Istiak, M.S. & Khaliduzzaman, A., 2022. Poultry and egg production: an overview. *Informatics in Poultry Production: A Technical Guidebook for Egg and Poultry Education, Research and Industry*, 3-12.

- Jeke, A., Phiri, C., Chitindingu, K. & Taru, P., 2018. Ethnomedicinal use and pharmacological potential of Japanese quail (*Coturnix coturnix japonica*) birdsmeat and eggs, and its potential implications on wild quail conservation in Zimbabwe: A review. *Cogent Food Agric.* 4(1), 1507305.
- Jiang, D., Wang, Q., Ding, F., Fu, J. & Hao, M., 2019. Potential marginal land resources of cassava worldwide: A data-driven analysis. *Renew. Sustain. Energy Rev.* 104, 167-173.
- Jocelyne, R.E., Béhiblo, K. & Ernest, A.K., 2020. Comparative study of nutritional value of wheat, maize, sorghum, millet, and fonio: some cereals commonly consumed in Côte d'Ivoire. *Eur. Sci. J.* 16(21), 118-131.
- Jones, B.R., 2002. Role of comparative psychology in the development of effective environmental enrichment strategies to improve poultry welfare. *Int. J. Comp. Psychol.* 15(2).
- Jones, B. & Manteca, X., 2009. Practical strategies for improving farm animal welfare: An information resource. *Welfare Quality: Lelystad, the Netherlands.*
- Jumadin, L., Maheshwari, H., Ulupi, N. & Satyaningtijas, A.S., 2022. Potency of bioactive compound of cassava leaf paste to support physiological performance of quail. *J. Trop. Anim. Sci. Technology.* 9, 354-361.
- Kabak, B., Dobson, A.D. & Var, I.I.L., 2006. Strategies to prevent mycotoxin contamination of food and animal feed: a review. *Crit. Rev. Food Sci. Nutr.* 46(8), 593-619.
- Kalinová, J., 2007. Nutritionally important components of proso millet (*Panicum miliaceum* L.). *Food*, 1(1), 91-100.
- Kanyinji, F. & Moonga, M., 2014. Effects of replacing maize meal with rumen filtrate-fermented cassava meal on growth and egg production performance in Japanese quails (*Cortunix japonica*). *J. Adv. Vet. Anim. Res.* 1(3), 100-106.

- Kareem, B., 2022. Evaluation of Glycaemic Index, Starch-Hydrolyzing Enzymes Inhibitory and Antioxidant Properties of Traditional Products of Select Biofortified Cassava Varieties (Doctoral dissertation, Kwara State University (Nigeria)).
- Kasankala, L.M., Kitunda, M.E., Towo, E.E., Ngwasy, G.M., Kaitira, L., Cyprian, C. & Mushumbusi, D., 2019. Antinutritional factors reduction from cassava (*Manihot esculenta crantz*) roots by grating or chipping processing technique in Mtwara Tanzania. *European J. Nutr. Food Saf.* 9(2), 163-171.
- Khan, R.U., Khan, A., Naz, S., Ullah, Q., Laudadio, V., Tufarelli, V. & Ragni, M., 2021. Potential applications of *Moringa oleifera* in poultry health and production as alternative to antibiotics: a review. *Antibiotics*, 10(12), 1540.
- Khattab, R.Y., Arntfield, S.D. & Nyachoti, C.M., 2009. Nutritional quality of legume seeds as affected by some physical treatments, Part 1: Protein quality evaluation. *LWT Food Sci. Technol.* 42, 1107–1112.
- Kinyua, M., 2022. Factors influencing Quail Farming: A critical literature review. *Anim. Health J.* 3(1), 38-53.
- Kuliah Sari, D.E., Sari, I.N.I. & Estiasih, T., 2021. Cyanide detoxification methods in food: A review. In *IOP Conf. Ser.: Earth and Environ. Sci.*, Malang, Indonesia, 25 August 2020, 733, 012099.
- Kyawt, Y.Y., Toyama, H., Htwe, W.M., Thaikua, S., Imura, Y. & Kawamoto, Y., 2015. Effect of whole cassava meal as substitutes for maize in the diets on the performance characteristics and egg quality of laying hens. *Nihon Danchi Chikusan Gakkaihou*, 58(1), 19-28.
- Li, S., Cui, Y., Zhou, Y., Luo, Z., Liu, J. & Zhao, M., 2017. The industrial applications of cassava: current status, opportunities and prospects. *J. Sci. Food Agric.* 97(8), 2282-2290.

- 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.
- Lonergan, S.M., Topel, D.G. & Marple, D.N., 2018. The science of animal growth and meat technology. Academic Press.
- Maggini, S., Pierre, A. & Calder, P.C., 2018. Immune function and micronutrient requirements change over the life course. *Nutrients*, 10(10), 1531.
- Manyelo, T.G., Ng'ambi, J.W., Norris, D. & Mabelebele, M., 2019. Substitution of *Zea mays* by *Sorghum bicolor* on performance and gut histo-morphology of Ross 308 broiler 5chickens aged 1–42 d. *J. Appl. Poult. Res.* 28, 647–657.
- Masenya, T.I., Mlambo, V. & Mnisi, C.M., 2021. Complete replacement of maize grain with sorghum and pearl millet grains in Jumbo quail diets: Feed intake, physiological parameters, and meat quality traits. *PLoS One*. 16(3), 0249371.
- Marareni, M. & Mnisi, C.M., 2020. Growth performance, serum biochemistry and meat quality traits of Jumbo quails fed with mopane worm (*Imbrasia belina*) meal-containing diets. *Vet. Anim. Sci* 10, 100141.
- Marcu, A., Vacaru-Opriș, I., Dumitrescu, G., Ciochină, L.P., Marcu, A., Nicula, M., Peț, I., Dronca, D., Kelciov, B. & Mariș, C., 2013. The influence of genetics on economic efficiency of broiler chickens growth. *J. Anim. Sci. Biotechnol.* 46(2), 339-346.
- Márquez Cardozo, C.J., Palacín Beltrán, J.R. & Fuentes Berrio, L., 2015. Effect of cassava-starch coatings with ascorbic acid and N-acetylcysteine on the quality of harte's plantain (*Musa paradisiaca*). *Rev. Fac. Nac. Agron. Medellín*, 68(2), 7689-7701.
- McDonnell, G. & Russell, A.D., 1999. Antiseptics and disinfectants: Activity, action, and resistance. *Clin. Microbiol. Rev.* 12(1), 147-179.

- Mensah, M.A., 2022. Cyanogenic Glycosides as Food Toxins. Analysis of Naturally Occurring Food Toxins of Plant Origin, 25-52.
- Minvielle, F., 2009. What are quail good for in a chicken-focused world? Worlds Poult. Sci. J. 65(4), 601—608.
- Mir, N.A., Rafiq, A., Kumar, F., Singh, V. & Shukla, V., 2017. Determinants of broiler chicken meat quality and factors affecting them: a review. J. Food Sci. Technol. 54, 2997-3009.
- Mnisi, C.M. & Mlambo, V., 2018. Growth performance, hematology, and serum biochemistry and meat quality characteristics of Japanese quail (*Coturnix coturnix japonica*) fed canola meal-based diets. Animal Nutrition, 4, 37–43.
- Mnisi, C.M., Marareni, M., Manyeula, F. & Madibana, M.J., 2021. A way forward for the South African quail sector as a potential contributor to food and nutrition security following the aftermath of COVID-19: a review. Agric. Food Secur. 10(1), 1-12.
- Mnisi, C.M., Oyeagu, C.E., Akuru, E.A., Ruzvidzo, O. & Lewu, F.B., 2023. Sorghum, millet and cassava as alternative dietary energy sources for sustainable quail production—A review. Front. Anim. 4, 1066388.
- Mohammed, B.R. & Ejiofor, C., 2015. The prospects and limitations of Japanese quail (*Coturnix coturnix japonica*) production in Nigeria-a review. Int. J. Multidiscip. Curr. Res. 3(4), 920-926.
- Mohammed, H.H., Said, E.N. & Abdel-Hamid, S.E., 2017. Impact of different litter materials on behaviour, growth performance, feet health and plumage score of Japanese quail (*Coturnix japonica*). Eur. Poult. Sci. 81(172).
- Molino, A.B., Garcia, E.A., Santos, G.C., Vieira Filho, J.A., Baldo, G.A.A. & Paz, I.A., 2015. Photostimulation of Japanese quail. Poult. Sci. 94(2), 156-161.
- Morne, P., 2017. Facts and Trends SA: Agriculture. Production vs Demand, South Africa, Pretoria, 1–3.

- Mondry, R., 2016. Quail farming in tropical regions. CTA.
- Montagnac, J.A., Davis, C.R. & Tanumihardjo, S.A., 2009. Nutritional value of cassava for use as a staple food and recent advances for improvement. *Com. Rev. Food Sci. Food Saf.* 8(3), 181-194.
- Mora, L.M., Moura, A.S.A.M.T., Scapinello, C., Bicudo, S.J., Araújo, I.G., Curcelli, F. & Barros, T.F.M., 2014. Digestible energy of unpeeled cassava root meal and its effect on growth performance and carcass traits in rabbits. *World Rabbit. Sci.* 22(2), 105-111.
- Mundia, C. W., Silvia, S., Kofi, A., & Wang, G., 2019. A regional comparison of factors affecting global sorghum production: The case of north America, Asia and Africa's Sahel. *Sustainability.* 11, 2135.
- Murdia, L.K., Wadhwani, R., Wadhawan, N., Bajpai, P. & Shekhawat, S., 2016. Maize utilization in India: an overview. *Am. J. Food Nutr.* 4(6), 169-176.
- Mutha, R.E., Tatiya, A.U. & Surana, S.J., 2021. Flavonoids as natural phenolic compounds and their role in therapeutics: An overview. *Futur. J. Pharm. Sci.* 7, 1-13.
- Morgan, N.K. & Choct, M., 2016. Cassava: Nutrient composition and nutritive value in poultry diets. *Anim. Nutr.* 2(4), 253-261.
- Mottet, A. & Tempio, G., 2017. Global poultry production: current state and future outlook and challenges. *Worlds Poult. Sci. J.* 73(2), 245-256.
- Moura, A.M.A., Melo, T.V. & Miranda, D.J.A., 2016. Synthetic pigments for Japanese quail fed diets with sorghum. *J. Vet. Anim. Sci.* 68, 1007-1014.
- Musigwa, S., Morgan, N., Swick, R., Cozannet, P. & Wu, S.B., 2021. Optimisation of dietary energy utilisation for poultry—a literature review. *Worlds Poult. Sci. J.* 77(1), 5-27.
- Nagy, K.A., 1987. Field metabolic rate and food requirement scaling in mammals and birds. *Ecol. Monogr.* 57(2), 111-128.

- Nambisan, B., 2011. Strategies for elimination of cyanogens from cassava for reducing toxicity and improving food safety. *Food Chem. Toxicol.* 49(3), 690-693.
- Nasar, A., Rahman, A., Hoque, N., Talukder, A.K. & Das, Z.C., 2016. A survey of Japanese quail (*Coturnix coturnix japonica*) farming in selected areas of Bangladesh. *Vet. World.* 9(9), 940.
- Newkirk, R., 2010. Soybean: Feed industry guide. Canadian International Grains Institute. Winnipeg, Canada. 26-35.
- Ngiki, Y.U., Igwebuike, J.U. & Moruppa, S.M., 2014. Utilisation of cassava products for poultry feeding: A review. *Int. J. Sci. Technol.* 2(6), 48.
- Nuwamanya, E., Baguma, Y. & Rey, M.C., 2016. An African perspective: developing an African bioresource-based industry—the case for cassava. In *Creating Sustainable Bioeconomies* (135-147). Routledge.
- Nyirenda, K.K., 2020. Toxicity potential of cyanogenic glycosides in edible plants. *Med. Toxicol.* 1-19.
- Okereke, C.O., 2012. Utilization of cassava, sweet potato, and cocoyam meals as dietary sources for poultry. *World J. Eng. Pure Appl. Sci.* 2(2), 63.
- Okoth, R.A., Matofari, J.W. & Nduko, J.M., 2022. Effectiveness of *Levilactobacillus brevis* fermentation on antinutrients and protein quality of leaves of selected cassava varieties. *Appl. Food Res.* 2(2), 100134.
- Omage, J. J., Agubosi, O.C.P., Bawa, G.S. & Onimisi, P.A., 2009. Evaluation of the nutritive value of quality protein maize on the growth performance and carcass characteristics of weaner rabbits. *Pak. J. Nutr.* 8(2), 106-111.
- Orr, A., Schipmann-Schwarze, C., Gierend, A., Nedumaran, S., Mwema, C., Muange, E., Manyasa, E. & Ojulong, H., 2020. Why invest in Research & Development for sorghum

- and millets? The business case for East and Southern Africa. *Glob. Food Sec.* 26, 100458.
- Panghal, A., Munezero, C., Sharma, P. & Chhikara, N., 2019. Cassava toxicity, detoxification and its food applications: a review. *Toxin Rev.* 40(1), 1-16,
- Parmar, A., Sturm, B. & Hensel, O., 2017. Crops that feed the world: Production and improvement of cassava for food, feed, and industrial uses. *Food Secur.* 9(5), 907-927.
- Peng, S. & Broom, D.M., 2021. The sustainability of keeping birds as pets: Should any be kept? *Animals*, 11(2), 582.
- Polkinghorne, R.J. & Thompson, J.M., 2010. Meat standards and grading: A world view. *Meat Sci.*, 86(1), 227-235.
- Priti, M. & Satish, S., 2014. Quail farming: an introduction. *Int. J. Life Sci.* 2(2), 190-193.
- Qaisrani, S.N., Murtaza, S., Khan, A.H., Bibi, F., Iqbal, S.M.J., Azam, F., Hussain, I. & Pasha, T.N., 2019. Variability in millet: Factors influencing its nutritional profile and zootechnical performance in poultry. *J. Appl. Poult. Res.* 28(2), 242-252.
- Quaye, W., Gayin, J., Yawson, I. & Plahar, W.A., 2009. Characteristics of various cassava processing methods and the adoption requirements in Ghana. *J. Root Crops*, 35(1), 59-68.
- Raber, J.M., Niekrasz, M., Linkenhoker, J. & Perdue, K.A., 2017. Veterinary Care. Management of Animal Care and Use Programs in Research, Education, and Testing, 733-770.
- Ravindran, V., 2013. Poultry feed availability and nutrition in developing countries. *Poult. Dev. Rev.* 2, 60-63.
- Rai, K.N., Gowda, C.L.L., Reddy, B.V.S. & Sehgal, S., 2008. Adaptation and potential uses of sorghum and pearl millet in alternative and health foods. *Compr. Rev. Food Sci. Food Saf.* 7(4), 320-396.

- Reincke, K., Vilvert, E., Fasse, A., Graef, F., Sieber, S. & Lana, M.A., 2018. Key factors influencing food security of smallholder farmers in Tanzania and the role of cassava as a strategic crop. *Food Secur.* 10, 911-924.
- Riber, A.B., 2020. Welfare issues affecting broiler breeders. In *Understanding the behaviour and improving the welfare of chickens*. Burleigh Dodds Science Publishing, 227-260.
- Rocha-e-Silva, R.C., Cordeiro, L.A.V. & Soto-Blanco, B., 2010. Cyanide toxicity and interference with diet selection in quail (*Coturnix coturnix*). *Comp. Biochem. Physiol. C Toxicol. Pharmacol.* 151(3), 294-297.
- Rodde, C., Chatain, B., Vandeputte, M., Trinh, T.Q., Benzie, J.A. & De Verdal, H., 2020. Can individual feed conversion ratio at commercial size be predicted from juvenile performance in individually reared Nile tilapia *Oreochromis niloticus*? *Aquac. Rep.* 17, 100349.
- Rodríguez, M.C., Yépez, C.V., González, J.H.G. & Ortega-Toro, R., 2020. Effect of a multifunctional edible coating based on cassava starch on the shelf life of Andean blackberry. *Heliyon*, 6(5), e03974.
- Rondoni, A., Asioli, D. & Millan, E., 2020. Consumer behaviour, perceptions, and preferences towards eggs: A review of the literature and discussion of industry implications. *Trends Food Sci. Technol.* 106, 391-401.
- Saleh, A.S., Zhang, Q., Chen, J. & Shen, Q., 2013. Millet grains: nutritional quality, processing, and potential health benefits. *Compr. Rev. Food Sci. Food Saf.* 12(3), 281-295.
- Salim, H.M., Kruk, Z.A. & Lee, B.D., 2010. Nutritive value of corn distillers dried grains with solubles as an ingredient of poultry diets: A review. *Worlds Poult. Sci. J.* 66(3), 411-432.
- Salvador, E.M., Steenkamp, V. & McCrindle, C.M.E., 2014. Production, consumption and nutritional value of cassava (*Manihot esculenta crantz*) in Mozambique: An overview.

- Santhi, D. & Kalaikannan, A., 2017. Japanese quail (*Coturnix coturnix japonica*) meat: characteristics and value addition. *Worlds Poult. Sci. J.* 73(2), 337-344.
- Saparatnanan, W., Kanto, U., Juttupornpong S. & Engkagul A., 2005. Utilization of cassava meal and cassava leaf in layer diets on egg quality and protein content in egg: animals. In: *Proceedings of 43rd Kasetsart University Annual Conference*; Bangkok, Thailand. 43-52.
- Sarfraz, N. & Khan, I., 2021. Plasmonic gold nanoparticles (AuNPs): properties, synthesis and their advanced energy, environmental and biomedical applications. *Asian J. Chem.* 16(7), 720-742.
- Sari, M., Isik, S., Onk, K., Tilki, M.U.A.M.M.E.R. & Kirmizibayrak, T., 2012. Effects of layer age and different plumage colors on external and internal egg quality characteristics in Japanese quails (*Coturnix coturnix japonica*). *Eur. Poult. Sci.* 76(4), 254-258.
- Shields, S. & Greger, M., 2013. Animal welfare and food safety aspects of confining broiler chickens to cages. *Animals*, 3(2), 386-400.
- Sibanda, B., Mhlanga, M., Maphosa, M. & Sibanda, R., 2023. Feed potential of small cereal grains in poultry production in semi-arid areas: A review. *Cogent Food Agric.* 9(2), 2263969.
- Statista. Available online: <https://www.statista.com/statistics/1134833/production-of-maize-in-south-africa/> (August 2022).
- Stefanello, C., Santos, T.C., Murakami, A.E., Martins, E.N. & Carneiro, T.C., 2014. Productive performance, eggshell quality, and eggshell ultrastructure of laying hens fed diets supplemented with organic trace minerals. *Poult. Sci.* 93(1), 104-113.
- Sugiharto, S. & Ranjitkar, S., 2019. Recent advances in fermented feeds towards improved broiler chicken performance, gastrointestinal tract microecology and immune responses: A review. *Anim. Nutr.* 5(1), 1-10.

- Szabo, E.A., Jansson, E., Miles, D., Hambridge, T., Stanley, G., Baines, J. & Brent, P., 2010. Responding to incidents of low level chemical contamination in food. In Ensuring Global Food Safety. Academic Press. 411-437.
- Szafraniec, G.M., Szeleszczuk, P. & Dolka, B., 2022. Review on skeletal disorders caused by *Staphylococcus* spp. in poultry. Vet. Q. 42(1), 21-40.
- Taiwo, K.A., 2006. Utilization potentials of cassava in Nigeria: the domestic and industrial products. Food Rev. Int. 22(1), 29-42.
- Tamburawa, M.S., Abubakar, Z., Salisu, N., Wudil, A.A., Hassan, A.M., Ibrahim, U., Zango, M.H., Nasir, M., Umar, A.M. & Sa'idu, S.S., 2019. Effect of dietary utilization of cassava root (*Manihot esculenta*) meal on growth performance and carcass characteristics of broiler chickens at finisher phase. Niger. J. Anim. Sci. Technol. 2(2), 63-71.
- Talukdar, A., Kalita, K.P., Saikia, R. & Choudhury, D., 2020. Effect of using Moringa oleifera leaf meal on quality and sensory parameters of Japanese quail eggs. Pharma Innov. J. 9, 219-221.
- Tavaniello, S., 2014. Effect of cross-breed of meat and egg line on productive performance and meat quality in Japanese quail (*Coturnix japonica*) from different generations.
- Teles, F.F.F., 2002. Chronic poisoning by hydrogen cyanide in cassava and its prevention in Africa and Latin America. Food Nutr Bull. 23(4), 407-412.
- Tenenbaum, D.J., 2008. Food vs. fuel: diversion of crops could cause more hunger. Environmental Health Perspectives, 116, 254-257.
- Tesfaye, E., Animut, G., Urge, M. & Dessie, T., 2013. Cassava root chips as an alternative energy feed ingredient in broiler ration. Int. J. Poult. Sci. 12(5), 298-306.
- Thakur, A., Sharma, V. & Thakur, A., 2019. An overview of anti-nutritional factors in food. Int. J. Chem. Stud, 7(1), 2472-2479.

- Thirumalaisamy, G., Muralidharan, J., Senthilkumar, S., Hema Sayee, R. & Priyadharsini, M., 2016. Cost-effective feeding of poultry. *Int. J. Sci. Environ. Technol.* 5(6), 3997-4005.
- Toppo, S., Mandal, A.B. & Elangovan, A.V., 2004. Dietary energy and protein requirements of egg type (CARI Sonali) starting chicks. *Anim. Nutr. Feed Technol.* 4(1), 17-22.
- Udensi, E.A., Ukozor, A.U.C. & Ekwu, F.C., 2005. Effect of fermentation, blanching, and drying temperature on the functional and chemical properties of cassava flour. *Int. J. Food Prop.* 8(1), 171-177.
- Udoro, E.O., Anyasi, T.A. & Jideani, A.I.O., 2021. Process-induced modifications on quality attributes of cassava (*Manihot esculenta Crantz*) flour. *Processes*, 9(11), 1891.
- Ukachukwu, S.N., 2005. Studies on the nutritive value of composite cassava pellets for poultry: chemical composition and metabolizable energy. *Livest. Res. Rural Dev.* 17(11).
- Underwood, G., Andrews, D. & Phung, T., 2021. Advances in genetic selection and breeder practice improve commercial layer hen welfare. *Anim. Prod. Sci.* 61(10), 856-866.
- Urugo, M.M. & Tringo, T.T., 2023. Naturally Occurring Plant Food Toxicants and the Role of Food Processing Methods in Their Detoxification. *Int. J. Food Sci.* 2023.
- Varkoohi, S., Pakdel, A., Babak, M.M.S., Javaremi, A.N., Kause, A. & Zaghari, M., 2011. Genetic parameters for feed utilization traits in Japanese quail. *Poult. Sci.* 90(1), 42-47.
- Wang, Z., Mhaske, P., Farahnaky, A., Kasapis, S. & Majzoobi, M., 2022. Cassava starch: Chemical modification and its impact on functional properties and digestibility, a review. *Food Hydrocoll.* 129,107542.
- Whitehead, C.C., 2002. Nutrition and poultry welfare. *Worlds Poult. Sci. J.* 58(3), 349-356.
- Wilkinson, J.M., 2011. Re-defining efficiency of feed use by livestock. *Animal*, 5(7), 1014-1022.
- Willems, O.W., Miller, S.P. & Wood, B.J., 2013. Aspects of selection for feed efficiency in meat producing poultry. *Worlds Poult. Sci. J.* 69(1), 77-88.

- Yanza, Y.R., Fitri, A., Suwignyo, B., Hidayatik, N., Kumalasari, N.R., Irawan, A. & Jayanegara, A., 2021. The utilisation of tannin extract as a dietary additive in ruminant nutrition: A meta-analysis. *Animals*, 11(11), 3317.
- Zahra, S. A., Butt, Y. N., Nasar, S., Akram, S., Fatima, Q. & Ikram, J., 2021. Food packaging in perspective of microbial activity: a review. *J. Microbiol. Biotechnol. Food Sci.* 2021, 752-757.
- Zainuddin, I.M., Fathoni, A., Sudarmonowati, E., Beeching, J.R., Gruissem, W. & Vanderschuren, H., 2018. Cassava post-harvest physiological deterioration: From triggers to symptoms. *Postharvest Biol. Technol.* 142, 115-123.
- Zancanela, V., Marcato, S.M., Furlan, A.C., Grieser, D.O., Ton, A.P.S., Batista, E., Perine, T.P., Del Vesco, A.P. & Pozza, P.C., 2015. Models for predicting energy requirements in meat quail. *Livest. Sci.* 171, 12-19.
- Zanu, H.K., Azameti, M.K. & Asare, D., 2017. Effects of dietary inclusion of cassava root flour in broiler diets on growth performance, carcass characteristic and haematological parameters. *Int. J. Livest. Prod.* 8(3), 28-32.
- Zaheer, K., 2015. An updated review on chicken eggs: production, consumption, management aspects and nutritional benefits to human health. *Food Sci. Nutr.* 6(13), 1208.
- Zekarias, T., Basa, B. & Herago, T., 2019. Medicinal, nutritional and anti-nutritional properties of Cassava (*Manihot esculenta*): A review. *J. Nutr.* 8(3), 34-46.

3 CHAPTER THREE – EFFECT OF RAW OR THERMALLY-TREATED CASSAVA TUBER MEAL ON PRODUCTIVE PERFORMANCE AND EGG QUALITY PARAMETERS IN JUMBO QUAIL HENS

Abstract

The study was undertaken to evaluate the effect of complete replacement of maize with raw or heat-treated cassava tuber meal (CTM) on productive performance, egg quality parameters, egg shelf life and rate of lay in Jumbo quail hens. A total of 240, six-week-old, Jumbo quail hens ($191\text{g} \pm 16.60$ live-weight) were randomly allocated to 60 cages (4 birds/cage) and assigned to five experimental diets with 12 replicates each. The diets were formulated as follows: a standard layer mash diet without CTM (CON), and a standard layer mash diet in which 100% of maize meal was replaced with raw (CTMR), boiled (CTMB), autoclaved (CTMA) and oven-dried CTM (CTMO). Experimental diets and freshwater were offered *ad libitum* throughout the 12-week feeding trial. Feeding lasted for 8 weeks during which feed intake (FI), body weight gain (BWG) and egg weight (EW) were determined. Feed conversion ratio (FCR) was calculated as a ratio of FI and EW. Eggs were collected daily to calculate rate of lay (ROL), while external and internal egg quality parameters were measured in two-weeks interval from 9 – 14 weeks of age. At 13 weeks of age, five eggs per pen were collected and stored to measure shelf life at a 5-day interval. The raw or CTM samples had varied responses on amino acid composition (i.e., methionine, lysine and threonine), however, oven-dried CTM resulted in poor AA composition. Moreover, raw CTM samples tended to have the highest levels of neutral detergent fibre, acid detergent fibre and crude protein than the heat-treated samples. Autoclaved CTM samples tended to have a higher ether extract content than the other samples. Diet CON promoted higher ($P < 0.05$) overall FI than diet CTMB. Furthermore, birds on diet CTMB had lower ($P < 0.05$) overall BWG than birds on CON diet. However, birds on diet CON had the highest ($P < 0.05$) FBW, followed by those on diet CTMR and the lowest (P

<0.05) FBW was from those on diet CTMB. There were no dietary influences on overall FCR and mortality. Overall FCR and mortality were not ($P > 0.05$) affected by the dietary treatments. In week 14, CON diet caused higher ($P < 0.05$) rate of lay (ROL) than diet CTMR. In weeks 10, 12 and, 14 eggs from quail birds on CTMA diet had higher ($P < 0.05$) egg colour values compared to CTMB which promoted lower egg colour values. Furthermore, birds reared on diet CON had the least ($P < 0.05$) shape index than those on diet CTMO. Fourteen-week-old birds fed diet CTMB and CTMO had smaller ($P < 0.05$) egg diameter compared to those fed with diet CON. Moreover, diet CTMA resulted in heavier ($P < 0.05$) eggshell weights than diet CTMR. Diet CON resulted in the lowest ($P < 0.05$) yolk index and the highest was from diets CTMA and CTMR. It can be concluded that although quail hens reared on maize-based diet showed the best performance, autoclaving treatment of CTM was more effective than oven-drying and boiling treatments suggesting that autoclaving treatment could improve the utility of CTM in layer quail diets.

Keywords: Cassava, Egg quality, Energy sources, Layer quail, Live performance

3.1 Introduction

Layer quail farming has potential to meet the increased demand for poultry eggs as affordable sources of animal proteins worldwide (Redoy *et al.*, 2017). Eggs are one of the most frequently consumed food items in the world, with the highest consumption being chicken eggs (Morris *et al.*, 2018). The consumption of eggs has risen by 14.1% per capita from 2010 to 2019 (FAO, 2022). Eggs have various industrial applications apart from the food sector. Thus, fast growing and highly prolific quail birds can be used to bridge the supply and demand gaps for eggs. Overall, quail are renowned for their fast growth rates, ability to reach maturity quickly, and high rate of egg production (300 – 320 egg/laying cycle). They are also known for their lower bird density requirements (200 – 250 and 150 – 200 cm², respectively in litter and cage system), lower feed consumption (20 – 25 g/adult bird/day) and lower susceptibility to common poultry diseases (Northcutt *et al.*, 2022). Quail eggs have a high nutritional profile with reported average values of nutrients; 13.1% protein, 1.1% minerals, and 11.2% lipids, (Panda & Singh, 1990). The 59 mg/100 g calcium, 220 mg/100 g phosphorus, 3.8 mg/100 g iron, 300 IU vitamin A and 158 Kcal energy contents per 100 g are 59 mg, 220 mg, 3.8 mg, 300 IU and 158 Kcal, respectively (Panda & Singh, 1990; Silva *et al.*, 2020).

However, sustainable layer quail production is currently restricted by high feed costs, which constitute more than 70% of total production costs (Abdurofi *et al.*, 2017). This is exacerbated by the reliance on maize, as a major energy source in conventional poultry diets (Ahiwe *et al.*, 2018). In most African countries, maize is considered a staple food source in the African continent and its market price vary depending on demand and availability (Dei, 2017). In tropical countries such as South Africa, maize production does not meet local demand due to erratic climatic conditions and the shortfalls are usually covered by foreign imports (Shiferaw *et al.*, 2011), hence its continuous use in poultry diets poses socio-economic and environmental sustainability challenges. Alternatively, highly adaptable and local plants such as cassava

(*Manihot esculenta*) can be propagated (Ngiki *et al.*, 2017) and used to support sustainable layer quail production. In South Africa, cassava tubers have little food value (Mnisi *et al.*, 2023) than maize and its use in quail feeds could reduce high feed-food competitions. Cassava tubers have a high energy value, which is comparable to maize. Moreover, cassava can be cultivated easily in tropical and subtropical regions, making it a readily available feed ingredient for small-scale poultry farmers (Ngiki *et al.*, 2017). However, raw cassava tubers contain secondary metabolites (such as cyanogenic glycosides) that can negatively affect nutrient utilisation and egg production in layers (Morgan & Choct, 2016). Therefore, it is important to adopt putative treatment methods, such as autoclaving, boiling and oven-drying to improve the nutritional value of cassava tuber meal (CTM) prior to its incorporation in layer quail diets. Thermal treatments (i.e., boiling and oven-drying) have been reported to reduce cyanogenic glycosides in cassava (Devi & Diarra, 2021). Similarly, autoclaving treatment has been recognised as an effective method to reduce cyanide levels by 29.7% (Feng *et al.*, 2003). According to Zainuddin *et al.* (2018), reducing the risk of cyanide poisoning depends on the employed treatment method. However, no studies have been reported to improve the feeding value of CTM with thermal treatments for use in layer quail diet. Thus, we evaluated the effects of total replacement of maize with raw or heat-treated CTM on productive performance and egg quality parameters in Jumbo quail hens. It was hypothesized that heat-treated CTM would improve performance and egg quality metrics compared to raw CTM when included in place of maize in a standard layer quail diet.

3.2 Materials and methods

3.2.1 Ethics statement

All employed procedures from feeding to slaughter were reviewed and approved by the North-West University's Animal Production Research Ethics Committee (approval no. NWU-00814.22-A5).

3.2.2 Study site

The study was conducted at Molelwane research farm (25°40.459' S, 26°10.56'E), which is situated in Mafikeng (North West, South Africa). Ambient temperatures around the area ranges between 20 and 37°C in summer and from -3 to 25°C in winter (Marareni *et al.*, 2020). The region receives 300 – 600 mm of annual rainfall (Marareni *et al.*, 2020).

3.2.3 Cassava procurement and processing

Fresh cassava tubers were acquired from a small-holder farmer in Masibekela village (25.8692° S, 31.8136° E) near Komatipoort town (Mpumalanga, South Africa). The tubers were transported to Molelwane farm where they were immediately peeled and sliced using hand knives, washed, and then sun-dried to constant weight. The tubers were equally divided into four groups from which three groups were subjected to boiling, autoclaving and oven-drying while the remaining was not processed. The processing methods were as follows:

- 1) *Boiling*: The tubers were boiled using tap water in a conventional stove set at a temperature range of 86 – 100°C for 40 minutes (Ismaila *et al.*, 2018).
- 2) *Autoclaving*: The tubers were placed in an autoclave (3870E Heidolph, Tuttnaeur, New York, USA) and set at a temperature of 121°C (7 psi) for 15 minutes.
- 3) *Drying*: The tubers were further sliced into ~10 mm pieces and oven-dried (Memmert Universal Oven UF 450, Federal Republic of Germany) at 55°C for 3 h (Dahal & Tamang, 2021).

Prior to laboratory analysis, the raw or heat-treated cassava samples were air-dried and ground to pass through a 1 mm sieve and then stored in pre-labelled airtight bags.

3.2.4 Laboratory analyses

Following the Association of Official Analytical Chemists (2005) international procedures, CTM was analysed in the lab for dry matter (DM), crude protein (CP), crude fibre (CF), ether extract (EE), and ash prior to being added to the feed. For a chemical analysis, CTM was milled to pass through a 1 mm sieve. Approximately 1 g of CTM was placed into pre-weighed crucibles and oven-dried at 105°C for 12 h to determine DM (method no. 930.15). The samples were removed from the oven after 12 hours, placed in desiccators to cool, and then weighed. The difference between the initial sample weight and the moisture weight was used to calculate the DM. After CTM was incinerated at 550°C for 12 hours, the ash content was calculated using the AOAC (method no. 942.05), the loss in weight and the remaining residues ash. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and crude fibre (CF) were analysed using an ANKOM^{DELTA} Fibre Analyser (ANKOM Technology, NY, USA) following the detergent methods by Van Soest *et al.* (1991). The NDF and ADF were determined by refluxing about 0.45 to 0.5 g samples with the neutral detergent solution for 1 h and acid detergent solution for 1 h 15 min, respectively. A heat stable α -amylase was used in determining NDF and was expressed inclusive of residual ash. The CF was determined using crude acid solution (0.255 N) followed by a crude base solution (0.313 N). Ether extract (EE) was determined using an ANKOM XT-20 extractor (ANKOM Technology, NY, USA) for 60 minutes (using Ethyl Ether as solvent). Samples for gross energy (GE) were analysed at the University of Pretoria (Gauteng, South Africa). Samples for CTM samples were analysed for amino acids (AA) at Stellenbosch University (Western Cape, South Africa) by hydrolysis of proteins using standard 6 M HCl acid digestion (AOAC method no. 982.30) followed by chromatographic

analysis using a Waters Acquity Ultra Performance Liquid Chromatograph (AccQ-Tag Ultra; Waters Corporation, Milford, NH, USA).

A modified method for determining free and potential cyanide in cassava roots was used to measure the HCN content (Brito *et al.*, 2009). This method uses the endogenous linamarase enzyme to hydrolyse linamarin and release CN-free cyanide, which was then measured using a colorimetric reaction with picrate solution. Exactly 5 g of prepared sample was taken in clean mortar and pestle. The extraction was then performed in 50 mL of distilled water by homogeneously milling the mixture for 1 to 2 minutes. The extract was filtered through Whatman No. 42 filter paper, which had a medium level of retention. The filtrate was then taken, and 5 mL of the aliquot was transferred to a clean test tube followed by the addition of 10 mL of alkaline picrate and 5 mL of distilled water. Similarly, a blank was made with each set of samples containing 0 mL of sample filtrate, 10 mL of alkaline picrate, and 5 mL of distilled water. The test tubes containing the sample and colourants were incubated in a water bath at 37°C for 15 minutes. Then, 15 µL of sulfuric acid was added to stop the reaction and increase the stability of reading. After thoroughly shaking each sample and the blank, the absorbance was measured at 535 nm. The HCN content was calculated using the formula below:

$$HCN \text{ content (mg/kg)} = \frac{(Y \times 50 \times 1000)}{(5 \times \text{sample weight})}$$

Where, $Y = 0.0304x + 0.0054$ ($R^2 = 0.9688$) and x = absorbance.

3.2.5 Diet formulation and analysis

Five isocaloric and isonitrogenous diets were formulated to be in a mash form according to the NRC (1994) guidelines to meet the nutritional requirement of layer quail (Table 3.1). The diets were formulated as follows: 1) CON = a standard layer mash diet without CTM, 2) CTMR = a standard layer mash diet in which 100% of maize meal was replaced with raw CTM, 3) CTMB = a standard layer mash diet in which 100% of maize meal was replaced with boiled CTM, 4) CTMA = a standard layer mash diet in which 100% of maize meal was replaced with autoclaved CTM, and 5) CTMO = a standard layer mash diet in which 100% of maize meal was replaced with oven-dried CTM. The nutritional composition of the diets was determined using the methods described in Section 3.2.4 and is presented in Table 3.1

Table Error! No text of specified style in document..**1.** Ingredient composition (g/kg as fed basis) of diets containing pre-treated cassava tuber meal and calculated values.

Ingredients	¹ Dietary treatments	
	CON	CTMd
Cassava tuber meal	0	437.3
Yellow maize (8,5%)	437.3	0
Soya oilcake (44%)	350.6	350.6
Sunflower oilcake (38%)	68.4	68.4
DL-Methionine	1.4	1.4
Lysine-HCL	1.0	1.0
Soya oil	65.1	65.1
Monocalcium-phosphate	56.1	56.1
Fine salt	1.6	1.6
Sodium bicarbonate	15.4	15.4
² Premix	3	3
Zinc bacitracin	0.055	0.055

¹Dietary treatments: CON = a standard layer mash diet without cassava tuber meal; CTMd = a standard layer mash diet in which maize was replaced with 100% cassava tuber meal.

²Premix: biotin (0.12 g), copper sulfate (8.0 mg), folic acid (0.7 mg), ferrous sulfate (80 mg), magnesium sulfate (100 mg), niacin (30 mg), pantothenic acid (10 mg), potassium iodide (0.34 mg), sodium selenite (0.25 mg), and zinc sulfate (79 mg), vitamin A (11,000 IU), vitamin B₁ (2.5 mg), vitamin B₂ (4.5 mg), vitamin B₆ (5.1 mg), vitamin D₃ (2,500 IU), vitamin E (25 IU), vitamin K₃ (2.0 mg).

3.2.6 Feeding management and experimental design

A total of 240, five-week-old Jumbo quail hens were purchased from Quailish Farm in Pretoria South Africa and transported by road to Molelwene Farm, following appropriate animal welfare guidelines. The hens were weighed upon arrival at Molelwane and the individual weights were used to evenly and randomly assign them into 60 cages (experimental units in one house) to produce 12 replicates per dietary treatment. Each cage (34 cm L × 27.5 cm W × 30 cm H) carried 4 hens and polythene sheets were used as bedding. An oral stress pack (electrolytes and vitamins) was administered for the first 3 days and the hens were accustomed to the cages and dietary treatments for a week before the commencement of measurements from 6 to 14 weeks. Clean water and experimental diets were supplied *ad libitum* on a daily basis using drinkers (1 L) and feeders (500 g). Regular washing and refilling of drinkers and feeders were done to avoid contaminations. The house temperature (30 – 33 °C) and humidity (60%) were monitored by hygrometer and adjusted using electric bulbs and heaters since the experiment was conducted in winter (May – July 2023) and rearing was conducted under natural lighting (12 h of daylight).

3.2.7 Productive performance

Collection and measurement of feed refusals was done daily before giving fresh feed to estimate FI per pen. The live weights of the birds were measured on a weekly basis from week 6 to week 14 of age. All the birds were weighed at the beginning of the trial to determine the initial weights (191 ± 16.60 g live-weight) and thereafter weighed weekly to determine body weight gain (BWG) according to the following formula:

$$BWG = \frac{W_{T_f} - W_{T_i}}{T_f - T_i}$$

Where, W_{T_f} is the final body weight per bird, W_{T_i} is the initial weight per bird, T_f is the final time (in days) and T_i is the initial time (in days).

Eggs were collected daily at 08H00 from week 7 to calculate rate of lay (ROL) using the following formula:

$$ROL (\%) = \frac{NE}{NH} \times 100$$

Where, NE is the number of eggs collected, and NH is the number of hens. The collected eggs were weighed (HM-200, A & D Co., Ltd., Tokyo, Japan) to determine egg weights (EWT). Mortalities were recorded on occurrence and the data was used to correct for feed conversion ratio (FCR), which was calculated as a ratio of FI and EWT. Mortality (%) was calculated as follows:

$$Mortality (\%) = \frac{\text{No. birds died per diet}}{\text{Total no. of birds per diet}} \times 100$$

3.2.8 Egg quality parameters

3.2.8.1 External parameters

An Electronic Digital Calliper was used to measure egg diameter/width and egg length. Shape index (SI) was calculated as ratio of egg width and egg length. Egg strength was measured using digital egg tester (DET-6500, Nabel Co., Ltd., Kyoto, Japan). Eggs were broken and the egg shells were washed with distilled water and dried at room temperature for three days. Thereafter, the shell weight (SW) was measured using a digital balance. Shell thickness (ST) was measured using a Digimatic Thickness Gauge (Mitutoyo 547-301, Kanagawa, Japan). Shape index (SI) and yolk index were calculated as follows:

$$Shape Index (\%) = \frac{Egg\ width}{Egg\ length} \times 100$$

3.2.8.2 Internal parameters

The eggs were cracked onto a flat surface, where an Electronic Digital Calliper was used to measure the yolk diameter, albumen and yolk heights. Yolk colour (YC) was determined using the Digital Yolk Colour FanTM (DSM, Gauteng, South Africa) whilst the egg was broken on

the flat surface. Haugh unit was calculated using the egg weight and albumen height (Haugh, 1937). The following formula was used to calculate Haugh unit:

$$\text{Haugh unit (HU)} = 100 \times \log(AH - 1.7 \times EW^{0.37} + 7.6)$$

Where, AH = average height of the albumen (mm) and EW = weight of egg (g).

$$\text{Yolk index} = \frac{\text{Yolk height}}{\text{Yolk diameter}}$$

3.2.9 Statistical analysis

The NORMAL option in the Proc Univariate statement was used to test for normality of the measured parameters. Data for productive performance and egg quality parameters were analysed using one-way ANOVA by means of general linear model procedure (PROC GLM) of SAS 9.4 (2013). The linear statistical model will be as follows:

$$Y_{ij} = \mu + D_i + E_{ij}$$

Where: Y_{ij} is the dependant variable, μ is the population mean, D_i is the effect of diets, and E_{ij} is the random error associated with observation ij , assumed to be normally and independently distributed. For all the statistical tests, significance was declared at $P < 0.05$, and the least square means (LSMeans) were separated using the probability of difference option in the LSMeans statement in SAS.

3.3 Results

3.3.1 Chemical components and essential amino acids of substrates and diets

Table 3.2 shows that raw CTM sample tended to have higher gross energy values than the heated-treated CTM samples. However, raw CTM sample tended to have the lowest DM, OM and ash contents, while oven-dried CTM had the highest OM content. Furthermore, raw CTM samples had the highest NDF, ADF, CF, and CP in comparison to the heated-treated CTM samples. However, autoclaved CTM samples tended to have the highest EE content than the other samples. Oven-dried CTM samples tended to have a poor concentration of essential AAs than the other samples. Raw CTM sample tended to have highest hydrogen cyanide (6.24 mg/kg HCN), followed by boiled CTM, autoclaved CTM and the lowest was from oven-dried CTM.

Table Error! No text of specified style in document..**2.** Proximate constituents (g/kg DM, unless stated otherwise) and essential amino acids (g /100 g DM) of raw or thermally-treated cassava tuber meal samples

	Cassava substrates ¹			
	_R CAS	_A CAS	_B CAS	_O CAS
Gross energy (Kcal/kg)	3,718.5	3,684.8	3,684.8	3,697.7
Dry matter (g/kg)	425.3	535.0	578.1	651.5
Organic matter	401.3	508.5	549.4	623.6
Ash	24.0	26.4	28.7	27.9
Neutral detergent fibre	236.1	149.5	151.8	164.9
Acid detergent fibre	107.0	75.1	71.1	63.3
Ether extract	85.0	89.8	86.6	52.9
Crude fibre	150.2	108.0	94.4	121.8
Crude protein	65.1	48.2	60.7	57.8
Histidine	0.07	0.06	0.08	0.08
Arginine	0.17	0.11	0.15	0.20
Threonine	0.08	0.08	0.08	0.08
Lysine	0.14	0.07	0.13	0.10
Methionine	0.08	0.00	0.07	0.07
Valine	0.12	0.11	0.12	0.11
Isoleucine	0.09	0.09	0.10	0.10
Phenylalanine	0.09	0.08	0.10	0.10
Leucine	0.16	0.16	0.18	0.17
² HCN (mg/kg)	6.24	3.62	4.98	3.16

¹Substrates: _RCASS = raw cassava tuber meal; _ACASS = autoclaved cassava tuber meal;

_BCASS = boiled cassava tuber meal; _OCASS = oven-dried cassava tuber meal.

²HCN = Hydrogen cyanide.

Table 3.3 shows the calculated metabolizable energy, proximate composition, and essential amino acids of dietary treatments. The gross energy tended to be higher in CTMR than in other diets. Crude fat in CON diet was found to be higher compared to other diets. Diet CTMO had numerically lower DM, ash and OM values than the other diets. Diet CTMR tended to have the lowest NDF and crude fibre values compared to other treatments, with the exception for ADF, which tended to be highest in CTMA. In addition, CON tended to have lower CP than the heat-treated CTM-containing diets. Diet CTMB tended to have lower essential AAs than other dietary treatments, except for lysine and methionine which tended to be higher in CTMB and CTMO, respectively.

Table Error! No text of specified style in document..**3. Proximate composition (g/kg DM, unless stated otherwise) and essential amino acids (g /100 g DM) of dietary treatments.**

	¹ Experimental diets				
	CON	CTMR	CTMA	CTMB	CTMO
Gross energy (Kcal/kg)	4,073	4,079	4,007	4,151	3,955
Dry matter (g/kg)	910.5	908.2	906.8	900.8	911.9
Organic matter (g/kg)	821.8	811.7	806.8	805.4	816.2
Neutral detergent fibre (g/kg DM)	115.3	92.4	106.5	103.9	106.4
Acid detergent fibre (g/kg DM)	54.0	55.9	67.7	62.5	66.3
Crude fat (g/kg DM)	283.9	226.9	252.1	265.3	265.8
Crude fibre (g/kg DM)	103.2	94.5	117.9	117.0	116.0
Crude protein (g/kg DM)	225.4	236.4	229.5	237.7	236.2
Ash (g/kg)	88.7	96.5	100.0	95.4	95.7
Histidine (g /100 g DM)	0.70	0.65	0.63	0.38	0.55
Arginine (g /100 g DM)	1.69	1.74	1.60	1.35	1.71
Threonine (g /100 g DM)	0.94	0.94	0.92	0.73	0.89
Lysine (g /100 g DM)	1.38	0.93	1.30	2.11	1.16
Methionine (g /100 g DM)	0.44	0.51	0.43	0.52	0.58
Valine (g /100 g DM)	1.17	1.06	1.02	0.96	1.06
Isoleucine (g /100 g DM)	1.03	0.94	0.93	0.89	0.96
Leucine (g /100 g DM)	2.00	1.67	1.60	1.57	1.73
Phenylalanine (g /100 g DM)	1.05	1.10	1.05	0.65	0.97
² HCN (mg/kg)	24.7	34.7	25.5	45.8	28.1

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

²HCN = Hydrogen cyanide.

3.3.2 Productive performance

Table 3.4 shows effects of complete maize replacement with raw or thermally-treated CTM on productive performance traits of Jumbo quail hens. There were no significant dietary effects on initial body weight, overall FCR and overall mortality. Diet CON promoted higher ($P < 0.05$) overall FI than diet CTMB, but both groups were similar ($P > 0.05$) to diets CTMO, CTMR and CTMA. Birds on diet CTMB had lower ($P < 0.05$) overall BWG than birds on CON diet. However, the CTMA and CTMR groups had similar ($P > 0.05$) overall BWG as the CON group. Diet CTMB was statistically similar ($P > 0.05$) to diet CTMO, but both diets were different ($P < 0.05$) to diet CON. Furthermore, birds on diet CON had the highest ($P < 0.05$) FBW, followed by those on diet CTMR and the lowest ($P < 0.05$) FBW was from those on diet CTMB. Nonetheless, both diets (CTMB and CTMR) were statistically similar to diets CTMA and CTMO in terms of FBW.

Table Error! No text of specified style in document..**4.** Effect of complete maize replacement with raw or thermally-treated cassava tuber meal on productive performance traits (means $\pm$ standard error; g/bird, unless indicated otherwise) of Jumbo quail hens.

² Parameters	¹ Experemental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
Initial body weight	202.2 $\pm$ 4.67	189.7 $\pm$ 4.67	185.0 $\pm$ 4.67	191.0 $\pm$ 4.67	187.1 $\pm$ 4.67	0.101
Overall FI	1994 $\pm$ 42.8 ^a	1887 $\pm$ 42.8 ^{ab}	1826 $\pm$ 42.8 ^{ab}	1760 $\pm$ 42.8 ^b	1906 $\pm$ 42.8 ^{ab}	0.005
Overall BWG	86.0 $\pm$ 5.08 ^a	67.1 $\pm$ 5.08 ^{ab}	67.5 $\pm$ 5.08 ^{ab}	41.6 $\pm$ 5.08 ^c	61.7 $\pm$ 5.08 ^{bc}	<0.0001
Final body weight	288.2 $\pm$ 5.41 ^a	256.7 $\pm$ 5.41 ^b	252.4 $\pm$ 5.41 ^{bc}	232.6 $\pm$ 5.41 ^c	248.8 $\pm$ 5.41 ^{bc}	<0.0001
Overall FCR (g:g)	3.0 $\pm$ 0.11	3.1 $\pm$ 0.11	2.9 $\pm$ 0.11	2.7 $\pm$ 0.11	2.7 $\pm$ 0.11	0.557
Overall mortality (%)	0.0 $\pm$ 4.11	4.8 $\pm$ 4.11	11.8 $\pm$ 4.11	8.3 $\pm$ 4.11	2.9 $\pm$ 4.11	0.293

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

²Parameters: FI = feed intake; BWG: body weight gain; FCR = feed conversion ratio (feed intake / egg weight).

3.3.3 Rate of lay

Table 3.5 shows the influence of diets containing raw or thermally-treated CTM on egg production of Jumbo quail hens. There were no dietary effects ($P > 0.05$) on rate of lay (ROL) in weeks 8, 10 and 12, except in week 14 ($P < 0.05$). Fourteen-week-old birds fed the CON diet had higher ($P < 0.05$) ROL than diet CTMR, but both groups were similar ($P > 0.05$) to all the other three groups. There were no significant dietary effects ($P > 0.05$) on egg weight of Jumbo quail hens from week 9 to week 14.

Table Error! No text of specified style in document..**5.** Effect of completely replacing maize with raw or thermally-treated cassava tuber meal on rate of lay (means $\pm$ standard error; 7 – 14 weeks) and egg weight (9 – 14 weeks)

	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
<i>Rate of Lay (%)</i>						
Week 8	1.79±0.818	2.43±0.818	1.39±0.818	1.19±0.818	0.00±0.818	0.323
Week 10	19.9±3.976	15.5±3.976	16.2±3.976	16.0±3.976	7.9±3.976	0.318
Week 12	45.6±5.203	28.7±5.203	39.7±5.203	34.0±5.203	34.7±5.203	0.213
Week 14	67.5±4.35 ^a	49.2±4.35 ^b	61.8±4.35 ^{ab}	53.6±4.35 ^{ab}	52.0±4.33 ^{ab}	0.025
<i>Egg weight (g)</i>						
Week 10	11.3±0.361	10.8±0.381	11.7±0.361	11.2±0.432	11.1±0.404	0.572
Week 12	11.2±0.340	10.9±0.340	11.2±0.340	11.2±0.340	10.9±0.340	0.887
Week 14	12.0±0.253	11.0±0.253	11.5±0.253	11.2±0.253	11.4±0.253	0.073

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

3.3.4 External and internal egg quality parameters

Table 3.6 shows effects of diets containing raw or thermally-treated CTM on external egg quality parameters of Jumbo quail hens. There were no significant dietary effects on external egg parameters, with the exception of shape index in week 10, and egg diameter and shell weight in week 14. Ten-week-old birds reared on diet CON produced eggs with the least ($P < 0.05$) shape index than those on diet CTMO. However, both groups were similar ($P > 0.05$) to the CTMR, CTMA and CTMB groups. Fourteen-week-old birds fed diet CTMB and CTMO produced eggs with smaller ($P < 0.05$) diameter compared to those fed with diet CON. Nonetheless, all three groups were similar ($P > 0.05$) to diets CTMR and CTMA. Diet CTMA resulted in heavier egg shell weight in fourteen-week-old birds than diet CTMR, but both groups were statistically similar ($P > 0.05$) to diets CON, CTMO and CTMB.

Table Error! No text of specified style in document..6. Effect of completely replacing maize with raw or thermally-treated cassava tuber meal on external egg quality parameters (mean $\pm$ standard error) of Jumbo quail hens from 9 -14 weeks

	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
<i>Week 10</i>						
Egg diameter (mm)	25.0±0.271	25.1±0.286	25.4±0.271	25.1±0.324	25.3±0.303	0.791
Egg length (mm)	33.4±0.394	32.6±0.416	33.0±0.394	33.2±0.471	32.6±0.441	0.574
Shell thickness (mm)	0.19±0.005	0.19±0.006	0.19±0.005	0.17±0.006	0.18±0.006	0.288
Haugh unit	84.4±0.01	85.1±0.355	84.5±0.336	84.8±0.402	84.9±0.376	0.531
Shell weight (g)	1.65±0.114	1.46±0.120	1.53±0.114	1.39±0.136	1.41±0.127	0.546
Shape index (%)	75.0±0.584 ^b	77.1±0.615 ^{ab}	77.2±0.584 ^{ab}	75.7±0.698 ^{ab}	77.8±0.653 ^a	0.015
Shell (%)	12.7±0.355	13.6±0.397	13.2±0.355	12.6±0.424	12.7±0.397	0.337
Breaking strength (N)	1.26±0.166	1.13±0.175	1.26±0.166	1.20±0.198	1.61±0.198	0.464
<i>Week 12</i>						
Egg diameter (mm)	25.1±0.278	25.4±0.278	25.3±0.278	25.1±0.278	25.0±0.278	0.858
Egg length (mm)	32.9±0.355	32.4±0.355	32.7±0.355	32.2±0.355	32.6±0.355	0.676
Shell thickness (mm)	0.18±0.004	0.19±0.004	0.19±0.004	0.18±0.004	0.19±0.004	0.104
Haugh unit	85.0±0.246	85.4±0.246	84.9±0.246	85.2±0.246	85.5±0.246	0.386
Shell weight (g)	1.38±0.041	1.35±0.041	1.44±0.041	1.34±0.041	1.35±0.041	0.447
Shape index (%)	76.6±0.608	77.9±0.608	77.5±0.608	77.9±0.608	77.1±0.608	0.537
Shell (%)	12.3±0.264	12.4±0.264	13.0±0.264	12.2±0.264	12.5±0.264	0.264
Breaking strength (N)	1.08±0.066	1.10±0.066	1.15±0.066	1.05±0.066	1.12±0.066	0.882
<i>Week 14</i>						
Egg diameter (mm)	26.1±0.230 ^a	25.0±0.230 ^b	25.3±0.230 ^{ab}	25.1±0.230 ^b	25.6±0.230 ^{ab}	0.021
Egg length (mm)	33.4±0.324	32.7±0.324	33.4±0.324	32.6±0.324	32.8±0.324	0.231
Shell thickness (mm)	0.19±0.003	0.19±0.003	0.19±0.003	0.18±0.003	0.19±0.003	0.37
Haugh unit	84.5±0.240	85.1±0.240	84.4±0.250	84.8±0.240	84.9±0.240	0.239
Shell weight (g)	1.60±0.040 ^{ab}	1.45±0.040 ^b	1.61±0.040 ^a	1.50±0.040 ^{ab}	1.50±0.040 ^{ab}	0.027
Shape index (%)	78.5±0.984	76.6±0.984	76.2±1.028	77.0±0.984	78.0±0.984	0.452
Shell (%)	13.5±0.308	13.3±0.308	14.0±0.321	13.5±0.308	13.2±0.308	0.489
Breaking strength (N)	1.43±0.056	1.11±0.056	1.28±0.056	1.14±0.056	1.24±0.056	0.002

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR

= a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize;

CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place

of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava

tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of

oven-dried cassava tuber meal in place of maize.

Table 3.7 shows effects of diets containing raw or thermally-treated CTM on internal egg quality parameters of Jumbo quail hens. In week 10, eggs from quail birds on CTMA had higher ($P < 0.05$) egg colour values compared to other the treatments, which did not differ ($P > 0.05$). However, at 12 weeks of age, birds on diets CTMB and CTMO had the lowest ($P < 0.05$) egg colour values, followed by those on diet CTMA, and the highest ($P < 0.05$) egg colour value was from diet CON. Nonetheless, both diets (CTMB and CTMO) were similar ($P > 0.05$) to diet CTMR. Furthermore, in week 14 of age, diet CON promoted a higher ($P < 0.05$) egg colour value, followed by CTMR and the least colour values were from CTMA, CTMB and CTMO diets, which did not differ ($P > 0.05$). Quail birds reared on diet CON had a longer ($P < 0.05$) yolk diameter than those reared on diets CTMR and CTMB, but all three groups were similar to diets CTMA and CTMO in terms of yolk diameter. Diet CON resulted in the lowest ($P < 0.05$) yolk index whereas diets CTMA and CTMR resulted in the highest, but all the groups were similar ($P > 0.05$) to diets CTMO and CTMB.

Table Error! No text of specified style in document..**7.** Effect of diets containing raw or thermally-treated cassava tuber meal on internal egg quality parameters (means $\pm$ standard error) of Jumbo quail hens from weeks 9 - 14

	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
<i>Week 10</i>						
Albumen height (mm)	3.55±0.022	3.60±0.023	3.62±0.022	3.60±0.026	3.62±0.025	0.161
Egg colour	4.52±0.261 ^a	1.73±0.275 ^b	2.40±0.261 ^b	1.57±0.312 ^b	1.53±0.292 ^b	<.0001
Yolk height (mm)	9.71±0.198	9.65±0.208	9.61±0.198	9.89±0.236	9.98±0.221	0.712
Yolk diameter (mm)	24.6±0.341	24.9±0.359	25.0±0.341	24.2±0.407	25.1±0.381	0.500
Yolk index	0.40±0.007	0.39±0.008	0.39±0.007	0.41±0.009	0.40±0.008	0.331
<i>Week 12</i>						
Albumen height (mm)	3.63±0.01	3.66±0.01	3.62±0.01	3.65±0.01	3.67±0.01	0.060
Egg colour	5.00±0.150 ^a	2.23±0.150 ^{bc}	2.77±0.150 ^b	1.87±0.150 ^c	2.03±0.150 ^c	<.0001
Yolk height (mm)	9.38±0.155	9.46±0.155	9.05±0.155	9.13±0.155	9.15±0.155	0.304
Yolk diameter (mm)	25.4±0.374	26.1±0.374	26.1±0.374	26.2±0.374	25.9±0.374	0.542
Yolk index	0.36±0.006	0.36±0.006	0.35±0.006	0.35±0.006	0.36±0.006	0.266
<i>Week 14</i>						
Albumen height (mm)	3.65±0.022	3.61±0.022	3.58±0.022	3.59±0.022	3.65±0.022	0.082
Egg colour	4.95±0.186 ^a	2.32±0.186 ^b	3.08±0.186 ^c	1.60±0.186 ^c	2.20±0.186 ^c	<.0001
Yolk height (mm)	9.21±0.154	9.62±0.154	9.48±0.154	9.15±0.154	9.41±0.154	0.189
Yolk diameter (mm)	26.9±0.248 ^a	25.8±0.248 ^b	25.8±0.248 ^{ab}	26.0±0.248 ^b	26.2±0.248 ^{ab}	0.022
Yolk index	0.34±0.006 ^b	0.37±0.006 ^a	0.37±0.007 ^a	0.35±0.006 ^{ab}	0.36±0.006 ^{ab}	0.017

¹Experimental diets: CON = A standard layer diet without cassava tuber meal; CTMR = a standard layer diet containing 100% of raw cassava tuber meal; CTMB = A standard layer diet containing 100% of boiled cassava tuber meal; CTMA = A standard layer diet containing 100% of autoclaved cassava tuber meal; CTMO = A standard layer diet containing 100% of oven-dried cassava tuber meal.

3.4 Discussion

Poultry use the energy for metabolism and other activities, which in the process generate heat, promote growth, meet maintenance needs, and increase productivity (Inaku *et al.*, 2011). Maize is a staple food for humans in many African countries, hence its total replacement with locally available energy sources could ensure sustainable poultry production systems. Cassava is a suitable substitute for maize due to its high energy value, but the presence of hydrogen cyanide may limit its utilization in conventional layer diets. Therefore, this current study employed thermal treatments (oven-drying, boiling and autoclaving) to inactivate the antinutritional activities of cyanides in cassava tubers that are known to negatively impact protein quality and AA bioavailability. Accordingly, cassava tubers contain essential AA (arginine, histidine, isoleucine, phenylalanine, threonine, tryptophan, and valine), which meets the minimum biological requirements for quail (Nassar, 2007; Ghazaghi *et al.*, 2023). In this study, DM and OM were numerically lower in raw CTM samples, which was expected given the high moisture content of cassava tubers. This could be due to higher moisture content compared to heated samples. Oven drying led to the highest DM and OM in the heat-treated CTM samples is a result of evaporation during the heat process. The gross energy content of peeled cassava roots has been reported to be 3675 kcal/kg (Fanelli *et al.*, 2023), which is relatively similar to the values (3718 kcal/kg) reported in this study. The high fibre content in raw CTM was attributed to the presence of cell wall components, which are partially broken down during thermal processing (Favaro *et al.*, 2008). Raw CTM had a higher crude protein content than thermally-processed samples, in which an indication of protein denaturation due to heat. Lower amino acid content in autoclaving CTM could be due to Maillard reactions, which can reduce the availability of certain amino acids at high temperatures and long drying times (Thaweewong & Anuntagool, 2023). Some essential amino acids could have been degraded during treatment method. The result of the proximate composition of the experimental diets used during the

laying phase of this study showed that the crude protein content (225.4 and 236.4 g/kg) agrees with the reports of Edache *et al.* (2007) and Bawa *et al.* (2012) who recommended 20 and 24% crude protein level for optimum egg production of Japanese quail. This implies that diets based on cassava tuber meal flavoured supplied the required crude protein for optimum growth and egg production of Japanese quails. The observed difference in values of proximate analyses of the diets might be because the diet formulation was done before the analysis. Raw CTM sample tended to have highest hydrogen cyanide (6.24 mg/kg HCN), followed by boiled CTM, autoclaved CTM and the lowest was from oven-dried CTM. According to McKey *et al.* (2010), sweet cassava contains less than 100 mg/kg of cyanogenic compounds per fresh root, while 'bitter' cassava contains more than 100 mg cyanogenic compounds. However, from the results obtained in this study, the cassava that was used can be classified as sweet cassava as the analysed HCN values were below 100 mg/kg. CTMB found to have higher HCN than other cassava-based diets. However, according to Ngiki *et al.* (2014), boiling eliminates about 90% of the free cyanide within 15 minutes compared to 55% of bound cyanide after 25 minutes. However, prolonged heating, which destroys the linamarase enzyme at $> 72^{\circ}\text{C}$, preserves glycosides and HCN. For example, cyanogenic glycosides in cassava produces hydrocyanic acid that can be harmful to animals in high concentrations (Omosuli *et al.*, 2017; Yulvianti & Zidorn, 2021). This compound is non-toxic, but when glycosides react with linamarase upon tissue damage it results in HCN as a defence mechanism (McMahon *et al.*, 2022).

The lack of dietary effect in initial body weight observed in this study conforms with the findings of Ojediran *et al.* (2023), who reported no dietary effects on initial body weights of Japanese quail. The overall FI was found to be higher in birds that were fed CON diet than in those that were fed CTM diets. These results correspond with the findings of Akapo *et al.* (2014), who reported that broiler chickens fed with peeled/unpeeled cassava root meal irrespective of inclusion levels (100 g/kg or 200 g/kg) showed low feed intake compared to

those fed with maize-control based diet. However, these results contradict with the findings of Malik *et al.* (2018), who reported the increase in total feed intake as the inclusion level (0, 25, 50 and 75%) of fermented cassava peel meal in replacement for maize increase in Japanese quail diet. This study observed higher overall body weight gain (BWG) and final body weight in birds that were reared under CON diet than to reared under CTM diets. These results agree with the findings of Akapo *et al.* (2014), who reported that control-fed broiler chickens had the highest final liveweight and body weight gain compared to those fed with diet containing 100 g/kg peeled cassava root meal. The absence of treatment effect on feed conversion ratio in Jumbo quail hens fed raw or heat-treated CTM as replacement for maize conforms with the findings of Abdullahi *et al.* (2018), who reported no dietary effects on feed conversion ratio when sun-dried cassava peel meal flavoured with honey was used to replace maize at 0, 50, 70 and 100% in the diets of growing Japanese quail. Similar observations were made by Kibret *et al.* (2021), where feed conversion ratio was not affected by maize replacement with cassava root meal in Bovan Brown layer diets. Additionally, the absence of dietary effects on overall mortality indicates that the inclusion and treatments of CTM in place of maize did not cause death.

Rate of lay (ROL) refers to the percentage of hens that laid an egg on a given day from the entire hen population (Dana *et al.*, 2011). The ROL was not significantly affected by the diet in weeks 8, 10, and 12 of age, but in week 14, quail fed the maize-based control diet laid many eggs to those fed the CTMR diet, which was anticipated given the presence of antinutrients in raw cassava tubers. This also means the heat treatments were effective in maintaining ROL as these treatments were similar to CON. Enyenihi *et al.* (2013), also reported that complete replacement of maize with peeled, fermented and gelatinized CTM had no effect on hen-day overall production of 13 months old chicken layer hens. In contrast, Villaver *et al.* (2022), reported high ROL in duck hens fed pure commercial diet then those fed a diet containing 40%

cassava meal. Lei *et al.* (2017) also reported that the incorporation of 20% cassava root meal had no detrimental effects on egg production and quality of layers.

Egg quality refers to a collective of an egg's characteristics that influence acceptance or preference by a consumer (Peri, 2006). In that regard, it is evident that egg quality could mean different things to consumers based on preferences and intended use. The measured external egg quality parameters, such as egg length, shell thickness, shape percentage, egg breaking strength and Haugh unit were not affected by complete replacement of maize with raw or heat-treated CTM. This suggest that the parameters are not easily influenced by nutritional factors. Birds fed with CON diet produced eggs with low shape index compared to those fed with CTMO diet at week 10. These results contradict with the reports of Bawa *et al.* (2012) who reported no significant difference in egg shape index when breeder Japanese quail were fed different protein levels. According to Duman *et al.* (2016), eggs are classified with respect to shape index (SI) as a sharp egg ($SI < 72$), a normal egg ($SI = 72 - 76$) or a round egg ($SI > 76$). In this current study, the CON and CTMB diets had normal egg shape, this means other thermally treated diets did not affect the egg shape. At week 14, Jumbo quail hens fed CON diet produced eggs with longer diameter compared to those fed with CTMR. Furthermore, the shell weight of the eggs produced by birds fed with CTMA diet was found to be heavier than those fed with CTMR diet. Contrary to these findings, Malik *et al.* (2018) who reported no treatment effects on egg quality parameters in laying Japanese quails fed a diet with 0, 25, 50 and 75% fermented cassava peel meal. Cassava-based rations proved to be the potential to improve the quality of eggs in terms of increasing the shell thickness and weight. Cassava roots and leaves contain vitamins and minerals, particularly calcium and phosphorus, which help develop eggshells (Montagnac *et al.*, 2009).

For internal egg quality parameters, dietary treatments affected only yolk diameter and yolk index in 14-week-old quail hens as well as yolk colour from week 9 to 14. Eggs from quail

fed the CON diet had a significantly brighter yellow egg colour which is attributable to carotene pigmentation in yellow maize. Similarly, Sapatattananan *et al.* (2005) observed lower yolk colour values in 23-42 weeks of age in Hisex layer hens fed a diet with cassava root meal compared to those fed a maize-based diet. The CTM is a relatively low source of xanthophylls, which are carotenoid pigments that contribute to egg yolk colour (Aregay *et al.*, 2021). When quail consume less xanthophylls, the yolk colour becomes light yellow. Cassava contains cyanogenic glycosides that can interfere with the absorption of carotenoids from the gut (Zekarias *et al.*, 2019). This further reduces the availability of xanthophylls for yolk pigmentation, hence eggs from the CTM group had a light colour than the maize group. Yolk diameter of eggs produced by birds fed with CON diet was found to be higher than those fed with cassava-based diets. These findings differ from those observed by Malik *et al.* (2018), which shows that the yolk diameter was not significantly affected by inclusion (25, 50 and 75%) of sun-dried cassava peel meal. Moreover, the yolk index of eggs produced by birds fed CTMR and CTMA diet was found to be higher than those produced by birds fed with CON diet. However, these results contradict those reported by Abu & Judah (2019) which shows that yolk index was highest in Japanese quail fed millet-based diet than those fed cassava flour-based diet.

3.5 Conclusion

The boiling treatments reduced overall feed intake, while both oven-drying and boiling treatments reduced overall body weight gain. Final body weight was compromised by thermally treated cassava. The inclusion of raw cassava compromised rate of lay in week 14. However, all the treatments had no improvement on egg production and weight. Oven-drying treatment increased shape index in week 10, while boiling and oven-drying reduced egg diameter whereas raw treatment reduced shell weight in week 14. The control treatment improved egg colour for the entire duration of the study. It can be concluded that although quail

hens reared on maize-based diet showed the best performance, autoclaving treatment of CTM was more effective than oven-drying and boiling treatments.

3.6 References

- Abdullahi, H. I., Ijaiya, A. T., Malik, A. A. & Egena, S. S. A. (2018). Growth response and nutrient digestibility of Japanese quails (*Coturnix coturnix japonica*) fed sun-dried and honey-flavoured cassava peel meal diets. In: Proceeding of the 43rd Annual Conference of Nigerian Society for Animal Production. 18th – 22nd March. Owerri, Imo State, Nigeria. P 214.
- Abdurofi, I., Ismail, M.M., Kamal, H.A.W. & Gabdo, B.H., 2017. Economic analysis of broiler production in Peninsular Malaysia. Int. Food Res. J. 24(2), 761.
- Abu, O.A. & Judah, F.I., 2019. Performance and egg quality traits of laying Japanese quail (*Coturnix coturnix japonica*) fed cereal grains and cassava flour as energy sources. J. Agric. Sci. Technol. 9364.
- Ahiwe, E.U., Omede, A.A., Abdallh, M.B. & Iji, P.A., 2018. Managing dietary energy intake by broiler chickens to reduce production costs and improve product quality. Animal husbandry and nutrition, 115, 115-145.
- Akapo, A.O., Oso, A.O., Bamgbose, A.M., Sanwo, K.A., Jegede, A.V., Sobayo, R.A., Idowu, O.M., Fan, J., Li, L. & Olorunsola, R.A., 2014. Effect of feeding cassava (*Manihot esculenta Crantz*) root meal on growth performance, hydrocyanide intake and haematological parameters of broiler chicks. Trop. Anim. Health Pro. 46, 1167-1172.
- AOAC, 2005. Official Methods of Analysis of AOAC International (16th ed.). Association of Official Analytical Chemists, Arlington, VA, USA.
- Aregay, M., Urge, M., Animut, G. & Girma, M., 2021. Effects of Substituting Maize with Ground Cassava Tuber on Egg Production and Quality of White Leghorn Hens. East Afr. J. Vet. Anim. Sci. 5(1), 23-30.

- Bawa GS, Lombin LH, Shmaki D, Karsin P & Musa U. 2012. Protein requirement of Japanese quail (*Coturnix coturnix japonica*) chicks in Nigeria. Niger. J. Anim. Prod. 39(1),153 – 160.
- Brito, V.H.S., Ramalho, R.T., Rabacow, A.P.M., Moreno, S.E. & Cereda, M.P., 2009. Colorimetric method for free and potential cyanide analysis of cassava tissue. Gene. Conserve. 8(34),1-11.
- Dahal, P. & Tamang, M.K., 2021. Effects of Different Processing Methods on Anti-Nutritional Factors of Cassava (*Manihot Esculenta Crantz*). J. Food Nutr. Disor. 10(5), 1-5.
- Dana, N., Vander Waaij, E.H. & Van Arendonk, J.A., 2011. Genetic and phenotypic parameter estimates for body weights and egg production in Horro chicken of Ethiopia. Trop. Anim. Health Pro. 43, 21-28.
- Dei, H.K., 2017. Assessment of maize (*Zea mays*) as feed resource for poultry. Poult. Sci. 1, 1-32.
- Devi, A. & Diarra, S.S., 2021. Factors affecting the utilisation of cassava products for poultry feeding. Egypt J. Vet. Sci. 52(3), 387-403.
- Duman, M., Şekeroğlu, A., Yıldırım, A., Eleroğlu, H.A.S.A.N. & Camcı, Ö., 2016. Relation between egg shape index and egg quality characteristics. Eur. Poult. Sci. 80, 1-9.
- Edache, J.A., Musa, U., Karsin, P.D., Esilonu, J.O., Yisa, A., Okpala, E.J. & Zwandor, N.J., 2007. The feeding value of cassava meal diets for growing Japanese quail (*Coturnix coturnix japonica*). Niger. J. Anim. Prod. 34(1), 77-82.
- Enyenihi, G.E., Esiegwu, A.C., Esonu, B.O., Uchegbu, M.C. & Udedibie, A.B.I., 2013. Gelatinization of fermented cassava tuber meal and its nutritive value for laying hens. J. Agric. Technol. 9, 1137-1149.

- Fanelli, N.S., Torres-Mendoza, L.J., Abelilla, J.J. & Stein, H.H., 2023. Chemical composition of cassava-based feed ingredients from South-East Asia. *Anim. Biosci.* 36(6), 908.
- Favaro, S.P., Beléia, A., Junior, N.D.S.F. & Waldron, K.W., 2008. The roles of cell wall polymers and intracellular components in the thermal softening of cassava roots. *Food Chem.* 108(1), 220-227.
- Feng, D., Shen, Y. & Chavez, E.R., 2003. Effectiveness of different processing methods in reducing hydrogen cyanide content of flaxseed. *J. Sci. Food Agric.* 83(8), 836-841.
- Food & Agriculture Organization of the United Nations. Available online: <http://www.fao.org/faostat/en/> (accessed on 16 March 2022).
- Ghazaghi, M., A. Hassanabadi, & M. Mehri. 2023. Apparent and standardized ileal amino acid digestibilities of corn, wheat, soybean meal, and corn gluten meal in quail chicks. *Poult. Sci.* 102(2), 102314.
- Inaku, E.N., Bawa, G.S., Olugbemi, T.S. & Buba, W., 2011. Nutritive value of yam feel meal in broiler diet. *Value Reorientation in Animal Production: A Key to National Food Security and sustainable Economy*, 481-483.
- Ismaila, A.R., Alakali, J.S. & Atume, T.G., 2018. Effect of local processing techniques on the nutrients and anti-nutrients content of bitter cassava (*Manihot Esculenta Crantz*). *Am. J. Food Sci. Technol.* 6(3), 92-97.
- Kibret, B., Demeke, S. & Beyene. A., 2021. Substitution of maize grain with cassava tuber on hen layer performance and egg quality. *Livestock Research for Rural Development.* 33(1), 1-6. <http://www.lrrd.org/lrrd33/1/berih3301.html>
- Lei, X.J., Park, J.H., Hosseindoust, A. & Kim, I.H., 2017. Effects of cassava (*Manihot esculenta crantz*) root meal in diets containing corn dried distillers grains with solubles

- on production performance, egg quality, and excreta noxious gas emission in laying hens. *Braz. J. Poult.* 19, 239-246.
- Marareni, M. & Mnisi, C.M., 2020. Growth performance, serum biochemistry and meat quality traits of Jumbo quails fed with mopane worm (*Imbrasia belina*) meal-containing diets. *Vet. Anim. Sci.* 10, 100141.
- McKey, D., Cavagnaro, T.R., Cliff, J. & Gleadow, R., 2010. Chemical ecology in coupled human and natural systems: people, manioc, multitrophic interactions and global change. *Chemoecology*, 20, 109-133.
- McMahon, J., Sayre, R. & Zidenga, T., 2022. Cyanogenesis in cassava and its molecular manipulation for crop improvement. *J. Exp. Bot.* 73(7), 1853-1867.
- Malik, A. A., Ijaiya, A. T., Aremu, A. & Akinwale, M. O., 2018. Growth response, Carcass characteristics and egg laying performance of Japanese quails (*Coturnix coturnix japonica*) fed diets containing varying levels of fermented cassava (*Manihot esculenta*) peel meal. *Niger. J. Anim. Prod.* 45 (2), 224 – 231.
- Mnisi, C.M., Oyeagu, C.E., Akuru, E.A., Ruzvidzo, O. & Lewu, F.B., 2023. Sorghum, millet and cassava as alternative dietary energy sources for sustainable quail production—A review. *Anim. Front.* 4, 1066388.
- Montagnac, J.A., Davis, C.R. & Tanumihardjo, S.A., 2009. Nutritional value of cassava for use as a staple food and recent advances for improvement. *Com. Rev. Food Sci. Food Saf.* 8(3), 181-194.
- Morgan, N.K. & Choct, M., 2016. Cassava: Nutrient composition and nutritive value in poultry diets. *Anim. Nutr.* 2(4), 253-261.
- Morris, S.S., Beesabathuni, K. & Headey, D., 2018. An egg for everyone: Pathways to universal access to one of nature's most nutritious foods. *Matern. Child Nutr.* 14, 12679.

- Nassar, N.M., 2007. Wild cassavas, *Manihot* spp. to improve the crop. *Gene Conserve*, 26, 387-414.
- Ngiki, Y.U., Igwebuike, J.U. & Moruppa, S.M., 2014. Utilisation of cassava products for poultry feeding: A review. *Int. J. Sci. Technol. Humanit.* 2(6), 48.
- Northcutt, J.K., Buyukyavuz, A. & Dawson, P.L., 2022. Quality of Japanese quail (*Coturnix coturnix japonica*) eggs after extended refrigerated storage. *J. Appl. Poult. Res.* 31(3), 100280.
- NRC, 1994. Nutrient Requirements for Poultry. 9th Edn., National Academy Press, Washington, DC. USA., ISBN -13:978-0-309-04892-7.
- Ojediran, T., Busari, O., Olagoke, O. & Emiola, A., 2023. Multi-processed cassava root meal: A suitable replacement for maize in Japanese quail diet. *Emerging Animal Species*, 9, 100035.
- Omosuli, S.V., Ikujenlola, A.V. & Abisuwa, A.T., 2017. Quality assessment of stored fresh cassava roots and ‘fufu’ flour produced from stored roots. *J. Food Sci. Nutr. Therapy.* 3(1), 9-13.
- Panda, B. & Singh, R.P., 1990. Developments in processing quail meat and eggs. *Worlds Poult. Sci. J.* 46(3), 219-234.
- Peri, C., 2006. The universe of food quality. *Food Qual. Prefer.* 17(1-2), pp.3-8.
- Redoy, M.R.A., Shuvo, A.A.S. & Al-Mamun, M., 2017. A review on present status, problems and prospects of quail farming in Bangladesh. *Bangladesh J. Anim. Sci.* 46(2), 109-120.
- Saparattananan, W., Kanto, U., Juttupornpong S. & Engkagul A., 2005. Utilization of cassava meal and cassava leaf in layer diets on egg quality and protein content in egg: animals. In: *Proceedings of 43rd Kasetsart University Annual Conference*; Bangkok, Thailand. 43-52.

- Shiferaw, B., Prasanna, B.M., Hellin, J. & Bänziger, M., 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Secur.* 3, 307-327.
- Silva, Y.L.D., Fernandes, T., Muniz, E.B., Marengoni, N.G., Carvalho, P.L.D.O. & Silva, N.L.S.D., 2020. Effect of storage time and temperature on the quality of Japanese quail eggs. *Bol. Ind. Anim.* 77, 1-16.
- Thaweewong, P. & Anuntagool, J., 2023. Change in free cyanide content of bitter cassava during incubation and drying and physical properties of dry-milled cassava flour. *Food Bioprod. Process.* 138, 139-149.
- Van Soest, P. J., Robertson, J. B. & Lewis, B. A., 1991. Methods for dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Villaver, J.P., Zacal, A.L., Gabaya, N.E. & Cantila, M.L., 2022. Egg production, quality, and hatchability rates of Philippine ducks (*Anas luzonica*) in response to low-cost cassava-based rations. *Int. J. Agric. Technol.* 18(2), 917-926.
- Yulvianti, M. & Zidorn, C., 2021. Chemical diversity of plant cyanogenic glycosides: an overview of reported natural products. *Molecules*, 26(3), 719.
- Zainuddin, I.M., Fathoni, A., Sudarmonowati, E., Beeching, J.R., Gruissem, W. & Vanderschuren, H., 2018. Cassava post-harvest physiological deterioration: From triggers to symptoms. *Postharvest Biol. Technol.* 142, 115-123.
- Zekarias, T., Basa, B. & Herago, T., 2019. Medicinal, nutritional and anti-nutritional properties of Cassava (*Manihot esculenta*): a review. *J. Nutr.* 8(3), 34-46.

4 CHAPTER FOUR - EFFECT OF RAW OR THERMALLY TREATED CASSAVA TUBER MEAL ON EGG SHELF LIFE, WELFARE INDICATORS, BLOOD PARAMETERS, VISCERAL ORGANS, AND CARCASS INDICES IN JUMBO QUAIL HENS

Abstract

This study determined the effect of total replacement of maize with raw or thermally-treated cassava tuber meal (CTM) on egg shelf life, welfare indicators, blood parameters, carcass characteristics and internal organ sizes of Jumbo quail hens. A total of 240, six-week-old quail hens (191 ± 16.60 g live-weight) were reared in 60 cages (4 birds/cage) to produce 12 replicates per dietary treatment. The treatments were a standard layer diet (CON) and CON in which 100% of maize was replaced with raw (CTMR), boiled (CTMB), autoclaved (CTMA) and oven-dried CTM (CTMO). At day 52, two birds per pen were randomly selected to determine latency-to-lie test (LTL), gait score and feather score. At the end of the feeding trial (14 weeks of age), all birds were slaughtered after stunning in a local abattoir and while bleeding, about 2 ml of blood samples were collected from two birds randomly selected per pen for serum biochemistry analyses. The slaughtered birds were used to determine carcass characteristics, and internal organ sizes. On day 5 of storage, CON produced eggs with the highest breaking strength while the lowest was from CTMR group. At day 10, eggs from birds on diet CON had the lowest albumen pH and the highest was from diet CON. The CTMA diet promoted higher egg colour values than CTMB which promoted lower egg colour values. The Kruskal-Wallis H test showed that there were no treatment effects on gait and feather scores but on latency-to-lie test. There were no treatment effects on haemato-biochemical parameters ($P > 0.05$). Birds fed diet CON had larger carcass weights than those fed diets CTMR and CTMB. Diets CTMO and CTMB resulted in hens with heavier ($P < 0.05$) wing weights than diets CON and CTMA. However, quail fed diet CTMA had the shortest ($P < 0.05$) back length while birds fed CTMB and CTMO had the longest ($P < 0.05$) back length. Diet CON caused lower 24-hour meat pH

than CTMB. Diets CTMO and CTMB resulted in hens with heavier wings than those in diets CON and CTMA. Diet CON caused lower 24-hour meat pH than diet CTMB. Although the hens reared on the maize-based control diet showed the best performance, autoclaving followed by oven-drying treatments of cassava tuber meal were more effective than the cooking treatment. This study also demonstrated that thermally treating cassava tuber meal does not compromise blood, sizes of internal organs and meat quality.

Keywords: Cassava, Energy sources, Layers, Physiological responses, Shelf-life, Welfare

4.1 Introduction

Quail farming is becoming increasingly popular due to its many advantages such as less space requirement, shorter production cycles, and high laying abilities (Jeke *et al.*, 2018; Batool *et al.*, 2021). Although chicken eggs have the highest consumption per capita, quail eggs are considered a delicacy in many African and Asian countries making them a valuable commodity in niche markets (Akinwumi *et al.*, 2019). However, large-scale quail egg production is limited by feed quality and availability as well as high market prices, which present sustainability challenges. Indeed, the poultry industry is currently facing a complex web of social, environmental and economic sustainability challenges that have negative impacts on operations and long-term viability (Kleyn & Ciacciariello, 2021). From a nutritional perspective, the use of conventional feed ingredients such as maize increases feeding expenses because maize has a high market demand given that it is also a staple food for many Africans. This results in high feed-food competitions between humans and animals for maize. Furthermore, optimum maize yield is mainly dependent on arable land, high rainfalls, good soil fertility and the application of fertilizers containing nitrogen, potassium, and phosphorus (Cullis *et al.*, 2019). Although it is a primary energy source in poultry diets (Dei, 2017; Thirumalaisamy *et al.*, 2016), its prices remain volatile making it an unsustainable ingredient for use in high-input layer quail production (Mnisi *et al.*, 2022). Alternatively, cassava (*Manihot esculenta*), which is a root vegetable crop that is locally available, highly adaptable and easy to cultivate, can be used as a substitute energy source in quail diets (Kanyinji & Moonga, 2014). Cassava tuber meal (CTM) has a high metabolizable energy value (16.2 MJ/kg) and is less prone to market price fluctuations, which makes it a more stable energy source for quail farmers (Kanyinji & Moonga, 2014). However, cassava contains anti-nutritional factors that can reduce nutrient digestibility and laying performance in quail (Apata & Babalola, 2012). For example, cyanogenic glycosides in cassava produces hydrocyanic acid that can be harmful to animals in

high concentrations (Omosuli *et al.*, 2017; Yulvianti & Zidorn, 2021). This compound is non-toxic, but when glycosides react with linamarase upon tissue damage it results in the production of an extremely toxic chemical called hydrogen cyanide (HCN) as a defense mechanism (McMahon *et al.*, 2022). Cyanide exacerbates nutritional deficiencies by interfering with the bird's ability to absorb vital minerals like iron and zinc (Bayata, 2019). The concentration of HCN varies according to the type of cassava, with bitter varieties having a significantly higher concentration than sweet varieties (Panghal *et al.*, 2019). High levels of HCN in poultry feed can cause toxicity, respiratory problems, paralysis, and even death (Ramteke *et al.*, 2019). Therefore, various heat treatment methods including autoclaving, cooking and oven-drying can be adopted to enhance the feeding value of cassava products. Abbas & Ahmad (2018) reported that autoclaving CTM improves nutrient bioavailability, texture, and palatability by reducing the availability of antinutrients. Likewise, autoclaving reduces the content of antinutrients, resulting in products with readily available nutrients (Udensi *et al.*, 2005). Additionally, treatment methods such as boiling/cooking improves the utility of cassava, by eliminating about 90% of free cyanide within 15 minutes and 55% of bound cyanide in 25 minutes (Ngiki *et al.*, 2014). Further, these methods preserve the relative stability of water-soluble vitamins (vitamin C and B-complex) and, therefore, enhance nutrient utilisation. Andama & Oloya (2017) showed that rapid air-drying reduced the total cyanide content of peeled cassava root chips by only 10 - 30%. However, to this end, no studies have attempted to enhance the energy value of CTM as a substitute to maize in laying Jumbo quail diets. Thus, this study investigated the effects of total replacement of maize with raw or heat-treated CTM on egg shelf-life indicators, welfare and blood parameters, visceral morphometry, and carcass and breast meat quality characteristic of laying Jumbo quail hens.

4.2 Materials and methods

4.2.1 Study site, analysis, diet formulation and experimental design

The study site, cassava procurement, analysis, diet formulation, and experimental design were as described in Chapter 3, sections 3.2.2, 3.2.3, 3.2.4, 3.2.5 and 3.2.6, respectively.

4.2.2 Shelf-life measurements

A total of 120 eggs per treatment (2 eggs / cage) were collected at week 6 and stored at room temperature (25°C) and evaluated on days 1, 5 and 10 of storage. Measurements of egg weight (EWT) were made using a digital scale (HM-200, A & D Co., Ltd., Tokyo, Japan). Egg breaking strength was measured using a digital egg tester (DET-6500, Nabel Co., Ltd., Kyoto, Japan). The eggs were broken on a flat surface where albumen height and yolk height were measured using an Electronic Digital Calliper, while yolk colour was determined using a Digital Yolk Colour Fan™ (DSM, Gauteng, South Africa). Albumen pH was determined by separating the albumen and yolk from the same egg and measured using a portable pH meter (Eutech pH25, Eutech Instruments, Spain) equipped with a penetrating electrode. The pH meter was calibrated with pH 4, 7 and 9 standard solutions (Eutech Instruments SA, Spain). Haugh unit (HU) was also determined using the mentioned formula from chapter 3.

4.2.3 Welfare indicators

At day 52 of the trial, two birds per cage were randomly selected for the latency-to-lie test (LTL). The LTL as defined by Berg & Sanotra (2003), focuses on the body interaction with water, as it is an unusual experience for quail. All the participating birds were individually placed in a plastic container filled with 3 cm of water at 32°C. The time it took for the bird to lie down and touch the water was recorded. This test is based on the principle that the longer the bird stays on its feet before lying down (touching the water), the better is its leg health. If

the bird was still standing after 10 minutes, the test was terminated, and the legs deemed to be strong and healthy.

The degree of feather coverage over the breast, known as feather score, was recorded in two birds per cage, according to the method of Gyles *et al.* (1962). A three-point arbitrary scale was used to score each bird based on how much skin showed through the pressed feathers: 1) represented no visible skin at all, complete feather cover; 2) represented a relatively small amount of skin showing; and 3) represented none at all. Each bird was stroked over the keel with the palm of the hand, moving from anterior to posterior.

The gait score, which can be defined as the ability of the bird to walk, was taken by randomly catching two birds/cage. Two researchers assessed the birds walking spontaneously and score the walking ability of a five-point scale ranging from 0 (normal gait or walking freely) to 5 (bird unable to walk) as described by Kestin *et al.* (1992).

4.2.4 Slaughter and collection of blood

At 14 weeks of age, all the hens were transported by road to a nearby poultry abattoir (Rooigrond, North West, South Africa). At the abattoir, the birds were rested for 2 hours, then electrically stunned and sacrificed using a sharp knife to cut the jugular vein and allowed to bleed out. The blood was allowed to drip in sterilized containers, from which about 4 ml of fresh blood samples were immediately drawn to represent two randomly selected birds per cage. The blood samples were then immediately transferred into sterilized test tubes for haemato-biochemical analysis.

4.2.5 Haemato-biochemical analyses

Whole blood analysis was performed within 24 hours of collection. An Automated IDEXX LaserCyte Haematology Analyzer (IDEXX Laboratories S.A. PTY, Midrand, South Africa) was used to determine platelets, red blood cells, lymphocytes, white blood cells, monocytes,

and neutrophils. For serum biochemistry, clotted blood samples were centrifuged (Hermle Labortechnik GmbH, Wehingen, Germany) at 1000 c/g for 15 min (Washington & Hoosier, 2012). The serum was thereafter analysed for total protein, glucose, total bilirubin, albumin, cholesterol, amylase, alkaline phosphatase (ALP), symmetric dimethylarginine (SDMA), and alanine transaminase (ALT) using an automated IDEXX Vet Test Chemistry Analyser (IDEXX Laboratories S.A. PTY, Midrand, South Africa).

4.2.6 Internal organs and carcass traits

All the slaughtered birds were used for post-mortem measurements. The weights of hot carcasses (HCW) were measured immediately after slaughter and then chilled in a cold room for 24 hours to determine cold carcass weight (CCW). The percentage of CCW on final body weight was calculated as dressing percentage. The carcasses were then dissected into various portions (breast, wing, thigh, drumstick, and back length), which were also measured. Keel bone size was also determined by measuring its length and width using a vernier calliper (150mm Carbon Fibre Electronic Digital Vernier Caliper Micrometer Gauge LCD). A digital scale (Labotec Precision Balance Series) was used to measure the relative weights of the proventriculus, cleaned ventriculus (gizzard), liver, small intestines, and large intestines. The length of the small intestine as well as the large intestines were measured using a tape measurer.

4.2.7 Meat quality traits

A pH meter (Corning Glass Works, Medfield, MA) with an Ingold spear-type electrode was used to measure breast meat pH from all carcasses immediately after slaughter and 24 hours after chilling. The pH meter was calibrated using standard solutions with pH values of 4, 7, and 10 for each cage. Breast meat colour coordinates: L^* (lightness), a^* (redness) and b^* (yellowness) were measured from the breast meat samples immediately and 24 hours post-slaughter using a Minolta colour-guide 45/0 BYK- Gardener GmbH machine, with a 20 mm

diameter measurement area and illuminant D65-daylight, 10° observation angle after 30 minutes blooming time. A Meullenet-Owens razor shear blade installed on a Texture Analyzer (TA-XT plus, Stable Micro Systems, Surrey, UK) was used to shear breast samples to assess the tenderness of breast meat. The shear force results were measured in Newtons (N).

4.2.8 Statistical analysis

Egg shelf life, blood parameters, meat quality, organ sizes, and carcass and breast meat quality characteristics were analysed using one-way ANOVA by means of PROC GLM of SAS 9.4 (2013). The linear statistical model was as follows:

$$Y_{ij} = \mu + D_i + E_{ij}$$

Where: Y_{ij} is the dependent variable, μ is the population mean, D_i is the effect of diets, and E_{ij} is the random error associated with observation ij , assumed to be normally and independently distributed. For all the statistical tests, significance was declared at $P < 0.05$, and the least square means (LSMeans) were compared using the probability of difference option in the LSMeans statement in SAS. A Kruskal–Wallis test was used to determine the effect of treatment on gait and feather scores of Jumbo quail hens.

4.3 Results

4.3.1 *Shelf-life indices*

Table 4.1 shows effects of raw or thermally-treated cassava tuber meal on egg shelf-life attributes of Jumbo quail hens over a storage period of ten days. Measures of shelf-life such as egg weight, albumen height, and yolk height were not significantly influenced by dietary treatments. However, treatment effects ($P < 0.05$) were observed on day 5 egg breaking strength, day 5 albumen height and day 10 albumen pH. The CON diet caused the highest ($P < 0.05$) breaking strength on day 5 while the lowest strength was observed on the CTMR group. Nonetheless, both diets promoted similar ($P > 0.05$) egg breaking strength to diets CTMA, CTMO and CTMB. Furthermore, at day 5, birds from diet CTMR produced eggs with higher ($P < 0.05$) albumen height compared to those from CTMA, which produced the lowest ($P < 0.05$). Eggs from birds on diet CTMA had the lowest ($P < 0.05$) albumen pH at day 10, whereas the highest albumen pH was from those on diet CON and CTMR. However, CTMO diet had similar ($P > 0.05$) albumen pH as group CTMA. Diet CTMB, CTMR and CON promoted statistically similar ($P > 0.05$) albumen pH.

Table Error! No text of specified style in document..**8.** Effects of raw or thermally-treated cassava tuber meal on egg shelf-life attributes (means $\pm$ standard error) of Jumbo quail hens over a storage period of ten days

	¹ Experimental diets					
	CON	CTMR	CTMA	CTMB	CTMO	<i>P</i> -value
<i>Egg weight (g)</i>						
Day 1	11.2±0.371	10.5±0.371	11.1±0.371	11.0±0.371	10.9±0.371	0.772
Day 5	10.8±0.423	10.3±0.423	11.4±0.423	10.9±0.423	10.6±0.423	0.494
Day 10	11.2±0.454	10.4±0.454	10.5±0.454	10.6±0.454	10.2±0.454	0.665
<i>Egg breaking strength (N)</i>						
Day 1	1.19±0.090	1.07±0.090	1.18±0.090	1.02±0.090	1.09±0.090	0.627
Day 5	1.42±0.103 ^a	0.93±0.103 ^b	1.31±0.103 ^{ab}	1.23±0.103 ^{ab}	1.31±0.103 ^{ab}	0.018
Day 10	1.09±0.088	1.17±0.088	1.25±0.088	1.18±0.088	1.12±0.088	0.725
<i>Albumen height (mm)</i>						
Day 1	3.53±0.046	3.58±0.046	3.64±0.046	3.65±0.046	3.69±0.046	0.143
Day 5	3.65±0.021 ^b	3.70±0.021 ^a	3.59±0.021 ^b	3.65±0.021 ^b	3.68±0.021 ^b	0.003
Day 10	3.66±0.049	3.56±0.049	3.55±0.049	3.57±0.049	3.60±0.049	0.545
<i>Yolk height (mm)</i>						
Day 1	9.49±0.231	9.71±0.231	9.70±0.231	9.26±0.231	9.97±0.231	0.275
Day 5	8.82±0.202	9.17±0.202	8.83±0.202	8.97±0.202	8.87±0.202	0.721
Day 10	9.04±0.254	8.71±0.254	8.83±0.254	9.08±0.254	8.76±0.254	0.779
<i>Albumen pH</i>						
Day 1	8.83±0.358	9.98±0.358	9.75±0.358	8.78±0.358	9.54±0.358	0.068
Day 5	9.47±0.272	8.68±0.272	9.67±0.272	9.31±0.272	9.55±0.272	0.101
Day 10	9.86±0.294 ^a	9.54±0.294 ^a	7.81±0.294 ^c	9.27±0.294 ^{bc}	8.37±0.294 ^{ab}	<.0001

¹Diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava

tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

4.3.2 *Welfare indicators*

Table 4.2 shows the effect of total replacement of maize with raw or thermally-treated cassava tuber meal on welfare indicators of Jumbo quail hens. A Kruskal-Wallis H test showed that there were no statistically significant dietary effects on gait and feather scores. However, there was a significant treatment effect in latency-to-lie test [$X^2(2) = 10.18$; $P = 0.0375$].

Table Error! No text of specified style in document..**9.** The effect of total replacement of maize with raw or thermally-treated cassava tuber meal on medians of welfare indicators of Jumbo quail hens

	¹ Experimental diets					<i>P</i> -Chi-square
	CON	CTMR	CTMA	CTMB	CTMO	
Gait score	33.71	29.38	28.71	31.88	26.83	0.7203
Feather score	31.00	28.50	29.75	30.25	33.00	0.976
Latency-to-lie (sec)	30.21	32.08	36.29	35.38	18.54	0.0375

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

4.3.3 Haemato-biochemical analyses

Table 4.3 shows that there were no treatment effects among the diets on haematological and serum biochemical parameters in Jumbo quail hens.

Table Error! No text of specified style in document..**10.** Effects of total replacement of maize with raw or thermally-treated cassava tuber meal on blood parameters (means $\pm$ standard error) of 14-week-old Jumbo quail hens

² Parameters	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
Neutrophils (%)	9.49 $\pm$ 5.33	5.51 $\pm$ 5.33	8.18 $\pm$ 5.33	28.17 $\pm$ 5.8	10.04 $\pm$ 5.3	0.053
				4	3	
Lymphocytes (%)	140 $\pm$ 14.0	120 $\pm$ 14.0	140 $\pm$ 14.0	127 $\pm$ 15.4	155 $\pm$ 14.0	0.473
	8	8	8	2	8	
Monocytes (%)	52.0 $\pm$ 15.4	38.1 $\pm$ 15.4	41.2 $\pm$ 15.4	51.7 $\pm$ 16.9	57.0 $\pm$ 15.4	0.900
	8	8	8	6	8	
Glucose (mmol/L)	249 $\pm$ 16.9	234 $\pm$ 16.9	242 $\pm$ 16.9	196 $\pm$ 18.5	241 $\pm$ 16.9	0.253
	0	0	0	2	0	
Calcium (mmol/L)	15.1 $\pm$ 0.81	14.6 $\pm$ 0.81	14.6 $\pm$ 0.81	12.9 $\pm$ 0.89	14.5 $\pm$ 0.81	0.445
Total protein (g/L)	4.74 $\pm$ 0.24	4.95 $\pm$ 0.24	4.26 $\pm$ 0.24	3.97 $\pm$ 0.27	4.57 $\pm$ 0.24	0.067
SDMA (μ g/dL)	12.8 $\pm$ 1.11	11.7 $\pm$ 1.11	10.5 $\pm$ 1.11	10.7 $\pm$ 1.21	10.4 $\pm$ 1.11	0.499
Phosphorus (mmol/L)	6.34 $\pm$ 0.66	7.47 $\pm$ 0.66	6.22 $\pm$ 0.66	7.64 $\pm$ 0.73	5.78 $\pm$ 0.66	0.232
Albumin (g/L)	1.45 $\pm$ 0.09	1.52 $\pm$ 0.10	1.40 $\pm$ 0.09	1.76 $\pm$ 0.10	1.43 $\pm$ 0.10	0.071
Cholesterol (mmol/L)	125 $\pm$ 10.1	124 $\pm$ 10.1	112 $\pm$ 10.1	119 $\pm$ 11.0	115 $\pm$ 10.1	0.873
Globulin (g/L)	3.29 $\pm$ 0.20	3.43 $\pm$ 0.20	2.85 $\pm$ 0.20	2.65 $\pm$ 0.21	3.13 $\pm$ 0.20	0.059
ALB/GLOB	0.45 $\pm$ 0.02	0.44 $\pm$ 0.02	0.49 $\pm$ 0.02	0.45 $\pm$ 0.02	0.48 $\pm$ 0.02	0.234
ALT (U/L)	11.2 $\pm$ 1.84	15.0 $\pm$ 1.84	10.0 $\pm$ 1.84	10.0 $\pm$ 1.84	12.2 $\pm$ 1.84	0.295
Amylase (U/L)	221 $\pm$ 25.9	232 $\pm$ 25.9	262 $\pm$ 25.9	249 $\pm$ 28.4	227 $\pm$ 25.9	0.796
Total bilirubin (mmol/L)	0.32 $\pm$ 0.07	0.42 $\pm$ 0.07	0.23 $\pm$ 0.07	0.32 $\pm$ 0.07	0.30 $\pm$ 0.07	0.523

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

²Parameters: ALT = Alanine Transaminase; ALB/GLOB = Albumen/globulin ratio; SDMA = symmetric dimethylarginine; WBC = white blood cell

4.3.4 Internal organs and carcass characteristics

Table 4.4 shows that there were no significant dietary effects ($P > 0.05$) on internal organs (gizzard, proventriculus, liver and intestines) of Jumbo quail hens.

Table Error! No text of specified style in document..**11.** Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on internal organ sizes (means $\pm$ standard error) of 14-week-old Jumbo quail hens

Parameters	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
Liver (g)	3.66 $\pm$ 0.13	3.67 $\pm$ 0.13	3.90 $\pm$ 0.12	3.99 $\pm$ 0.13	3.65 $\pm$ 0.13	0.206
Gizzard (g)	2.77 $\pm$ 0.09	2.88 $\pm$ 0.09	2.73 $\pm$ 0.09	2.79 $\pm$ 0.09	2.89 $\pm$ 0.09	0.614
Proventriculus (g)	0.82 $\pm$ 0.06	0.86 $\pm$ 0.06	0.88 $\pm$ 0.05	0.91 $\pm$ 0.06	0.84 $\pm$ 0.06	0.785
Small intestine (g)	6.28 $\pm$ 0.26	6.30 $\pm$ 0.26	6.33 $\pm$ 0.25	6.71 $\pm$ 0.27	5.90 $\pm$ 0.26	0.332
Large intestine (g)	1.56 $\pm$ 0.47	2.79 $\pm$ 0.47	1.88 $\pm$ 0.46	2.17 $\pm$ 0.50	2.43 $\pm$ 0.47	0.405
Small intestine (cm)	73.9 $\pm$ 2.40	70.8 $\pm$ 2.40	70.8 $\pm$ 2.30	70.7 $\pm$ 2.50	74.5 $\pm$ 2.40	0.644
Large intestine (cm)	14.0 $\pm$ 0.88	14.7 $\pm$ 0.88	15.7 $\pm$ 0.84	15.3 $\pm$ 0.92	12.8 $\pm$ 0.88	0.146

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

Table 4.5 shows that there were no dietary effects on carcass traits of Jumbo quail hens, except on HCW, CCW, wing and back length. Quail hens fed with CON diet had larger ($P < 0.05$) HCW and CCW compared to those that fed with diets CTMR and CTMB, but all three diets were similar ($P > 0.05$) to diets CTMO and CTMA. Diets CTMO and CTMB resulted in hens with heavier ($P < 0.05$) wing weights than diets CON and CTMA. Nonetheless, all diets were similar ($P > 0.05$) to diet CTMR. Quail birds fed diet CTMA had the shortest ($P < 0.05$) back length while birds fed CTMB and CTMO had the longest ($P < 0.05$) back length. However, all three diets were similar ($P > 0.05$) to diets CTMR and CON.

Table Error! No text of specified style in document..**12.** Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on carcass characteristics of Jumbo quail hens

² Parameters	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
² HCW (g)	168±4.13 ^a	147±4.13 ^b	163±3.97 ^{ab}	149±4.32 ^b	154±4.13 ^{ab}	0.003
³ CCW (g)	167±4.16 ^a	146±4.16 ^b	161±4.00 ^{ab}	148±4.35 ^b	153±4.16 ^{ab}	0.004
Thigh (g)	6.1±0.22	6.9±0.22	6.7±0.21	6.8±0.23	6.9±0.22	0.074
Wing (g)	4.1±0.12 ^b	4.5±0.12 ^{ab}	4.8±0.12 ^b	4.7± 0.13 ^a	4.6±0.12 ^a	0.007
Drumstick (g)	4.1±0.12	4.3±0.12	4.1±0.12	4.3±0.13	4.3±0.12	0.629
Breast (g)	17.4±0.45	18.3±0.45	18.2±0.44	19.1±0.47	18.4±0.45	0.144
Back (cm)	10.1±0.16 ^{ab}	10.0±0.16 ^{ab}	9.5±0.15 ^b	10.4±0.16 ^a	10.2±0.16 ^a	0.007
Thigh (cm)	4.4±0.06	4.6±0.06	4.5±0.06	4.4±0.06	4.5±0.06	0.684
Drumstick (cm)	55.3±0.93	54.7±0.93	53.4±0.90	52.5±0.98	52.9±0.93	0.186
Wing (cm)	10.8±0.12	10.6±0.12	10.9±0.12	10.6±0.12	10.5±0.12	0.151
Keel length (mm)	46.5±1.64	48.0±1.64	49.5±1.58	48.0±1.72	49.7±1.64	0.619
Keel diameter (mm)	20.8±0.80	20.2±0.80	19.4±0.77	18.6±0.84	18.8±0.80	0.265

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

²Parameters: HCW = hot carcass weight; CCW = cold carcass weight.

4.3.5 Breast meat quality parameters

Table 4.6 shows the effect of replacing maize with raw or thermally-treated CTM on meat pH, temperature and colour measured immediately and 24 hours after slaughter of Jumbo quail hens. There were no dietary effects ($P > 0.05$) on breast meat quality parameters measured immediately and 24 hours post-slaughter, except for 24-hour breast meat pH. Diet CON caused lower ($P < 0.05$) breast meat pH after 24 hours of slaughter than diet CTMB, but both groups had similar meat pH to CTMA, CTMO and CTMR groups.

Table Error! No text of specified style in document..**13.** Effect of total replacement of maize with raw or thermally-treated cassava tuber meal on breast meat quality attributes in Jumbo quail hens

	¹ Experimental diets					<i>P</i> -value
	CON	CTMR	CTMA	CTMB	CTMO	
<i>Immediately after slaughter</i>						
pH	5.74±0.05	5.76±0.05	5.78±0.04	5.78±0.05	5.83±0.05	0.654
Temp (°C)	23.0±0.48	24.0±0.48	22.3±0.47	23.5±0.51	24.0±0.48	0.083
<i>L</i> * (lightness)	45.2±0.82	45.8±0.82	46.0±0.78	45.2±0.85	43.8±0.82	0.309
<i>a</i> * (redness)	8.10±0.28	7.96±0.27	7.85±0.26	7.86±0.29	8.01±0.27	0.961
<i>b</i> * (yellowness)	1.03±0.12	1.01±0.12	0.68±0.12	0.89±0.13	1.12±0.12	0.090
<i>24 hours after slaughter</i>						
pH	5.90±0.05 ^b	5.97±0.05 ^{ab}	5.96±0.05 ^{ab}	6.14±0.05 ^a	6.00±0.05 ^{ab}	0.023
Temp (°C)	14.9±1.57	14.4±1.57	18.6±1.51	13.7±1.64	15.0±1.57	0.210
<i>L</i> * (lightness)	43.0±0.44	42.5±0.44	42.7±0.43	41.8±0.46	42.6±0.44	0.502
<i>a</i> * (redness)	10.6±1.01	8.54±1.01	8.67±0.97	8.60±1.05	8.57±1.01	0.521
<i>b</i> * (yellowness)	2.51±0.27	1.65±0.27	2.11±0.26	1.47±0.28	1.59±0.27	0.050
Shear force (N)	6.36±0.56	6.56±0.56	6.33±0.54	5.74±0.58	6.94±0.56	0.680

¹Experimental diets: CON = a conventional layer mash diet without cassava tuber meal; CTMR = a conventional layer mash diet containing 100% of raw cassava tuber meal in place of maize; CTMB = a conventional layer mash diet containing 100% of boiled cassava tuber meal in place of maize; CTMA = a conventional layer mash diet containing 100% of autoclaved cassava tuber meal in place of maize; CTMO = a conventional layer mash diet containing 100% of oven-dried cassava tuber meal in place of maize.

4.4 Discussion

Evaluation of egg shelf-life indicators in layers is important to evaluate the effectiveness of diets in maintaining or prolonging the storage period of eggs. Contrary to external quality, an eggs' internal quality begins to decline as soon as it is laid (Kumari *et al.*, 2020). Thus, while nutritional and management factors of hens play a role in internal quality of eggs, handling and storage practices also have a major impact on the quality of eggs that reach consumers. Similarly, albumen quality is a typical egg quality indicator that is determined by genetic and environmental factors such as temperature and time (Samli *et al.*, 2005). Consequently, the most important factors influencing egg quality during storage are relative humidity and temperature (Menezes *et al.*, 2009). The findings of this study indicate that complete replacement of maize with CTM in the diet of Jumbo quail hens had no influence on most shelf-life attributes throughout the 10-day storage period. However, there was a significant difference observed in albumen height at day 5 of storage. Birds from diet CTMR produced eggs with higher ($P < 0.05$) albumen height compared to those from CTMA, which produced the lowest ($P < 0.05$). Albumen height is related to the structure of the firm albumen, which changes overtime as the ovomucin complex, which accounts for 2 to 4% of the albumen protein content, degrades (Northcutt *et al.*, 2022). The reduction in albumen height as days of storage increased conforms to earlier report (Ogunwole *et al.*, 2017) that, gaseous diffusion of CO_2 and O_2 from the thick albumen during storage resulted to reduced albumen height. Moreover, a notable difference was observed in albumen pH on day 10 where eggs from quail fed the control diet had a significantly higher albumen pH compared to eggs from quail fed with CTMA, which had a lower albumen pH. The increase in pH of albumen occurs because of dissociation of carbonic acid (H_2CO_3), one of the components of the buffer system of albumen, forming water and carbon dioxide (Mota *et al.*, 2017). This reaction is accelerated when the storage temperature of the eggs is high. Under natural conditions, the CO_2 diffuses through the shell

and is lost at the environment, and the pH of the albumen increases, making the pH of the albumen alkali (Biladeau & Keener, 2009). Furthermore, the thickness of the shell membranes in quail eggs from birds fed with CON diet helped to maintain moisture and limit loss of carbon dioxide and pH changes.

The significant treatment effect observed in the latency-to-lie test indicates that the time taken by quail hens to lie down varied depending on the type of cassava tuber meal in their diets. This could imply differences in comfort levels, or perceived safety among the treatment groups. These results also suggest that body weight contributes to the results of poultry's leg health tests like gait score and latency-to-lie (Santos *et al.*, 2022). Autoclaved cassava resulted in the longest latency-to-lie compared to other treatments. The longer latency-to-lie indicates a better ability to support their body weight (i.e., leg strength) (Santos *et al.*, 2022). Autoclaving involves high-pressure steam treatment, which may alter the nutritional composition or texture of the cassava tuber meal. This alteration could influence the birds' perception of the feed or affect their gastrointestinal tract, potentially leading to differences in behaviour.

Blood is typically used as a physiological indicator to determine a bird's nutritional status, general health issues, and diseases (Akinosun *et al.*, 2020). In addition, blood serves as a pathological reflector of an animal's status after exposure to illnesses and other conditions (Etim *et al.*, 2014). There were treatment variations on haematological parameters, which implies that the health of the blood cells in Jumbo quail hens was not adversely affected in response to maize replacement with raw or thermally-processed CTM. Even though there were no significant dietary effects, the CTMR group had numerically low values in terms of blood. There were no dietary effects on serum indices such as glucose, cholesterol, and amylase observed in this study, this means that the birds were not energy deficient. In addition, serum indices obtained in the current study are consistent with the reference values reported by Scholtz *et al.* (2009), for Japanese quail fed with soybean products. Biochemical enzymes are

typically stored by the cells that synthesized them, and high serum enzyme levels are indicative of cell damage (Washington & van Hoosier, 2012). This confirms that there were no liver damages as a result of incorporating CTM, given that all the liver enzymes (AST, ALP, and ALT) used as markers of liver function were not altered (Washington & van Hoosier 2012). Biochemical indices such as blood urea nitrogen, uric acid, and creatinine are biomarkers of renal function (Donsbough *et al.*, 2010). However, there were also not influenced by the complete replacement of maize with CTM. Furthermore, there was an absence of dietary alterations on glucose, total protein, albumin and globulin, this means that the birds were not protein deficient Creatinine is the preferred indicator of measuring renal function because it is not influenced by factors such as diet and hydration (Mitruka & Rawnsley, 1981), than blood urea nitrogen, which increases as a result of high protein diet or vigorous activity and also decreases when a low-protein diet is offered or when an animal is experiencing liver failure (McLaughlin & Fish, 1994). This suggests that feeding diets containing raw or heat-treated CTM in place of maize had no negative impact on the kidneys and liver of the hens.

The digestive system supports the body to absorb nutrients to meet normal physiological, metabolic and anatomical requirements. Healthier birds have stronger intestines, which help them digest and use nutrients more efficiently (Yang *et al.*, 2009). Most visceral organs of Jumbo quail hens showed no negative effects from consuming diets with raw or heat-treated CTM in place of maize, signifying that the birds had no challenge in utilising the diets. However, the results of the current study differ with those of Ojediran *et al.* (2023), who found that birds fed processed cassava root meal had lower empty proventriculus weights compared to birds fed control diets. This could imply efficient digestion in quail fed with the cassava containing diet. The treatments had no influence on the liver of Jumbo quail hens, suggesting that the presence of secondary metabolites in cassava did not require serious detoxification by the liver, which could be the reason the liver enzymes were also not affected.

Carcass traits are a crucial economic indicator even in layer quail farming because they inform the welfare of the birds. Therefore, the price of quail products and overall revenue are influenced by reductions in carcass weights. Diet, sex, age and the genetic makeup of the birds all have a significant influence on muscular development and carcass conformation (López-Pedrouso *et al.*, 2019). In this study, there were observed dietary alterations on back and wing lengths of the hens. The observed variations in wing and back lengths among the treatment groups, with quail fed the control diet exhibiting longer wings and backs, could be attributed to the differences in body development. The maize-based diet promoted higher feed intake, which explains the increase in carcass weights of the birds, however, CTMA and CTMO results were similar to the ones of CON diet. This means that the treatments (CTMA and CTMO) did not have compromising effect on the weights of the birds in diets fed CTMA and CTMO. These results align with a study by Ojediran *et al.* (2023) who observed that the HCW of quail fed a diet containing 100% cassava tuber meal was significantly lower than that fed a control diet. Similarly, Edache *et al.* (2013) found that quail fed a diet containing 42% CTM had significantly lower HCWs than those fed a control diet. This indicate that replacement of maize with cassava meal did not have adverse effects on carcass yield. This study demonstrates that autoclaved and oven-dried CTM can be a viable alternative to maize in the diet of Jumbo quail hens without compromising their carcass traits. This is critically important considering the economic and environmental benefits associated with utilizing cassava as a feed source.

This study demonstrates that replacing maize with raw or treated CTM in the diet of Jumbo quail hens does not have a significant impact on meat pH, temperature, and colour immediately after slaughter. Meat temperature, another crucial factor influencing meat quality, also remained unaffected by the CTM treatments. The observed lack of dietary effects on meat pH immediately after slaughter corroborates a report by Vieira *et al.* (2022), who reported no treatment effects on meat quality immediately after slaughter of slow-growing broilers fed

cassava residues. Furthermore, meat colour, which is a key determinant of consumer acceptability, was also not influenced by the dietary treatments. This aligns with previous study, indicating that 20% inclusion peel meal can be effectively incorporated into poultry diets without altering meat colour (Abu *et al.*, 2015). This study suggests that CTM can be effectively utilized as a maize substitute in the diet of Jumbo quail hens without compromising fresh meat quality.

At 24 hours postmortem, meat pH was affected by the dietary treatments. Birds reared at CTMB diet (6.14) were found to have higher meat colour than birds reared at CON diet (5.90). According to Deminiciis *et al.* (2022), a normal pH of a quail breast should range between 5.7 and 6.0. Furthermore, Mir *et al.* (2017) reported that meat colour attributes depend on myoglobin content, whereby poor oxygenation of myoglobin is associated with high pH leading to dark meat. Genchev *et al.* (2010) also reported that a normal redness (a^*) of quail meat should range between 5.1 and 14. In this study, Jumbo quail hens fed CTMC showed a higher pH compared to other diets, which indicates that the meat from quail fed with CTMC had poor oxygenation of myoglobin, although there was no treatment effect on meat colour, but CTMC had numerically lower redness. According to Medina-Meza *et al.* (2014), cooking can increase lipid oxidation due to heat and exposure to oxygen. Lipid oxidation products react with myoglobin, denaturing it and reducing its ability to hold oxygen, leading to browning reactions which contribute to a less red or more brown meat color (Mancini & Hunt, 2005). Nonetheless, the absence of dietary effects on meat pH immediately after slaughter, yellowness, lightness, and shear force, means that feeding diets with raw or heat-treated cassava does not compromise the appearance, texture, and stability of Jumbo quail meat. However, cooking treatment needs to be reviewed as it negatively affected the meat pH.

4.5 Conclusion

Egg storage at room temperature affected egg breaking strength and albumen pH with the control diet producing higher values. Birds fed with CTMO were not strong enough to stand for the required time in order to pass the latency-to-lie test. There were no significant differences in haemato-biochemical analysis, internal organs and carcass characteristics. This demonstrates that the incorporation of raw or thermally processed cassava tuber meal does not compromise blood parameters, visceral morphometry, and meat quality. The meat pH was affected only after 24 hours of slaughter, CON diet compromised the meat pH. Although Jumbo quail reared on maize-based control diet showed the best performance, autoclaving followed by oven-drying treatments of cassava tuber meal were more effective and enhanced carcass traits of cassava tuber meal than cooking treatment.

4.6 References

- Abbas, Y. & Ahmad, A., 2018. Impact of processing on nutritional and antinutritional factors of legumes: A review. *Ann. Food Sci. Technol.* 19(2), 199-215.
- Abu, O.A., Olaleru, I.F. & Omojola, A.B., 2015. Carcass characteristics and meat quality of broilers fed cassava peel and leaf meals as replacements for maize and soyabean meal. *J. Agri. Vet. Sci.* 8(3), 41-46.
- Akinosun, A.A., Balogun, A.S., Shobanke, I.A., Raji, M.O., Oloko, A.B. & Bako, B.A., 2020. Haematological indices of broiler chicken fed varying levels of aloe-vera gel in water. In the 45th Annual Conference of the Nigerian society for animal production (NSAP), Abubakar Tafawa Balewa University, Bauchi, Nigeria, 16 – 19 March 2020 (Vol. 3030, p. 388).
- Akinwumi, A.O., Atandah, R.A., Olawuyi, B.S., Olagoke, O.C., Ojebiyi, O.O. & Odunsi, A.A., 2019. Comparative Evaluation on Preference and Composition of Different Avian Egg Types. *Int. J. Agric. Sci. Res.* 6(5), 2348 – 3997.
- Andama, M. & Oloya, B., 2017. Effectiveness of traditional processing techniques in reducing cyanide levels in selected cassava varieties in Zombo District, Uganda. *Int. J. Biotechnol. Food Sci.* 2(4), 121-125.
- Apata, D.F. & Babalola, T.O., 2012. The use of cassava, sweet potato and cocoyam, and their by-products by non-ruminants. *Int. J. Food Sci. Nutr. Eng.* 2(4), 54-62.
- Batool, F., Bilal, R.M., Hassan, F.U., Nasir, T.A., Rafeeqe, M., Elnesr, S.S., Farag, M.R., Mahgoub, H.A., Naiel, M.A. & Alagawany, M., 2021. An updated review on behavior of domestic quail with reference to the negative effect of heat stress. *Anim. Biotechnol.* 1-14.

- Bayata, A., 2019. Review on nutritional value of cassava for use as a staple food. *Sci J Anal Chem.* 7(4), 83-91.
- Berg, C. & Sanotra, G.S., 2003. Can a modified latency-to-lie test be used to validate gait-scoring results in commercial broiler flocks? *Anim. Welf.* 12(4), 655 - 659.
- Biladeau, A.M. & Keener, K.M., 2009. The effects of edible coatings on chicken egg quality under refrigerated storage. *Poult. Sci.* 88(6), 1266-1274.
- Cullis, C., Lawlor, D.W., Chimwamurombe, P., Bbebe, N., Kunert, K. & Vorster, J., 2019. Development of marama bean, an orphan legume, as a crop. *Food Energy Secur.* 8(3), 00164.
- Dei, H.K., 2017. Assessment of maize (*Zea mays*) as feed resource for poultry. *Poult. Sci.* 1, 1-32.
- Deminicis, R.G.D.S., Meneghetti, C., Garcia Júnior, A.A.P., Cruz, C.L.D.S., Deminicis, B.B. & Maciel, B.M., 2022. Performance, meat quality, and lipidemia of meat-type quails fed with diets containing essential oils. *Cienc. Rural*, 52, p.e20210547.
- Donsbough, A.L., Powell, S., Waguespack, A., Bidner, T.D. & Southern, L.L., 2010. Uric acid, urea, and ammonia concentrations in serum and uric acid concentration in excreta as indicators of amino acid utilization in diets for broilers. *Poult. Sci.* 89, 287-294.
- Edache, J.A., Musa, U., Karsin, P.D., Esilonu, J.O., Yisa, A., Okpala, E.J. & Zwandor, N.J., 2007. The feeding value of cassava meal diets for growing Japanese quail (*Coturnix coturnix japonica*). *Niger. J. Anim. Prod.* 34(1), 77-82.
- Etim, N.N., Williams, M.E., Akpabio, U. & Offiong, E.E., 2014. Haematological parameters and factors affecting their values. *Agri. Sci.* 2(1), 37-47.
- Genchev, A., Ribarski, S. & Zhelyazkov, G., 2010. Physicochemical and technological properties of Japanese quail meat. *Trakia J. Sci.* 8(4), 86-94.

- Gyles, N.R., Kan, J. & Smith, R.M., 1962. The heritability of breast blister condition and breast feather coverage in a White Rock broiler strain. *Poult. Sci.* 41(1), 13-17.
- Jeke, A., Phiri, C., Chitindingu, K. & Taru, P., 2018. Ethnomedicinal use and pharmacological potential of Japanese quail (*Coturnix coturnix japonica*) birdsmeat and eggs, and its potential implications on wild quail conservation in Zimbabwe: A review. *Cogent Food Agric.* 4(1), 1507305.
- Kanyinji, F. & Moonga, M., 2014. Effects of replacing maize meal with rumen filtrate-fermented cassava meal on growth and egg production performance in Japanese quails (*Cortunix japonica*). *J. Adv. Vet. Anim. Res.* 1(3), 100-106.
- Kestin, S.C., Knowles, T.G. Tinch, A.F. & Gregory, N.G., 1992. The prevalence of leg weakness in broiler chickens and its relationship with genotype. *Vet. Rec.* 131, 190 – 194.
- Kleyn, F.J. & Ciacciariello, M., 2021. Future demands of the poultry industry: will we meet our commitments sustainably in developed and developing economies?. *Worlds Poult. Sci. J.* 77(2), 267-278.
- Kumari, A., Tripathi, U.K., Maurya, V. & Kumar, M., 2020. Internal quality changes in eggs during storage. *Int. J. Sci. Environ. Techn.* 9(4), 615-624.
- López-pedrouso, M., Cantalapiedra, J., Munekata, P.E.S., Barba, F.J., Lorenzo, J.M. & Franco, D., 2019. Carcass characteristics, meat quality and nutritional profile of pheasant, quail and Guinea fowl. In: more than beef, pork and chicken the production, processing, and quality traits of other sources of meat for human diet. Springer international publishing, Berlin, Germany. 269–311.
- Mancini, R.A. & Hunt, M., 2005. Current research in meat color. *Meat Sci.* 71(1), 100-121.

- McLaughlin, R.M. & Fish, R.E., 1994. Clinical biochemistry and hematology. In: Manning, P.J., Ringler, D.H., Newcomer, C.E. (Ed.). The Biology of the Laboratory Rabbit (2nd ed.). Academic Press, San Diego, USA. 111–127.
- McMahon, J., Sayre, R. & Zidenga, T., 2022. Cyanogenesis in cassava and its molecular manipulation for crop improvement. *J. Exp. Bot.* 73(7), 1853-1867.
- Medina-Meza, I.G., Barnaba, C. & Barbosa-Cánovas, G.V., 2014. Effects of high pressure processing on lipid oxidation: A review. *Innov. Food Sci. Emerg. Technol.* 22, 1-10.
- Menezes, P.C.D., Lima, E.R.D., Medeiros, J.P.D., Oliveira, W.N.K.D. & Evêncio-Neto, J., 2012. Egg quality of laying hens in different conditions of storage, ages and housing densities. *R. Bras. Zootec.* 41, 2064-2069.
- Mitruka, B.M. & Rawnsley, H.M., 1981. Clinical, biochemical and hematological reference values in normal experimental animals and normal humans. Masson Publishing, New York, USA.
- Mnisi, C.M., Marareni, M., Manyeula, F. & Madibana, M.J., 2021. A way forward for the South African quail sector as a potential contributor to food and nutrition security following the aftermath of COVID-19: a review. *Agric. Food Secur.* 10(1), 1-12.
- Mir, N. A., A. Rafiq, F. Kumar, V. Singh, & V. Shukla. 2017. Determinants of broiler chicken meat quality and factors affecting them: a review. *J. Food Sci. Technol.* 54, 2997–3009.
- Northcutt, J.K., Buyukyavuz, A. & Dawson, P.L., 2022. Quality of Japanese quail (*Coturnix coturnix japonica*) eggs after extended refrigerated storage. *J. Appl. Poult. Res.* 31(3), 100280.
- Ngiki, Y.U., Igwebuike, J.U. & Moruppa, S.M., 2014. Utilisation of cassava products for poultry feeding: A review. *Int. J. Sci. Technol.* 2(6), 48.

- Ogunwole, O.A., Adesope, A.I., Raji, A.A. & Oshibanjo, O.D., 2017. Effect of partial replacement of dietary maize with cassava peel meal on egg quality characteristics of chicken during storage. *Niger. J. Anim. Sci.* 19(2), 140-152.
- Ojediran, T., Busari, O., Olagoke, O. & Emiola, A., 2023. Multi-processed cassava root meal: A suitable replacement for maize in Japanese quail diet. *Emerging Animal Species*, 9, 100035.
- Omosuli, S.V., Ikujenlola, A.V. & Abisuwa, A.T., 2017. Quality assessment of stored fresh cassava roots and 'fufu' flour produced from stored roots. *J. Food Sci. Nutr. Therapy.* 3(1), 9-13.
- Panghal, A., Munezero, C., Sharma, P. & Chhikara, N., 2019. Cassava toxicity, detoxification and its food applications: a review. *Toxin Rev.* 40(1), 1-16.
- Ramteke, R., Doneria, R. & Gendley, M.K., 2019. Antinutritional factors in feed and fodder used for livestock and poultry feeding. *Act. Sci. Nutr. Health*, 3(5), 39-48.
- Samli, H.E., A. Agma & N. Senkoylu., 2005. Effect of storage time and temperature on egg quality in old laying hens. *J. Appl. Poult. Res.* 14, 548-553.
- Santos, M.N., Widowski, T.M., Kiarie, E.G., Guerin, M.T., Edwards, A.M. & Torrey, S., 2022. In pursuit of a better broiler: walking ability and incidence of contact dermatitis in conventional and slower growing strains of broiler chickens. *Poult. Sci.* 101(4), 101768.
- Scholtz, N., Halle, I., Flachowsky, G. & Sauerwein, H., 2009. Serum chemistry reference values in adult Japanese quail (*Coturnix coturnix japonica*) including sex-related differences. *Poult. Sci.* 88, 1186–1190.
- Thirumalaisamy, G., Muralidharan, J., Senthilkumar, S., Sayee, R.H. & Priyadharsini, M., 2016. Cost-effective feeding of poultry. *Int. J. Sci. Environ.* 5(6), 3997-4005.

- Udensi, E.A., Ukozor, A.U.C. & Ekwu, F.C., 2005. Effect of fermentation, blanching, and drying temperature on the functional and chemical properties of cassava flour. *Int. J. Food Prop.* 8(1), 171-177.
- Vieira, S.S., Vieira, E.D.S., Barbosa, F.R.S., Lima, A.D.C.S., Marinho, A.M., Reis, C.P.D., Tavares, F.B., Oliveira, L.R.S., Alves, K.S. & Neta, E.R.D.S., 2022. Cassava residues in the diet of slow-growing broilers. *Acta Amaz.* 52, 189-198.
- Washington, I.M. & van Hoosier, G., 2012. *Clinical biochemistry and haematology*. University of Washington, Seattle, WA, USA. Pp. 59-91.
- Yang, Y., Iji, P. A. & Choct, M., 2009. Dietary modulation of gut microflora in broiler chickens: a review of the role of six kinds of alternatives to in-feed antibiotics. *World Poult. Sci. J.* 65, 97-114.
- Yulvianti, M. & Zidorn, C., 2021. Chemical diversity of plant cyanogenic glycosides: an overview of reported natural products. *Molecules*, 26(3), 719.

5 CHAPTER FIVE - GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATION

5.1 General discussion

The world population will increase by 2 billion over the next 26 years, from the current 7.7 billion (United Nations, 2019). To meet this population growth, it is necessary to expand the current range of plant and animal foods that are used in conventional animal feeds. Global production of poultry meat and eggs as well as their consumption has consistently increased over the years and is expected to continue to increase to meet the nutritional demand of the rapidly growing human population (Mardoia, 2016). As reported by Thea *et al.* (2018) poultry products are increasing in popularity as they are inexpensive, readily available, and low-fat sources of animal protein. Thus, it is necessary to explore new approaches in an attempt to maintain a balance between food supply and demand. Chicken products are the most commonly

consumed poultry products. To improve the prevailing situation, dietary diversification is touted as a promising alternative, which focuses on the use of readily accessible nutrient-dense foods such as quail products (Deway *et al.*, 2009). Therefore, it is crucial to expand the industry by introducing new species of birds such as quail. Due to high feed costs, the poultry industry has suffered more than any other livestock industry (Beriso, 2022). Feed cost is expected to continue in the upward swing (Conolly, 2012). The ability of laying hen diets to provide high quality nutrients that meet the nutritional needs of laying hens is critical for optimal egg production. In commercial poultry production, feed is the main cost factor in the production of eggs and meat (Gebeyew *et al.*, 2015). According to Mnisi & Mlambo (2018) the reason for the increase in animal feed prices is the use of expensive plant energy sources such as corn in the formulation process. Therefore, it is crucial to find and evaluate replacement feed sources that are affordable without compromising egg quality or laying hen performance (Nuhu, 2010). Cassava is one of the energy sources that can be used to substitute maize. Thus, this study was designed to improve the feed value of cassava tuber meal as an alternative energy source in Jumbo quail hens using different thermal processes. This experiment explored the hypothesis that boiling, autoclaving and oven-drying of cassava tuber meal (CTM) in place of maize would promote similar performance, egg quality traits, rate of lay, shelf-life indices, blood parameters, internal organs, carcass traits, meat quality parameters and welfare indicators in Jumbo quail hens. A total of 240, five-week-old Japanese quail hens were allocated randomly into 60 cages. Each cage (34 cm L × 27.5 cm W × 30 cm H) carried 4 hens and the cages were replicated 12 times per diet. Diets were formulated by replacing 100% maize with raw or treated (autoclaving, boiling and oven-drying) cassava in a standard basal diet. Chapter 3 reported that raw or thermally treated CTM had an influence on performance and egg quality parameters. Even though quail hens reared on maize-based diet showed best performance, autoclaving followed by oven-drying treatments of CTM were more effective and enhanced the nutritional

value of CTM than boiling treatment. Therefore, the tested hypothesis is rejected because the maize-based control performed better than the thermally treated cassava-containing diets in terms of performance and egg quality parameters in Jumbo quail hens. Chapter four reported that there was no treatment effect observed on haemato-biochemical analysis, internal organs, meat quality parameters, and welfare indicators. However, treatment effect was observed on shelf life and carcass characteristics. Therefore, the alternative hypothesis which states that boiling, autoclaving and oven-drying of CTM in place of maize meal would not alter welfare indicators, physiological responses, and carcass and breast meat quality traits in Jumbo quail hens was partially accepted.

5.2 Conclusion

The results of this study showed that autoclaving and oven-drying treatments enhanced overall growth performance, rate of lay, and egg quality parameters, and carcass traits. It can be concluded that although quail hens reared on maize-based diet showed the best performance, autoclaving followed by oven-drying treatments of CTM were more effective than boiling treatment. This study also demonstrated that thermally treated CTM does not compromise blood parameters, visceral morphometry, and meat quality.

5.3 Recommendations and future prospects

It can be recommended that the utility of CTM can be improved upon treatment with autoclaving and oven-drying to reduce the antinutritional activities of secondary metabolites and improve nutritional value of CTM. However, this may be more beneficial to laying quail hens when partial inclusion levels are used. Further research can also be conducted to evaluate the effect of chemically-treated cassava tuber meal and exploring the long-term effects of CTM on meat quality parameters, such as tenderness, water holding capacity, and sensory attributes.

This would be valuable in fully assessing its suitability as a maize substitute in Jumbo quail production.

5.4 References

- Beriso, Y., 2022. International Journal of Current Research and Academic Review Review of Nutritional Value of Sorghum for Chicken Feeding. *Int. J. Curr. Res. Acad. Rev.*, 10(01), 34–47.
- Conolly, A., 2012. Seminar presentation on “Pushing the boundaries – Performance and profitability”. *Poultry International Magazine*, Mark Clement (ed). January 2012. 18 www.WATTAgNet.com
- Gebeyew, K., Mohamed. A. & Urge. M., 2015. The effect of replacing maize with sorghum on carcass characteristics and economics feasibility on commercial broiler chicken. *Poult. Fish Wildl. Sci.* 3-30.
- Mardoia, M., 2016. Effects of dietary polyphenol-rich grape by-products on growth performance, some physical parameters meat and meat products quality in chickens. Madrid Spain. 1–244.
- Mnisi, C.M. & Mlambo, V., 2018. Growth performance, haematology, serum biochemistry and meat quality characteristics of Japanese quail (*Coturnix coturnix japonica*) fed canola meal-based diets. *Anim. Nutr.* 4, 37-43.
- Nuhu, F., 2010. Effect of *Moringa oleifera* leaf meal (MOLM) on nutrient digestibility, growth, carcass and blood indices of weaner rabbits (MSc Thesis). Kwame Nkrumah University of Science and Technology. Zambia. Pp. 1-75.
- Thea, K., Megan, O.M. & Lesley, L.D., 2018. Nanotechnology in the food sector and potential applications for the poultry industry. *Trends. Food. Sci. Technol.* 72, 62–73.
- United Nations, 2019. World population prospects 2019. In: department of economic and social affairs. New York, USA. 40.

6 LIST OF APPENDICES

6.1 Ethics Certificate of the study



Private Bag X1290, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Fax: 018 299-4910
Web: <http://www.nwu.ac.za>

Research Ethics Regulatory Committee
Tel: 018 299-4949
Email: ethics@nwu.ac.za

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **North-West University Animal Production Sciences Research Ethics Committee (NWU-AnimProdREC)** on 03/11/2022, the NWU Animal Production Sciences Research Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCORE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Enhancing the feed value of cassava tuber meal using different treatment methods for Jumbo quail hens

Study Leader/ Supervisor (Principal Investigator)/Researcher: Prof K Mhisi

Student: Gazl A

Ethics number:

N	W	U	-	0	0	8	1	4	-	2	2	-	A	6
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Institution Study Number Year Status
Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type: Single Study

Commencement date: 2022/11/04

Expiry date: 2023/11/03

Risk Category:

2

Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

Special in process conditions of the research for approval (if applicable):

- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the NWU-AnimProdREC. Ethics approval is required BEFORE approval can be obtained from these authorities.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- The study leader/supervisor (principal investigator)/researcher must report in the prescribed format to the NWU-AnimProdREC:
 - annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and
 - without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.
- The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the NWU-AnimProdREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.
- Annually a number of studies may be randomly selected for an external audit.
- The date of approval indicates the first date that the study may be started.
- In the interest of ethical responsibility, the NWU-SCORE and NWU-AnimProdREC reserves the right to:

- request access to any information or data at any time during the course or after completion of the study;
- to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;
- withdraw or postpone approval if:
 - any unethical principles or practices of the study are revealed or suspected;
 - it becomes apparent that any relevant information was withheld from the NWU-AnimProdREC or that information has been false or misrepresented;
 - submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or
 - new institutional rules, national legislation or international conventions deem it necessary.
- NWU-AnimProdREC can be contacted for further information or any report templates via UPenyu.Maruma@NWU.ac.za or 016 300 2726.

The NWU-AnimProdREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the NWU-AnimProdREC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely



Prof Upenyu Maruma
Chairperson NWU Animal Production Sciences Research Ethics Committee

Original details: C:\Users\22151630\Desktop\ETHICS APPROVAL LETTER OF STUDY.docx
8 November 2018

Current details: C:\Users\22151630\Desktop\Monitoring and Reporting\Quarterly\Annual\Certificates\Templates\Research Ethics Approval Letter\9.1.5.4.1 NWU-AnimProdREC Unicat Approval Letter.docx
3 December 2018

File reference: 9.1.5.4.2

6.2 Language Editing Certificate



UNIVERSITY OF
MPUMALANGA

Creating Opportunities

Faculty of Agriculture & Natural Sciences
School of Agricultural Sciences
P. Bag x11283
Riverside
Nelspruit 1209

13th March 2024

TO WHOM IT MAY CONCERN

RE: ENGLISH LANGUAGE EDITING – A GAZI [Student No: 43391338; ORCID: 0000-0001-5750-2405]

This serves to confirm and certify that the language and grammatical errors in the thesis by the candidate at caption entitled "Enhancing the feed value of cassava tuber meal using different treatment methods for Jumbo quail hens" have been corrected. The candidate has been advised on the correct usage of English and the necessary amendments have been made.

Sincerely,

A handwritten signature in black ink, appearing to read "Victor Mlambo", written over a horizontal line.

Prof. Victor Mlambo, Pr. Sci. Nat. (Animal Science)
Tel: +27 13 002 0249
E-mail: Victor.Mlambo@ump.ac.za

6.3 Turnitin Report

23257539:Gazi_Dissertation_draft_4.docx

ORIGINALITY REPORT

25%

SIMILARITY INDEX

20%

INTERNET SOURCES

18%

PUBLICATIONS

7%

STUDENT PAPERS

PRIMARY SOURCES

1

Submitted to North West University

Student Paper

2%

2

www.ncbi.nlm.nih.gov

Internet Source

1%

3

www.frontiersin.org

Internet Source

1%

4

Submitted to Federal University of Technology

Student Paper

1%

5

repository.nwu.ac.za

Internet Source

1%

6

repository.futminna.edu.ng:8080

Internet Source

1%

7

G. Mhlongo, C.M. Mnisi. "Effect of seaweed (Ecklonia maxima) on apparent nutrient digestibility, growth performance, and physiological and meat quality parameters in Boschveld cockerels", Poultry Science, 2022

Publication

1%

8

journals.plos.org

Internet Source