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Editorial Note: Journal of Technological Sciences (JTS) Volume 2, Issue 2, 2025

This issue of the *Journal of Technological Sciences* presents six manuscripts that collectively demonstrate the breadth and interdisciplinary scope of contemporary research. The contributions span environmental modeling, food science and nutrition, biodiversity conservation, and natural product chemistry applications in agriculture, reflecting a strong commitment to addressing both regional and global challenges through applied research.

The first study applies advanced geospatial techniques to analyze the impacts of urbanization on wetlands. It highlights how rapid urban expansion affects fragile ecosystems and emphasizes the value of predictive tools in promoting sustainable urban planning and environmental conservation. The second paper provides a systematic review of the use of dairy products as carriers of probiotics. It synthesizes current knowledge on functional foods and underscores the growing importance of probiotic-enriched dairy products in improving human health. The third manuscript addresses the urgent issue of elephants. By integrating environmental variables with spatial analysis, the study identifies key factors influencing poaching activities. The findings offer practical insights that can inform more effective and targeted conservation and anti-poaching strategies.

The fourth contribution explores the acaricidal potential of *Cissus quadrangularis* as a natural alternative for controlling cattle ticks. This research supports the development of eco-friendly and sustainable livestock management practices, reducing reliance on synthetic chemicals while enhancing animal health and productivity. The fifth paper investigates the proximate composition and functional properties of selected pearl millet and finger millet varieties. The study reinforces the nutritional and economic importance of these traditional grains. The sixth manuscript examines how farmers' entrepreneurial competencies influence agricultural performance.

In conclusion, this issue underscores the importance of integrating technological innovation with local knowledge systems to address key challenges in environmental sustainability, public health, and agriculture. The contributions reflect high scholarly standards, and appreciation is extended to both authors and reviewers. It is hoped that this collection will inspire further research, encourage interdisciplinary collaboration, and advance the field of sciences.

Stephen Nyoni, PhD, MRSC

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Predictive Spatio-Temporal Modelling of Urbanization Impacts on Wetlands in Monavale Vlei, Harare, Using Cellular Automata–Markov 2012–2022

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Abstract

Urbanization is a major driver of wetland ecosystems, especially in the rapidly growing city of Harare, Zimbabwe. Monavale Vlei, situated in the Manyame River sub-catchment, is an important component in maintaining ecological and hydrological balance for Harare. This paper uses the Cellular Automata–Markov (CA-Markov) model to evaluate past wetland change dynamics (2012-2022) and forecast future land use and land cover (LULC) change up to 2032. The results show extreme wetland change and conversion due to urban expansion, with water resources projected to decrease by 63.4%, forest cover by 14.9%, and built-up areas to expand by 11.5%. However, some forest recovery (31.2%) and further urban expansion (26.3%) are also expected. These projections confirm the imbalanced effects of urbanization, with its critical hydrological and ecological processes being disproportionately endangered. The results of this study indicate that urban sprawl not only affects biodiversity and groundwater recharge but also affects agricultural and livelihood processes, making the population more susceptible to waterborne diseases. This study stresses the need for urgent conservation and policy measures to address wetland degradation and ensure sustainable urban development in Harare.

Keywords: Land Use/Land Cover (LULC), wetland loss, urbanization, MOLUSCE (Modules for Land Use Change Evaluation)

Introduction

Wetlands are some of the most valuable ecosystems in terms of their ecological services. Wetlands support biodiversity, regulate hydrological cycles, protect against floods, act as water filters, store carbon, and support a wide range of species (Turner, 2021). Unfortunately, wetlands are increasingly threatened by human activities, especially urbanization. Urbanization often takes place in low-lying areas, which are often wetlands, making them highly susceptible to destruction.

In Zimbabwe, the situation in Harare, the capital city, is a case in point. Harare has experienced rapid population growth and urbanization, leading to the encroachment and conversion of wetlands, such as Monavale Vlei, which is part of the Manyame River sub-catchment, a major water source for the city. The loss of wetlands in Harare not only affects the ecological services but also has implications for the livelihoods of people's, including agriculture, fishing, and access to water. In addition, the loss of wetlands makes the city more susceptible to waterborne diseases and environmental problems (Sithole & Goredema, 2013; Feresu et al., 2015). Currently, it has been reported that over 50% of Harare's wetlands have been lost due to the expansion of informal settlements and urbanization (Harare Wetlands Trust, 2021). Understanding the causes and effects of this environmental change requires tracking and measuring wetland loss. Tracking variations in wetland area over time can be effectively accomplished using remote sensing data and geospatial techniques, such as spatial time series analysis. Researchers can identify, quantify, and chart the dynamic processes of wetland conversion and loss through the examination of a series of satellite images or other spatial data.

Analysis of land use and land cover (LULC) change is a vital tool for studying wetland change under urbanization. Land use is the human use of land, while land cover is the physical and biological characteristics of the Earth's surface (Meyer & Turner, 1992; Turner, 2021). Human-induced LULC change, such as the conversion of wetlands into built-up areas, affects the functions of ecosystems and leads to environmental degradation (Amin & Fazal, 2012).

Remote sensing and Geographic Information Systems (GIS) are effective methods for analyzing and measuring LULC change over time. Satellite imagery provides spatial data on land cover at various temporal resolutions, enabling the analysis of conversion patterns and trends (Chuvieco, 2020; Khan et al., 2015). Unlike conventional LULC analysis, which typically involves the comparison of two images at two points in time, predictive models such as Cellular Automata–Markov (CA–Markov) models enable the simulation of future landscape changes based on trends identified in past observations. This method not only helps to determine past wetland conversion but also enables the estimation of the future potential for urban and ecological change.

However, despite global knowledge of wetland degradation, the literature has concentrated on other parts of the world rather than on Africa. In Harare, the wetlands are still under threat from the informal settlements, industries, and population increase. It is important to understand these dynamics to develop sustainable strategies for urban planning and wetland conservation.

Taking these factors into consideration, this research will concentrate on Monavale Vlei in Harare, Zimbabwe, to examine the effects of urbanization on wetland change and predict future changes. In particular, this research will attempt to quantify wetland loss and land cover change in Monavale Vlei from 2012 to 2022, as well as predict future changes in wetland status and urban expansion trends up to 2032 using Cellular Automata–Markov modeling. Furthermore, this research will attempt to evaluate the possible ecological and hydrological effects of wetland conversion due to the continued effects of urbanization. By achieving these research objectives, this study will provide informed insights for decision-makers, urban planners, and environmental managers in Harare to promote sustainable urban development and wetland conservation.

Materials and Methods

Study Area

Monavale Vlei is a wetland situated in the northwestern outskirts of Harare, Zimbabwe, in the Manyame River sub-catchment (roughly 17°47′S latitude and 31°2′E longitude). The wetland is estimated to cover about 120 hectares, making it one of the largest natural wetlands remaining in the Harare municipal area. Monavale Vlei is an important component of Harare's hydrology, recharging groundwater, regulating surface water, and sustaining biodiversity.

The climate in the study area is subtropical with a clear wet and dry season, typical of the highveld climate of Zimbabwe. The area receives an average annual rainfall of 750 mm to 1,000 mm, with the wettest months being November to March, while the dry months are May to August, which are normally cold. This seasonality affects hydrological processes in the wetland and its catchment. Presently, Monavale Vlei is protected by the municipality, but it is not recognized as a Ramsar site. The level of protection afforded to this wetland is only through local government control and management, which seeks to ensure a balance between conservation and the demands of urban development. Even with this level of protection, Monavale Vlei is still facing threats of encroachment by informal settlements, agriculture, and the expansion of urban infrastructure.

The wetland is home to a range of plant and animal species, some of which are indigenous wetland species that rely on the wetland's hydrological role. The importance of Monavale Vlei, both ecologically and hydrologically, and the challenges posed by Harare's rapid growth as an urban centre, make this wetland an important case study for understanding the effects of urbanization on wetland ecosystems.

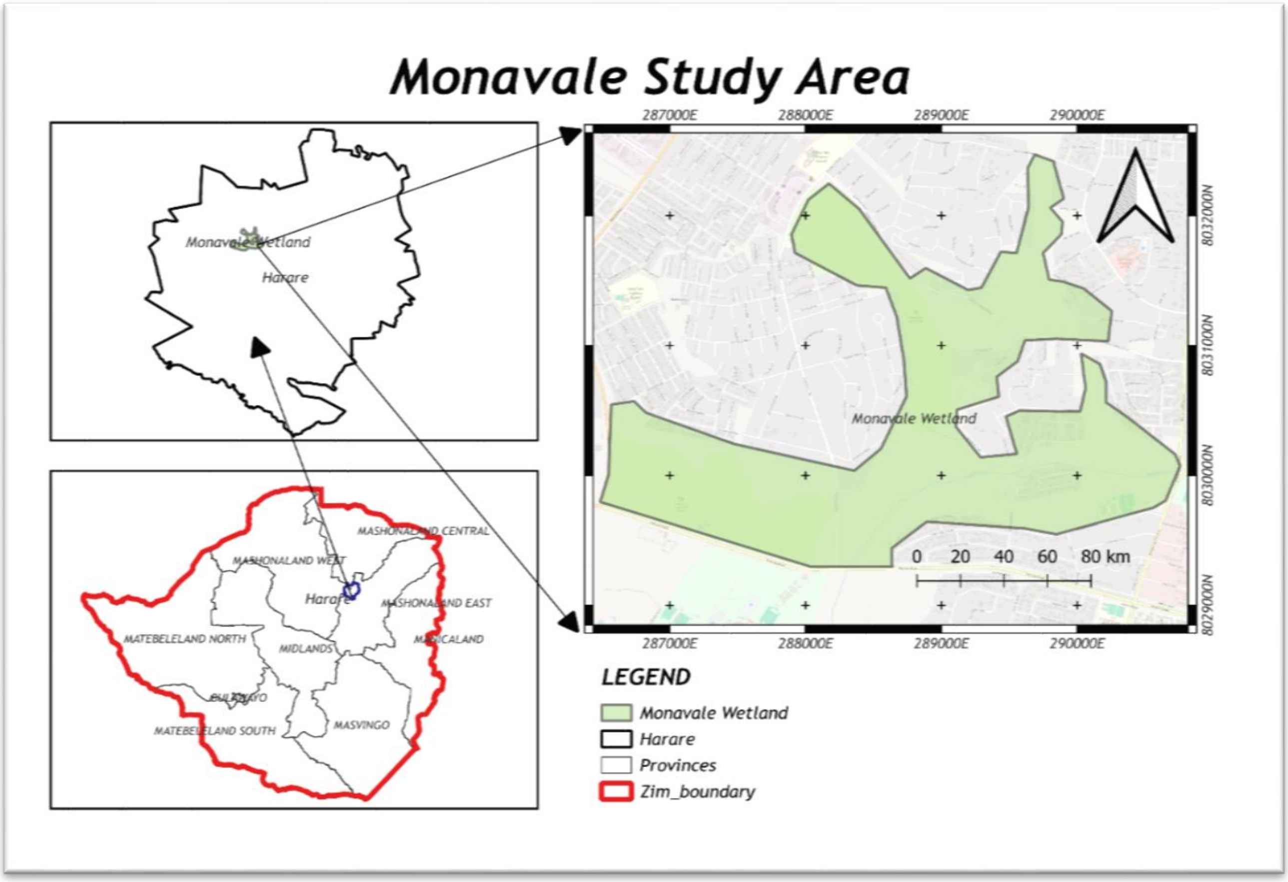


Figure 1: Study Area

To determine the Land Use and Land Cover changes in wetland extent in Monavale.

Data acquisition

To monitor the changes in wetland extent in Monavale, multispectral satellite images were acquired in 2012 and 2022. Both images were downloaded from United States Geological Survey (USGS). The satellite images were chosen based on their quality, focusing on scenes without significant line scan errors. ArcMap was used for classification.

Table 1: Table showing satellite image specifications

Data	Year of acquisition	Bands	Resolution	Cloud cover	Source
LANDSAT 7 ETM	2012	Multi-spectral	30	< 10%	United Sates Geological Survey (USGS)
LANDSAT 8 OLI	2022	Multi-spectral	30	< 10%	United Sates Geological Survey (USGS)

Satellite image pre-processing and classification

The satellite images for 2012 (Landsat 7 ETM+) and 2022 (Landsat 8 OLI/TIRS) were downloaded and analyzed using ArcMap. The images were first georeferenced to enable alignment with the existing geographic coordinates. Landsat 7 ETM+ and Landsat 8 OLI images were analyzed using their respective band combinations. For instance, water features were extracted using Bands 5, 6, 4 for Landsat 7 and Bands 6, 5, 4 for Landsat 8; built-up areas used 6, 3, 2 for Landsat 7 and 7, 4, 2 for Landsat 8; forested areas used 7, 6, 4 for Landsat 7 and 7, 6, 5 for Landsat 8; and bare land used 5, 4, 3 for Landsat 7 and 6, 5, 4 for Landsat 8.

To reduce noise and improve classification accuracy, the Semi-Automatic Classification Plugin (SCP) in ArcMap was used to extract features. The supervised classification was performed by digitizing the training samples as polygons for the four classes of land cover: bare land, water features, built-up areas, and forests. Google Earth Pro was used as the reference material for validatingthe training samples. The final result for each year was a classified raster layer that depicted LULC.

For change detection, a change matrix was developed to detect the transition of classes from 2012 to 2022. For spatial transition modeling, the MOLUSCE plugin was employed to develop a transition potential map, which helped to provide input for predictive analysis on future LULC dynamics.

Accuracy Assessment: The accuracy of classification was assessed using a confusion matrix, which helped to compute the user's accuracy (probability that a pixel assigned to a particular class actually belongs to that class) and producer's accuracy (probability that a reference pixel of a particular class was assigned to that class). The overall accuracy of the classification achieved a Kappa value of 0.899, which revealed very high agreement between the classified map and the reference map. Class-wise accuracy statistics, including producer and user accuracies, were provided for each LULC class.

Table 2: Table showing land use classes on the image classification.

Class Name	**Description**
Water bodies	Rivers, dams, ponds, open water
Forest	Trees, grasslands
Built-up	Settlement, commercial, roads
Bare land	Open areas

Detecting changes in land use was carried out to find out the rate of change that had taken place following the classification and the acquisition of the land use maps. Post-classification change detection was performed by QGIS using a semi-automatic classification plugin (SCP), to quantify the changes that had occurred to the classes of interest. Data from the land use maps was exported to Excel to produce a bar graph representing the changes that had occurred in the land use classes. The Spearman's rho correlation was then used to determine the relation between the degradation of the Monavale Vlei that is the change in LULC, and urbanization.

To analyze the effects of the LULC changes in the wetland.

To analyze the effects of Land Use and Land Cover changes in the Monavale Vlei, a Google Forms yes/no questionnaire was designed to gather insights and observations from the residents living in the areas surrounding the wetland, which are Sherwood Park in the northern part, Meyrick Park in the west, Westlea in the south and Milton Park in the eastern of the wetland. These four areas were used to create the four groups to capture the qualitative data which was then analyzed to determine the effects of urbanization in the wetland. Non-probability sampling/judgmental sampling/purposive sampling were used to choose five respondents from each suburb. This sampling method was used to make sure respondents had long-term knowledge of the wetland and had observed the changes. The questionnaires included observed changes in LULC by the residents, observed ecological impacts and socioeconomic effects of the changes to the residents. SPSS was then used to calculate the statistical relationship between respondents' responses and the effects of LULC changes in the Monavale Vlei.

To predict the future LULC of Monavale wetland in relation to the environment.

To predict the future LULC of Monavale Vlei, the study used machine learning in QGIS. The multi-temporal LULC maps of 2012 and 2022 were loaded into Quantum GIS. A Digital Elevation Model (DEM) was also downloaded. The DEM was used to account for elevation limitations. For example, to enhance prediction accuracy by adding topographic information into LULC changes, since urban development favors flat terrains. The multi-temporal maps and the DEM were checked for their consistency in size, bands, classes, spatial resolution and if they have an aligning coordinate system. The Modules for Land Use Change Evaluation (MOLUSCE) plugin was then used to initiate the prediction process. To check the geometry of the raster layers, the 2012 LULC map was added as the initial map, the 2022 LULC map as the final map and the DEM as the spatial variable. After that, Pearson's correlation was used for evaluating correlation and a class statistics table and a transition matrix were made to create a transition potential map. The transition potential modelling was done using the Artificial Neural Network (Multi-layer Perceptron) and the neural network was trained. The Cellular Automata was then used to create the prediction map of 2032 and to also calculate the percentage of correctness, which was 89.89%, to validate the map.

Results

To determine the change in land use and land cover types in Monavale.

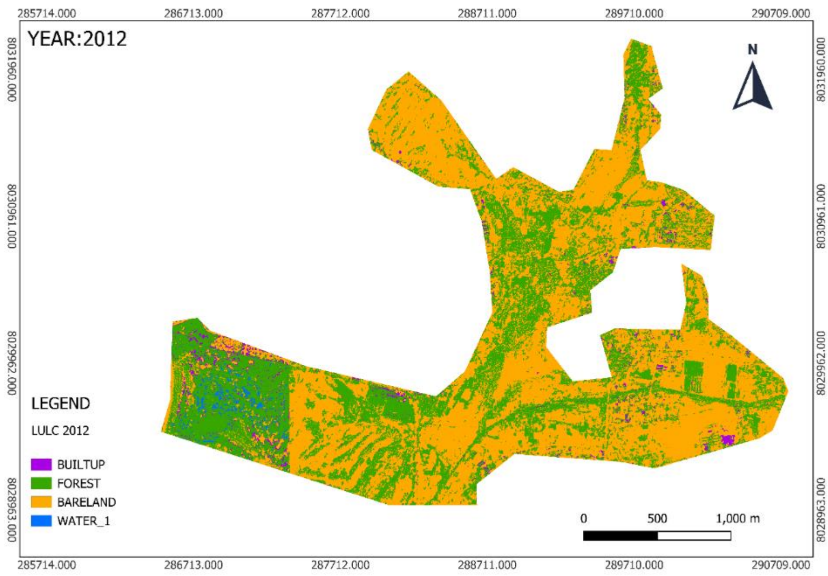


Figure 2: LULC Map for Monavale in 2012

The resultant land use land cover map for 2012 showed that the Monavale Vlei had a total land area of 5.38km^2. Area and percentage cover of individual classes showed that forest had the highest proportion 1.82km^2 which was 46.5% of the total land uses assigned by the supervised classification. Bare land had the second-highest cover at 1.83 km2 (33.8%), followed by Built-up at 0.91 km2 (16.9%), which occupied 16.9% of the wetland. Water bodies accounted for the least, at 7.6% of the area, or 0.41 km2.

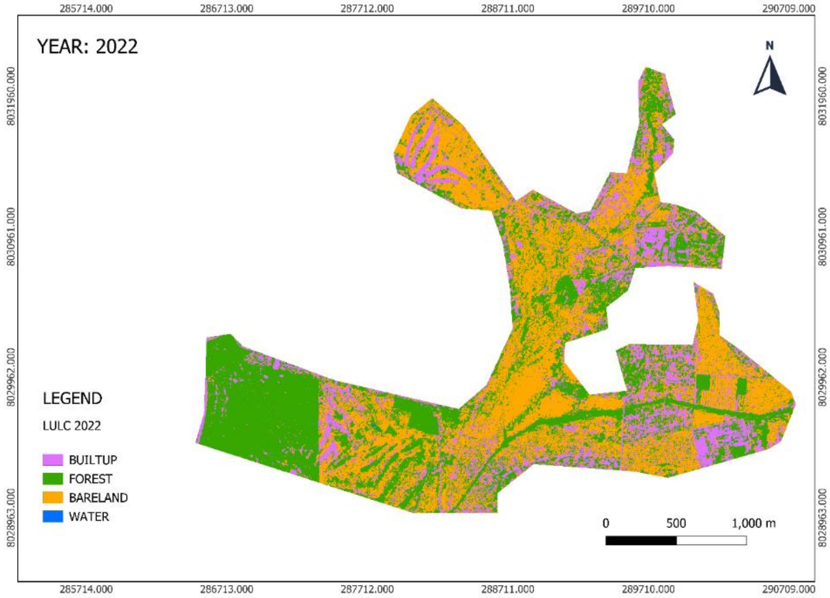


Figure 3: LULC Map for Monavale Vlei in 2022

In 2022, bare land had 1.75km^2 (32.5%) taking the highest proportion of the area followed by forest, which covered 31.6% (1.70km^2). The third class had 28.4%(1.52km^2). Water bodies occupied 0.41 km^2, which is 2.9% of the area. Urban development was more concentrated in the South-East of Monavale Vlei.

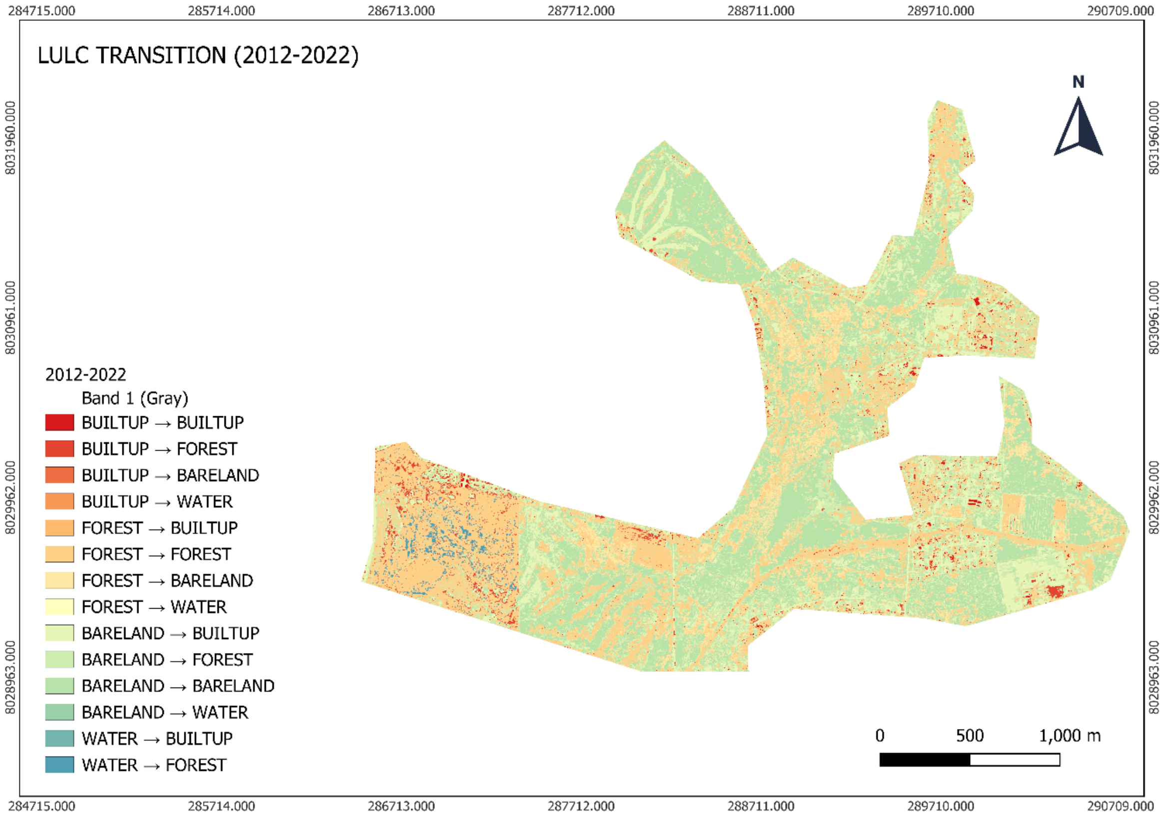


Figure 4:A Monavale Vlei LULC transition potential map from 2012 to 2022

The transition potential map shows LULC changes in square kilometres (km^2) over 10 years that is from 2012 to 2022 showing key trends and pressures on the Monavale wetland ecosystem. It shows the potential losses of each LULC class to another.

Table 3: Change detection matrix from one class to another.

CHANGE 2012-2022	**AREA**
BARELAND-BARELAND	1.688219
BARELAND-BUILTUP	0.898337
BARELAND-FOREST	0.549474
BARELAND-WATER	0.000043
BUILTUP-BUILTUP	0.031562
FOREST-BARELAND	0.694227

FOREST-BUILTUP	0.018877
FOREST-FOREST	1.39178
FOREST-WATER	0.001029
WATER-FOREST	0.03666

The table highlights the quantities of area changes, from one class to another over a decade (2012-2022). The areas correspond to a specific land use transition. Bare land to bare land: 1.688219km^2 of bare land remained bare. This class has the largest persistence, indicating stable bare areas. 0.898337km^2 of bare land transitioned into built-up indicating urbanisation. 0.549474km^2 of bare land also transitioned to forest showing some reforestation efforts or the area was turned into agricultural space. 0.000043km^2 of bare land turned into water. 0.031562km^2 of built-up remained as built-up. 1.39178km^2 of forest remained forest while 0.018877km^2 transitioned into built-up. This shows the occurrence of urban sprawl and 0.694227km^2 of forest turned into bare land due to deforestation. 0.001029km^2 of forest transitioned into water. 0.03666km^2 of water transitioned into forest.

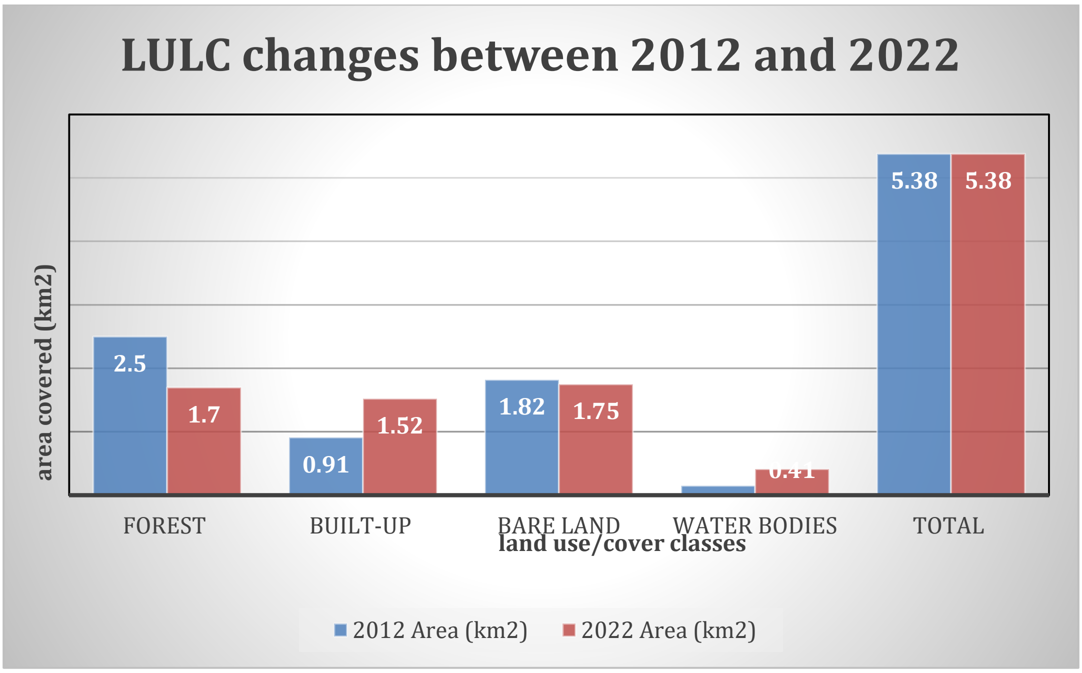


Figure 5: Bar Graph showing LULC changes between 2012 and 2022

The data presents LULC changes between 2012 and 2022, with two sets of numerical values corresponding to each year. The LULC classes include forest, built-up, water bodies and bare land. The first set of values that is of 2012 shows 2.5km^2, 0.91 km^2, 1.82 km^2 and 0.15km^2, while the second set of 2022 displays 1.7 km^2, 1.52 km^2, 1.75 km^2 and 0.41 km^2. The table shows that the forest area in 2012 was 2.50 km^2 which is 46.5% of the total area, and it decreased to 1.70 km^2 (31.6%) in 2022. The area covered by the forest decreased by 0.80 km^2 which is -14.9% relative to 2012. The area covered by built-up was 0.91km^2 (16.9%) in 2012 and it increased to 1.52km^2 (28.4%) in 2022. This is a 11.5% increase in built-up areas. In 2012, bare land was 1.82 km^2 which is 33.8% of the total area. In 2022, bare land decreased to 1.75 km^2 (32.5%). The water bodies in 2012 covered 7.6% of the total area (0.41 km ^{2}) and, in 2022, they covered 2.9% of the total area (0.15 km^2).

Table 4: A table showing the Spearman's Rho Correlation results.

			forest	built-up	bare land	water
Spearman's rho	forest	Correlation Coefficient	1.000	-1.000	1.000	1.000
		Sig. (2-tailed)	.	.	.	.
		N	2	2	2	2
	built-up	Correlation Coefficient	-1.000**	1.000	-1.000	-0.8000
		Sig. (2-tailed)	.	.	.	.
		N	2	2	2	2
	bare land	Correlation Coefficient	1.000**	-1.000**	1.000	-1.000
		Sig. (2-tailed)	.	.	.	.
		N	2	2	2	2
	water	Correlation Coefficient	-1.000**	1.000**	-1.000**	1.000
		Sig. (2-tailed)	.	.	.	.
		N	2	2	2	2

Correlation is significant at the 0.01 level (2-tailed).

Forest cover has a strong negative correlation with built-up areas of -1.000. This shows that as built-up increases, forest cover is lost, indicating that urbanization is causing deforestation in the Monavale Vlei. Forest cover has a positive correlation with bare land of 1.000, meaning that there is also bare land in the forests and this highlights that urban is expanding directly into forests. The correlation of forest and water is positive (1.000). This indicates that as forest cover decreases, the quality and quantity of water also decrease. Built-up and bare land have a correlation coefficient of -1.000, showing a perfect negative correlation. This shows that as built-up increases, bare land decreases indicating that urbanization is expanding and taking up the bare land. There is a strong negative but not perfect correlation between built-up and water. This means that as urbanization increases, the quality and quantity of water are affected and it declines. There is a negative correlation of -1.000 between bare land and water. This indicates that as bare land increases due to deforestation and urbanization, water decreases due to the degradation of wetlands.

To analyze the effects of LULC change on the Monavale wetland

Demographics

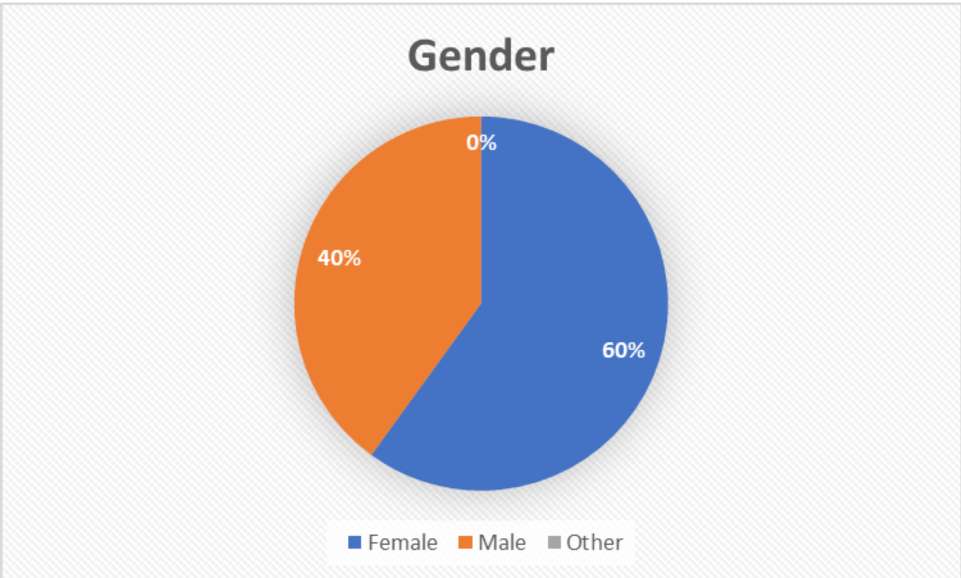


Figure 6: A pie chart showing gender data.

The questionnaire data show a clear gender imbalance among the 20 respondents who answered. Females, highlighted in blue, greatly outnumber males, shown in orange, making up 60% of the responses (12 people), while males make up 40% (8 people). The survey had no responses from gender-diverse or non-binary participants.

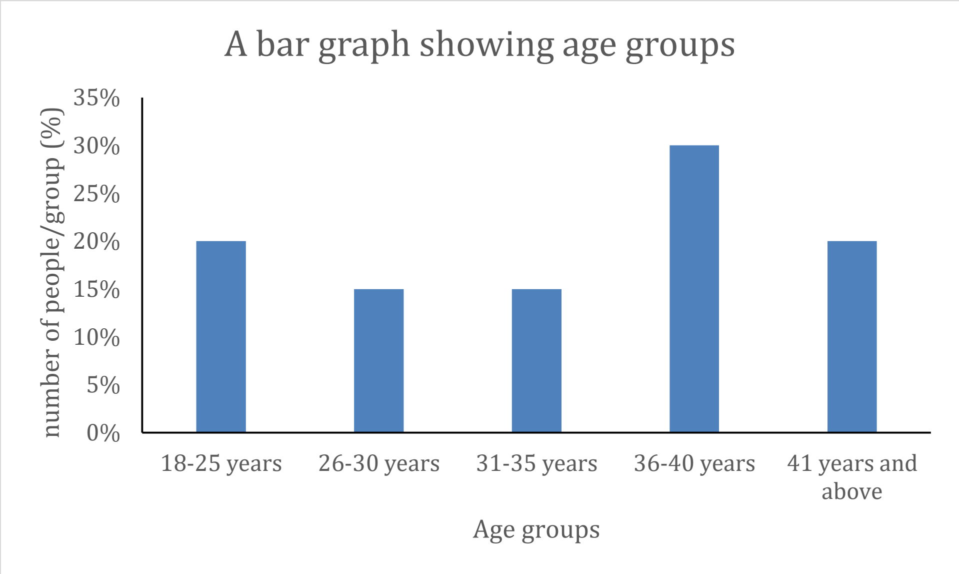


Figure 7: A bar graph showing age groups

The data from the questionnaires presents the age of 20 participants. The most numerous group is 36-40 years (30%, 6 participants), followed by 18-25 years and 41 years and older (20% each, 4 participants). The least numerous groups are 26-30 years and 31-35 years (15% each, 3 participants). The bar graph shows this spread. It is highest for the 36-40 age group and is well distributed across younger and older participants. This shows that the participants are diverse but more middle-aged.

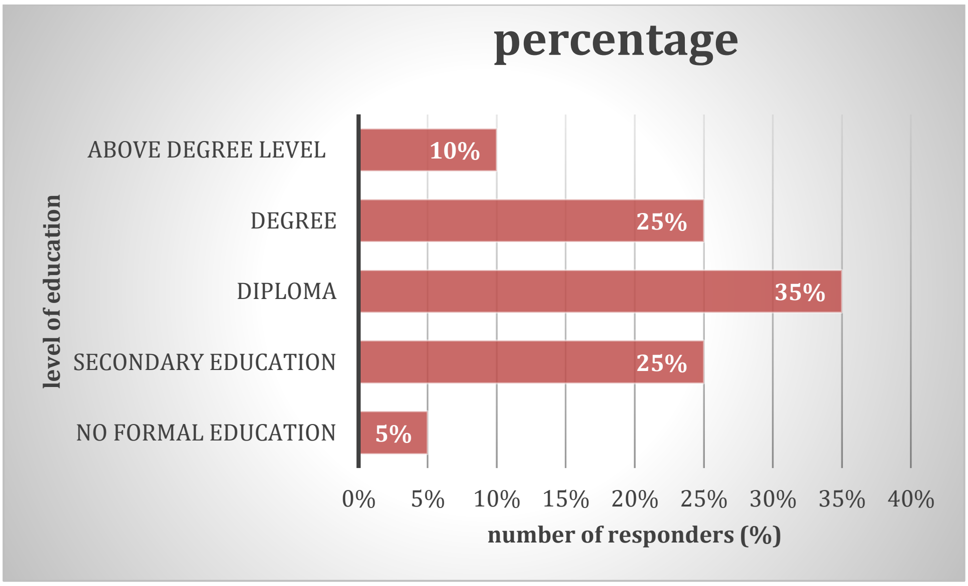


Figure 8: A bar chart showing educational levels.

The data from the questionnaires presents the educational levels of 20 respondents. The most common group is those with Diplomas (35%, 7 people). Secondary and Degree follow, both at 25% (5 people each). Fewer people indicated an above degree level (10%, 2 people). Only 5% (1 person) had No formal education. The bar graph shows this spread, indicating that most individuals have at least a secondary education, with diplomas as the most prevalent qualification. The figures show a grouping of respondents with medium education, with very few at the extremes.

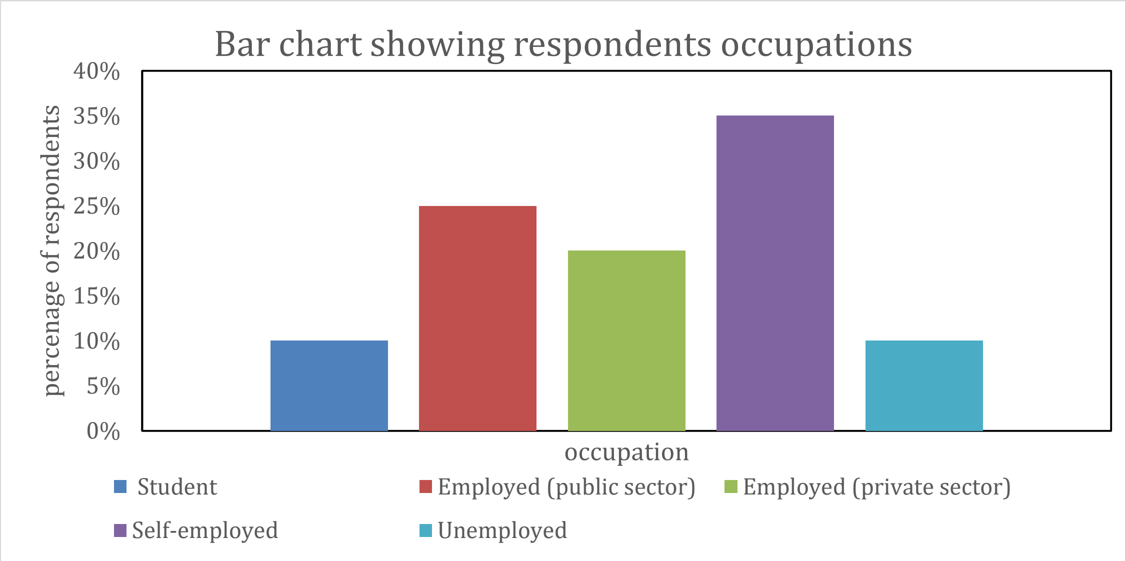


Figure 9: A bar showing respondents occupations.

The occupations of 20 people are reflected in the questionnaire data. The most dominant group is the self-employed (35%, 7 people), followed by employees in the public sector (25%, 5 people) and the private sector (20%, 4 people). Students and the unemployed make up 10% each (2 people). The bar chart illustrates this clearly, highlighting self-employment as the most common occupation. It suggests that the respondents have different employment statuses but most are entrepreneurs.

Table 5: Table showing chi-square tests for the demographics.

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2.500[a]	3	.475
Likelihood Ratio	3.278	3	.351
N of Valid Cases	20		

Pearson Chi-Square: $\chi^2(3) = 2.500$, $p = 0.475$) as $p>0.05$.

There was no significant relationship between demographics and perceptions of wetland changes. The characteristics of the demographic results did not influence the respondents' responses in any way.

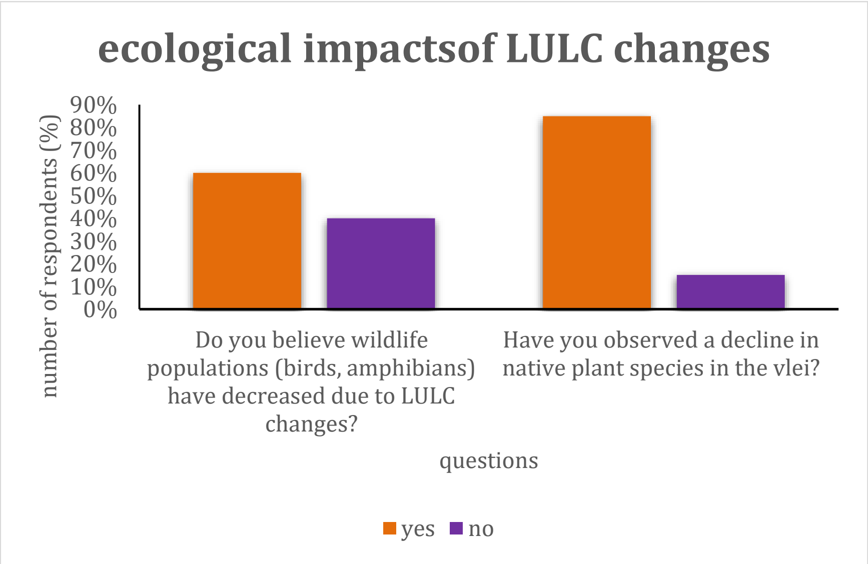


Figure 10: A bar chart showing ecological impacts of LULC.

The survey outcomes indicate widespread community perception of environmental impacts from Land Use/Land Cover (LULC) change in Monavale Vlei. A very high 85% of respondents indicated they had noticed declines in native plant species, indicating widespread visible vegetation degradation. While still elevated, somewhat fewer (60%) believed that wildlife numbers (birds, frogs) had decreased, indicating either fewer visible animal losses or less public awareness of wildlife trends compared to plants. There is a wide range in the variation of plant (85%) and animal (60%) observations.

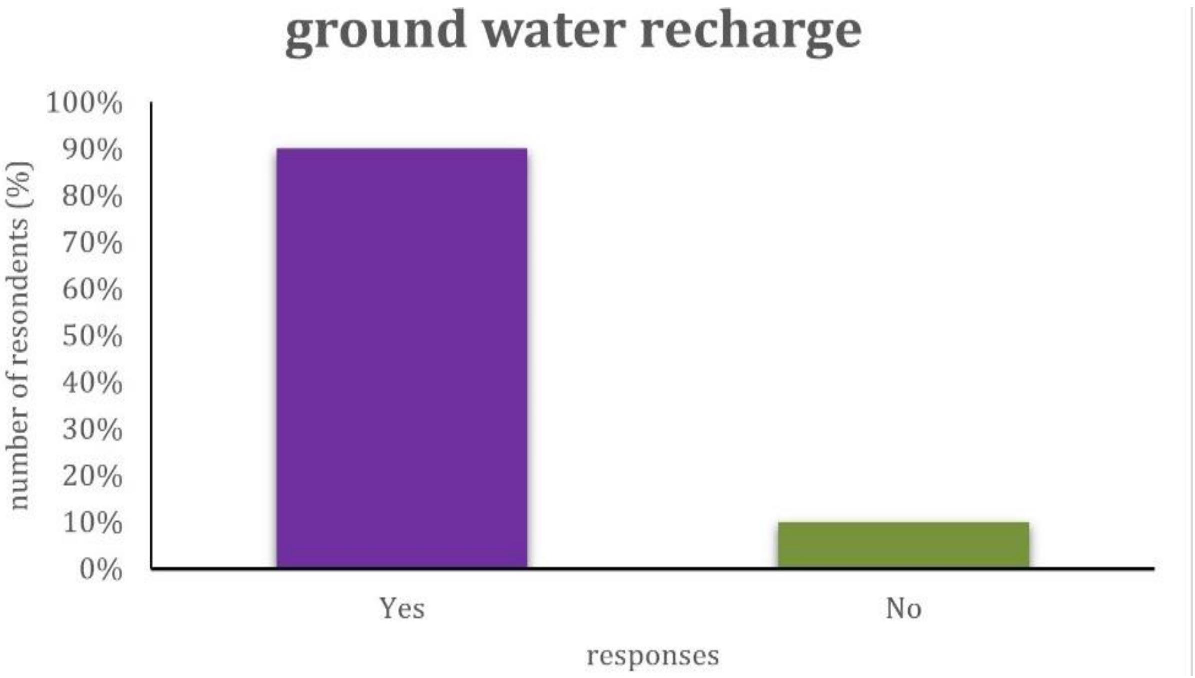


Figure 11: A bar chart showing the effects of LULC on groundwater.

The results of the survey demonstrate that almost all participants share the same opinions regarding the hydrological impacts of Land Use/Land Cover (LULC) changes in Monavale Vlei, with 90% in favor of groundwater recharge being affected and 10% not.

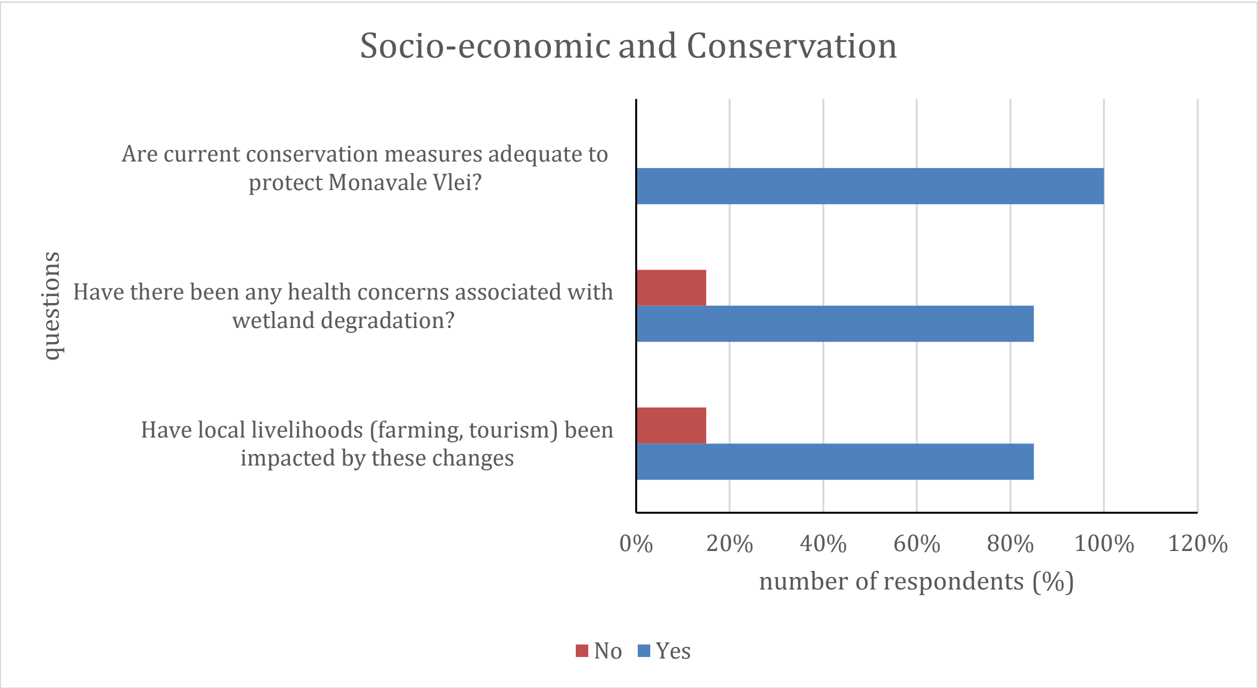
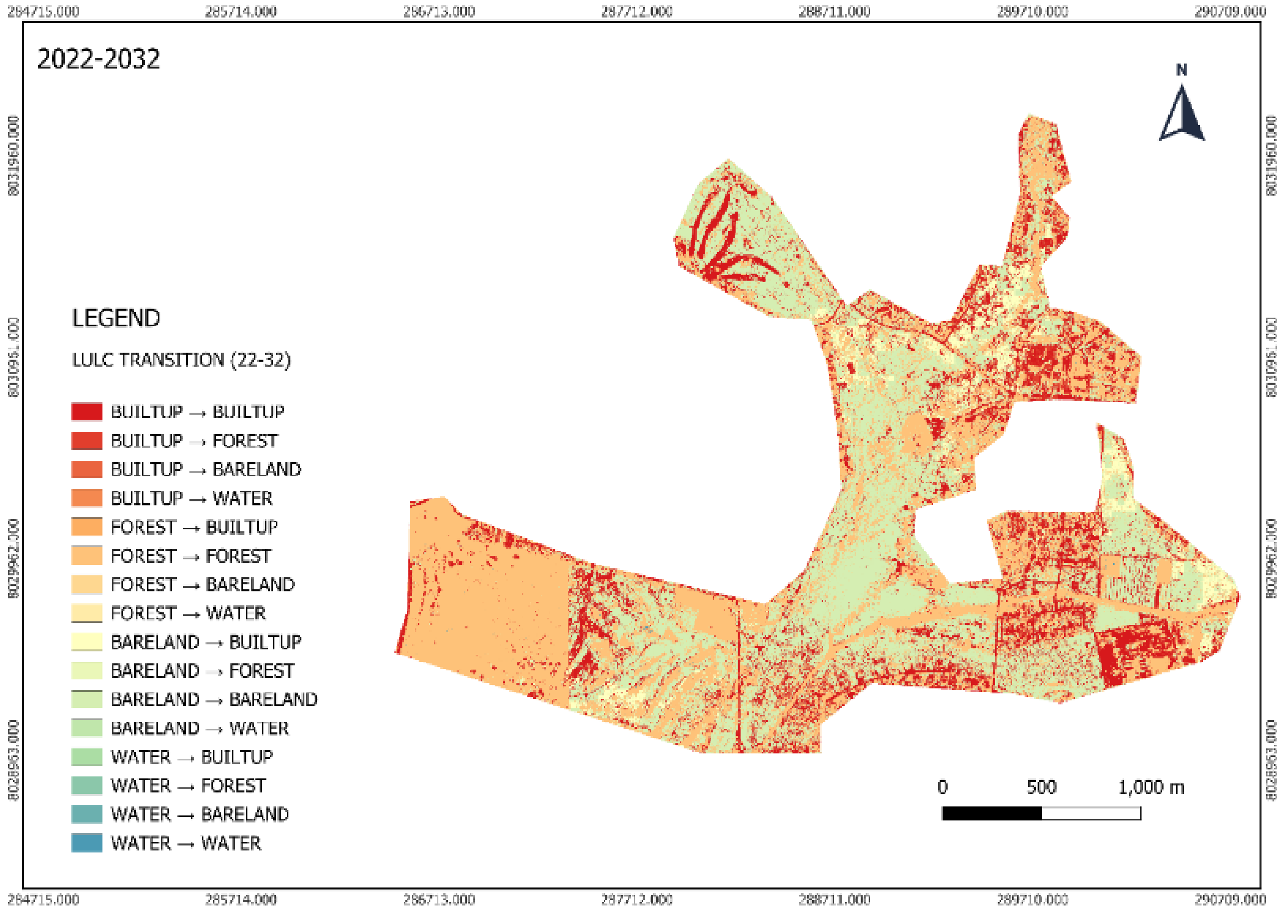


Figure 12: a bar chart showing the socio-economics and conservation efforts.

The survey findings identify key socioeconomic and conservation concerns in Monavale Vlei, with 85% of respondents reporting impacts on local livelihoods (tourism, agriculture) and health problems related to wetland degradation. Notably, 100% believe that current conservation initiatives are insufficient to protect the vlei, indicating broad dissatisfaction with protection efforts to date. The identical 85% rates for both the effect on jobs and health also show that both issues are of equal concern to residents.



To predict the future extent of Monavale wetland in relation to the environment.

Figure 13: A Monavale Vlei LULC transition potential map from 2022 to 2032

This 2022-2032 transition map shows future land use changes based on observed trends, indicating transitions amongland use classes.

Table 6: Table showing class transitions from 2022 to 2032.

CHANGE 2022-2032	**AREA**
BARELAND –BUILTUP	0.295395
BARELAND –FOREST	0.155988
BARELAND -BARELAND	1.828475
BUILTUP -BUILTUP	0.834817
FOREST -BUILTUP	1.987281
FOREST -FOREST	1.987281
FOREST -BARELAND	0.173394
FOREST -WATER	0.000002
WATER_ -FOREST	0.000005
WATER_-WATER	0.001159

1.828475km^2 of bare land will remain constant. 0.155988 km^2 of bare land will transition to forest 0.295395 km^2 of bare land might also change to built-up. 0.834817km^2 of built-up might remain constant. 1.987281 km^2 of forest will remain as forest. 1.987281 km^2 of forest will change to built-up. The forest might lose 0.173394 km^2 of its area to bare land. 0.000002km^2 which is very rare. 0.000005km^2 of water will change to forest while 0.001159km^2 will remain unchanged. Urbanisation will be dominant in bare land and as well as encroaching into forests.

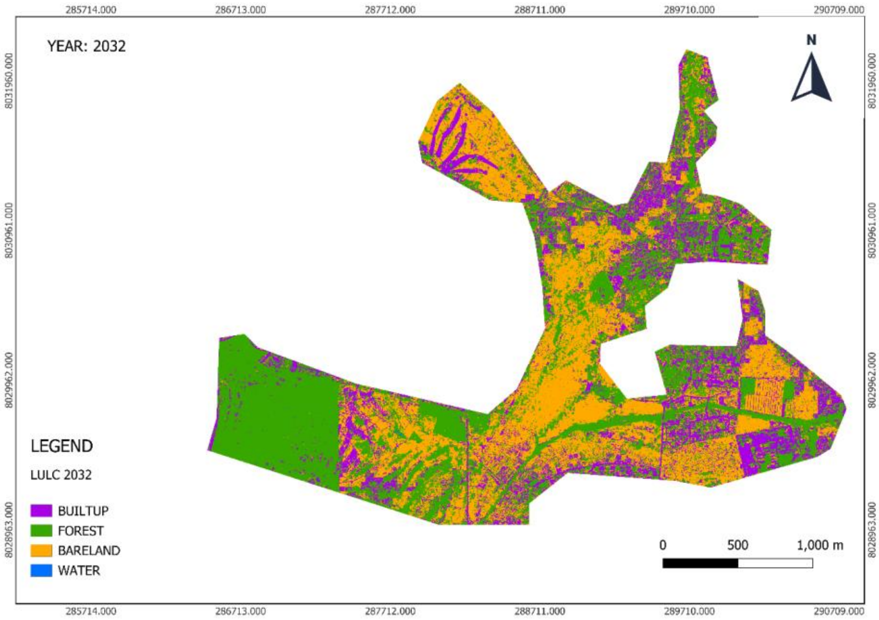


Figure 14: Monavale Vlei predicted LULC map for 2032

Figure 14 is the predicted visualisation of Monavale Vlei LULC changes after a decade from 2022 (2032). This map predicts the 2032 land cover of Monavale Vlei, focusing on four significant classes: Built-up, Forest, Bare land, and Water. Its spatial arrangement displays important trends, including forest regeneration in certain areas (green) and urban growth (red/built-up), whilst bare land (brown) and water (blue) zones may shrink due to urbanisation and/or climatic stresses.

Table 7: Table showing LULC changes from 2022 to 2032

class	**2022**		**2032**		**Change**	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area changed (km^2)**	**Area changed (%)**
Forest	1.70	31.6	2.23	41.4	0.53	31.2
Built-up	1.52	28.4	1.92	35.7	0.4	26.3
Bare land	1.75	32.5	1.14	21.2	-0.61	-34.9
Water bodies	0.15	2.9	0.09	1.7	-0.06	-40
Total	5.38	100	5.38	100		

The 2022-2032 projected land use and land cover map of Monavale Vlei showing changes in land cover. Forests are predicted to increase by 0.53 km^2 (31.2%), raising their share from 31.6% to 41.4% of the total area, indicating that reforestation or natural regrowth is progressing well. Urban areas will also increase by 0.4 km^2 (26.3%), from 28.4% to 35.7%, indicating urban sprawl, likely at the expense of other land-type classes. Bare land will decrease sharply by 0.61 km^2 (-34.9%), from 32.5% to 21.2%. Bodies of water should decrease by 0.06 km^2 (-40%). Overall, the data shows two significant trends: forests are recovering, and cities are spreading out, with bare land serving as the major source for both changes. Total area remains steady at 5.38 km^2 with neither loss nor gain, but within the area, it is dynamic.

Discussion

The results of this research highlight the role of urbanization in the loss of wetlands in Monavale, Harare, as validated by spatial time-series analysis and surveys of communities around the study area. Land use/land cover (LULC) changes between 2012 and 2022 indicated a loss of 14.9% of forest cover and an increase of 11.5% in built-up areas, showing the encroachment of urban development into the wetland ecosystems. Water bodies experienced the most degradation because decreasing by 63.4%, perhaps due to drainage, pollution, and land conversion. These trends align with global patterns in which severe urbanization has led to wetland deterioration, as evidenced by case studies in China and India (Naikoo et al., 2020). The perfect negative correlation (-1.000) between built-up areas and forest cover (Spearman's Rho) also supports urbanization as the main cause of wetland degradation in Monavale. The findings were supported by community survey results, where 90% of the respondents noted LULC changes (Zhou et al., 2024), 85% noted a decrease in wildlife and native plant species, and a further 85% attributed urbanization to decreased groundwater recharge, concurring with the research done by . Significantly, all of the respondents (100%) believed that existing conservation efforts were insufficient and expressed the urgent need for policy intervention similarly to study done in India (Shan et al., 2021).

The CA-Markov predictive modelling as also used by (Ahmad et al., 2017) in analysing LULC in India, predicted recovery of forest cover (31.2%) by 2032 and urbanization will expand by (26.3%) similarly to a research by (Gidey et al., 2017) in Ethiopia. The predictions, however, assume that the existing trends will continue to be unchanged and might not capture unplanned development or climatic variability and sudden policy changes, indicating the model limitations. The effects of these changes are significant. The CA-Markov model demonstrated strong predictive accuracy, with an 89.9% correctness rate and high Kappa agreement values (Kappa location = 0.94, Kappa histogram = 0.94), indicating reliable alignment between simulated and observed land-use changes, though the overall Kappa (0.04) suggests minor discrepancies in class-specific transitions.

Degradation of wetlands has compromised biodiversity, as interview respondents from surveys reported reductions in native vegetation and animals, mirrored by observations from comparable studies in Harare (Kamete, 2018). Flood risk increases as the number of water bodies decreases (Cloke et al., 2017). This is because wetlands lose their natural ability to filter runoff, as seen in other areas that are becoming more urbanised (Faulker, 2004). 85% of those who answered said that the degradation of wetland areas due to construction pollution had negative effects on people's ability to earn a living through activities like farming and tourism.

The same number were also worried about the health risks that came from waterborne diseases, as found out Nyoni et al. (2023). The results are consistent with findings from other research on the effects of continued urbanization in sub-Saharan Africa (Jombo et al., 2017).

The findings of the study highlight the necessity of improved land-use policies that incorporate wetland conservation into urban planning systems, as advocated by Chirisa et al. (2014). Since community awareness is high (90%), participatory strategies that incorporate local individuals into conservation efforts can strengthen policy implementation. Additionally, adopting monitoring technologies, such as real-time GIS and remote sensing, would enable institutions like the Environmental Management Agency (EMA) to track wetland transformation more accurately. However, the study's shortcomings are its reliance on a limited temporal dataset (2012–2022) and potential survey bias towards respondents in their middle age, which present opportunities for future research. The inclusion of previous decades (e.g., 1990–2010) in the analysis would add greater historical context, and the inclusion of climate data would enhance predictive modelling. Generally, this research demonstrates that urbanization is a key driver of wetland degradation in Monavale with great ecological and socioeconomic implications. Although predictive models suggest some scope for forest regeneration, the continued expansion of built-up areas remains a threat. To reduce these effects, policymakers need to prioritize wetland preservation by strengthening land-use regulations, promoting public involvement, and enhancing technological monitoring.

In the absence of such interventions, Harare might lose the remaining wetlands, increasing environmental and public health concerns. The research contributes to an emerging body of scholarship on sustainable urban growth in Zimbabwe and provides actionable recommendations for conservation planning.

Conclusions

This dissertation offers a broader examination of wetland degradation in Monavale Vlei, Harare, attributable to urbanisation. The study employed spatial time series analysis to quantify land use and land cover (LULC) changes, including forest decrease, urban development, and water body depletion, while predictive modelling explained future trends under existing conditions. Community surveys enhanced these findings by documenting local opinions of ecological and socio-economic repercussions, indicating a consensus on the insufficiency of current conservation strategies. The study highlights the essential function of wetlands in preserving biodiversity, enhancing water quality, and mitigating floods, while illustrating how urban development threatens these ecological services. The study addresses a deficiency in localised research regarding wetland loss in Zimbabwe, providing practical insights for policymakers, urban planners, and environmental agencies. The findings, by agreeing with global literature on wetland degradation, enhance broader conversations on sustainable development in urbanising environments. The report ultimately endorses a balanced strategy for urban growth that prioritises environmental sustainability alongside economic development.

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Current status on the use of dairy products as carriers of probiotics in Africa: A systematic review

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Abstract

The use of probiotics in African fermented dairy products has notably increased because of their potential to improve nutrition, support gut health, and provide economic benefits to rural and urban communities that rely on fermented dairy for income generation. In many parts of Africa, probiotic-enriched dairy products provide a low-cost dietary intervention in settings affected by high rates of diarrhoea, malnutrition, and limited access to healthcare. These products have demonstrated improved sensory quality, enhanced microbial safety, and health-promoting effects. Despite the growing popularity of probiotics in Africa, there remains limited documentation and research on their adoption and use in dairy products. This systematic review assessed the current application of probiotics in African fermented dairy products and identified trends in product type, regional distribution, probiotic strains, and functional properties. A literature search using AGORA, Google Scholar, Scopus, and Web of Science identified 26 relevant studies. East Africa recorded the highest number of publications (42.31%), followed by Southern Africa (26.92%), West Africa (23.08%), and North Africa (7.69%). The most documented products were yoghurt and sour milk followed by kefir, cheese, infant formula, acid-alcoholic fermented milk, and other locally prepared fermented milk products. Probiotic strains such as Lactobacillus rhamnosus, Lactobacillus plantarum, and Bifidobacterium lactis showed strong acidifying ability, flavour development activity, exopolysaccharide production, and health promoting functions including pathogen inhibition and immune support. A major research gap identified is the limited use of diverse *probiotic strains across the continent and the shortage of in vitro and in vivo validation studies. Overall, the findings show that African fermented dairy products have significant potential as affordable carriers of probiotics that can contribute to improved nutrition, strengthen community livelihoods, and better health outcomes.*

Keywords: Probiotics, Lactic acid bacteria, Traditional dairy products, Commercial dairy products, Africa

Introduction

Sub-Saharan Africa is the region most affected by the HIV pandemic in the world (UNAIDS, 2020) and has the highest infant mortality rate (UNICEF, 2021). People living with HIV and immune-compromised or malnourished children are more at risk of life-threatening diarrhoea (WHO, 2017). Diarrhoeal diseases are the third leading cause of mortality in children under five years old and are responsible for the estimated deaths of 443,832 children annually (WHO, 2024). In sub-Saharan Africa, the recurrence of diarrhoea is one of the main factors that contribute to chronic malnutrition in children under five years of age, leading to stunting and wasting (Mpofu, 2015). Functional foods have emerged as a therapeutic tool to counteract the incidence of infectious diseases and noncommunicable diseases (NCD). There is therefore need for the food industry to integrate nutritional and health-promoting components into these food products.

FAO/WHO (2001) defined probiotics as live microorganisms, which when consumed in adequate amounts confer a health effect on the host. The health benefits of probiotics are attributed to the ability of the microorganism to protect the gastrointestinal tract against colonisation by exogenous microbes (Egbuna & Tupas, 2020). The consumption of probiotics is associated with alleviation of acute rotavirus diarrhoea (Grandy *et al*., 2010), inflammatory bowel disorders, lactose intolerance and urinary tract infections (FAO/WHO 2001; Tamime, 2007). To obtain the desirable therapeutic effects of a product, the viable count of probiotic bacterium should be present over 6 log cfu mL^{-1} at the time of consumption to compensate for the reduction in probiotic viability during passage through the gastrointestinal tract (Marinova *et al*., 2019). Probiotic strains have to meet the requirements associated with the production technology of the product (Cruz *et al*., 2012).

Globally, the proven technological and health benefits of bacterial strains of *Lactobacillus* and *Bifidobacterium* strains have driven exponential growth in the probiotic market. In

Africa, this presents a significant opportunity to develop affordable, culturally relevant functional foods that address local health and nutrition challenges. However, information on the market share and specific characteristics of probiotic dairy products across the continent remains limited. While native fermented dairy products have been part of African diets for centuries, their commercialisation faces hurdles such as the high cost of cultures and inadequate infrastructure (Mukisa, 2016; Ukeyima *et al*., 2010). Although studies have documented the functionality of traditionally fermented milk products (Abdelgadir *et al*., 2008; Franz *et al*., 2014; Mathara *et al*., 2008) and viability of probiotic strains in African fermented products (Brett *et al*., 2021; Mpofu *et al*., 2014; Parker *et al*., 2018), the existing literature is fragmented. A systematic synthesis is lacking on how probiotic dairy products in Africa vary by type, origin, dairy source, fermentation method and probiotic strain, which are the key factors that influence their efficacy, acceptability and scalability. Therefore, this systematic review aims to assess the current status of probiotic use in African dairy products, analyse trends in product types, regional distribution, probiotic strains and their functional properties, and identify key research gaps to inform future research and development.

Methodology

Literature search

A comprehensive literature search was conducted to assess the current status of the use of dairy products as carriers of probiotics in Africa. The review followed the RepOrting standards for Systematic Evidence Syntheses (ROSES) guidelines to ensure methodological rigor and transparency. The search was confined to the period from 1999 to 2021. This timeframe was selected to capture the modern evolution of probiotic research and application in Africa. The year 1999 marks the period when research on African fermented dairy products emerged. Extending the search to 2021 allowed for the inclusion of the most recent developments, including the introduction of low-cost dried probiotic starter cultures and increased documentation of both commercial and traditional fermented dairy products available at the time of analysis.

Search strategy

The literature search was performed across four electronic databases including AGORA, Google Scholar, Scopus, and Web of Science. Grey literature was also identified on organisational websites including the Food and Agriculture Organisation (FAO), World

Health Organisation (WHO) and Yoba for Life. To ensure reproducibility, the full search strings used for each database are as follows:
AGORA: ("dairy products" OR fermented milk") AND ("probiotics" OR "lactic acid bacteria") AND ("Africa" OR "Sub-Saharan Africa")
Google Scholar: "probiotic dairy products in Africa" OR "African fermented milk probiotics"
Scopus: TITLE ABS KEY ("dairy product" OR "fermented milk") and ("probiotic" OR "lactic acid bacteria") AND (Africa OR "African country") AND PUBYEAR > 1998 AND PUBYEAR < 2022
Web of Science: TS= ("dairy product" OR "fermented milk") AND (probiotics OR "lactic acid bacteria) AND (Africa)

The search strategy combined keywords and Boolean operators (AND, OR) as shown. In addition, cross-referencing was used to identify articles on the use of probiotics in traditionally fermented dairy products and commercially fermented dairy products in African regions.

The review was limited to English-language publications, which may have excluded studies published in Francophone and Arabic-speaking regions in Africa. Publication bias was also considered, as there could be bias towards the publication of positive results. To mitigate this bias, grey literature and organisational reports were actively searched. Database searching was combined with cross-referencing to minimise the omission of relevant studies.

Study selection criteria

The selection criteria of titles, abstracts, and full text of searched articles were based on (i) the study type, where articles, reviews and reports were published in a peer-reviewed journal, (ii) geographic focus, where studies conducted in Africa were selected, (iii) content of the research focused on the use of dairy products, (iv) study specifying the type of probiotic strains used in dairy product and the product exhibiting probiotic potential, in the case of traditionally fermented dairy products, and (v) articles published in English. Studies were excluded based on (i) the study focused on non-dairy products, (ii) non-probiotic study, (iii) geographic irrelevance if a study was conducted outside of Africa, (iv) non-peer-reviewed sources of conference abstracts, editorials and articles, (v) duplicate publications.

Screening and quality appraisal

The database searches yielded 123 articles. After removing 37 duplicates, titles and abstracts were screened, resulting in 63 articles retrieved at full text. Thirty studies were excluded at this stage, primarily for geographic irrelevance (n = 14), focus on non-dairy products (n = 3), non-peer reviewed (n=2) or lack of probiotic function (n=11). The methodological quality of the remaining 33 articles was critically evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Systematic Reviews and Research Syntheses (Aromataris *et al*., 2015). The seven studies excluded had limitations, which included incomplete reporting of sampling methods and limited detail on laboratory analytical procedures in some traditionally fermented product studies. The remaining 26 studies included in the review met the minimum criteria. The studies had clear objectives, appropriate methodology and reporting of results. The ROSES flow diagram for systematic review in Figure 1 indicates the literature search strategy.

Categorisation of identified literature

Data collected from identified articles were extracted, and the information included: author(s), year of publication, type of dairy product, product name, country of origin, type of fermentation (traditional or controlled), dairy source (bovine or non-bovine), probiotic strains used, initial probiotic count and probiotic count at time of consumption.

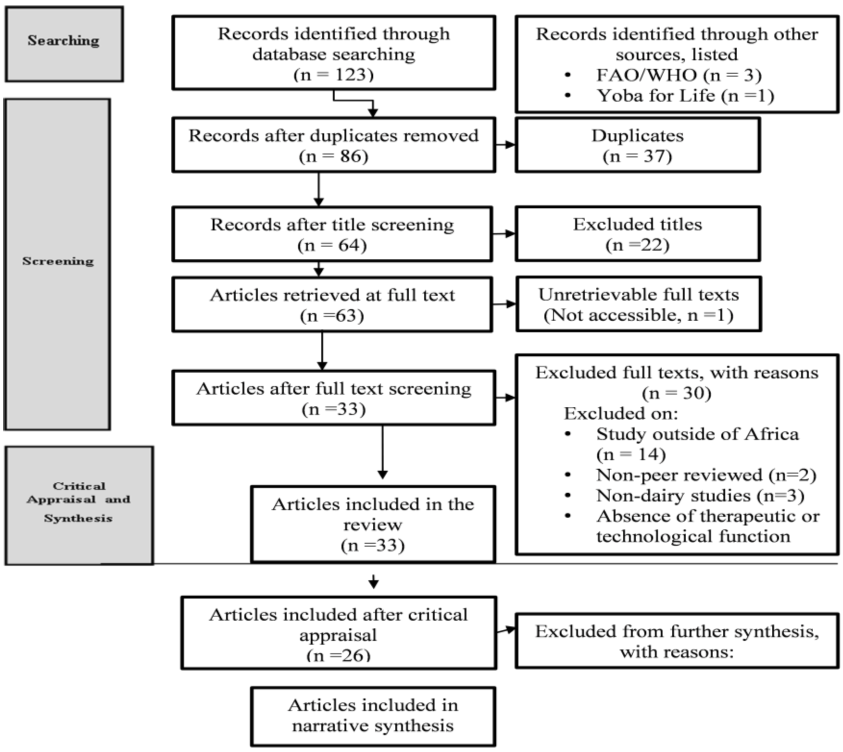
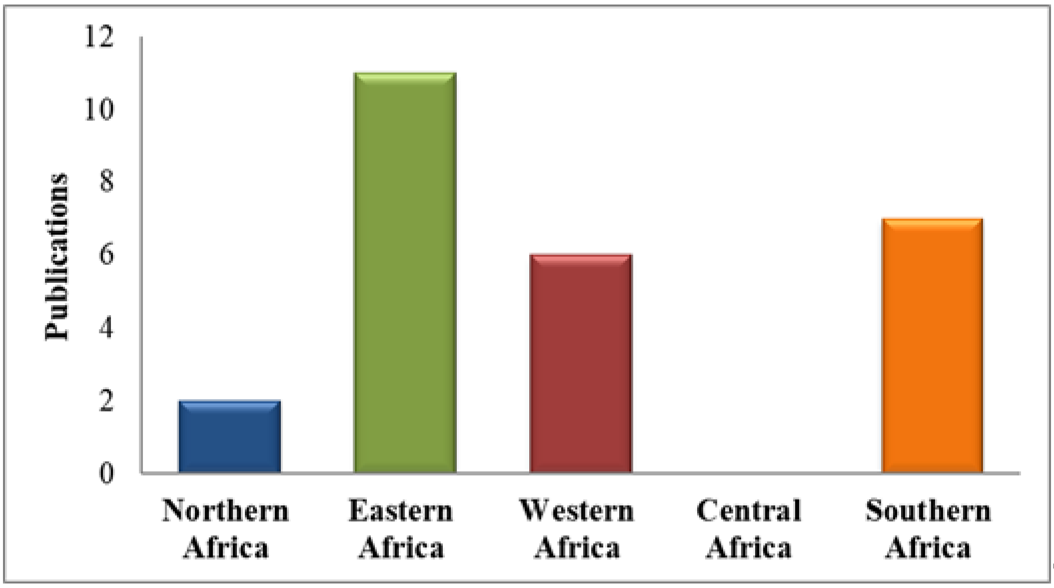


Figure 1: Literature search strategy

Results and discussion

Distribution of the identified articles

The study showed the distribution of published articles on probiotic dairy products in various regions in Africa (figure 2). The highest number of publications amounting to 42.31% (11/26) originated from East African countries such as Uganda, Ethiopia, Kenya, and Tanzania followed by studies conducted in Southern Africa, contributing to 26.92% (7/26) of the articles reviewed. The figure shows that 23.08% (6/26) of the articles originated in Western Africa and the lowest number of articles were recorded from North Africa, with only two articles published in Sudan and Morocco (7.69%). Out of the five regions in Africa, no articles were published in Central African countries. This shows that research on probiotic dairy products is still limited in this region, or this phenomenon can be ascribed to Central Africa being a Francophone region.



The increase in publications in East Africa can be attributed to the rise in community-based projects (Reid *et al.*, 2018). Research institutions have been driving research on the incorporation of commercial probiotic strains in fermented dairy products as possible intervention strategies to combat malnutrition and chronic infections as evident in 42% of the articles published in East Africa (Mukisa, 2016; Nduti *et al.*, 2016; Westerik *et al.*, 2019). Pilot plants producing *yoba* and *fiti* probiotic yoghurts have been established in Kenya, Tanzania and Uganda, thereby leading to increased research on probiotic dairy products (Reid *et al.*, 2018).

Southern Africa is the second leading region in publications on probiotic dairy products, with 57% of the articles from the region documenting the use of commercial probiotic strains in products such as *mutandabota* from Zimbabwe, and kefir and infant formula from South Africa (Mpofu *et al*., 2014; Urban *et al*., 2008; Witthuhn, 2004). There has been a relative increase in the dissemination of information on the utilisation of probiotics in southern Africa since 1999 (Gadaga *et al*., 1999). At the same time, the commercialisation of probiotic dairy products is still threatened by several challenges including the lack of industrial funding for the high cost of development of probiotic cultures and lack of infrastructure for storage of these cultures. Despite the unavailability of commercial probiotic strains sourced from Africa, native fermented dairy products with probiotic potential have been documented across Africa and have contributed substantially to the use of dairy products as vehicles for probiotics in the continent (Adesokan *et al*., 2011; Akabanda *et al*., 2014).

Bovine and non-bovine milk sources in Africa

The review identified the sources of bovine and non-bovine milk sources used in the African continent (Table 1), with the bovine contributing a higher percentage at 84.62% (22/26) than non-bovine sources at 15.38% (4/26). Up to date, traditional bovine milk derivatives represent a large ratio of probiotic product innovations (Ranadheera *et al*., 2018). Traditionally fermented dairy products have been derived from bovine milk in cattle-keeping regions in the highlands of East Africa, Sudanian, Savanna, and North African regions (Agyei *et al*., 2020). On the other hand, non-bovine milk from animal species such as goats, sheep, camel, and donkeys has also been consumed in Africa (Agyei *et al.,* 2020). Camel milk was identified as the most documented non-bovine milk source in the production of traditional dairy products that have probiotic potential in the Eastern and Northern regions of Africa.

Several studies characterised probiotic properties of fermented camel milk derivatives, namely *ititu* from Ethiopia (Seifu *et al*., 2012); *suusac* in Kenya (Lore *et al*., 2005); *lben* in Morocco (Ouadghiri *et al*., 2008) and *gariss*, a Sudanese product (Ashmaig *et al*., 2009). Although non-bovine milk sources contribute about 17% of global milk production (Ranadheera *et al*., 2018), the availability of various types of dairy sources could contribute to the diversity of commercial and traditional dairy product types in Africa. Variations in milk composition bring about different characteristics of the product. Therefore, this study identified a gap in limited documentation of probiotic dairy products from non-bovine milk sources in Africa.

Distribution of dairy products based on type of fermentation

The type of fermentation of dairy products was classified into traditional fermentation and controlled fermentation as shown in Tab 1. Identified probiotic dairy products in Africa comprised of 57.69% (15/26) of traditionally fermented products and 42.31% (11/26) of products fermented under controlled conditions. Traditional fermentation of milk has been a result of a shortage of requisite facilities to preserve this highly perishable food product in resource-poor countries (Agyei *et al*., 2020). Natural fermentation is initiated by the complex natural microbiota in milk or through back slopping method in gourds or other fermentation vessels (Nakavuma & Nasinyama, 2012; Seifu *et al*., 2012). Back slopping method which involves the addition of a small portion of previously fermented milk as an inoculum for the next batch has been used in countries across the African continent (Franz *et al*., 2014; Moonga *et al*., 2020). Apart from significantly contributing to food security, nutrition security and socio-economic development of resource-poor countries, dairy products produced by spontaneous fermentation are vehicles of beneficial microorganisms, predominantly lactic acid bacteria (Agyei *et al*., 2020). Challenges in traditional fermentation include variations in the microbial composition of milk which in turn affects product attributes such as taste, aroma and flavour (Moonga *et al*., 2020; Seifu *et al*., 2012). The study also reviewed that spontaneous fermentation of traditional dairy products involved a mixture of LAB and in some studies, the dominant LAB were non-probiotic species such as *Lactococcus lactis* in sour milk *(*Moonga *et al*., 2020; Nakavuma & Nasinyama, 2012; Osvik *et al*., 2013)*.* On the other hand, controlled fermentation utilised pure probiotic strains as single starter cultures or in combination with the traditional thermophilic starter culture such as *Streptococcus thermophillus* C106 under monitored conditions (Mpofu *et al*., 2014; Mukisa & Birungi, 2018). Other controlled fermentations include single strains of *Weissella Cibaria* NN20 (Nduti *et al*., 2018) or in combination with *Lactobacillus rhamnosus GR-1* (Nduti *et al*., 2016).

Table 1: Overview of fermented probiotic dairy products in Africa

Region	**Primary product types**	**Fermentation type**	**Main dairy sources**	**Most frequently reported probiotic strains**	**Key examples**
East Africa	Yoghurt, sour milk, cottage cheese, locally fermented milk	Predominantly controlled for yoghurt; Traditional for sour milk and indigenous products	Primarily bovine; some camel milk (non- bovine)	*Lactobacillus plantarum*, *L. rhamnosus* (GG, GR-1, yoba 2012), *Weissella cibaria*, *Leuconostoc mesenteroides*, *Enterococcus faecalis*	Yoba for Life yoghurt (Uganda), Fiti yoghurt (Kenya), Amabere amaruranu (Kenya), Kule naoto (Kenya), Kwerionik (Uganda)
North Africa	Sour milk, acid–alcoholic fermented milk	Mainly traditional	Camel milk (non-bovine)	*L. plantarum*, *L. paracasei*, *L. brevis*, *Leuconostoc mesenteroides*, *L. fermentum*	Gariss (Sudan), Lben (Morocco)
Southern Africa	Sour milk, yoghurt-like products, kefir, biologically acidified infant formula	Mix of traditional and controlled	Bovine; Some products non-bovine	*Lactobacillus plantarum*, *L. helveticus*, *L. fermentum*, *Leuconostoc spp.*, *Bifidobacterium lactis*, *Enterococcus faecalis*	Mabisi (Zambia), Mutandabota (Zimbabwe), Amasi (Zimbabwe & South Africa), Kefir (South Africa)
West Africa	Yoghurt, yoghurt-like,	Predominantly traditional for	Predominantly bovine	*L. fermentum*, *L. plantarum*, *L.*	Nunu (Ghana), Dègu (Côte

	sour milk	local products; Controlled for products fermented using commercial probiotic strains		*helveticus*, *L. rhamnosus yoba 2012*, *Leuconostoc mesenteroides*, *Enterococcus faecium*	d'Ivoire), Lait cailé (Senegal), Nono (Nigeria), Fènè (Mali)

1 **Supplementary Table 1**: Commercial dairy products and traditional fermented dairy products with probiotic potential identified in Africa

Reference	**Type of fermented dairy product**	**Product name**	**Country of origin**	**Type of fermentation**	**Dairy source**	**Probiotic strains**	**Initial probiotic levels**	**Probiotic levels at the point of consumption**
East Africa								
Chevez & Burton (n.d)	Yoghurt	Yoba for Life probiotic yoghurt	Uganda	Controlled	Bovine	*Lactobacillus rhamnosus* GG	-	9.40 log cfu mL^{-1}
Tesfaye *et al*., (2011)	Cottage Cheese	Ayib	Ethiopia	Traditional	Bovine	*L. acidophilus* *L. brevis* *L. paracasei ssp paracasei* *L. plantarum*	-	-
Mukisa & Birungi (2018)	Yoghurt	Matooke-based probiotic dairy yoghurt	Uganda	Controlled	Bovine	*L. rhamnosus* yoba 2012	7 log cfu mL^{-1}	9 log cfu mL^{-1}
Nduti *et al*. (2018)	Other locally prepared fermented	Fermented milk	Kenya	Controlled	Bovine	*Weissella Cibaria* NN20	-	-

	milk products							
Nduti *et al*. (2016)	Yoghurt	Fiti yoghurt	Kenya	Controlled	Bovine	*Lactobacillus rhamnosus* GR-1 *Weissella cibaria* NN20	-	-
Nyambane *et al*. (2014)	Other locally prepared fermented milk products	Amabere amaruranu	Kenya	Traditional	Bovine	*Lactobacillus plantarum*, *Leuconostoc mesenteroides*	6.42 log cfu mL^{-1}	8.32 log cfu mL^{-1}
Nakavuma & Nasinyama (2012)	Sour milk	Kwerionik	Uganda	Traditional	Bovine	*Lactobacillus plantarum*, *Enterococcus faecalis*, *Lactobacillus paracasei* subsp *paracasei*, *Lactobacillus casei* subsp *casei*, *Enterococcus faecium* and *Leuconostoc*	9 log cfu mL^{-1} (total LAB)	5 log – 6 log cfu mL^{-1} (total LAB)

						mesenteroides subsp *mesenteroides*		
Seifu *et al.* (2012)	Sour milk	Ititu	Ethiopia	Traditional	Non-bovine (camel)	*Lactobacillus plantarum* *Enterococcus faecalis* *Lactobacillus salivarius*	-	-
Van Tienen *et al*. (2011)	Yoghurt	Probiotic supplemented Moringa yoghurt	Tanzania	Controlled	Bovine	*L. rhamnosus* GR-1	7.85 log cfu mL^{-1}	8.6 log cfu mL^{-1}
Mathara *et al.* (2008)	Sour milk	Kule naoto	Kenya	Traditional	Bovine	*L. acidophilus* *L. paracasei* *L. fermentum* *L. rhamnosus*	7.2 log cfu mL^{-1}	9.2 log cfu mL^{-1}
Lore *et al.* (2005)	Other locally prepared fermented milk product	Suusac	Kenya	Traditional	Non-bovine (camel)	*L. mesenteroides* subsp. *mesenteroides* *L. plantarum*	-	6.8 log cfu mL^{-1}
Northern								

Africa								
Ashmaig *et al*. (2009)	Sour milk	Gariss	Sudan	Traditional	Non-bovine (camel)	*Lactobacillus plantarum* (dominant) *Lactobacillus plantarum*, *L. animalis*, *L.brevis*, *Lactobacillus divergens*, *L. rhamnosus*, *L. paracasei*, *L. fermentum*, *L. alimentarium*	-	-
Ouadghiri *et al*. (2008)	Acid – Alcoholic fermented milk	Lben	Morocco	Traditional	Non-bovine (camel)	*Lactobacillus paracasei*, *Lactobacillus plantarum*, *Leuc. Mesenteroides*, *Leuc. pseudomesenteroides*	-	9.69 log – 10.81 log cfu mL^{-1} (total LAB)

Southern Africa								
Moonga *et al.* (2020)	Sour milk	Mabisi	Zambia	Traditional		*Streptococcus salivarius, Lactobacillus helveticus*	-	-
Mpofu *et al.* (2016)	Yoghurt-like	Mutandabota	Zimbabwe	Controlled	Bovine	*L.rhamnosus* yoba	5.5 ± 0.1 log cfu mL^{-1}	9.1 ± 0.4 log cfu mL^{-1}
Mpofu *et al.* (2014)	Yoghurt-like	Mutandabota	Zimbabwe	Controlled	Bovine	*L. rhamnosus* yoba	5.8 ± 0.3 log cfu mL^{-1}	8.8 ± 0.3 log cfu mL^{-1}
Osvik *et al.* (2013)	Sour milk	Amasi	South Africa	Traditional	Bovine	*Lactobacillus paracasei strain KLDS1.0653 Lactobacillus plantarum strain Leuconostoc pseudomesenteroides strain IMAU6000 Enterococcus faecalis* strain CTC328	-	-

Urban *et al*. (2008)	Infant formula	Biologically acidified milk formula with *Bifidobacterium lactis*	South Africa	Controlled	-	*Bifidobacterium lactis*	-	-
Witthuhn *et al*. (2004)	Kefir	Kefir	South Africa	Controlled	Bovine	*Lactobacillus fermentum* *Leuconostoc lactis,* *Leuconostoc mesenteroides ssp. Mesenteroides*	- - -	6.04 log cfu mL^{-1} 7.62 log cfu mL^{-1} 7.72 log cfu mL^{-1}
Gadaga *et al*. (1999)	Sour milk	Amasi	Zimbabwe	Traditional	Bovine	*Lb. paracasei subsp. paracasei, Lb. plantarum, Lb. acidophilus, Ent.*	-	-

						faecum and *Ent. faecalis*.		
Western Africa								
Brett *et al*. (2021)	Yoghurt	Probiotic fermented dˆeguˆ	Cote d′Ivoire	Controlled	Bovine	*L. rhamnosus* yoba 2012	-	-
Parker *et al*. (2018)	Yoghurt	Lait cailé	Northern Senegal	Controlled	Bovine (milk powder)	*L. rhamnosus* yoba 2012	-	-
Akabanda *et al*. (2014)	Yoghurt- like	Nunu	Ghana	Traditional	Bovine	*Lactobacillus fermentum* (LF-22-16), *Lactobacillus plantarum* (LP-8-2), *Lactobacillus helveticus* (LH-22-7), and *Leuconostoc mesenteroides* (LM-14-11), *Ent. faecium*	-	-
Wullschleger *et al*. (2013)	Sour milk	Fènè	Mali	Traditional	Bovine	*Lb. fermentum*, *Lb. plantarum*,	-	-

						W. confusa		
Adesokan *et al*. (2011)	Yoghurt-like	Nono	Nigeria	Traditional	Bovine	*L. casei*, *L. fermentum* and *L plantarum*	-	-
Obodai & Dodd, (2006)	Yoghurt-like	Nyarmie	Ghana	Traditional	Bovine	*Leuconostoc mesenteroides* ssp. *Mesenteroides*, *L. helveticus*	-	-

Probiotic dairy products in Africa identified through literature

Owing to the diversity of Africa's food culture, various products were identified as suitable carriers of probiotic microorganisms through a literature search. Figure 3 shows the distribution of product types documented across the continent. In reference to figure 3 yoghurt and yoghurt-like products, 42.31% (11/26) were the most documented product type. Yoghurt products refer to fermented milk produced using standard yoghurt starter cultures, with or without added probiotic strains, while yoghurt-like products refer to traditional or modified fermented milk products that resemble yoghurt in texture, acidity and sensory characteristics. The figure also shows that sour milk products 30.77% (8/26) were the second most documented products. Other product categories such as acid-alcoholic fermented milk, cheese, infant formula and kefir appear in much smaller proportions and contributed 3.85% (1/26) each to the distribution of dairy probiotic product types in Africa. Out of twenty-six publications, 11.54% (3/26) were categorised under other locally prepared fermented milk products. These were identified from articles that cited the product name nevertheless not specifying the dairy product types. This trend confirms that yoghurt-based products remain the most widely studied and utilised probiotic carriers across Africa.

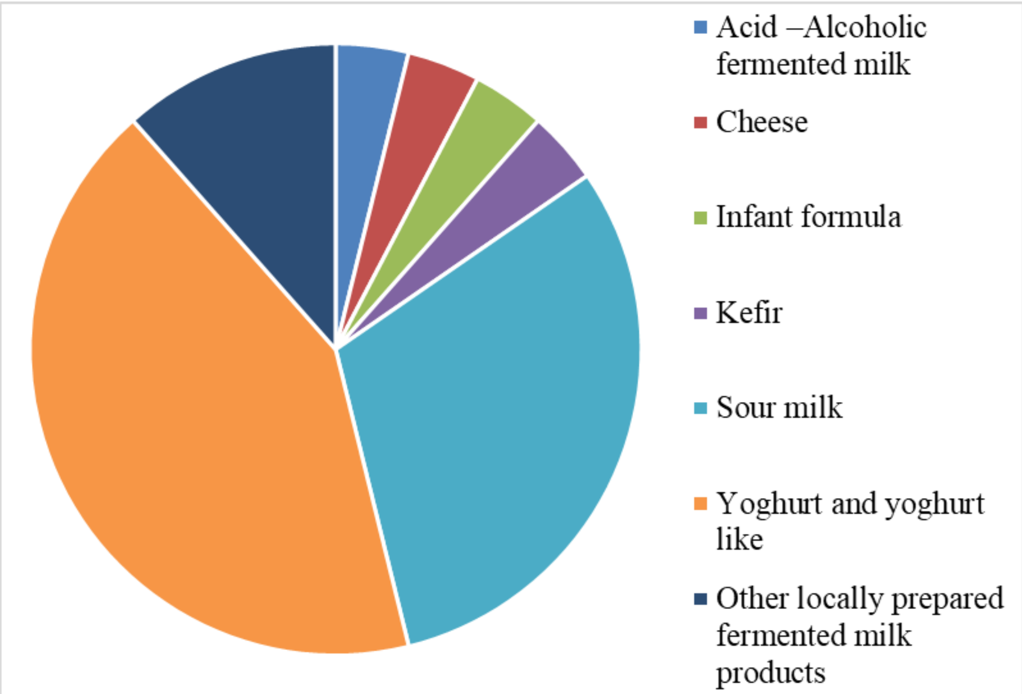


Figure 2: Types of probiotic dairy products identified in Africa

These findings concluded that yoghurt products such as *yoba, fiti, matooke* yoghurt, *lait cailé* and *dˆeguˆ* were identified as suitable carriers of probiotics. Additionally, yoghurt-like products including *mutandabota*, *nyarmie*, *nono* and *nunu* were amongst Africa's most documented vehicles for probiotics. Yoghurt-like products resemble the physical, chemical and organoleptic characteristics of yoghurt. after 24 hours (Obodai & Dodd, 2006). Probiotic yoghurt has become the most acceptable fermented milk product owing to its characteristic attributes which contribute to a positive image among consumers apart from its functional properties (Sarkar, 2018). In a few studies from Tanzania, Uganda and Zimbabwe, indigenous plant-based ingredients were incorporated into probiotic dairy products. The studies have reported an increase in viable probiotic cell counts (Van Tienen *et al*., 2011; Mpofu, *et al*., 2014; Mukisa & Birungi, 2018).

Sour milk products identified through literature include *amasi*, *fènè, gariss, ititu, kule naoto kwerionik* and *mabisi*. Amasi is a popular fermented milk product in southern African countries namely Zimbabwe and South Africa (Gadaga *et al*., 1999). Zambian *mabisi* and Mali's *fènè* follow a similar protocol as that of *amasi* production leaving a thicker white coagulant with a characteristic sour taste and a cottage cheese-like consistency (Gadaga *et al*., 1999; Moonga *et al*., 2020). Sour milk products such as *ititu* and *gariss* are derivatives of camel milk produced by pastoralists in Ethiopia and Sudan, respectively. In the case of *ititu* fresh camel milk is spontaneously fermented in smoked containers wrapped with a piece of cloth at ambient temperatures (Seifu *et al*., 2012). Moreover, *gariss* is produced by semi-continuous fermentation which takes place in leather bags of tanned goat skin which are entrenched in green grass and are subjected to shaking during movement as they are carried on the bags of the camels. This study revealed that the diversity in culture among ethnic groups in Africa brings about slight variations in the process of making sour milk products.

Some probiotic dairy products such as kefir are less documented in Africa due to limited consumption across the continent. Nevertheless, published articles available on kefir beverages in Africa remain limited except for South Africa contributing to research on the mass cultivation of kefir grains (Witthuhn, 2004). Kefir is a fermented milk beverage produced by a starter culture known as kefir grain that contains complex microbiota including species of lactic acid bacteria, yeasts, acetic acid bacteria and mycelial fungi (Witthuhn *et al*., 2005; Witthuhn, 2004). The review also indicated that research on kefir dates back to nearly two decades ago, showing that no research has been published in recent years. Therefore, there is a need for more research to fill the gap in the functional properties of kefir in Africa. The use of cheese or infant formula as probiotic carriers unfortunately suffers the same fate as kefir in Africa. One article was published on *ayib*, a soft cheese produced from skim milk in Ethiopia (Tesfaye *et al*., 2011). An article was published on infant formulas (Urban *et al*., 2008) and the probable reason for limited documentation is the lack of infrastructure and technologies such as microencapsulation required for the incorporation of viable probiotic strains.

Probiotic species isolated from fermented dairy products in Africa

A quantitative frequency analysis was performed on the probiotic strains documented across the 26 reviewed studies (Table 2). The analysis yielded 53 discrete strain mentions, corresponding 15 bacterial species or 17 distinct strains when commercial variants were specified. The distribution reveals the predominance of *Lactobacillus plantarum,* identified in 13 studies (24.5%), highlighting its ecological adaptability and prevalence in traditional fermentation across the continent. Strains of *Lactobacillus rhamnosus* were collectively the second most frequently reported (17 %), with the yoba variant being the most documented strain within the species. The variant was recorded in 6 studies (11.3%) from multiple regions. This distribution outlines a contrast in probiotic application in Africa where a diverse indigenous microbial ecosystem is dominated by *L. plantarum* in traditional products while *L. rhamnosus* yoba is strategically being used in commercial development of probiotic products.

Table 2: Frequency distribution of probiotic strains identified in studies of African fermented dairy products (n=26)

Rank	***Probiotic Species/*Strain**	***Frequency (Count)***	***Frequency (%)***
1	*Lactobacillus plantarum*	13	24.5%
2	*Lactobacillus paracasei*	6	11.3%
3	*Leuconostoc mesenteroides*	6	11.3%
4	*Lactobacillus fermentum*	5	9.4%
5	*Lactobacillus rhamnosus*	9	17.0%
5a	*L. rhamnosus yoba*	6	11.3%
5b	*L. rhamnosus GG*	1	1.9%
5c	*L. rhamnosus GR-1*	2	3.8%
6	*Lactobacillus acidophilus*	3	5.7%
7	*Enterococcus faecium*	2	3.8%

8	*Enterococcus faecalis*	2	3.8%
9	*Lactobacillus helveticus*	2	3.8%
10	*Weissella cibaria*	2	3.8%
11	*Bifidobacterium lactis*	1	1.9%
12	*Lactobacillus alimentarium*	1	1.9%
13	*Lactobacillus brevis*	1	1.9%
14	*Streptococcus salivarius*	1	1.9%
15	*Weissella confusa*	1	1.9%

Counts represent the number of studies in which each species or strain was reported.

Probiotic species isolated from traditionally (uncontrolled) fermented dairy products

Probiotic species isolated from traditionally (uncontrolled) fermented dairy products in Africa The study revealed that traditionally fermented dairy products contributed to 57.69% of the studies conducted on probiotic dairy products in Africa (Tab 1). This shows that traditionally fermented dairy products with probiotic potential have significantly contributed to the varied diet of most African countries.

Microbial composition

The study indicates that these products are fermented by mixtures of multiple LAB strains, as shown in Table 1. In the genus *Lactobacillus* species identified in the study include *L. acidophilus*, *L. casei*, *L. paracasei*, *L fermentum, L. rhamnosus*, *L. plantarum and L. helveticus* (Fontana *et al*., 2019; Jensen *et al*., 2012; Klein *et al*., 1998). The results revealed that *L. plantarum* is the most dominant probiotic LAB isolated from fermented milk products namely *amasi, amabere amururanu*, *ititu*, *fènè*, *garis*, *kwerionik*, *lben, nono, nunu, ayib and suusac* (Adesokan *et al*., 2011; Akabanda *et al*., 2014; Ashmaig *et al*., 2009). *Lactobacillus plantarum* is the most dominant strain in traditionally fermented dairy products because it possesses an adaptable metabolism that allows it to ferment various carbohydrates, including monosaccharides, disaccharides and polysaccharides that are found in dairy substrates. Strains of *L. plantarum* can ferment galactose, ribose, mannose, mannitol, fructose, sucrose, maltose, esculin, gentiobose among other sugars (Mathara *et al*., 2004).

Other frequently identified probiotic strains including *L. fermentum* isolated from *garis*, *kule naoto* and *nunu*, *L. paracasei* isolated from *amasi*, *garis*, *itutu*, *kule naoto*, *kwerionik* and *lben* and *L. acidophilus* exhibited a viable count of 6 log cfu mL^{-1} to 10 log cfu mL^{-1} (Mathara *et* *al*., 2008; Nakavuma & Nasinyama, 2012; Seifu *et al*., 2012). These findings indicated that the products possess probiotic functions as they met the criterion to have a viable bacterium count above 6 log cfu mL^{-1} (Mpofu *et al*., 2014) thereby conforming to FAO/WHO guidelines (FAO/WHO, 2006).

PCR analysis of naturally fermented products such as *nyarmie* and *nunu* indicated the presence of *L. helveticus* (Akabanda *et al*., 2014; Obodai & Dodd, 2006), nonetheless, falling into the category of less frequently isolated LAB together with *L. alimentarium*, *L. rhamnosus*, *L. Salivarus*, *S. salivarius* and *Leuconostoc* species. Probiotic viable counts of *Leuconostoc mesenteroides* subsp *mesenteroides* were isolated in *suusac* as well as *kwerionik* and *lben* (Lore *et al*., 2005; Nakavuma & Nasinyama, 2012; Ouadghiri *et al*., 2008). *Streptococcus* species such as *S. salivarius* were also identified as probiotic species in traditionally fermented dairy products (Wescombe *et al*., 2012). In the genus *Enterococcus*, Ec. *faecium*, *Ec. faecalis* exhibit probiotic functions (Klein *et al*., 1998). Probiotic *Weisella* species such as *W. confusa* were also identified as probiotic species (Bourdicho, 2021).

Fermentation methods

Fermentation methods used in traditionally processed dairy products play an important role in determining the microbial composition and functional properties of the final products. The review showed that these techniques vary across African regions and are shaped by long standing cultural practices that influence the selection and dominance of probiotic species. A key method is back-slopping, which refers to the practice of using a portion of a previously fermented batch to initiate fermentation of milk. This method promotes the transfer and propagation of a diverse consortium of lactic acid bacteria (Akabanda *et al*., 2014).

In addition, the use of different fermentation vessels and handling practices contributes to the distinct characteristics observed in products. In *suusac* and *kwerionik* the occurrence of probiotic species is influenced by the conditions in the fermentation vessel. The use of smoked gourds or charcoal-treated gourds in the production of fermented milk products creates a selective environment that allows for the growth of desirable LAB with unique functionalities (Lore *et al*., 2005; Nakavuma & Nasinyama, 2012). The natural microflora in dairy milk also affects the process of natural fermentation (Akabanda *et al*., 2014).

Challenges in traditionally fermented dairy products

Although traditionally fermented dairy products in Africa contain diverse probiotic species, several challenges that limit their quality and potential for wider commercial use were identified. Studies on *nyarmie* and *nunu* highlighted the drawback of the use of the back-slopping method, resulting in products with variable quality and stability (Akabanda *et al*., 2014; Obodai & Dodd, 2006).

Safety concerns were also identified in the review. Some traditionally fermented products contained species of genera *Enterococcus* and *Weisella that* have been identified as opportunistic pathogens (Fairfax *et al*., 2014; Wullschleger *et al*., 2013). Strains of *E. faecium* were isolated from *nunu*, *kule naoto*, *lben* and *suusac* (Akabanda *et al*., 2014; Mathara *et al*., 2008; Ouadghiri *et al*., 2008). A study in Mali revealed that *fènè*, a sour milk product contained *W.confusa* strain. Therefore, one of the main hindrances to the commercialisation of traditionally fermented dairy products with probiotic potential can be attributed to the lack of safety assessment of probiotic strains found in dairy products in Africa.

Probiotic strains used in controlled fermentation of dairy products

Publications on commercial probiotic strains showed that *Lactobacillus rhamnosus* GG was the most used strain in African countries. Twenty-three percent (6/26) of the studies conducted in Africa utilised the generic probiotic variant known as *Lactobacillus rhamnosus* yoba. Production of yoba yoghurt has been an enormous success in the Eastern parts of Africa namely Uganda, Kenya and Tanzania (Chevez & Burton, n.d; Westerik *et al*., 2018). Other countries including Cote d'Ivoire, Senegal and Zimbabwe have conducted studies on dairy products containing *Lactobacillus rhamnosus* yoba (Brett *et al*., 2021; Mpofu *et al*., 2014; Parker *et al*., 2018). Again, the *L. rhamnosus* yoba strain has increasingly been integrated into native dairy products in Sub-Saharan Africa.

Incorporation of health-promoting probiotics into traditionally fermented dairy products has emerged as a possible solution to combat nutrition insecurity in resource-poor communities, where the prevalence of malnutrition is high (Mpofu *et al*., 2014; Parker *et al*., 2018). *Lait caillé*, a fermented milk product, prepared in wooden bowls known as *lahals* in northern parts of Senegal (Parker *et al*., 2018) and *mutandabota*, a Zimbabwean food product prepared by mixing cow's or goat milk with dry baobab fruit pulp (Mpofu, 2014) were enriched with *Lactobacillus rhamnosus* yoba 2012. The results from the study by Parker *et al*. (2018) indicated a 20 to 60-fold increase in the total viable probiotic count of *L. rhamnosus* yoba. Outcomes of this study were comparable to those depicted from the Zimbabwean study where *L. rhamnosus* yoba thrived in the product and a viable count of 8.8 ± 0.4 log cfu mL^{-1} was recorded at the time of consumption (Mpofu *et al*., 2014).

The second most documented probiotic strain used in Africa was *Lactobacillus rhamnosus* GR-1. Two studies from Kenya and Tanzania showed that *L.rhamnosus* GR-1 was used in *fiti* yoghurt and probiotic yoghurt supplemented with moringa, respectively (Nduti *et al*., 2016; Van Tienen *et al* ., 2011). *Weissela cibaria* NN20 strain was identified in two articles in Kenya (Nduti *et al.*, 2016; Nduti *et al*., 2018). In a study by Nduti *et al*. (2016), the strain was also incorporated into *fiti* yoghurt. After a successful trial, *Weissela cibaria* NN20 was then isolated from a local fermented cereal product known as '*kimere*' and used to produce a fermented milk product. In the case of probiotic *nono* production in Nigeria, pure strains of *L. casei*, *L. fermentum* and *L. plantarum* were used as starter cultures (Adesokan *et al*., 2011). A similar study was carried out in Ghana, where *Lactobacillus fermentum* (LF-22-16), *Lactobacillus plantarum* (LP-8-2), *Lactobacillus helveticus* (LH-22-7), and *Leuconostoc mesenteroides* (LM-14-11), were isolated from a traditional product known as *nunu* for starter culture production (Akabanda *et al*., 2012). The use of probiotic cultures of *Bifidobacterium lactis* was reported in a study on formulas in South Africa (Urban *et al*., 2008). Other probiotic cultures documented including *Lactobacillus fermentum, Leuconostoc lactis* and *Leuconostoc mesenteroides ssp. Mesenteroides* were isolated in kefir grains, which are used to produce kefir beverages (Witthuhn *et al*., 2004).

Overall, *Lactobacillus rhamnosus* strains GG and GR-1 are the most used commercial probiotics across Africa. Two probiotic strains exhibited favourable properties making them suitable for applications in Africa. The innovation of a shelf-stable dried bacterial consortium of either *L. rhamnosus* GG or *L. rhamsnosus* GR-1 with *Streptococcus thermophilus* C106 has given rise to increased studies on probiotics in Africa (Chevez & Burton, n.d; Kort & Sybesma, 2012; Westerik *et al*., 2018). Nevertheless, *L. rhamsosus* GG is the most studied probiotic bacterium with proven health benefits upon oral intake (Kort *et al*., 2015; Westerik *et al*., 2018). The consumption of *yoba* probiotic yoghurt has proven to be beneficial in the prevention of diarrhoea, common cold, skin conditions and allergies in children in Uganda

(Chevez & Burton, n.d) and these characteristics might have led to the increased use of the probiotic culture. On the other hand, *Lactobacillus rhamnosus* GR-1 is the second most scientifically documented *L. rhamnosus* strain (Westerik *et al*., 2018). *L. rhamnosus* GR-1 *fiti* yoghurt has expanded the reach of probiotics in Kenya and Mwanza through social enterprises (Reid *et al*., 2018). Apart from the known health benefits, of these two strains, the successful utilisation in Africa is ascribed to the affordability of both the starter cultures as well as the products. This phenomenon is of utmost importance in resource-poor countries as most probiotic products such as capsules are inaccessible and highly-priced (Westerik *et al*., 2019).

Effect of probiotic strains on technological properties of fermented dairy products

Probiotic strains of lactic acid bacteria (LAB) in fermented dairy products influence the technological properties of yoghurt, including improving textural properties, taste, aroma, and health-promoting properties. This section will delve into the technological properties of probiotic strains in Table 1.

Acidification activity of probiotic strains

The acidity of fermented dairy products is attributed to lactic acid, the primary organic acid produced during fermentation by lactic acid bacteria (Mukisa & Birungi, 2018). The propagation of probiotics in fermented milk products results in the lowering of pH from 6.7 to around 4.3. The acidification properties of probiotics influence their application as primary starter cultures or as adjuncts in starter cultures. For instance, *L. fermentum*, *L.mesenteroides* and *L. plantarum* demonstrated fast acidifying properties in the production of 'nunu' (Akabanda *et al*., 2014). *L. fermentum* is dominant in traditionally processed dairy products in Africa therefore bringing about similar characteristics in these products (Akabanda *et al*., 2012).

Homofermentative bacterium such as *L. plantarum* in *amabere amaruranu* plays a vital role in the development of lactic acid. The study also suggests that the characteristic sour taste is a result of *L.plantarum* activity (Nyambane *et al*., 2014). Homofermentative pathways produce lactic acid as the main product whilst heterofermentative metabolism by LAB produces other by-products such as carbon dioxide, acetic acid or ethanol (Chen *et al*., 2017). Rapid acidification by these probiotic strains is essential in flavour and aroma development of fermented dairy products (Akabanda *et al*., 2014). Another study by Seifu *et al*. (2012)

indicated that *L.salivarius* demonstrated strong acidifying activity in skim milk. On the other hand, the decrease in pH of fermented milk affects propagation and survival of probiotics as in the case of *L. rhamnosus* yoba. The bacterium grows at the lowest pH range of 4.4 to 3.4 (Mpofu *et al*., 2014).

Influence of probiotics on flavour

Flavour and aroma development in fermented milk products is mainly caused by biochemical reactions by lactic acid bacteria. The typical fresh, buttery, sweet and fruity aroma of fermented products such as yoghurt is attributed to carbonyl compounds (C4) compounds namely acetaldehyde, diacetyl and acetoin (Chen *et al*., 2017). These compounds are produced through the glycolytic pathway or citrate metabolism of the genera *Lactococcus, Leconostoc* and *Weisella* (Chen *et al*., 2017). Citrate is the principal precursor of diacetyl in fermented dairy products (Adesokan *et al*., 2011). For instance, the functional significance of *Leuconostoc* spp is to convert citrate to aroma compounds, namely diacetyl and acetoin (Akabanda *et al*., 2012). This characteristic has been significant in traditional dairy products such as *nunu* and *suusac* (Akabanda *et al*., 2014; Lore *et al*., 2005).

However, Gadaga *et al*. (1999) reported that *L.mesenteroides* and *L.plantarum* produced *amasi*, a sour milk product with less consumer preference compared to that produced by *Lactococcus lactis* subsp. *lactis biovar diacetylactis*. In *nono* production *Lactobacillus casei* N18 demonstrated the higher diacetyl content (1.65 g/mL), *Lactobacillus brevis* N15 exhibited the lowest amount (0.9g/mL), whilst a mixed starter of *L.casei* N18 and *L.plantarum* N07 produced the highest quantity of diacetyl (2.40g/mL) (Adesokan *et al*., 2011). Mpofu (2015) attributed the aroma and textural properties of probiotic-enriched *mutandabota* to diacetyl and acetoin produced by *Lactobacillus rhamnosus* GG (LGG).

On the other hand, probiotic strains such as *Weissela cibaria* NN20 indicated weak flavour development in a fermented milk product albeit the viscosity and pH of the product were comparable to that of traditional yoghurt (Nduti *et al*., 2018). Other flavour compounds are derived from the proteolytic activity of probiotic strains such as *L. plantarum* and *L. helveticus* to produce flavour compounds such as amine, ammonia, aldehydes, alcohols, indoles and phenols (Chen *et al*., 2017). Lipid hydrolysis by LAB also gives rise to flavour compounds although its contribution is less significant in products such as yoghurts *(Chen et al*., 2017). In the case of kefir beverage, the distinct flavour is a result of the symbiotic interactions between LAB, acetic acid bacteria and yeasts such as *Saccharomyces*, *Candida* and *Kluyveromyces* species (Witthuhn, 2004).

Influence of probiotics on texture

Textural properties of dairy products are some of the key factors that influence consumer perception. Probiotic bacteria exhibit functional properties in improving the stability, rheology and texture of fermented dairy products due to their ability to synthesise exopolysaccharides (EPS) (Han *et al*., 2016; Zhi *et al*., 2018). Only one study on probiotic-fermented dairy products in Africa highlighted the significance of exopolysaccharides produced by probiotics. A study by Akabanda *et al*. (2014) revealed that *L. helveticus, L. fermentum*, *L.plantarum* and *L. mesenteroides* exhibited good exopolysaccharide production capabilities within the range of >100-150µg/mL whilst *Ent. faecium* demonstrated poor capabilities. This goes on to show that the viscosity of traditionally processed dairy products such as *ititu*, *suusac*, *fènè*, *amabere amaruranu* and *nyarmie* may be accredited to the presence of good EPS-producing LAB strains mentioned above.

Although the literature on exopolysaccharide production by probiotic LAB is limited in Africa, exopolysaccharides are applied as thickening, stabilising, gelling or emulsifying agents in food products (Akabanda *et al*., 2014). Nduti *et al*. (2018) found that *Weissella Cibaria* NN20 produced a fermented milk product with good viscosity that was comparable to that of yoghurt produced by traditional yoghurt cultures. This might have been because *Weisella* species are good producers of dextran-like homopolysaccharides (Vasanthakumari *et al*., 2015).

Influence on health

Global studies show similar trends in probiotic functionality, with *Lactobacillus* species, particularly *L. plantarum* reported as dominant microorganism in fermented foods across Europe and Asia, which mirrors their prevalence in African fermented dairy products (Yilmaz *et al*., 2022; Adesulu-Dahunsi *et al*., 2022). In vitro and in vivo studies have been carried out on the health-promoting properties of probiotic strains isolated from both traditionally processed and commercially processed dairy products in Africa.

In addition to the already available literature on functional properties of LGG, Mpofu *et al*., (2016) investigated the antimicrobial properties of yoba *mutandabota* using the five enteropathogens including *Listeria monocytogenes*, *Salmonella* spp., *Campylobacter jejuni*, *Escherichia coli* O157:H7 and *Bacillus cereus*. The conclusive results indicated that after three hours into the potential consumption time of yoba *mutandabota*, none of the tested pathogens were detected (>3.5 log inactivation), resembling the 99.9% inactivation of pathogenic bacteria (Mpofu *et al*., 2016). Evidence from clinical meta-analyses further demonstrates that *Lactobacillus rhamnosus* GG reduces the duration of acute gastroenteritis and prevents acute diarrhoea among children (Szajewska *et al*., Sazawal *et al*., 2006).

Akabanda *et al*. (2014) found out that LAB isolates in *nunu* exhibited antimicrobial effects against *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella typhi* and *Pseudomonas aeruginosa* using the agar-well diffusion method. Mathara *et al*. (2008) carried out an in-depth analysis of the functional properties of LAB isolated from *kule naoto*. The study indicated that some isolated LAB strains tested positive for acid and bile tolerance, adhesion to human cell line, antigenotoxic characteristics and resistance to antibiotics. Another study in Kenya indicated that *Weissela cibaria* NN20 in fermented milk products showed the ability to sequester aflatoxin B1 (AFB1) in vitro (Nduti *et al*., 2018). Yilmaz *et al.* (2022) revealed that L. plantarum strains in fermented foods can reduce aflatoxins, which suggests their role in maintaining food safety and preventing spoilage.

Several in vivo studies have been carried out to determine the effects of probiotics in dairy products on human health in Africa. These include probiotic yoghurt on reduction of aflatoxin biomarker in Kenya (Nduti *et al.,* 2016), lowering of cortisol using probiotic yoghurt in Cote d'Ivoire (Brett *et al*., 2021), reduction of heavy metals in Tanzania using probiotic yoghurt (Bisanz *et al*., 2014), increase in CD4 counts in people living with HIV in Tanzania (Irvine *et al*., 2010). However, human trials remain limited in Africa due to the high costs associated with randomised control trials (Mukisa, 2016). In 2006 the Food and Agriculture Organisation and World Health Organisation emphasised the need for in vitro tests to predict the ability of probiotics to function in the human body (FAO/WHO, 2006).

Conclusion

This research indicated that a large variety of traditionally fermented dairy products in Africa (15/26) are potential carriers for beneficial microorganisms as evident in the number of viable cells recommended for probiotic products (> 6 log cfu mL^{-1}). There has been an increase in the use of pure probiotic strains over the past two decades, though research on probiotic dairy products is still relatively low in Africa (11/26). A total of seven dairy product types were identified from studies conducted in Africa. The findings of this study also revealed that the characteristics of the dairy products identified vary with the methods of fermentation used, the microbial composition, the type of dairy source and the geographical location. The study also revealed that access to probiotic cultures for fermentation increases shelf life and microbial safety, reduces spoilage through controlled fermentation, and increases health properties by delivery of beneficial bacteria in both traditional and commercial dairy products in Africa

Recommendations

Despite the successful utilisation of *Lactobacillus rhamnosus* strains in dairy products, further research is required on the application of other probiotic strains in Africa. This can be achieved by modification of other probiotic strains to meet the conditions in Africa. Isolation of probiotic strains from traditionally fermented dairy products for potential use as starter cultures can be a possible solution in increasing the use of probiotics in Africa. There is also a need for increase of in vitro and in vivo assay for validation of species derived from traditionally fermented dairy products that exhibit probiotic functions. There are untapped areas of research such as the incorporation of probiotics in products such as cheese and ice creams to boost the immunity of customers.

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An investigation into the environmental factors influencing elephant poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe.

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Abstract

This study investigates the environmental factors influencing elephant (Loxodonta Africana) poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe. Using data collected during ranger patrols (local, extended, strategic and aerial patrols) and secondary data sources (reports) were also used from 2018 to 2022 for poaching statistics while elephant collar data was obtained from 09 collared matriarchs that were being monitored over the same period. The research also examines the elephant poaching hotspot, the relationship between elephant poaching and seasonal distribution, boundary, rivers, boreholes, roads and vegetation cover using Arcgis 10.3 tools. The results show a significant relationship between dry season elephant distribution and poaching of elephants, also a strong relationship between boundary, rivers and poaching of elephants and no relationship between roads, boreholes and poaching of elephants. The results also showed that the elephant poaching hotspots is in the north western of RIFA which is near to the mighty Zambezi River and also the boundary between Zambia and Zimbabwe. This study concludes that boundary, rivers and dry season as main drivers of elephant poaching in RIFA area. These finding highly recommends the wildlife managers to increase patrol in the North western area of Rifa and also increase the border patrols.

Keywords: elephant poaching; vegetation cover; hotspot; collared; monitored; boundary

Introduction

The poaching of African elephants (*Loxodonta Africana*) for ivory is a major concern throughout Africa with poaching contributing to the major declines in the populations of the species in most African countries (Kyando et al., 2017). African elephants are among approximately 30,000 species of animals and plants that are listed by the Convention on International Trade in Endangered Species (CITES) list as endangered (Sibanda et al., 2016) and the African elephants are listed under Appendix I of the CITES (Maingi et al., 2012). Despite a ban on the international ivory trade, African elephants are still being poached in large numbers. Tens of thousands of elephants are being killed every year for their ivory tusks. The ivory is often carved into ornaments and jewellery, with China being the destination and the biggest consumer market for such products (WWF, 2020). While the highest driver for elephant poaching has been ivory, there has been a lot of change with some now targeting the elephant for meat and others for both meat and ivory (Sibanda et al., 2016).

An estimated 22,000 African elephants were illegally killed across Africa in 2012 with the most serious threats to the species' survival across the continent being habitat loss, human-elephant conflict, and illegal killing for meat which have been compounded by an explosion of organized ivory poaching syndicates, especially in Zimbabwe (Sibanda et al., 2016). Monitoring of Illegal Killing of Elephants (MIKE) covers 60 sites across Africa, within which more than 19,000 elephant carcasses have been detected by rangers to date (Kuiper et al., 2020). An understanding of the spatial distribution or pattern of poaching activities is fundamental for purpose of reducing these poaching activities. However, the conservation efforts to protect elephants are challenging due to their vast habitat range, and as such conservation efforts focused on high-risk areas provide a more efficient management method than randomly patrolling entire habitat areas (Shaffer and Bishop, 2016).

Several studies have explored relationships among elephant abundance, environmental variables, and human factors. Several of these studies identified distance to water as the primary environmental factor influencing the density of the elephant population at the local level (Verlinden and Gavor 1998; Redfern et al. 2003). In the Congo Basin, found that the abundance of many mammal species increased with distance from roads because of hunting pressure. Other studies have looked at the relationships between elephants and vegetation has successfully utilized satellite-derived vegetation indices such as the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI) as proxies for vegetation productivity (e.g., Chamaillé-Jammes et al. 2007; Hien et al. 2007; Loarie et al. 2009).

At the global scale, a major perspective used to explain crime is based on factors that increase the motivation to commit a crime and those that enhance the opportunity for criminal activity (Van Dijk 1994). Cohen and Felson (1979) came up with the concept of distance decay, which suggests that most offences occur relatively close to the domicile of a local offender. The distance-decay concept implies that crimes will tend to cluster where opportunities and motivated offenders are plentiful, and guardianship is missing or weak. In the case of elephant poaching, we can expect poaching activity to be intense where elephants are most abundant and where transportation of the poached ivory directly to the ivory traders or through middlemen is easiest because this provides the poacher with the highest return on effort. Likewise, we can expect poaching activity to be tempered by the poacher's fear of detection by game rangers and law enforcement. Indeed, Milner-Gulland and Leader-Williams (1992) found that the probability of capture was a highly significant factor in the poacher's decision to hunt black rhinos and elephants in the Luangwa Valley in Zambia. Several studies have explored relationships among elephant abundance, environmental variables, and human factors. Several of these studies identified distance to water as the primary environmental factor influencing the density of the elephant population at the local level (Verlinden and Gavor 1998; Redfern et al. 2003). In the Congo Basin, Blake et al. (2008) found that the abundance of many mammal species increased with distance from roads because of hunting pressure.

Although elephant population in Zimbabwe is increasing, poaching of elephants in protected areas which are proximity to country's boarder has changed and the factors causing this has not been yet established. This has caused poaching mitigatory measures to be insufficient to end or reduce the poaching incidences, thereby requires immediate attention to ensure enhanced elephant conservation in these protected areas and in the country at large. According to the studies done in the past six years poaching incident were mainly located in the north eastern side of Hurungwe Safari Area, but there has been an increase of poaching incidences on the south western side of Hurungwe safari Area mainly RIFA concession. The escalating crisis of elephant poaching in the Hurungwe Safari Area, Zimbabwe, demands urgent attention and action. Previous research highlighted that poaching activities were primarily concentrated in the Nyakasanga region of the Hurungwe Safari Area. However, recent data has revealed a concerning shift, with poaching incidents increasingly clustering in the Rifa section over the past few years. This study aims to uncover the underlying factors driving this change. This includes assessing whether the movement patterns of elephants have made them more vulnerable in certain areas or if poaching tactics have evolved in response to anti-poaching efforts in Nyakasanga. This study also aims to unfold when and where the shifts occurred, offering insights into the timing and potential triggers of increased poaching activity. The previous study done by Sibanda et al 2015 was basing on the location of carcass rather than movement of elephants in Hurungwe safari Area, this study will therefore correlate the movement of elephants and poaching incidence. Since the collaring of elephant in Rifa no studies were done to reveal the factors causing the shift of poaching incidence from north east to the south western of Hurungwe Safari Area, the present study will therefore work as a baseline data for the seasonal movement of elephant in Rifa. Elephant poaching mitigation are determined by the behavior and occurrence of the poaching incidence and factors influencing poaching, the present study aims to unfold the relationship between environmental factors the movement of collared elephant. Moreover, the study will come up with scientific based information which will guide Park manager and policy makers to come up with informed decision in elephant conservation. The aim of the paper is to investigate the environmental factors influencing elephant *(Loxodonta Africana)* poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe

Materials and Methods

Study Area

The study was conducted in the HSA–RIFA section of the Zambezi Valley within the Hurungwe Safari Area in northern Zimbabwe. The study area covers approximately 619 km² and is located between 16°6′59.76″S and 29°9′47.52″E. Elevation ranges from 350 m above sea level in the Zambezi floodplain to 1050 m along the Zambezi Escarpment. The terrain consists of a sparse dendritic river network draining into the Zambezi River.

The area has an average annual rainfall of 650 mm, falling mainly between November and April. However, the rainfall is very erratic, and droughts are a regular occurrence. The average minimum temperatures range from 9 °C in July to 22 °C in December, while the average maximum temperatures range from 15 °C in July to 30 °C in December. The relative humidity is highest during the rainy season, especially between November and January, and frost has never been recorded below the escarpment. The vegetation types below the escarpment are characterized by mopane woodland with scattered baobab trees, while the higher ground is dominated by Brachystegia species. The area supports a wide range of wildlife, including elephants, fish, birds, and a variety of insects.

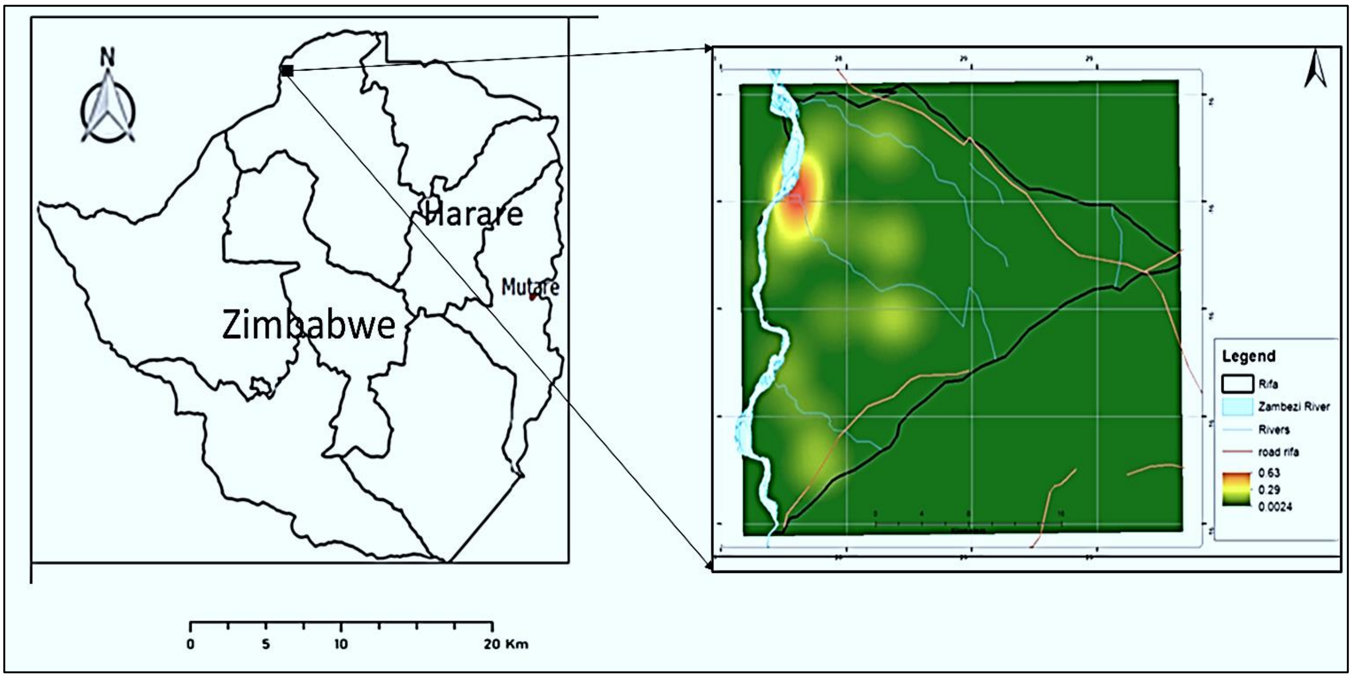

Figure 1: Map of Zimbabwe showing the location of RIFA

Data Collection

The data for this research was collected between 2018 and 2022 using both primary and secondary sources. The primary data was collected using ranger patrols (local, extended, strategic, and aerial), where the locations of elephant carcasses were recorded using handheld GPS devices. The data was recorded in decimal degrees and later used to create Microsoft Excel spreadsheets with corresponding dates and location information. In addition, movement information was collected from nine collared elephant matriarchs who were being tracked during the same period.

The secondary data was collected from patrol reports and mortality reports that were filed at the station to confirm the information collected from the field. This information is part of a protected area law enforcement data management system and was deemed accurate for the purpose of this study.

Variables that were thought to affect the risk of poaching, such as vegetation cover, distance to water sources, distance to the park boundary, and seasonality, were used in a logistic regression model in ArcGIS. This helped to determine the strength of the relationship between the variables and the risk of poaching, as well as the variables that had the greatest influence on the risk of poaching.

Lastly, the spatial distribution of the elephants during the different seasons was overlaid with the spatial distribution of the poaching incidents during the different seasons using GIS. Regression analysis was used to determine the relationship between the spatial distribution of the elephants and the poaching incidents.

Data Analysis

Spatial and statistical data analysis was performed using ArcGIS 10.3. To analyze the multi-temporal distribution of poaching hotspots between 2018 and 2022, Kernel Density Estimation (KDE) was applied to the georeferenced poaching incident data obtained from ranger records, ground observations, and aerial surveys. This approach allowed the creation of a continuous surface layer to represent the density and aggregation of poaching incidents in the study area, facilitating the detection of spatial hotspots over time.

Spatio-temporal distribution of elephants was identified using GPS collar data from the nine monitored matriarchal elephants. Seasonal movement patterns were analyzed through home range estimation by KDE, while spatio-temporal clustering analysis was employed to examine changes in elephant distribution over time. Seasons were divided into wet (November to April), dry (May to October), and a transitional autumn phase (April to May).

Presentation of Results

Quantifying Multi-Temporal (2018–2022) Distribution of Poaching Hotspots in RIFA

The map(Figure 2) shows the spatial distribution and level of elephant poaching incidents in the RIFA section of the Hurungwe Safari Area using Kernel Density Estimation (KDE). The map color gradient indicates the level of poaching, with red areas indicating very high-density hotspots, yellow areas indicating moderate-density hotspots, and green areas indicating low-density or negligible poaching activity. The park boundary is shown by a black line, rivers are shown in blue, roads are shown in red, and the Zambezi River marks the western boundary of the study area.

The results show a very prominent primary hotspot in the north-western corner of the park, right along the boundary of the Zambezi River. This region has the highest kernel density values (close to 0.63), which indicate a high level of spatial aggregation of poaching incidents.

The high level of poaching incidents along the river boundary indicates that access to water sources and international routes may play a significant role in poaching incidents.

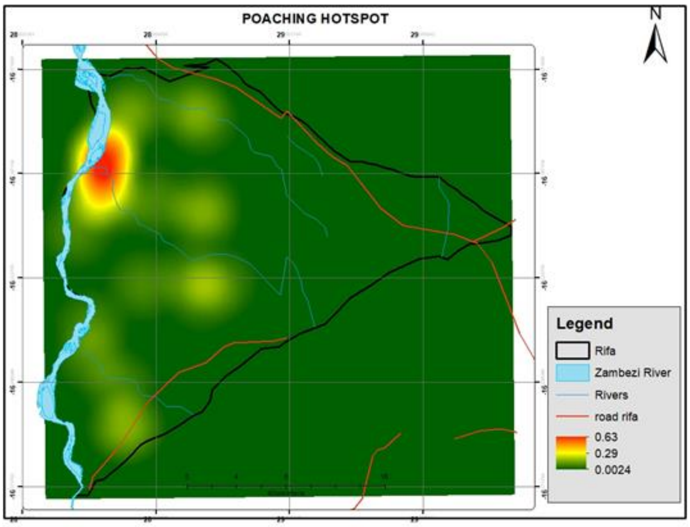

Figure 2 Poaching hotspots in RIFA

Assessing Environmental Factors Influencing Poaching Hotspots in RIFA

The map Figure 3 shows the spatial distribution of vegetation cover in the RIFA section of the Hurungwe Safari Area using the Normalized Difference Vegetation Index (NDVI). The NDVI index is shown using a color gradient, where green represents dense vegetation, yellow represents moderate vegetation cover, and orange to reddish colors represent low vegetation density. The park boundary is shown in black, the Zambezi River along the western boundary, and seasonal rivers in the park are also shown. Black spots show the recorded cases of poaching.

The dense vegetation cover is shown along the western boundary of the park, especially around the Zambezi River, where dense green patches are shown. The central and eastern parts of the park show moderate vegetation cover (yellow color), while low vegetation density is shown in some parts of the escarpment and the interior. This trend indicates a positive spatial relationship between vegetation density and poaching incidence. Dense vegetation around permanent water sources, especially along the Zambezi River, could offer opportunities for concealment and ambush points for poachers to attack elephants. On the other hand, regions with low vegetation density appear to have relatively lower levels of poaching incidence, possibly because of the lack of cover. In general, the NDVI map indicates that vegetation spatial structure is a significant environmental variable that affects the spatial distribution of poaching incidents in the study area.

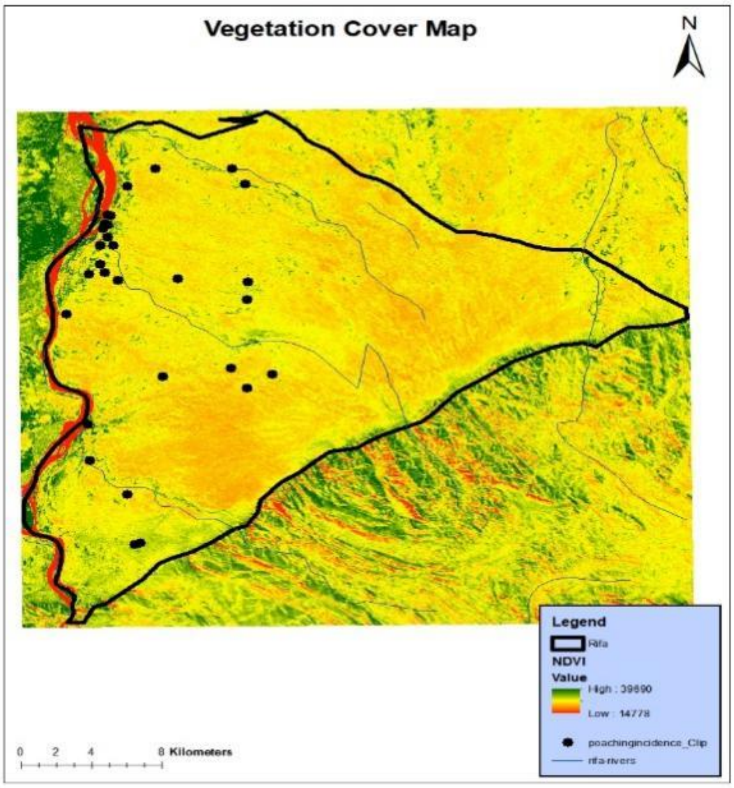

Figure 3: Poaching incidences and vegetation cover.

Relationship between poaching incidents and roads

From the scatter plot, it can be observed that there is a strong positive relationship between the presence of roads and the predicted elephant poaching incidents in the RIFA/Hurungwe Safari Area, as indicated by the high value of R^2 at 0.71. This value indicates that 71% of the variation in the level of poaching can be explained by the presence of roads or road density, which can be considered as an important conduit for poaching activities in the Mid-Zambezi Region. Although the regression line indicates a steady increase in the level of poaching, there is considerable clustering of data points, especially in the higher range, which helps to identify "hotspots" where the risk of poaching is at its highest. This indicates that although roads are the most important environmental factor, the level of poaching may be further fueled by the convergence of transport infrastructure with other local factors such as water points or patrol gaps.

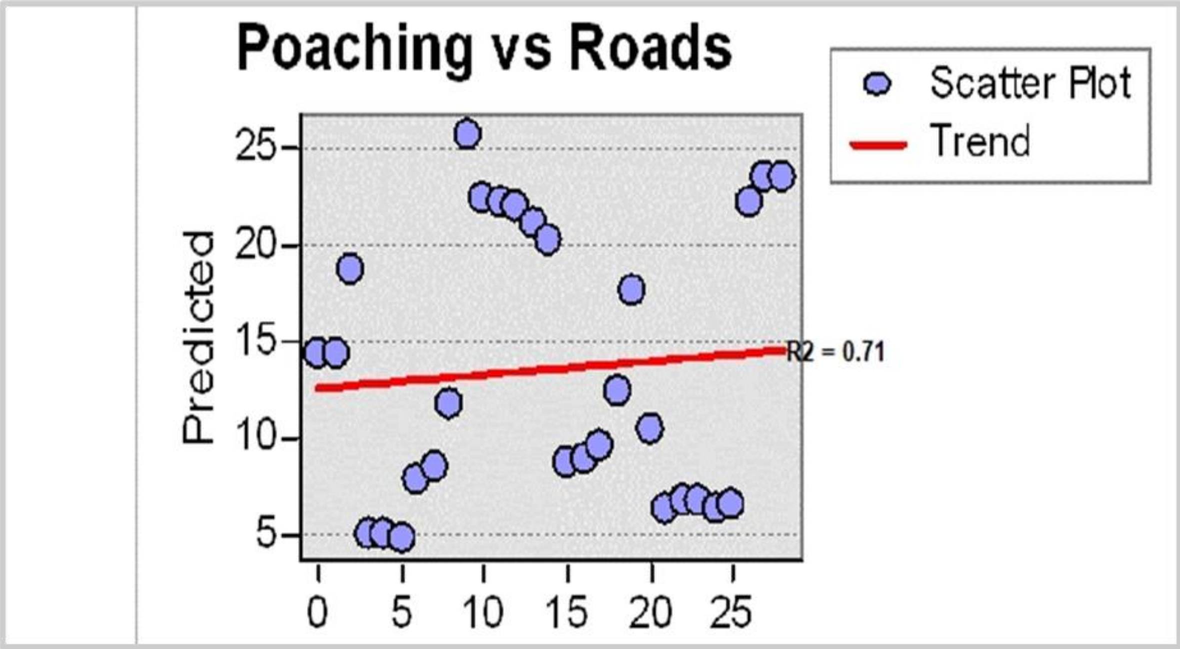

Figure 4 Poaching Vs roads

Relationship between poaching incidents and boreholes

Analysis of the results shows a clear negative correlation between borehole distribution and the predicted number of elephant poaching incidents in the RIFA area of the Hurungwe Safari Area. The scatter diagram shows that areas with low borehole distribution have high levels of predicted poaching, while areas with high borehole distribution have low levels of poaching. The regression analysis shows a high coefficient of determination ($R^2 = 0.81$), which means that about 81% of the variation in poaching levels can be explained by the distribution of boreholes. The strong statistical relationship between the two variables underscores the importance of water as a key environmental factor that shapes the dynamics of elephant poaching. The negative trend line confirms that as artificial water sources increase, the number of predicted poaching incidents declines, which means that boreholes can be a critical factor in reducing elephant concentration around scarce natural water sources and, in turn, reducing the risk of being attacked by poachers.

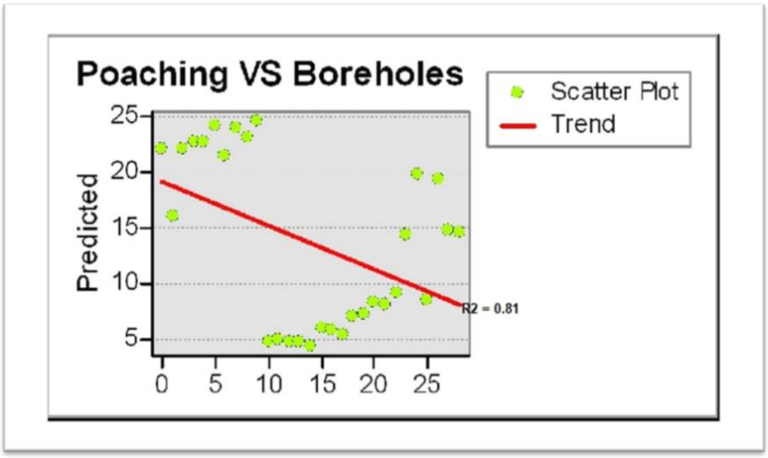

Figure 6 Poaching Vs Borehores

Poaching Vs Rivers

The scatter diagram illustrating the correlation between Rivers and Predicted Poaching incidents in the RIFA/Hurungwe Safari Area indicates a strong positive linear relationship, as indicated by the high $\mathbf{R^2}$ value of 0.66. The value of this coefficient indicates that 66% of the variability in poaching incidents can be explained by the distance or density of riverine systems, thereby establishing them as a key environmental determinant of poaching hotspots. The sharp upward trend of the red trend line in the scatter diagram also indicates a strong positive correlation between the riverine variable and the predicted poaching rate, which can be attributed to the fact that these water sources are known to harbor animals in predictable numbers, making them high-risk areas for poaching elephants. The points in the scatter diagram are also seen to be concentrated in the higher range of the spectrum, thereby establishing that riverine areas in the Mid-Zambezi Region are key determinants of illegal poaching activities.

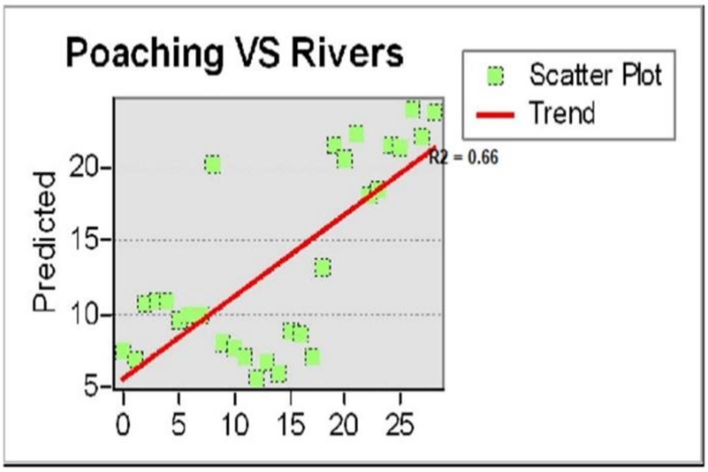

Fig 9 Relationship between poaching incidents and rivers.

Poaching Vs Boundary

The data shows a strong positive correlation between environmental proximity factors and predicted poaching activity, with boundary proximity being the most influential factor. The "Poaching VS Boundary" scatter plot shows the strongest predictive capability with an R^2 value of 0.83, indicating that about 83% of the variation in poaching activity can be accounted for by proximity to the borders of the safari area, which are often easy points of entry and exit for poachers. Likewise, the "Poaching VS Rivers" analysis reveals a strong positive trend and a strong R^2 value of 0.66, indicating that water sources are important hotspots where animals are particularly susceptible to poaching. Collectively, these findings indicate that elephant poaching in the RIFA/Hurungwe Safari Area is highly predictable and concentrated in space along administrative boundaries and water sources.

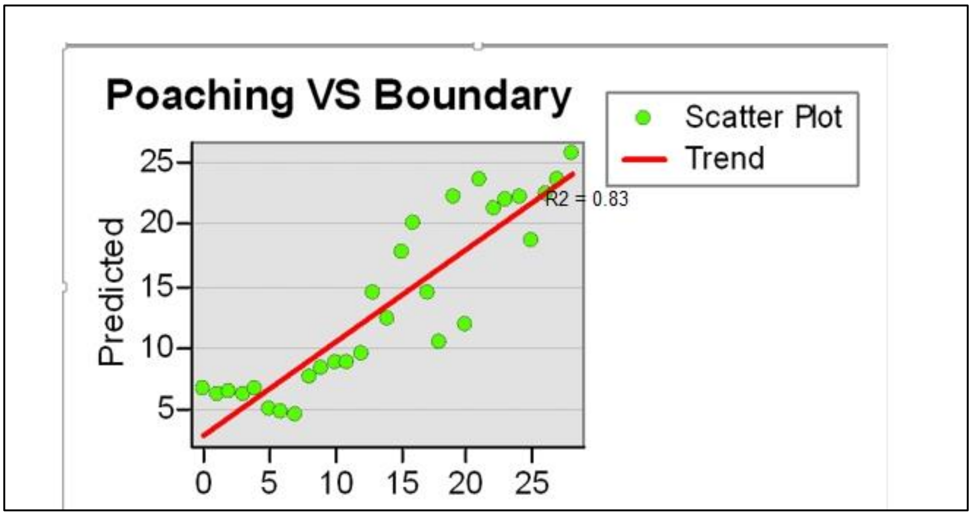

Fig 10. Relationship between poaching and the boundary.

Relationship between poaching incidents and Seasons

The overall dataset suggests that the poaching of elephants in the RIFA/Hurungwe Safari Area is mainly a function of spatial accessibility and seasonal vulnerability, with proximity to the boundary being the most significant predictor. The analysis of "Poaching VS Boundary" reveals an excellent R^2 value of 0.83, suggesting that 83% of the variation in poaching can be attributed to the boundaries of the area, followed by rivers (R^2 = 0.66), which are identifiable hotspots for the exploitation of wildlife resources. Moreover, the longitudinal analysis of the trends from 2018 to 2023 suggests that the Dry Season poaching cases have been steadily ahead of all other seasons, possibly because of the animals' concentration around scarce water sources, while the Autumn and Wet Season poaching cases have generally been on a downward trend.

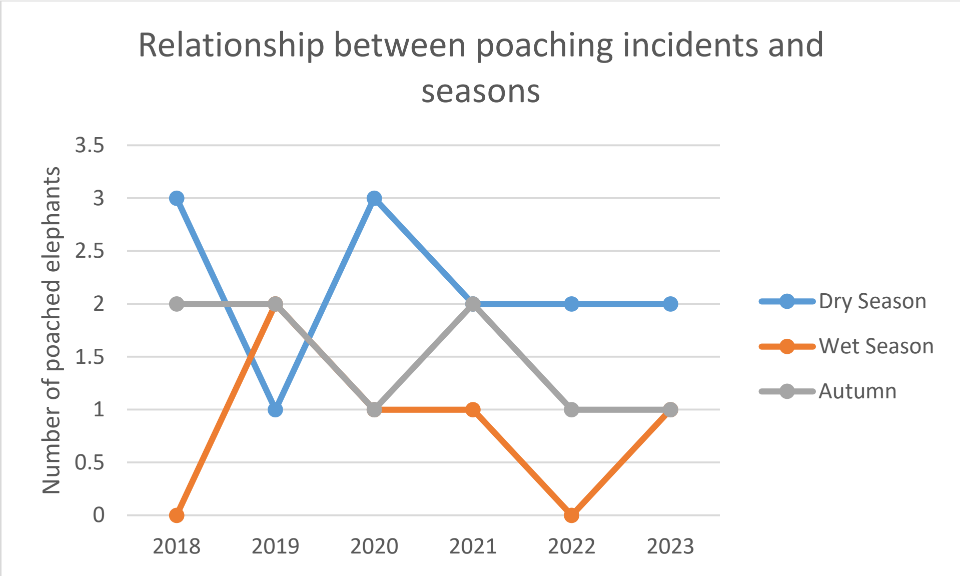

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Figure 2:graph showing the trend of poaching incidents between seasons.

Overlay Analysis of Wet, Autum and Dry Season and Poaching Hotspots

Dry Season

The Dry Season is the point of greatest poaching activity and thus greatest risk. The heatmap(Figure 12) indicates a broad, densely populated "red" hotspot in the northwest, particularly where the region intersects with large bodies of water. This is a spatial pattern that is strongly confirmed by the statistical relationship between poaching and rivers ($R^2 = 0.66$), where elephants are driven to congregate around scarce water sources during this time of year. Longitudinal data indicates that while poaching was highest in 2018 and 2020, it has been a steady level of two elephants per year since 2023.

Wet Season

In the Wet Season, the poaching events are much more evenly spread out over the landscape than in other seasons. Although there is still a major hotspot that can be seen in the northwest, this is not as intense, and the “purple” hotspots of activity are more spread out into the interior of the safari region. This is probably due to the fact that the water availability allows the elephant populations to range away from the main river systems, making them more difficult for poachers to follow. Looking at the historical data, there is a great deal of variation in this season, with a total of two incidents in 2019, but then none at all in 2022.

Autumn Season

The Autumn Season is a transitional phase and is marked by a moderate level of poaching activity distribution. The hotspots during the Autumn Season are not as extreme as those in the Dry Season but are more concentrated than those in the Wet Season. Although the northwestern boundary continues to be a hotspot, in line with the overall result that the proximity to boundaries is the most significant predictor of poaching (R^2= 0.83), the total number of incidents has been steadily declining. The number of incidents per season peaked at two incidents in 2018 and 2021 but reduced to one incident per season in both 2022 and 2023.

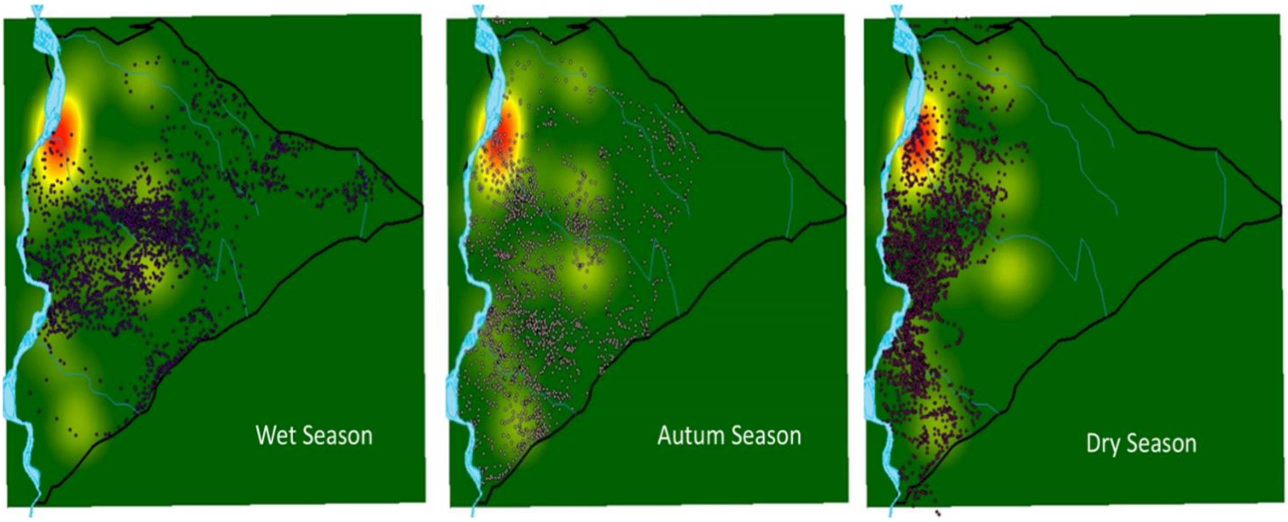

Figure 12 Overlay Analysis

Discussion of Results

The study on elephant poaching in the RIFA section of the Hurungwe Safari Area shows that poaching is not a random event but a predictable spatial and temporal process that is driven by environmental and accessibility-related factors.

Spatial Dynamics and Connectivity.

The most important result is the location of the first hotspot in the north-western corner of RIFA along the Zambezi River, which has high kernel density values (~0.63). The susceptibility of this region is largely because of its close proximity to international borders and administrative boundaries, which act as important entry and exit points for poachers. The "Poaching VS Boundary" analysis had the highest predictive ability (R^2= 0.83), which means that 83% of the variation in poaching can be explained by proximity to boundaries. Moreover, transport infrastructure is an important factor; road density enables illegal activities (R^2 = 0.71), which acts as a channel for the transportation of ivory out of the Mid-Zambezi Region. These results confirm findings in the literature that regions with high accessibility and porous boundaries are preferred targets for the illegal wildlife trade (Linkie et al., 2010; Maingi et al., 2012).

Environmental Drivers: Water and Vegetation

Water availability is found to be a clear positive driver of poaching activity. Natural water sources have a strong positive correlation with poaching events (R^2= 0.66), as the predictable animal aggregation points at water sources make elephants highly susceptible. On the other hand, the presence of boreholes has a strong negative correlation (R^2= 0.81), where more boreholes result in fewer poaching events by diffusing elephant aggregations. Vegetation density further adds to the susceptibility; high NDVI values (dense vegetation) along the Zambezi River are associated with high poaching events, probably acting as hiding and ambushing sites for poachers. The "concealment effect" of dense vegetation near water sources is a well-acknowledged factor in poaching vulnerability modeling (Ndaimani et al., 2014).

Seasonal Vulnerability

Temporal analysis shows that the Dry Season is the most vulnerable period. During this season, elephants are compelled to aggregate around natural water sources, resulting in hotspots in the northwest. Conversely, the Wet Season is characterized by a larger dispersal of both elephant and poaching incidents, as the availability of water in the interior enables herds to range away from the predictable river courses. The Autumn Season is a transition period, where a trend of reduced incidents has been observed since 2021. The changing seasons highlight the need for adaptive patrol plans based on the movement patterns of the wildlife (Wittemyer et al., 2008). The paper concludes that the poaching of elephants in the RIFA section of the Hurungwe Safari Area is a very predictable event that is influenced by the combination of spatial accessibility, environmental resource availability, and seasonality. The most important factor in the distribution of poaching is the proximity to the administrative boundaries of the park (R^2 = 0.83), which are porous entry and exit points for poachers, followed by the proximity to the roads (R^2 = 0.71), which are important transport conduits for the ivory. In terms of environmental factors, the permanent water sources and dense riverine vegetation (NDVI) are high-risk hotspots, especially in the northwestern corner of the park where the Zambezi River is located. However, the fact that the negative correlation between borehole distribution and poaching is quite strong (R^2 = 0.8) indicates that the provision of artificial water sources can be an effective measure to distribute the elephant population and make them less vulnerable. However, the fact that the intensity of the incidents is quite high during the Dry Season, as indicated by the Kernel Density Estimation, indicates that there is a substantial temporal window of opportunity where management should be focused to counter the exploitation of wildlife at water sources.

Conclusion

In summary, the research proves that elephant poaching in the RIFA section of the Hurungwe Safari Area is a non-random, spatially predictable process that is influenced by a combination of high accessibility corridors and resource dependency. The most important factor in determining poaching risk is proximity to administrative boundaries (R^2 = 0.83), followed by road density (R^2= 0.71), which are both factors that make it easy for poachers to illegally enter the area and quickly remove ivory. From an environmental perspective, the presence of permanent water sources and dense vegetation cover along the Zambezi River represents a hotspot, especially in the northwestern corner of the area where the NDVI analysis indicates that poachers take advantage of the dense foliage to hide. Nevertheless, the negative correlation between borehole distribution and poaching events (R^2= 0.81) reveals that the provision of artificial water sources is an extremely effective means of dispersing elephant populations and making them less vulnerable to attack.

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Exploring the Acaricidal Activity of *Cissus quadrangularis* against cattle ticks

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Abstract

Ticks pose a significant challenge in cattle production, leading to accelerated disease transmission and substantial economic losses. Chemical acaricides have limitations, including environmental pollution, inaffordability, and inavailability. Therefore, natural remedies are preferred by most rural farmers in developing countries like Zimbabwe. Cissus quadrangularis (C.quadrangularis) is one of the plants used traditionally for medicinal and ethnoveterinary purposes. The study aimed to evaluate the acaricidal activity of C. quadrangularis extract against cattle ticks. Randomised controlled trials were conducted on forty cattle infested with ticks. The experimental groups (n = 10) were treated with 1%, 3% and 5% C. quadrangularis extract, and the control group (n = 10) were treated with a placebo. The assessment was carried out over a 4–8-week baseline, whereby the extract or placebo was sprayed twice a week for 4 weeks and then weekly for the additional 4 *weeks. Tick counts were performed at baseline (Week 0), 4 weeks, and 8 weeks. Compared to the placebo group, the experimental groups showed a reduction in tick counts at 4 weeks and 8 weeks, respectively. Bioassays (petri dish, tick climbing repellent and fingertip) were also done to evaluate the repellent effects of C.quadrangularis. The assays demonstrated acaricidal activity of C.quadrangularis against cattle ticks, offering a promising natural remedy for tick control that can be considered as an alternative to synthetic acaricides, and for inclusion in the Integrated Pest Management (IPM) methods. Further studies are needed to determine and validate the bioactive compounds in C. quadrangularis that possess acaricidal activity.*

Key words: acaricide; chemical acaricides; natural remedy; placebo; bioactive compounds

Introduction

Income generation and food security are the primary goals of farming in the developing Sub-Saharan countries. Farmers in semi-arid regions, where there is little rainfall, place more emphasis on animal production than crop production. Matabeleland South province (Zimbabwe) is in farming region five, where cattle ranching is the common activity. The peasant farmers in this region, for increased income, means of survival and food security, rear cattle and goats, mostly among other livestock (Chitura et al., 2018; Kunaka et al., 2023). Both smallholder farmers and commercial farmers invest in cattle for an income source, meat and milk production, socio-economic status, as well as for barter trade (Chakale et al., 2022; Tshabalala et al., 2015).

Cattle farming is affected by disease outbreaks, especially tick-borne infections such as heartwater, Theileriosis and Boutonneuse fever (Anjarwalla et al., 2016; Chitura et al., 2018; Mkwanazi et al., 2022). Ticks are persistent pests that not only cause failure in animal production but also transmit diseases, both from animal to animal and from animal to humans. Of all the ectoparasites, ticks are the most significant arthropod disease vectors (Wanzala, 2017), causing severe economic losses through increased livestock morbidity and mortality rates. Examples of tick-borne diseases or tick-associated diseases include bovine dermatophilosis, rickettsioses, lyme, hemorrhagic fever and tick-borne encephalitis (Mugambi et al., 2012; Ndhlovu & Masika, 2013; Wanzala, 2017).

In Zimbabwe, the Department of Veterinary Services (DVS) is making tireless efforts to control pests that affect animal production, especially cattle. The journey of tick control by the DVS started long ago and is still going on. Initially, cattle ticks were controlled by dipping (Hlatshwayo & Mbati, 2005), the use of vaccines, biological pest control (use of entomopathogenic fungi), as well as synthetic chemical control methods (Ndhlovu & Masika, 2013; Mawela et al., 2019), where the animals are being sprayed on the affected parts. All these efforts of tick control have shortcomings, such as inaccessibility to poor farmers due to their cost (Chitura et al., 2018; Marume et al.,2017 Beltrão Molento et al., 2020), poor distribution network (in rural areas these pesticides are rarely sold), inappropriate application may lead to pest resistance and chemical residues in meat or milk that can go up in the food chain (biomagnification) causing death and diseases to untargeted pests including humans (Anjarwalla et al., 2016; Kumar & Nattuthurai, 2012; Wellington et al., 2017). Studies also indicated that overuse or continuous exposure to synthetic pesticides causes human health risks such as cancer, defects in the immune system and the development of metabolic diseases such as diabetes, infertility, as well as disruption of the endocrine system (Anjarwalla et al., 2016). These drawbacks are instigating researchers to find safer, efficient, affordable and accessible pesticides that improve cattle production in both rural and commercial farming.

Plant pesticides have been used since time immemorial; our ancestors have been the custodians of this knowledge. Use of plants as efficient acaricides, pesticides or insecticides was developed through long periods of observations as well as trial and error methods (Chakale et al.,2022; Chitura et al., 2018), where different plants were tried against various ailments (Magwede et al., 2014). This intuitive knowledge was passed from generation to generation through word of mouth, observation or apprenticeship (Chitura et al.,2018; Magwede et al., 2014). Without documentation, the knowledge of ethnomedicine can be lost. Furthermore, knowledge on medicinal plants is limited to specific ethnic groups (Chitura et al., 2018); therefore, it is the mandate of this study to document how people in Matabeleland are benefiting from plant acaricides so that other ethnic groups with access to the same plant(s) can benefit.

Plant-based acaricides have been shown to have very good properties over chemical acaricides. For example, studies done by (Adenubi et al., 2018; Anjarwalla et al., 2016; Mkwanazi et al., 2022; Onyango et al., 2018; Quadros et al., 2020; Saravanan, 2022; and Wellington et al., 2017) revealed that they are affordable, easily accessible, biodegradable, eco-friendly, unharmful, and no residues are left in the animal or its product (meat/milk), hence no withdrawal period is required when using plant–based acaricides. Additionally, plants such as *Lippia javanica, Aloe vera, C. quadrangularis, Allium sativum* and *Capsicum annuum* are commonly used traditionally as acaricides or pesticides for both animals and plants, yet their documentation is limited.

C.quadrangularis is an indigenous perennial succulent plant belonging to the Vitaceae family. In the study area, it is commonly known as Veldt grape, *Murunjurunju* or *Intelezi*. All parts of the plant are believed to be medicinal (Hamid & Patil, 2023; Marume et al., 2017; Moto et al., 2018; Onyango et al., 2018), but most acaricidal studies were done on its leaves or stem (Ndlovu & Masika, 2013; Nyahangare, 2015; Wellington et al., 2017). Besides various pharmacological effects identified on *C. quadrangularis*, it is well known for bone, fracture or wound healing in animals (Barbosa et al., 2023; Brahmkshatriya et al., 2015; Camil and Lokesh , 2020; Marume et al., 2017; Samaranayake et al., 2015; Zahan et al., 2022) and for treating diarrhoea in cattle (Barbosa et al., 2023; Bhuvaneswari et al., 2024). Ethnobotanical studies done in Southern Africa, including Zimbabwe, identified C. quadrangularis as a common plant used for tick infections and tick-borne diseases (Magwede et al., 2014; Ndlovu & Masika, 2013; Phaahla et al., 2025), but limited literature is available on its scientific evaluation and validation. This study aimed to evaluate the efficacy of *C. quadrangularis* extract in controlling cattle ticks. Ethnoveterinary practices practised in the study area, especially on tick management, are not documented yet; hence, the thrust of this study. The present study, therefore, was conducted as the first attempt to record and explore the efficacy of C. quadrangularis in managing tick infestations.

Methods and Materials

Plant collection and identification: The stem of *C. quadrangularis* was collected in Gwanda district. The sample was assigned a voucher specimen number, deposited, and positively identified at the National Herbarium and Botanical Garden of Zimbabwe.

Plant preparation: the *C. quadrangularis* stem was then collected, washed to remove dust and any other form of dirt, and chopped into small pieces for easy drying under the shade. The dried parts were then ground in a motor and pestle into fine powder. During trials, fresh stems were crushed and soaked in water for two hours and sprayed or applied to the affected area.

Plant extraction and preparation: Traditional method (infusion) of extraction was used, whereby the plant powder was soaked in water overnight (to allow the active ingredients to dissolve and concentrate) in a closed plastic container. Extracts of different concentrations (1%, 3% and 5%) were prepared. The concentrations were obtained by adding 10g,30g and 50g of plant powder per one litre of water, respectively.

Tick identification: The tick type was identified by the local veterinary officers as *Amblyomma hebraeum,* commonly known as the Bont tick (Fig. 1).

Fig. 1: Example of the type of ticks found infesting cattle in the study area

Ethical Approval: In order to perform animal experiments, ethical approval (MRCZ/A/2986) was obtained from the Medical Research Council of Zimbabwe (MRCZ); hence, the experiment followed the standard protocols approved by the MRCZ. Volunteers for the fingertip assay signed informed consent forms before participation. The researchers explained the risks associated with the study. The participants also confirmed that they have no allergies or skin problems associated with being in contact with *C. quadrangularis* powder, sap or jelly.

Field Experimental design: A purposive sampling technique was conducted to select forty cattle infested with ticks. Randomised controlled trials were conducted where a random number generator was used to assign cattle into groups, namely control and experimental groups. The experimental group (n = 10) was treated with 1%, 3% and 5% Cissus quadrangularis extract, respectively, and the control group (n = 10) was treated with a placebo (distilled water). To differentiate the groups of cattle, the cattle were tagged as ACS1 – ACS10 (experimental group 1%), BCS1 – BCS10 (experimental group 3%), CCS1 – CCS10 (experimental group 5%) and P1 – P10 (control group). The tags' meanings were only known to the chief researchers. The assessment was carried out over a 4 - 8-week baseline, whereby the extract or placebo was sprayed twice a week for 4 weeks and then weekly for the additional 4 weeks. Tick counts were recorded at baseline before the experiment (week 0), 4 weeks, and weekly for the following 5 - 8 weeks. Tick counts were done on the most infested parts, such as the perineal region of the cattle. Research assistants were double-blinded as they counted ticks. They were neither told which group was control or experimental nor the meaning of the tags. They were randomly assigned to a group on every count; no one was meant to be in a specific group. Three people were counting each cattle, and the average number was adopted.

Data analysis: Using SPSS software version 23, tick counts at week 0, 4 and 8 were expressed as standard error of means. Tick counts were recorded before and after spraying of *C. quadrangularis* concentration, under the following: (i) live ticks attaching on cattle (before spraying), then after spraying (ii) dropped live ticks, (iii) dead ticks and (iv) remaining ticks (attaching on the cattle). Comparative analysis of the 4 groups was done using Two-way ANOVA. Paired Samples T-test and one-sample T-test were done to assess the efficiency of the *C. quadrangularis* extract in controlling cattle ticks.

In vitro studies: Bioassays to evaluate the repellent effects of *C. quadrangularis* solution were done following the modified methods recorded by Adenubi et al. (2018). Only the petri dish, tick climbing repellency and fingertip bioassays were done. Before the assays, the ticks were acclimatised for 15 minutes (Luseba et al., 2016). ***Petri dish bioassay***: The filter paper was divided into two. The *C. quadrangularis* solution was uniformly applied on the other half, and a placebo was also uniformly applied on the other half. The filter paper was placed in a petri dish, and the ticks were released at the centre so that they could move around the filter paper. At intervals (5,10,15,20,25,30 mins), tick counts were recorded. After 30 minutes, the percentage repellency was calculated. The assay was done in triplicate.

Tick climbing repellent bioassay: Two sticks (rods) were taken as experimental (treated with *C. quadrangularis* solution) and control (placebo), treated with distilled water. The rods were then put in a glass tube with a filter paper attached at the base of each rod. To maintain the number of ticks that had already climbed up the rods, the glass tube was then plugged with a wet cotton cloth. The repellent effect was proven by the number of ticks that failed to climb up the treated rods versus those that managed to climb up the untreated rod at five-minute intervals for thirty minutes. The assay was repeated 3 times to get the average number of ticks repelled.

Fingertip bioassay: Treated and untreated bands were attached (untreated band below the treated band) on the fingertips of three volunteers. The finger tips were then placed vertically, with the untreated part immersed in a tick-infested area. Ticks that managed to climb up to the treated band were considered not repelled, but those that fell off were considered repelled. The number of ticks from both bands was counted at five-minute intervals for 30minutes. The repellency effect was then calculated.

Data analysis: The mean and standard deviation of each assay were calculated using SPSS software version 23. For bioassays, percentage tick repellency was calculated using the formula:

$$\text{Percentage tick repellency} = \left(\frac{[C-T]}{[C]}\right) \text{X } 100$$

Where: *C is the number of ticks in the control/untreated part*

T is the number of ticks in the experimental/treated part

Average percentage tick repellency for each bioassay was calculated using the following formula:

$$\text{Average tick repellency percentage} = \frac{\sum Pi}{Ni} \text{x}100$$

Where: $\sum Pi$ is the total number of percentage repellency for intervals

Ni is the number of intervals recorded during the experiment

Results

The results indicated that *C. quadrangularis* is very effective in tick control after three trials using different concentrations (1%, 3% and 5%). The study results indicated that more than half of the ticks that were attaching initially dropped at week 4 in all experimental groups, then dismally at week 8, especially in the 5% concentration group. (Table 1). This simply means the *C. quadrangularis* extract enables the ticks to detach from the host, thereby proving the efficacy of *C.quadrangularis* in controlling cattle ticks.

Table 1: Comparative analysis of Tick counts at week 0, 4 & 8

Treatment	**Weeks**					
	Week 0		**Week 4**		**Week 8**	
	Dropped	**Attached**	**Dropped**	**Attached**	**Dropped**	**Attached**
Placebo	0	14±01	1±0.58	13±0.58	1±0.58	13±0.58
CS 1%	0	14±01	7±01	7±01	8±01	6±01
CS 3%	0	14±01	7±1.15	7±1.15	10±0.58	4±0.58
CS 5%	0	14±01	11±0.58	3±0.58	13±0.58	1±0.58

Comparing with the control group, the study also proved that *C. quadrangularis* is very efficient, since the number of dropping ticks at week 8 is far more than the number recorded in the control group (Table 1 and Fig. 2). This was also recorded on the attached ticks, at week 8 only (1±0.58) One tick was seen attaching on the 5% treatment and 13±0.58 were seen attaching to the placebo (control group). The 5% treatment proved to be the best; therefore, its efficacy was evaluated and shown in Fig. 3, and also the concentration was used in repellent bioassay analysis.

The graphical comparative analysis (Fig. 2) of the three levels of *C.quadrangularis* concentrations of 1%, 3% and 5% shows that the three concentration levels exhibit different mean numbers of ticks dropped. At week 4, the placebo group had the least number of ticks dropped, approximately 10%, while the CS1% and CS3% concentrations had an equal number of ticks dropped at approximately 50%, yet the CS5% concentration resulted in the highest number of ticks dropped at approximately 80%.

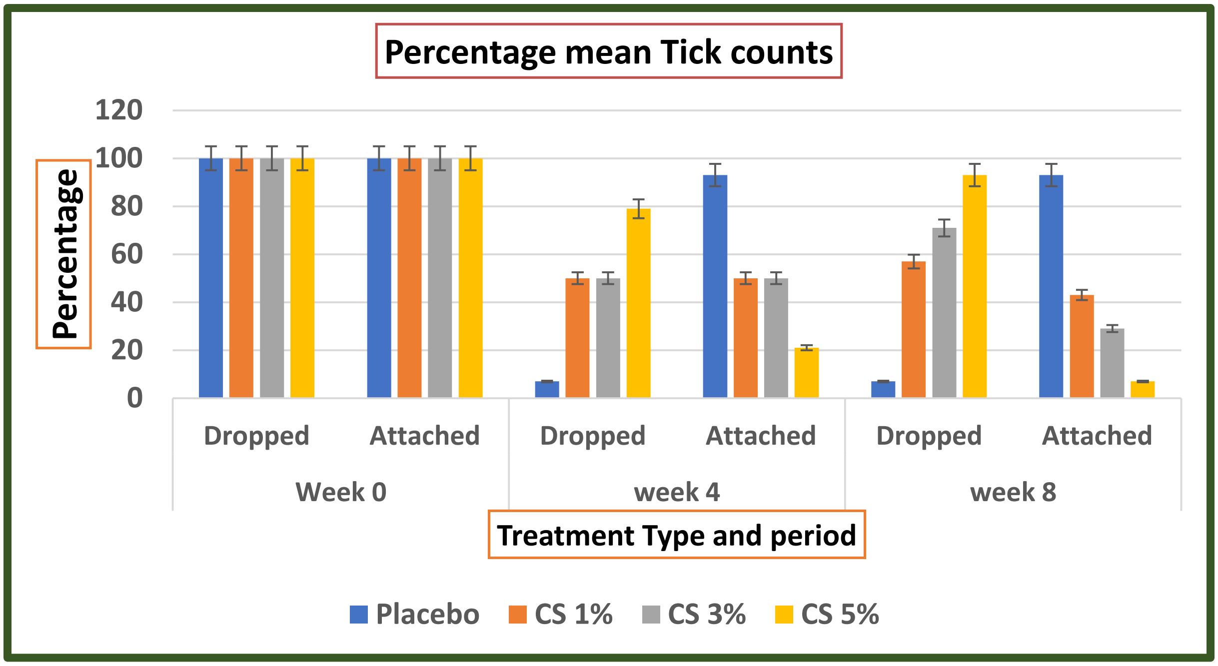

Fig 2: Comparative mean number of ticks by relative status at week 4 and week 8

The number of ticks attached remained high in the placebo group, with approximately 90% ticks still attached at week 4. At week 8, CS1%, CS3%, and CS5% had approximately 50%, 70%, and 90% of the ticks dropped, respectively, while in the placebo group, the same number of ticks had dropped as at week 4, indicating no change in the placebo group. The number of ticks still attached at week 4 indicates a major difference in the effect of these three levels of *C. quadrangularis* concentrations, with CS1% leaving approximately 41% attached, CS3% leaving approximately 30% attached, and CS5% leaving approximately less than 10% of the ticks attached.

Furthermore, the Analysis of Variance (ANOVA) was used to test whether there were differences in the effectiveness of the 3 levels (1%, 3% & 5%) of *C. quadrangularis* concentration in treating ticks on cattle. The null hypothesis assumed equality of the three *C. quadrangularis* concentration levels mean effect, while the study hypothesis assumed that at least two of the three *C. quadrangularis* concentration levels mean effect are not equal. From the ANOVA table, we obtained a high F-value of 3.75, which is greater than the F-Critical value of 3.38. Since our F-statistic value is greater than the F-critical value, 3.75 > 3.38, we reject the null hypothesis and conclude that at least two concentration levels of *C. quadrangularis* have statistically different mean effects on controlling tick infestation on cattle. The P-value of 0.01675 is less than the significance level of 0.05 (P=0.01675 < 0.05), which implies that there are statistically significant differences between the effectiveness of the three concentration levels of *C. quadrangularis* in controlling ticks on cattle. Therefore, we conclude that, at 5% level of significance, the three *C. quadrangularis* concentration levels (1%, 3%, & 5%) have statistically significant differences in their effectiveness in cattle tick control.

Fig. 3 also agrees with Fig. 2 above on the fact that at week 8, there were no ticks (whether dead or live attached to the plant leaf) at 5% concentration treatment. The efficacy of the 5% *quadrangularis* concentration acaricidal solution was also evidenced in bioassay experiments that proved the repellent effect of *C. quadrangularis* (Table 2 and Fig. 4).

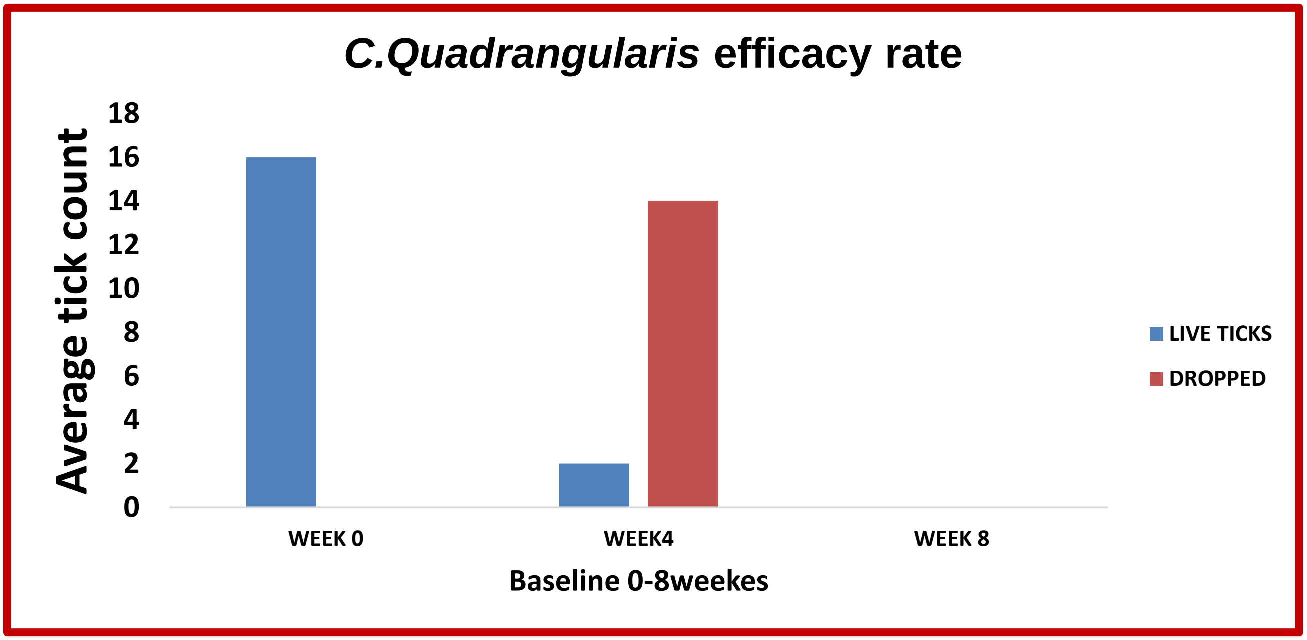

Fig. 3: Overall efficacy rate of *C. quadrangularis* acaricide

The ticks were repelled from the treated solution rather than the untreated/placebo, as shown in Table 2:

Table 2: Percentage Repellent effect of 5% *C. quadrangularis* acaricide

	Total Ticks	climbed	Repelled
Petri dish	100	7±0.58	93±0.58
Tick Climbing	100	3±0.58	97±0.58
Finger Tip	100	7±0.58	93±0.58

The results on bioassays indicate that the average repelled ticks per assay is over 90% (petri dish -93%, tick climbing 97% and fingertip 93%). On the same note, the percentage tick repellency (Fig. 4) was 89% for the Petri dish and Finger Tip assays, and 100% for the Tick climbing repellency assay. These results give enough evidence on the effectiveness of *C. quadrangularis* acaricidal activity since the percentage repellent effect is almost < 89%.

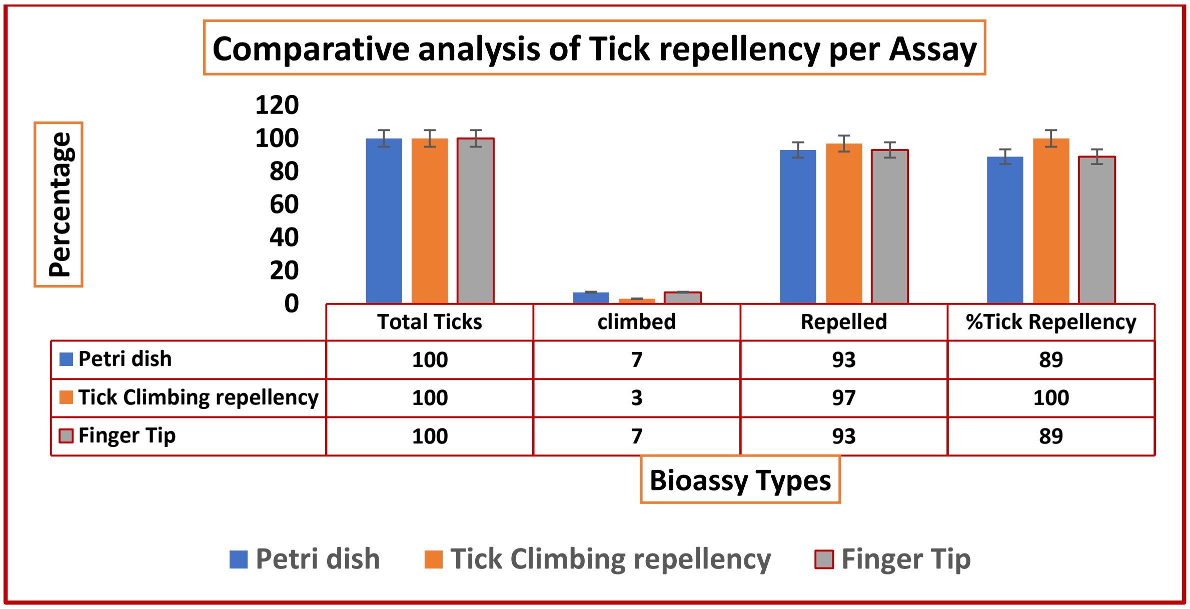

Fig. 4: Comparative analysis of Tick repellency per Assay

Discussion

Use of trials in order to come up with valid results on the use of *C. quadrangularis* was done to validate the efficacy of the plant and to support the results of some studies, such as Magwede et al. (2018), where *C.quadrangularis* was the most mentioned plant for controlling ticks. Also, Fouche et al. (2017) tested thirteen plants, and the study proved that *C. quadrangularis* (1%) was the most effective acaricidal plant among the tested and was less toxic towards both the targeted and other organisms.

Additionally, the use of stem in our experiment proved to be more efficient. Although the whole plant (meaning every part) of *C. quadrangularis* is both medicinal and acaricidal (Onyango et al., 2018), we preferred to use the stem for its flesh and succulent nature. Various studies, such as Chenniappan et al. (2020), Luseba et al. (2016), Nyahangare et al. (2019 and Zaki et al. (2020, used the stem in their experiments, and their results proved that the stem of *C. quadrangularis* possesses both pharmacological and acaricidal properties. Ndhlovu and Masika (2017) also used the *C. quadrangularis* stem in their experiment to control cattle ticks and dermatophilosis in Zhombe, and their results proved that *C. quadrangularis* is efficient, environmentally benign and safe for users (Saravanan, 2022), since no itching or skin irritation complaints were received during the study.

In addition, the results indicated that the use of infusion as a preparation method is effective. One of the trials done during this study was to compare the topical application and spraying of the extracts, and it proved that spraying is more effective than topical application. In contrast to Ndhlovu and Masika (2013), where the stem infusion was rubbed on the affected area, the current study proved that spraying is most effective, though the results produced by both experiments were similar. Extraction by infusion has proved to be easy, cheaper (especially in rural areas) and most effective since it allows bioactive compounds to be completely extracted in water (Magwede et al., 2014; Ndhlovu & Masika, 2017).

The results of bioassays proved that *C. quadrangularis* acaricidal solution is eco-friendly and can deter as well as repel pests (Nyahangare et al., 2019). During the observations, no other creatures were observed dead; thus, controlling ticks using *C. quadrangularis* does not kill other beneficial organisms, but only affects the targeted ones. These results are in support of various studies such as Anjarwalla et al. (2016); Taha & Baioumy Ali (2020), Quadros et al. (2020) and Wellington et al. (2017). This observation on the use of *C. quadrangularis* as an acaricide that is cheap, easy to prepare, efficient, safe and environmentally friendly was also reported by (Anjarwalla et al., 2016; Taha & Baioumy Ali, 2020; Ndhlovu & Masika, 2013; Nyahangare et al., 2019; Quadros et al., 2020).

Furthermore, the results also showed that the *C. quadrangularis* remedy does not kill the pests, but has repellent and deterrent activity (Anjarwalla et al., 2016; Quadros et al., 2020; Taha & Baioumy, 2020). It can be argued that the bioassay done for *C. quadrangularis* acaricide was for thirty minutes, but those recorded in Adenubi et al. (2018) were done for sixty minutes. This can be attributed to the fact that for the petri dish bio assay, there were no ticks in the treated side at 15 minutes, and on tick climbing, no tick was recorded at 20 minutes. Then, on a fingertip bioassay, the repellent effect was seen at ten-minute intervals; hence, 30 minutes was necessary. The *C.*

quadrangularis solution proved to be very effective and safe for use within a short period through the bioassays done. The results of bioassays strongly support the results of field trials, as they also show that *C. quadrangularis* is very effective in repelling pests such as ticks (Fouche et al., 2016**;** Ndhlovu & Masika, 2013; Nyahangare et al., 2019).

Although the study proved the efficacy of *C. quadrangularis* in different aqueous concentrations, further studies are recommended, as these are preliminary results limited to one study area and tick type. Organic solvents should be tested on the efficacy of *C. quadrangularis*, as well as its acaricidal effect on other types of cattle and ticks found in different locations.

Conclusions

C.quadrangularis treatment demonstrated significant acaricidal activity against ticks on cattle, offering a promising natural remedy for tick control that can be used as an alternative to chemical acaricides. It is natural, efficient, easily accessible and very easy to prepare, which makes it a better alternative to the chemical acaricides in the market. Also, by exhibiting tick control agents, the *C. quadrangularis* extract solution can be included in the Integrated Pest Management (IPM) method. Based on this, the following recommendations can be made:

- Documentation of natural remedies of acaricides made from other plants should be promoted so that rural farmers have a choice in tick control
- Further studies are needed to determine and validate the bioactive compounds in *C. quadrangularis* that have potential acaricidal activity.
- Use of plant-based acaricides can be incorporated and used as an alternative to chemical acaricides.
- Conservation of indigenous plants should be prioritised to promote both sustainable Agriculture and livelihoods
- In vitro and in vivo studies on the safety and efficacy of plant-based acaricides such as *C. quadrangularis* for the standardisation of these acaricidal agents.

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Proximate properties, tannin content and functional characteristics of selected pearl millet and finger millet varieties cultivated in Zimbabwe.

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Abstract

Pearl and finger millet grains are important climate-smart crops that are relatively underutilised in Zimbabwe. The objective of this study was to characterise the proximate, functional and tannin content of pearl (Okashana 1, PMV 2 and PMV 3) and finger millet (FMV 1 and FMV 2) varieties cultivated in Zimbabwe. Proximate analysis results were: moisture content 13.10 % (Okashana 1), 12.15 % (PMV 2), 13.43 % (PMV 3), 13.15 % (FMV 1) and 13.55 % (FMV 2); carbohydrate content was 65.57 % (Okashana 1), 69.23 % (PMV 2), 64.53 % (PMV 3), 72.57 % (FMV 1) and 69.91 % (FMV 2); crude protein of 9.81 % (Okashana 1), 7.29 % (PMV 2), 10.92 % (PMV 3), 5.98 % (FMV 1) and 9.14 % (FMV 2); crude fat content was 5.39 % (Okashana 1), 6.10 % (PMV 2), 5.97 % (PMV 3), 1.95 % (FMV 1) and 1.49 % (FMV 2); crude ash content of 2.93 % (Okashana 1), 2.13 % (PMV 2), 1.83 % (PMV 3), 2.95 % (FMV 1) and 2.36 % (FMV 2); and crude fibre content was 3.20% (Okashana 1), 3.10% (PMV 2), 3.30% (PMV 3), 3.40% (FMV 1) and 3.55% (FMV 2). The tannin content (catechin equivalent) of the grain varieties was 0.107 % (Okashana 1), 0.071 % (PMV 2), 0.020 % (PMV 3), 0.200 % (FMV 1) and 0.406 % (FMV 2). The functional properties results were: water absorption capacity 1.32 ml/g (Okashana 1), 1.21 ml/g (PMV 2), 1.26 ml/g (PMV 3), 1.34 ml/g (FMV 1) and 1.29 ml/g (FMV 2); oil absorption capacity 1.16 ml/g (Okashana 1), 1.35 ml/g (PMV 2), 1/17 ml/g (PMV 3), 1.17 ml/g (FMV 1) and 1.44 ml/g (FMV 2); and dispersibility of 73.33% (Okashana 1), 74.66 % (PMV 2), 75.33 % (PMV 3), 79.33 % (FMV 1) and 75.00 % (FMV 2). The millet varieties demonstrated potential to be utilized in developing food products that could help address food and nutritional security and the best varieties are PMV 3 and FMV 2.

Keywords: Food security, proximate composition, functional properties, underutilisation, droughts.

Background

Food security is defined as the state in which every person always has physical, social, and economic means to acquire adequate, safe, and nutritious food that meets their nutritional requirements and food choices for an active and healthy life (Chitondo, Chanda & Phiri, 2024). Food insecurity is largely felt by children, pregnant women, and low-income households (Food and Agriculture Organization [FAO], 2024; World Food Programme [WFP], 2024). Generally, food security has been difficult to achieve in Southern Africa as the agricultural environment is exposed to multifaceted stress such as heat stress, temperature increases and frequent droughts (Mutengwa, Mnkeni & Kondwakwenda, 2023).

In 2023, the effects of the El Nino phenomenon were felt worldwide and in the Southern African region, it was characterized by a temperature rise of 5 °C, subnormal rainfall (WFP, 2024), harvest loss and food insecurity (United Nations Office for the Coordination of Humanitarian Affairs [OCHA], 2024). Southern Africa's agricultural industry is majorly reliant on rainfall for farming thus making it prone to the negative effects of El Nino-induced below-average rainfall (Mutengwa *et al.,* 2023). The effects of the El Nino on harvest losses were forecasted to compromise farmers' livelihoods in year 2024, especially the subsistence farmers, resulting in them failing to cater to their basic needs (OCHA, 2024) and having minimal opportunities to generate income.

Maize is the staple and the most grown rain-fed cereal by smallholder farmers in Zimbabwe (Zimbabwe Vulnerability Assessment Committee [ZimVAC], 2020), as well as in other countries in Southern Africa. It requires at least 600 mm of evenly distributed rainfall to reach full maturity. Insufficient rainfall received during the 2023/2024 farming season has led to a decline in maize yield, thus leading to food insecurity. Therefore, there is an increasing need to promote the cultivation of drought-tolerant and underutilized cereals such as pearl and finger millets in low-rainfall areas.

Pearl millet (*Pennisetum glaucum*) is the third most grown cereal in Zimbabwe after maize and wheat (ZimVAC, 2020). Pearl millet can grow well in areas plagued by high temperatures, drought and high saline soils (Krishnan & Meera, 2018), compared to wheat and maize (Phiri *et al.,* 2019). Finger millet (*Eleusine coracana*) is the least grown millet in Zimbabwe (ZimVAC, 2020). Like pearl millet, finger millet grows well in semi-arid areas without much effect on production yield. Finger millet has been dubbed as one of the most nutritious cereals (Ambati & Sucharitha, 2019).

Pearl millet grains are used to make porridges, flatbreads, couscous, desserts, and alcoholic beverages such as opaque beer, mbeg, merissa, and non-alcoholic beverages namely: boa, mahewu, pombe and marewa in Africa and India (Adebiyi *et al.*, 2018). Previous studies have also shown that finger millets can be incorporated into the production of baked goods such as biscuits, bread and muffins.

Despite the historical and nutritional significance of Zimbabwe's indigenous pearl and finger millet varieties, a critical research gap exists as their proximate composition, functional properties, and tannin levels remain largely uncharacterized and unpublished. This oversight stems from a historical research bias favouring major staples like maize, which has left these climate-smart crops scientifically neglected. Recent agronomic studies explore their genetic yield potential; the fundamental quality traits of the grain itself have been overlooked. Consequently, the food industry lacks the empirical data needed for product development, nutritionists cannot quantify their precise dietary value, and the traditional knowledge held by rural communities remains scientifically unvalidated.

Furthermore, the Zimbabwean government has pushed for cultivation of small grains such as pearl and finger millet in semi-arid areas to curb the effects of erratic rainfall through the Pfumvudza (Zero tillage/Intwasa) initiative. This has the potential to further increase the availability of millet grains in the long term. Hence the study intends to complement the efforts of the Zimbabwean government to help increase food security within climate vulnerable communities.

Therefore, this study seeks to fill this void by systematically characterizing these properties, thereby providing the essential baseline data required to unlock the full nutritional, industrial, and food security potential of Zimbabwe's native millet landraces.

Methods

Raw materials

Four pearl millet varieties (PMV 1, PMV 2, PMV 3 and Okashana 1) and two finger millet varieties (FMV 1 and FMV 2) grown in Zimbabwe were acquired from Matopos ICRISAT. The millet varieties were cleaned, sorted and stored in airtight zip lock bags at 20ºC.

Flour preparation

The pearl and finger millet grains were milled using a laboratory mill (Perten Instruments, Model 3310) and passed through a 180 µm mesh sieve to obtain uniform millet flour. The milled flours were packaged in zip-lock type polyethylene plastic bags and stored at room temperature.

Proximate composition

The moisture content, crude fat, crude protein and crude ash were determined using methods described by the Association of Official Analytical Chemist (AOAC, 2005). Total carbohydrate was calculated using the difference method (100 − % protein + % fat + % ash + % moisture)

Moisture content

The moisture content was determined using a method 925.10 outlined by Association of Official Analytical Chemist (AOAC, 2005). The crucibles were washed, dried for 60 seconds in an oven, cooled in a desiccator for 20 minutes and then weighed (W1). 10 g of the sample was put into the crucibles and then weighed again (W2). The samples were dried in the oven at 105°C for 3 hours, then allowed to cool in a desiccator, reweighed and oven dried again, this was repeated several times until constant weight was noted (W3).

% Moisture content = $(W_2 – W_3) / (W_2 – W_1)$

Where, W_1 = weight of the crucible

W_2 = weight of the crucible + sample before drying

W_3 = weight of the crucible + sample after drying

Crude fat

Crude fat of the samples was extracted following method 920.39 as stipulated by AOAC (2005). A clean filter paper free from any impurities was weighed (W_1). 1 g of the sample was placed on the filter paper, then gently folded and tied, the sample was weighed again (W_2). Crude fat was extracted from the sample using the Soxhlet method. Hexane was poured into a 500 ml round bottom flask until it reached a three-quarter mark. Then the flask was connected onto the Soxhlet extractor with a reflux condenser and placed on an electric mantle heater. The refluxing of the solvent indicated the start of the 6-hour extraction process. The condenser was then detached and disconnected; the fatless sample was collected and oven dried at 105ºC for 2 hours until a constant weight was reached. The weight of the fat (W_3) was calculated as the difference between the weight of the defatted sample before and after drying.

Crude Fat (%) = $(W_2 – W_1) / W \times 100$

Crude protein

Crude protein of the samples was determined using method 975.09 (AOAC, 2005). 0.105 g of the sample, 2 g of potassium sulfate and 0.05 g cupric sulfate were placed in a Kjeldahl flask. 2 ml of concentrated sulfuric acid was then added to each Kjeldahl flask and placed in a digestion unit and heated to prompt the start of digestion. The samples were acid-digested for 45 minutes and the hydrolysate was allowed to cool down before the addition of 10 ml of distilled water to it. 5 ml of boric acid and 20 ml of distilled water were mixed together in a 100 ml Erlenmeyer flask. The flask was connected to a digestion bulb on the condenser of the nitrogen distillation unit and the tip of the condenser was immersed into the Erlenmeyer flask with boric acid solution. Then 10 ml of the sodium hydroxide solution was placed in the distillation unit container and gradually added to the Kjedahl flask until the boric acid solution turned green. The green solution was then titrated against normalized hydrochloric solution until the green color disappeared. A few more drops of hydrochloric acid were added to the sample until it turned light-red salmon in colour. The amount and strength of normalized solution needed to titrate the sample was noted. The nitrogen and protein were calculated using the formulas below:

% Nitrogen= [(ml HCl (N HCl) (14.007) (100)]/ (mg sample weight)

% Crude protein= (% nitrogen) (6.25 correction factor)

Crude fibre

Crude fibre was determined using a method 962.09 outlined by AOAC (2005). 5 g of the sample was transferred into a 1 L conical flask. 100 ml of sulphuric acid (0.255 mol/L) was heated to boiling point and then added into the conical flask containing the sample. The contents were then boiled for 30 minutes, ensuring that the level of the acid was maintained by the addition of distilled water. After 30 minutes, the contents were then filtered through a muslin cloth held in a funnel. The residue was rinsed thoroughly until its washing was no longer acidic to litmus. The residue was then transferred into a conical flask. 100 ml of sodium hydroxide (0.313 mol/L) was then brought to a boil and then added into the conical flask containing the sample. The contents were then boiled for 30 minutes, ensuring that the level of the acid was maintained by the addition of distilled water. After 30 minutes, the contents were filtered through a muslin cloth held in the funnel. The residue was rinsed thoroughly until its washing was no longer alkali. The residue was then introduced into an already dried crucible and ashed at 600°C.

$$\text{Crude fibre\%} = \frac{\text{Final weight of crucible} - \text{initial weight of crucible}}{\text{Weight of sample}} \times 100$$

Crude ash

Method 923.03 outlined by AOAC (2005) was used to determine the crude ash of the samples. Firstly, a crucible was pre heated in the oven at 105 °C for 30 minutes, then cooled in the desiccator for an hour and its weight was noted (W_1). 1 g of the sample was put into the crucible thus giving it a new weight (W_2). The sample was then ashed in a muffle furnace at 55 °C for 3 hours until the sample turned whitish in colour. It was then cooled in a desiccator and its final weight was noted (W_3).

Ash (%) = $(W_2 - W_3) / (W_2 - W_1)$

Where,

W_1 = weight of the crucible

W_2 = weight of the crucible + sample before ashing

W_3 = weight of the crucible + sample after ashing

Carbohydrates

Total carbohydrate was calculated by difference as cited by Reddy, Shivakumara and Aneesha (2019) using the following formula:

Carbohydrates (%) = 100 – (% Moisture + % Ash + % Fat + % Protein + %Fibre)

Tannins

Condensed tannins were determined using the modified Vanillin-HCl in methanol method according to Price, Van Scoyoc and Butler (1978). 0.25 g of the sample was weighed into a 50 ml Erlenmeyer flask, and then 10 ml of 4 % HCI in methanol (v/v) was added and the content shaken for 20 min using Ratek Orbital Incubator. The sample was then centrifuged at 2060 ×g for 20 minutes and then 1 ml of the sample extract was mixed with 5 ml of Vanillin-HCI reagent. Then the absorbance was read at 500 nm using UV/VIS Spectrophotometer (model UV-1100, manufacturer Biobase) after 20 minutes. Sample blanks were prepared using 4% HCl in methanol, and catechin was employed as the reference standard. A standard curve was prepared using catechin at concentrations ranging from 5 to 100 µg/mL in 4% HCl in methanol. The standard equation (regression equation) for the catechin calibration curve used was:

$y=mx + c$

Where:

y: is the absorbance measured at 500 nm.

x: is the catechin concentration in µg/mL.

m: is the slope of the line (representing the sensitivity of the method).

c: is the y-intercept (ideally close to zero after blanking).

Tannin content in samples was expressed as % catechin equivalent using this calibration curve.

Water absorption capacity

The water absorption of the flour samples was determined using a method by Awuchi, Igwe and Echeta (2019), with minor modifications. Firstly, 2 g of the sample was mixed with 10 ml of distilled water for 5 minutes using a magnetic stirrer, and then centrifuged at 3500rpm for 30 minutes. The supernatant was then discarded, and the residue weighed. Water absorption capacity was calculated using the formula below:

Water Absorption Capacity (ml/g) = (Volume of water absorbed / Weight of the sample used)

$$\text{Water Absorption Capacity}\frac{\text{ml}}{\text{g}} = \text{Volume of water}\frac{\text{absorbed}}{\text{Weight}}\text{ofthe sample used}$$

Oil absorption capacity

Oil absorption capacity was determined using the method stipulated by Akume, Ariahu and Acham (2019). Firstly, 10 ml of oil was mixed with 1 g of the flour sample in a beaker and stirred using a magnetic stirrer for 3 minutes. Then the suspension was centrifuged at 3500 rpm for 30 minutes, and the supernatant was measured into a 10 ml granulated cylinder. The equation below was used to calculate oil absorption capacity:

Oil absorption capacity (ml/g) = (Volume of water absorbed / Weight of the sample used) x 100

Dispersibility

Dispersibility of the samples was determined by a method described by Olapade, Babalola and Aworh (2014). Firstly, 10 g of the flour sample was vigorously mixed with distilled water into a 100 ml measuring cylinder and then allowed to stand for 3 hours. The volume of settled particle was recorded and subtracted from 100.

Results and Discussion

Proximate composition

Table 1. Proximate composition of pearl and finger millet varieties grown in Zimbabwe

Parameters (%)	Pearl millet varieties			Finger Millet varieties	
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Moisture	13.10±0.14^{ab}	12.15±0.21^{a}	13.45±0.07^{b}	13.15±0.49^{ab}	13.55±0.07^{b}
Carbohydrates	65.57±0.10^{b}	69.23±0.13^{c}	64.53±0.08^{a}	72.57±0.42^{e}	69.91±0.01^{d}
Crude Protein	9.81±0.01^{d}	7.29±0.01^{b}	10.92±0.02^{e}	5.98±0.03^{a}	9.14±0.02^{c}
Crude Fat	5.39±0.02^{c}	6.10±0.04^{e}	5.97±0.05^{d}	1.95±0.02^{b}	1.49±0.02^{a}
Crude Ash	2.93±0.04^{d}	2.13±0.04^{b}	1.83±0.04^{a}	2.95±0.06^{d}	2.36±0.04^{c}
Crude Fibre	3.20±0.14^{a}	3.10±0.14^{a}	3.30±0.14^{a}	3.40±0.14^{a}	3.55±0.07^{a}

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different (P ≤ 0.05).

Moisture content

Moisture content is a crucial parameter for the storage of grains including millet. Generally, the ideal is to have grains and flour with a lower moisture content as this helps them achieve a longer shelf life. Several authors have recorded the moisture content of pearl millet to be 6.85% (Efe-Ejiofor & Oparaodu, 2019), 11.31 % (Munchi & Dashora, 2024), and 12.05 % (Verma *et al.*, 2025) and 12.2 % (Pawar *et al.* 2020). Shankaramurthy and Somannavar (2019), recorded a moisture level of 12.86 % in finger millet while other authors found it to be 7.30 % (Eke-Ejiofor & Oparaodu, 2019); 9.15 % (Verma *et al.*, 2025) and 12.69 % (Munshi & Dashora, 2024). The differences observed could be due to grain moisture content before milling, milling processes and storage conditions. Grains from humid areas tend to have a high moisture content, while wet milling produces flour with a higher moisture content when compared to dry milling due to the soaking step (Puramshetty *et al.*, 2025) and flours stored in airtight containers tend to be drier than those stored in packages that generate moisture (Jain *et al.* 2024).

Carbohydrates

The carbohydrate content range observed in this study for pearl millet and finger millet varieties is within the ranges reported in literature. PMV 3 had the least carbohydrate content amongst both pearl and finger millet varieties. Shankaramurthy and Somannavar (2019), recorded a carbohydrate content of 66 % in pearl millet which is comparable to Okashana 1. In finger millet, Shankaramurthy *et al.* (2019) found the carbohydrate content to be 71% and it is comparable to FMV1 and FMV2 results found in this study. The carbohydrate content observed in this study reflects the starch packing density within the millet endosperm which occurs at multiple hierarchical levels such as molecular, helical, crystalline, and granular with amylose content critically influencing packing density (Shi *et al.,* 2023). The higher carbohydrate content in FMV 1 suggests densely packed starch granules with A-type crystalline structure typical of cereals (Thieme, 2024), contributing to its high-water absorption capacity as water molecules penetrate amorphous regions within the packed structure. Conversely, pearl millet varieties exhibited lower carbohydrate (64.53–69.23%) but higher fat content, indicating that lipid bodies are interspersed among starch granules, potentially affecting overall granule packing and contributing to their distinct functional properties. The variation in carbohydrate content among varieties likely reflects differences in amylose: amylopectin ratios, with higher amylose content generally associated with more rigid, compact granule structure (Shi *et al.,* 2023). Furthermore, the differences normally observed in different studies involving grains could be due to the genetic and environmental aspects that influence grain composition (Itiat and Grace, 2023). Current breeding initiatives intensively select specific carbohydrates such as high amylose or high fibre types and waxy types, these consequently affect the overall carbohydrate content (Saini *et al.*, 2020). Environmental aspects such as saline soils lead to reduced kernel size and starch content (Mukami *et al.*, 2020).

Crude protein

Overall, crude protein in both pearl and finger millet varieties significantly varied from each other. It corroborates with the findings of multiple researchers such as 10.50 % (Kumari *et al.*, 2022) and 10.57 % (Owheruo, Ifesan & Kolawole, 2019). However, Jandu and Kawatra (2019), reported a different protein range (11.81 to 12.48 %) among three pearl millet cultivars (HC-30, HHB-67 and WHC-901). FMV 2 recorded content comparable to the 9.53 % found in Milky cream finger millet variety (Ramashia *et al.*, 2019). In this current study, brown coloured finger millet varieties were used, and they had a protein content almost similar to the one reported by Ramashia *et al.*, (2019). The protein discrepancies may be linked to genetic, morphological, and agronomic variations (Anitha *et al.*, 2024). Additionally, the different analytical methods adopted by authors for the estimation of parameters could also be a reason for the variance (Anitha *et al.*, 2024).

Crude Fat

In this present research, all the pearl millet varieties had more fat than the finger millet varieties. This supports findings by Rani *et al.* (2018), that pearl millet generally has more fat than any other millet. The fat content in pearl millet was comparable to 6.87 % reported by Munshi and Dashora (2024). Due to its higher fat content than all the other cereal grains, pearl millet products have a low shelf life because of the oxidation of unsaturated fatty acids (Padmaja *et al.*, 2024). The fat content of finger millet in this study was 1.95 % for FMV 1 and 1.49 % for FMV 2. Jayawardana *et al.* (2019), reported a fat content range of 1.40 to 1.41 % in finger millet. Also, in the same grain Hiremath and Geetha (2019) found a fat content of 1.30 to 1.90 %.

Crude ash

The ash content reported in this study for pearl millet was higher than 1.57 % and 1.61 % reported by Eke-Ejiofor and Oparadou (2019) and Munshi and Dashora (2024), respectively. A similar trend was noted in finger millet. Verma *et al.* (2025), reported a lower ash content of 1.96 %. Ash content is generally considered an indicator of a food's mineral content (Eke-Ejiofor and Oparaodu, 2019), hence, pearl and finger millet flour contain significant amounts of minerals as per the findings of this study. A study by Joshi *et al.* (2025) postulated that environmental pressures like high temperatures, high saline soils, high salt levels, and low water accessibility can influence the mineral content variations in food. In addition, Anitha *et al.* (2024) alluded that the variations in pearl millet mineral content are mainly attributed to genotypic diversity.

Crude fibre

The findings of the study are comparable to the crude fibre of 3.87 % found in a South African variety (Hassan *et al.*, 2021). Finger millet generally has a crude fibre content that varies between 2.0 and 3.6 % (Gebre, 2019). The results observed in finger millet under study were in the general range stipulated by Gebre (2019). The variations are linked to genotypic attributes, prevailing climatic factors and soil nutrient quality (Dias-Martins, 2018).

Tannins

Table 2. Tannin content of pearl and finger millet varieties cultivated in Zimbabwe

Tannins

Parameter	Pearl millet varieties			Finger Millet varieties	
	Catechin equivalent (%)				
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Tannin Content	0.107±0.000[c]	0.071±0.000[b]	0.020±0.001[a]	0.200±0.000[d]	0.406±0.000[e]

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different ($P \leq 0.05$).

Tannins are one of the main antinutrients found in finger millet (Gebre, 2019). There were clear differences in tannin content among the millet varieties in this study. FMV 1 and FMV 2 showed higher tannin contents which fall in the general range of 0.04 - 3.74 % as suggested by Gebre, 2019. In comparison, pearl millet had lower values with PMV having the lowest tannin content. The recorded values are also comparable to those reported in a study by Samtiya *et al.* (2021), who reported tannin contents of 3.07-4.35 mg/g (0.307-0.435 %) in pearl millet flours. Other studies have also reported generally low tannin content in millets, which can range widely depending on genotype and grain colour, where coloured varieties have more tannins than the white ones (Aanchal *et al.*, 2024). Additionally, finger millet often exhibits higher condensed tannins compared to pearl millet. This is because of its testa, which has multiple layers such that it binds more phenolics (Ramashia *et al.*, 2025). This aligns with the higher tannin levels observed in the finger millet varieties in this study. In general, tannins form complexes with proteins, inhibiting digestive enzymes and lowering protein digestibility (Sheethal *et al.*, 2022). This alters the nutritional quality of the flours if they are to be are used in complementary or weaning foods.

Despite the absence of processing, the low tannin levels observed in raw pearl millet varieties indicate that these are inherently low-tannin cultivars, which is a good trait for nutritional quality. Tannin content in millets is primarily genetically controlled, with wide variation existing among cultivars, i.e. low tannin varieties exist naturally (Khatri et al., 2023).

However, various processing methods can further reduce tannin concentrations. Dehulling, soaking and roasting as pre-processing techniques reduce tannin content and have been proven to increase the in vitro protein digestion of pearl millet (Samtiya *et al.*, 2021). Also, germination has been reported to reduce tannin levels in both finger and pearl millets as it facilitates leaching and enhanced enzymatic breakdown of polyphenols (Karki *et al.*, 2024). However, tannins that are found in the testa and are not involved directly in germination can become relatively concentrated in pearl millet grains, especially at higher germination temperatures (Sneha *et al.*, 2023). These factors should always be considered when there are product applications that require high protein quality or low antinutrient content.

Functional Properties

Table 3. Functional properties of pearl and finger millet varieties grown in Zimbabwe

Parameters	**Pearl millet varieties**			**Finger millet varieties**	
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Water absorption capacity (ml/g)	1.32±0.05a	1.21±0.10a	1.26±0.07a	1.34±0.07a	1.29±0.08a
Oil absorption capacity (m/gl)	1.16±0.02a	1.35±0.01a	1.17±0.12a	1.17±0.19a	1.44±0.08a
Dispersibility (%)	73.33±0.58a	74.66±1.52a	75.33±1.52a	79.33±0.58b	75.00±2.00a

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different (P ≤ 0.05).

Water absorption capacity

The recorded water absorption capacity (WAC) of the pearl millet varieties under study were similar to 1.13 ml/g reported by Ramashia *et al.* (2019). Furthermore, the WAC of pearl millet flour was established to be between 1.54 and 1.86 ml/g by Pawase *et al.* (2021). The finger millet varieties used in this study had water absorption capacities which collaborated findings reported by Ramashia *et al.* (2019), who studied the WAC of finger millet flours and it varied from 0.93 to 1.23 ml/g. Khatonia and Das (2020), reported a WAC of 1.21 ml/g in finger millet flour.

High values of WAC are often associated with elevated levels of dietary fiber and protein. These enhance water binding through hydrogen bonding and capillary action within the flour (Mukhtar *et al.*, 2025). The relatively high WAC observed in both pearl and finger millet flours in this study can therefore be attributed to their high fiber content and complex proteins. The relatively high fiber content across all varieties provides abundant hydroxyl groups that form hydrogen bonds with water molecules, thereby contributing to water retention in the flour (Cheng *et al.,* 2026). The protein content, particularly in varieties such as PMV 3, contributes to WAC through the hydrophilic amino acid side chains that readily associate with water. The relatively low WAC observed in PMV 2 correlates with its lower protein content as compared to other pearl millet varieties (Flori and Alavi, 2023).

The relatively narrow range of WAC values recorded suggests that overall water-binding capacity of these flours is comparable. This can be as a result of the influence of starch (which constitutes the major fraction of the flours) on water absorption behavior. Starch granules absorb water and swell upon hydration. The degree of swelling is influenced by the amylose-to-amylopectin ratio and the crystalline structure of the granule (Saini *et al.,* 2020). Amylopectin, which is branched, creates open ends that easily bind to water whilst linear amylose packs densely and restricts the penetration of water. The higher WAC in FMV1 suggests amylopectin-dominated starch, while the lower WAC in PMV2 and PMV3 may suggest higher amylose that restricts absorption (Saini *et al.,* 2020).

Also, the fine particle size distribution resulting from milling (180 µm mesh) would have increased the surface area available for hydration, thereby potentially enhancing WAC in all the samples.

Flours such as these, with high water absorption capacity, can be used in food systems where moisture retention, dough consistency and viscosity development are important. Findings of this study therefore indicate that pearl and finger millet flour can successfully be used in the formulation, development and processing of baked products, porridges and composite flours (Culetu *et al.*, 2021).

Oil Absorption Capacity (OAC)

The oil absorption capacity of Okashana 1 was the least but was not significantly different from the other two pearl millet varieties. These findings are in agreement with those reported by Pawase *et al.* (2021), who found the OAC of five pearl millet varieties ranging from 1.23 to 1.57 ml/g. Such similarities suggest that oil-binding behaviour in pearl millet flours is relatively stable across varieties when processed under comparable conditions. The observed OAC of finger millet flours used in this study also align with the findings of Khatoniar and Das (2020).

OAC differences among millet flours can be influenced by grain composition. It is highly influenced by the presence of hydrophobic components in the flour matrices. The non-polar amino acid side chains (e.g., leucine, isoleucine, valine, phenylalanine) of proteins which attract oil molecules enhance the absorption of oil (Arepally *et al.,* 2023). Also, the hydrophobic components of starch and fiber can also entrap oil through physical encapsulation and surface adsorption. Additionally, the amount of fat naturally found in the flour (endogenous fat) may influence its ability to absorb additional oil, as the inherent fats make the flour matrix more hydrophobic (Hasmadi *et al.,* 2020)

FMV 2 showed the highest OAC despite having the lowest fat content among all varieties suggesting that in this case, proteins and the presence of hydrophobic amino acid residues are more dominant in oil binding rather than the endogenous fat. Okashana 1 showed the lowest OAC despite having moderate protein and fat content, indicating that for this variety, protein structure and hydrophobic sites may be more important than absolute protein quantity. The relatively higher OAC observed in PMV 2 correlates with its high fat content. This suggests that the endogenous lipids contribute to its hydrophobic nature. The PMV2 variety also had moderate protein content, which may provide additional oil-binding sites.

The practical importance of OAC is that it influences flavor retention, mouthfeel and palatability. Oil is a carrier of flavor compounds hence flours that have a good oil-binding ability retain aroma compounds during processing and cooking, enhancing the sensory quality of finished products (Hasmadi *et al.*, 2020). The moderate to high OAC values observed across all varieties suggest that they would do well in fried products, meat extenders, bakery items, and formulations where fat incorporation is desired (Ramashia *et al.,* 2019).

Dispersibility

Pearl millet varieties had a dispersibility similar to the findings of a study by Eke-Ejiofor and Oparaodu (2019), who found a dispersibility level of 73 % in pearl millet flour. In finger millet varieties, the dispersibility was higher in FMV 1 compared to FMV 2. Similarly, Bajo *et al.* (2021), found the dispersibility of finger millet flour to be 77. 333%.

Dispersibility is influenced by multiple compositional and physical factors. Factors such as particle size distribution, surface characteristics and flour matrix structure affect how flour particles are dispersed in aqueous systems. Finer particles with uniform size distribution tend to disperse more readily, while irregular or coarse particles are more likely to clump and form lumps (Lin *et al.,* 2019). The surface characteristics of flour particles depends on their surface properties, such as how well they attract water (hydrophilicity) and their electrical charge. These factors affect how they mix with water and their aggregation. In addition, the chemical composition of the flour, particularly the type and structure of its proteins and starch, also affects how the particles behave when water is added (Hasmadi *et al.*, 2020). High protein content can reduce dispersibility as the proteins may promote aggregation through hydrophobic interactions or disulfide bridging (Ramashia *et al.,* 2019). However, starch granules with intact structures tend to settle more rapidly than those with damaged surfaces. The hydrophilic nature of fibre may enhance dispersibility by promoting penetration of water and encouraging separation of particles.

In this study, FMV 1 demonstrated the highest dispersibility while having the lowest protein content. This suggests that the lower protein content may reduce aggregation, allowing particles to remain suspended. The pearl millet varieties (Okashana 1, PMV 2 and PMV 3) with higher protein content showed slightly lower dispersibility. This is consistent with the hypothesis that proteins can promote particle aggregation.

Overall, both pearl and finger millet varieties under study had high dispersibility values and this indicates that the flours will not clump or form lumps during rehydration. These characteristics are advantageous in foods where rapid and uniform dispersion is desired resulting in a smooth and consistent quality. The flours can be applied in the formulation of instant porridges, beverages, soup thickeners and dough systems. A smooth, lump-free consistency is an important quality attribute in complementary foods and instant mixes, where consumer acceptability depends on texture (Ramashia *et al.*, 2019)

Limitations

Tannins were determined using the Vanillin method. This is one of the most common methods used in tannin determination. However, HPLC-based methods that are more specific and sensitive could have been used for the analysis of tannins.

Conclusions

The study successfully established the baseline composition and quality traits of five Zimbabwean millet varieties. The study quantified the nutritional make-up of the grains. Carbohydrates were the highest component, ranging from 64.53% (PMV 3) to 72.57% (FMV 1). Crude protein varied significantly, with PMV 3 having the highest among pearl millets (10.92%) and FMV 1 the lowest overall (5.98%). Crude fat was distinctly higher in pearl millets (ranging from 5.39% to 6.10%) compared to finger millets (1.49% to 1.95%). Crude fibre was relatively consistent, ranging from 3.10% (PMV 2) to 3.55% (FMV 2). The study revealed a clear distinction of the tannin content between the grain types. Finger millet varieties contained significantly higher tannins, with FMV 2 recording the highest at 0.406% catechin equivalent. Pearl millet varieties had lower tannin levels, with PMV 3 having the lowest at just 0.020%. The study determined how the flours would behave during processing. Water Absorption Capacity (WAC) ranged from 1.21 ml/g (PMV 2) to 1.34 ml/g (FMV 1), indicating good moisture retention. While Oil Absorption Capacity (OAC) ranged from 1.16 ml/g (Okashana 1) to 1.44 ml/g (FMV 2), indicating good flavour retention and all varieties showed high dispersibility (>73%), with FMV 1 being the highest at 79.33%, suggesting they will not form lumps when mixed with water. In conclusion, while all varieties demonstrated potential for food product development, PMV 3 emerged as the most nutritionally valuable due to its high protein and low tannin content, making it ideal for complementary foods. Conversely, FMV 2 was distinguished by its high tannin and oil absorption capacity, rendering it suitable for traditional brewing and functional foods where antioxidant properties are desired. The selection of the best variety is therefore contingent upon the specific product application and target consumer needs.

The significance of this study is that it fills a critical research gap by providing the first comprehensive, published dataset on the proximate, functional, and anti-nutritional (tannin) properties of specific pearl (Okashana 1, PMV 2, PMV 3) and finger (FMV 1, FMV 2) millet varieties cultivated in Zimbabwe. Prior to this, despite government initiatives like Pfumvudza promoting small grains, the food industry and nutritionists lacked the empirical data needed to utilize these specific varieties. This study scientifically validates the nutritional potential of these indigenous crops, moving them from being characterized merely as "drought-tolerant" to being recognized as quantifiable "smart-nutri cereals" with specific industrial applications.
Beyond general knowledge about millets, this study provides specific new insights into Zimbabwean varieties. Varietal specificity highlighted that not all millets are the same. For example, within the pearl millets, PMV 3 (10.92% protein) is nutritionally superior in protein content to PMV 2 (7.29% protein). This allows for informed selection based on nutritional goals. Furthermore, the tannin-colour/type link provided specific data confirming that the finger millet varieties (FMV 1 and FMV 2) have significantly higher tannin levels than the pearl millet varieties. This quantifies the trade-off between their known antioxidant potential and the need for processing to improve protein digestibility. The study provides local data confirming that Zimbabwean pearl millet varieties have a fat content significantly higher than local finger millet varieties and even other cereals, which directly impacts their potential shelf-life stability in processed products.

Based on the specific functional and nutritional data, PMV 3 can be used in the production of high protein complementary foods such as infant porridges or weaning blends because it has the highest protein content (10.92%) and the lowest tannin content (0.020%) among the samples, meaning protein digestibility will be higher with less need for extensive pre-processing. FMV 2 has potential to be used in fermented alcoholic beverages such as the traditional opaque beer or functional foods targeting antioxidant benefits because of its high tannin content (0.406%) which is desirable for the characteristic astringency and clarity in traditional brewing. If used for food, the data signals that roasting or malting must be applied as a pre-processing step to reduce tannins. Furthermore, PMV 2 & FMV 2 can be employed in the production of flavour-intensive or fried products like extruded snacks, flatbreads with added fat. These varieties have the highest Oil Absorption Capacity (1.35 and 1.44 ml/g respectively). They can bind and retain fats and oil-soluble flavours effectively, enhancing the palatability and mouthfeel of fried or oil-rich snack foods.

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Modeling Entrepreneurial Competence Areas of Farmers as Predictors of Agricultural Performance.

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Abstract

This paper explores the effect of entrepreneurial competences on Agricultural Performance. It provides a model to address knowledge gaps amid a continued decline in the agro-sector's contribution to Zimbabwe's gross domestic product (GDP). We sampled 384 farmers as the respondents. We analysed the data using Spearman's rank-order correlation to determine the relationship between the variables. The Spearman's rank-order correlation showed that there was a strong, positive correlation ($r_s = 0.946$, $p < 0.05$). On the ANOVA (Analysis of Variance) the polynomial model of action significantly affects agricultural performance, $F(2, 381) = 1542.612$, $p < 0.05$ where $F_{critical} \approx 3.02$. The positive beta weights showed that an increase in entrepreneurial competence also increased farmers' agricultural performance. The study recommends that governments implement an 'agro-entrepreneurial framework' which entails the training of farmers in entrepreneurial competences. This paper fills a knowledge gap due to limited research in entrepreneurial competences and agriculture. This then gives significance to theories and frameworks that underpin this study in asserting that entrepreneurial competences can work in synergy to induce better agricultural performance. The theoretical framework derived from this study is of interest to policymakers to help design an effective entrepreneurial farmer training strategy.

Keywords: entrepreneurial competences, agricultural performance, agricultural training, agro-entrepreneurial framework

Introduction and Overview

Agricultural contribution to the Gross Domestic Product (GDP) continues to be in decline, leaving Zimbabwe in a net food-importing status. The reliance on government input support seems to have stifled innovativeness and creativity by downplaying entrepreneurial competency as a necessity, thus resulting in a skill gap. The reliance on input support with an expectancy of high output is oblivious to other factors that this study seeks to explore and provide a model to fill knowledge gaps in this area. Mutambara (2016) notes that free inputs have not been beneficial, and they created an unhealthy dependency syndrome among farmers. There is a high farm failure rate, poor performance and food security remains elusive. The farm failures exacerbate poverty likelihood which is against the expectations of the United Nations Sustainable Development Goals (SDGs) in particular SDG 1 which emphasises the eradication of poverty. This study intends to contribute to the body of knowledge by modeling entrepreneurial competencies as a strategy to induce better agricultural performance in Zimbabwe and to proffer solutions to the government and other stakeholders on improving agricultural performance. Indeed, economic growth through improved agricultural performance resonates with SDG 8 which focuses on decent work and economic growth. The study population comprised farmers of various capacities and capabilities picked at random from the eight provinces of Zimbabwe, excluding the metropolitan provinces of Bulawayo and Harare.

Zimbabwe is a landlocked country in Southern Africa. It covers an area of over 39 million hectares. Of this hectarage, 33.3 million hectares are used for agricultural activities. Thus, agriculture is the largest industry, comprising 75% of the country’s employment capacity. Maiyaki (2010) noted that for the Zimbabwean economy, there is a need to revive the industry, although such a task hinges on a strong agricultural base so that agro-allied industries can be established.

The World Bank (2019) noted that the agricultural sector accounted for 8.3 per cent of Zimbabwe’s GDP from both subsistence and commercial farmers, from 19.02 per cent in 2008. The value of the GDP share in 2018 for Zimbabwe was 8.3 per cent, against a global average of 10.43 per cent. The maximum ever attained in Zimbabwe was 21.86 per cent in 1967, and the lowest was 6.75 per cent in 1992. (World Bank, 2019). Currently, the sectorial contribution of Agriculture to the GDP has marginally improved to 9.3 per cent (Zimstat, 2025).

To date, there has been an overall decline in the production of food security crops since the pre-land form era. Maiyaki (2010) notes that the decline from 1996 for maize is due to low production by the commercial farming sector and escalation of input costs. Other researchers have attributed low productivity to a variety of factors, such as insecurity of land tenure, financial issues, and climatic conditions, such as drought. (Chavunduka, Dipura & Vudzijena, 2020). This decline in agricultural output is contrary to the SDG 1 expectations which advocate for no poverty targets in a population and SDG 2 calls for the promotion of policies that promote zero hunger. Resettled farmers are still active on the farms, but land productivity is low. Moyo (2024) points out that this downward trend has continued with particular reference to maize production in Zimbabwe.

However, low productivity is not peculiar to Zimbabwe, as Sheahan and Barret (2017) observe that the agricultural industry in Africa is a perennial underperformer and productivity is sluggish with limited uptake of entrepreneurial activities. This view is shared by Sancho (2010), who notes that, in Latin America, the indices for entrepreneurship uptake in agriculture and rural communities are low compared to those in Asia. This is, although entrepreneurship is key to stimulating rural and agricultural development through the exploitation of business opportunities.

Earlier researchers such as DeTienne and Chandler (2004), view the core of agricultural entrepreneurship as a focus on the identification and pursuit of opportunities, emphasizing the creative, alertness, and networking components of entrepreneurial undertaking. Other studies in Kwara State, Nigeria, show that agricultural entrepreneurship is low and significantly influenced by the socioeconomic characteristics of farmers. (Omotesho, Adesiji, Akanbi, Awoyemi and Ekwemuka, 2019). In concurrence, Ndlovu, Krüger and Meyer (2023) point out that women agricultural entrepreneurs are beset with challenges that impact on their productivity contributing to underachievement. The challenges include low entrepreneurial aptitude, capital constraints and gender discrimination. However, they contend that there is a need for capacity building through training and upskilling.

Thus, Deekor (2019) advocates for policies that include the training of current and prospective farmers in agricultural entrepreneurship. This advocacy hinges on the cognitive approach based on empirical research, which shows a positive relationship between farm performance and entrepreneurial competences and skills. Deekor (2019), citing De Wolf and Schoorlemmer (2008), noted that production skills are a basic requirement for success in the farming business. SDG 4 emphasises quality education and this study acknowledges the impact of training or educating farmers in entrepreneurial competences so as to improve agricultural performance. There is an emphasis on farmers becoming businesspeople because of various input combinations and the growing complexity of farming as a business. The presence of entrepreneurial competence areas in agriculture is a precursor to the development of a sustainable rural economy. (Esiobu, Onubuogu, and Ibe, 2015). Thus, the influence of entrepreneurial competences in agriculture has the capacity to achieve SDG 11 through capacitating sustainable cities and communities driven by the economic gains from improved agricultural performance.

Objectives of the Study

1. To determine the effect of Ideas and Opportunities Competences areas on Agricultural Performance.
2. To assess the effect of Resources Competences areas on Agricultural Performance.
3. To ascertain the effect of Into Action Competences areas on Agricultural Performance.
4. To ascertain the impact of the combined effect of entrepreneurial competence areas on Agricultural Performance.
5. To establish whether there is any direct or indirect effect of entrepreneurial competence areas on Agricultural Performance.

Theoretical Framework

The research leans on various theories that explicate the role of entrepreneurship as a basis for business performance. The theories illuminate the role of entrepreneurial competence areas through their attendant constructs as catalysts for improved agricultural performance. The ideas and opportunities competence areas relate to the recognition and seizing of opportunities through the adoption of innovation to foster a competitive edge. This resonates with Schumpeter's Innovation Theory (Sledzik, 2015) which postulates that an entrepreneur seizes an opportunity through innovativeness towards economic development. Innovation is also part of SDG 9 on the cluster of industry, innovation and infrastructure. Thus, this theory is a pillar of the understanding of ideas and opportunities competence areas.

Resource competence areas have specific indicators such as steadfast focus and problem-solving. The Self-efficacy theory, whose proponent is Albert Bandura (1977) gives an understanding on how an entrepreneur's inherent competences and capabilities influence improved performance on confronting situations (Waddington, 2023). The theory resonates with the resource competence areas in that it explicates how the innate abilities have operational value through influencing a cause-and-effect reflection of the confidence needed to focus on achieving a desired outcome. Due to the broad spectrum of resource competence areas, the mobilisation, management and human resources constructs resonate with the Scientific Management Theory whose proponent is Frederick Winslow Taylor. (Mahmood et al, 2012). This theory extrapolates the role of specialisation of tasks in pursuit of improved performance.

Into Action competence areas have underlying competences such as networking and teamwork. The synergic relationship can be explained through the O-Ring Theory postulated by Michael Kremer (1993) though later developed by Oliver Fabel (2004). The theory has an integral value in action competence areas in that it reinforces teamwork impact as it shows that if one individual in the production process falters, the entire production may fail. Thus, this theory underscores the role of the other constructs such as communication, negotiation, teamwork and networking in business performance.

Conceptual Framework

In this study, THREE independent variables were identified as follows;

1. Ideas and Opportunities Competences Areas,
2. Resources Competences Areas and
3. Into Action Competences Areas.

Agricultural Performance is the dependent variable.

Conceptual Model

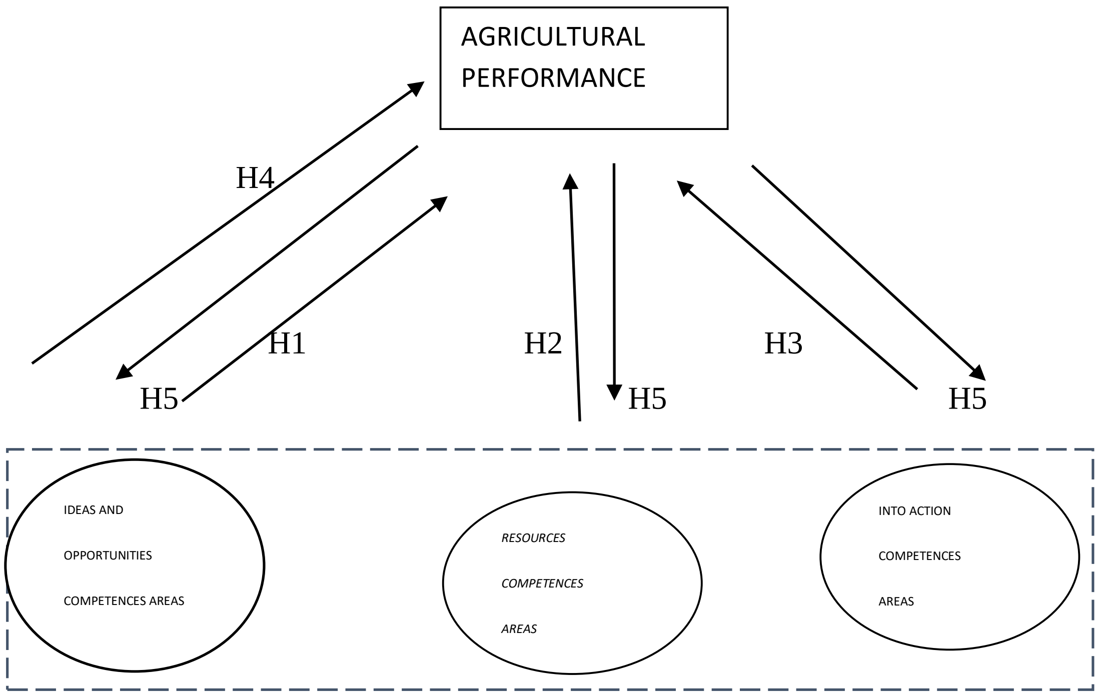

Figure 1 The conceptual model of the study

Source : Author (2023)

The following are the hypotheses derived from the conceptual framework as depicted in Figure 1.

H1 There is a significant effect of Ideas and Opportunities Competences Area on Agricultural Performance.

H2 There is a significant effect of Resources Competences Area on Agricultural Performance.

H3 There is a significant effect of Into Action Competences Area on Agricultural Performance.

H4 There is a significant impact of the combined effect of entrepreneurial competence areas on Agricultural Performance.

H5 There is a direct or indirect effect of entrepreneurial competence areas on Agricultural Performance.

Research Methodology

This study employed a positivist philosophy with an emphasis on knowledge, favourable sensory indications rather than negatives (Alakwe, 2017). In positivism reality is observable and measurable. Causal explanations and predictions are more critical as reality can be true, false or meaningless. This philosophical approach encompasses prediction, estimation and forecasting as the core objectives. The particular research findings or the contribution to the body of knowledge from positivism philosophy can be validated through empirical evidence that shows the cause-and-effect relationship of the entrepreneurial competence areas and agricultural performance.

Setting

The population for this study consisted of small-scale farmers and medium- and large-scale farmers numbering 1,580,000 (Kuhudzayi, 2018) scattered throughout the eight non-metropolitan provinces of Zimbabwe. A true value of 1,500,000 was deemed acceptable at 95% confidence. The study adopted stratified random sampling with a sample size of 384 farmers. Data were collected using, questionnaires with structured questions on a Likert scale. The research instrument was pretested in a pilot study in Matebeleland North Province, involving 48 respondents. The data collection was carried out in the years 2022 to 2023.

This study employed questionnaires as the main instrument to obtain data. The study employed survey research in which numeric descriptions of responses were captured for analysis. This study used a descriptive, exploratory, and explanatory cross-sectional survey. (Asenahabi, 2019). The data were analysed using quantitative methods employing descriptive statistics, inferential statistics, Spearman Correlation Coefficient, Shapiro-Wilk test, Kruskal-Wallis H-test, and regression analysis.

Sample Size Determination

The Slovin formula (Pagoso, Garcia and Guerrero de Leon, 1992) also known as Yamane's formula (1967) was used to determine the sample size and Cochrane (1977) work was used to determine the minimum required sample size.

It is given by

$$n = \frac{N}{1+Ne^2}$$

Where n =sample size

N= Total Population (1,500,000 farmers)

And e=0.05 (margin of error)

Thus n= 1,5000/1+(1,500,000) *0.05²

This translates to n= 1,500,000/3,751

=399.89 thus the sample size is 399

For the minimum required sample size, it was determined using Cochran (1977) formula (Mweshi and Sakyi, 2020)

Whereby $n_o = \frac{z^2pq}{e^2}$

Whereas n_o = sample size

z = critical value of desired confidence

p = estimated proportion of an attribute that is present in the population

q = 1-p

e = desired level of precision

thus, for this research $n_o = (1.96)^2(0.5)(0.5)/(0.05)^2$

= 384.16

= 384

Ethical Considerations

Verbal Informed Consent

Respondents gave information truthfully with full consent and were not under any form of duress. For this study, the researcher explained that the research was for both academic and practical purposes so as to increase the scope of knowledge and assured the respondents that there was no risk whatsoever in partaking. Verbal consent was preferred during the administration of the questionnaire and respondents were advised of the research aims and given an assurance of the maintenance of anonymity. Written consent was not sought for. The respondents gave a verbal informed consent facilitated at the introductory segment of the questionnaire. Thus, a prospective respondent could decline to give consent and therefore not participate in the questionnaire responses.

This approach was chosen due to logistical challenges associated with written consent in rural Zimbabwean farming communities, where literacy levels and access to printing facilities are variable. Verbal consent was ethically justified as the study posed minimal risk, and participants were explicitly informed of their right to withdraw at any stage. Consent was recorded by researchers via annotated checkboxes on the questionnaire, confirming participation approval.

Ethics Approval and Consent to Participate

When conducting this study, the authors observed the following ethical tenets such as anonymity, beneficence, deception, informed consent and plagiarism. These ethical tenets are consistent with the expectations of the Graduate Studies Directorate at Chinhoyi University of Technology who granted approval for this study. Sawicka-Gutaj, Gruszczyński, Guzik, Mostowska and Walkowiak (2022) attest that these expectations or standards are consistent with the principles outlined in the 1964 Helsinki Declaration and all its attendant amendments on ethical tenets involving human subjects. In this study the research instrument was designed in such a manner that there was no provision for the name and contact details of the respondents. In this study the respondents were advised that the research and information gleaned from the instrument will fill a knowledge gap and ultimately benefit the agriculture industry. The authors avoided extolling the benefits of the research on individual level and adopted a holistic approach. In this study the purpose of the research was fully communicated to the respondents and the enquiry was above board with no hidden or misrepresented inclinations. The authors acknowledged all information obtained from other works and shunned plagiarism so as to safeguard the integrity of this study.

Consent for Publication

All the Authors are willing for the publication of this manuscript.

Statement of Approval of The Manuscript

All the Authors attest their approval for this manuscript.

Results and Discussion

Testing of Research Hypothesis 1

H1 There is a significant effect of Ideas and Opportunities Competences on Agricultural Performance.

Table 1: Correlations for ideas and opportunities competences and agricultural performance

			idea_ave	profitability_ave
Spearman's rho	idea_ave	Correlation Coefficient	1.000	.946**
		Sig. (2-tailed)	.	.000
		N	384	384
	profitability_ave	Correlation Coefficient	.946**	1.000
		Sig. (2-tailed)	.000	.
		N	384	384

**. Correlation is significant at the 0.01 level (2-tailed).

Source : Author (2023)

As depicted on Table 1, a Spearman's rank order correlation was run to determine the relationship between idea and opportunity competencies and farmers' agricultural performance, represented by profitability. There was a strong positive correlation between the ability to have idea competency areas and profitability (r_s = 0.946, p =*0.000*<0.05). This means that those with higher idea and opportunity competencies are more likely to come up with innovative ideas that can lead to new products and services, thereby leading to improved agricultural performance.

Studies conducted in Africa by Adeyeye et al. (2019) show a strong positive correlation between opportunity-driven intention and business growth. There was a significant and positive correlation between opportunity-driven entrepreneurship at 0.434, significant at $p<0.01$, and necessity-driven motive at 0.247 at $p<0.05$. These findings are consistent with those of the present study.
This empirical evidence shows a strong confirmation of the findings on testing this hypothesis.

Testing of Research Hypothesis 2

H2 There is a significant effect of Resources Competences on Agricultural Performance.

Table 2: Correlations for Resources Competences and Agricultural Performance

			resources_ave	profitability_ave
Spearman's rho	resources_ave	Correlation Coefficient	1.000	.947**
		Sig. (2-tailed)	.	.000
		N	384	384
	profitability_ave	Correlation Coefficient	.947**	1.000
		Sig. (2-tailed)	.000	.
		N	384	384

**. Correlation is significant at the 0.01 level (2-tailed).

Source : Author (2023)

As alluded to in Table 2, a Spearman's rank order correlation was used to determine the relationship between resource competences and agricultural performance, represented by a proxy of profitability. There was a strong positive correlation between the ability to possess resource competences and profitability ($r_s = 0.947$, $p<0.05$). Thus, those with higher resource competencies are more likely to exhibit improved agricultural performance. These results confirm earlier findings on the self-efficacy indicator of resource competences by Maluda and Alias (2022), who showed that it had a positive impact on entrepreneurship. This study showed that self-efficacy could be further enhanced through training. Msuga et al. (2008) showed that well-organized smallholder farmers with management skills have a higher likelihood of increasing production and productivity. In their view, well-organized smallholder farmers have adequate knowledge and understanding of productivity variation. These farmers exhibit farm-specific variables, such as education, access to finance and extension services, and tenancy.

In support of these findings, Hidayah et al. (2013) further asserted that management aptitude and competencies can improve productivity by examining technical efficiency in Indonesia. These results concur with the findings of Mujuru (2014) on studies conducted in Dotito, Mashonaland Central (Zimbabwe), which showed that farmers who exhibited indicators of resource competences and aptitudes, such as management skills, operated their agricultural businesses successfully.

This empirical evidence shows a strong confirmation of the findings on testing this hypothesis.

Testing of Research Hypothesis 3

H3 There is a significant effect of Into Action Competences on Agricultural Performance.

Table 3: Correlations for Into Action Competences and Agricultural Performance

			action_ave	profitability_ave
Spearman's rho	action_ave	Correlation Coefficient	1.000	.954**
		Sig. (2-tailed)	.	.000
		N	384	384
	profitability_ave	Correlation Coefficient	.954**	1.000
		Sig. (2-tailed)	.000	.
		N	384	384

**. Correlation is significant at the 0.01 level (2-tailed).

Source : Author (2023)

As shown in Table 3, a Spearman's rank order correlation was run to determine the relationship between Into-Action competences and agricultural performance, represented by the proxy of profitability. There was a strong positive correlation between the ability to possess resource competences and profitability (r_s = 0.954, p <0.05). This means that those with higher Into-Action competences are more likely to exhibit improved agricultural performance. In conformity with these findings, studies by Eschker et al (2017) on rural enterprises in Hispanic countries, showed that those with networking support and marketing exhibited successful business performance.

Sandada et al. (2014) examined strategic planning as an indicator of action competences. Their study showed in the regression results that strategic planning factors had an adjusted R^2 value of 0.47, which implies that the strategic planning factors explained 47 percent of the variance in the business performance of SMEs. The beta coefficients show that strategic planning significantly contributes to business performance. (β =0.27, p<0.05). Karel et al. (2013) showed that the existence of a detailed written strategic plan had a significant positive effect on selected business performance indicators, and this result was confirmed by 80 percent of the studied performance parameters.

This empirical evidence shows a strong confirmation of the findings on testing this hypothesis.

Testing of the Research Hypothesis 4

H4 There is a significant impact of the combined effect of entrepreneurial competence areas on Agricultural Performance.

Table 4: Model Summary[b]

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.943[a]	.890	.890	.51534	.890	1542.612	2	381	.000	1.714

a. Predictors: (Constant), action_nw_2, action_nw

b. Dependent Variable: profitability_ave

Source : Author (2023)

As expressed in Table 4, the summary table provides the R (0.943) and adjusted R-squared (0.890). Thus, this model is predicting 89 per cent of the variance in performance represented by profitability. The Durbin-Watson value of 1.714 shows a positive autocorrelation in the residuals, meaning that the model does not fit well.

Table 5: ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	819.344	2	409.672	1542.612	.000[b]
	Residual	101.182	381	.266		
	Total	920.527	383			

a. Dependent Variable: profitability_ave

b. Predictors: (Constant), action_nw_2, action_nw

Source : Author (2023)

As can be seen from Table 5 depicting the ANOVA table, the polynomial model of action significantly predicts high agricultural performance, F (2, 381) = 1542.612, *p* <0.05.

Table 6: Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	3.444	.043		79.507	.000		
action_nw	1.100	.026	1.048	41.594	.000	.454	2.201
action_nw_2	.094	.016	.149	5.907	.000	.454	2.201

a. Dependent Variable: profitability_ave

Source: Author (2023)

Thus the resultant Regression Equation will be:

Y=β0 + β1X1 + β2X2

Substituting:

Agricultural Performance=3.444 +1.100action_nw + 0.094action_nw_2

Multiple regression was conducted to determine the best linear combination of idea and opportunity competencies, resources, and action capabilities of the farmers for predicting the profitability of the farms. The models show high multicollinearity for the independent variables; hence, they were dropped. After investigating the possibility of a polynomial model, it was shown that the higher-dimensional values of action fit the data. The combination of variables significantly predicted profitability, $F(2, 381) = 1542.612$, $p < 0.05$, with both variables significantly contributing to the prediction.

From standard F-Tables:

$F_{critical}(2,381) \approx 3.02$

At $\alpha = 0.01$, it would be approximately:

$F_{critical}(2,381) \approx 4.66$

Therefore since $1542.612 > 3.02$ the model is statistically significant.

The positive beta weights in Table 6, show that an increase in in-action competencies also increases the profitability of farmers. The model achieved an adjusted R-squared value of 0.89 as shown in Table 4, indicating that the model explains 89 per cent of the variance in agricultural performance. In support of these results, other research by Abaho et al. (2016) shows that entrepreneurial competence and agricultural performance are positively and significantly related. ($r=0.460$ at 0.01 level, 2 tailed, $p < 0.01$). They assert that the findings imply that when a business owner exhibits entrepreneurial competence, the business is likely to attain a higher sales volume. The results of the regression analysis showed that entrepreneurial competence has the capacity to predict 30.4per cent of the variance in business performance. (Adjusted $r^2=0.304$). The implication is that a change in entrepreneurial competence causes a 30.4per cent change in business performance, which may be represented by sales and profits *ceteris paribus.*

The results of this study are further supported by Kamuri (2023), who found that the independent variable (entrepreneurial competence) and the dependent variable (business performance) exhibited a linear relationship, and the p-values were greater than the level of significance of 0.05. Entrepreneurial competence was regressed on business performance, and the results were interpreted using R^2 values and p -values at $p<0.05$. The coefficient of 0.539 implied that a unit increase in entrepreneurial competences increased performance by 0.539 units, suggesting that there is a positive and significant relationship between entrepreneurial competence and performance. The multiple regression analysis showed that an R^2 value of 0.637 implies that entrepreneurial competences explain 63.7per cent of business performance.

Testing of Research Hypothesis 5

H5 There is a direct or indirect effect of entrepreneurial competence areas on Agricultural Performance.

Table 7: Root Mean Square Error of Approximation

Item	**Result**
Chi-Square	647.553
Df	167
P value	0.00
RMSEA	0.087
RMSEA CI	(0.08, 0.094)
RMSEA p value	0.00
CFI	1
SRMR	0.024

Source: Author (2023)

The diagonally weighted least squares (DWLS) estimator as depicted in Table 7, was used for the analysis. Nonlinear minimization with bounded constraints (NLMINB) method was used for optimization. The model used in the analysis had 103 parameters, on a total of 384 observations. The chi-square statistic was significant $\chi^2 = 647.553,\ \mathrm{df} = 167,\ \mathrm{p} <$

0.001 and this is expected given the sensitivity of χ^2 to sample size. The Satorra-Bentler scaled chi-square for the model $\chi^2/(\text{df})$ =647.553/167=3.88, which was statistically significant at the p-value scaled = 0.00 <0.05. This means that there is a difference between the model-implied and the actual covariance matrices. At 3.88, the model demonstrates an acceptable but not excellent fit. Since the Root Mean Square Error of Approximation (RMSEA) is less than 0.1, but above 0.05, it is concluded that the model is an acceptable fit, judging from the RMSEA estimate of 0.084 and the 90 percent CI [0.08, 0.094]. However, a p-value less than 0.05 does not significantly support this claim of close fit. A Comparative Fit Index (CFI) value of 1 and a Standardized Root Mean Square Residual (SRMR) of 0.024 threshold values provided evidence that the model was adequate and fitted the data reasonably well.

Table 8: Standardised Coefficients (Factor Loadings)

LV	Item	Coefficient	Lower CI	Upper CI	SE	Z	p-value
Ideas	ido7	0.999701	0.998757	1.000645	5.82E-04	2075.636	0
Ideas	ido8	0.997002	0.995863	0.99814	5.81E-04	1716.471	0
Ideas	ido9	0.998532	0.99747	0.999595	5.42E-04	1842.302	0
Ideas	ido10	0.998717	0.998021	0.999412	3.55E-04	2815.523	0
Ideas	ido11	1.000865	0.999969	1.001761	5.57E-04	2189.619	0
Resources	resoc12	1.009361	1.005532	1.01319	0.001954	516.6484	0
Resources	resoc13	0.981459	0.974692	0.988227	0.003453	285.2331	0
Resources	resoc14	0.997074	0.995347	0.9988	8.81E-04	1132.005	0
Resources	resoc15	0.993605	0.99146	0.99575	0.001094	907.9589	0
Action	into_ac16	0.999334	0.998312	1.000356	5.22E-04	1916.115	0
Action	into_ac17	1.000549	0.999289	1.00181	6.43E-04	1555.661	0
Action	into_ac18	0.998151	0.997136	0.999166	5.18E-04	1927.961	0
Action	into_ac19	0.997495	0.996071	0.998919	7.26E-04	1373.111	0
Action	into_ac20	0.992099	0.989193	0.995005	0.001483	669.0964	0
Profitability	profi26	0.999076	0.998548	0.999605	2.70E-04	3703.988	0
Profitability	profi27	0.999168	0.998659	0.999676	2.59E-04	3850.791	0
Profitability	profi28	0.999057	0.998523	0.999592	2.73E-04	3662.096	0
Profitability	profi29	0.999276	0.998847	0.999705	2.19E-04	4565.916	0
Profitability	profi30	0.99893	0.998375	0.999486	2.83E-04	3525.595	0
Profitability	profi31	0.999187	0.998608	0.999767	2.96E-04	3381.115	0
Profitability	ideas	0.994265	0.992161	0.99637	0.001074	925.9779	0
Profitability	Resources	0.992105	0.98924	0.99497	0.001462	678.7883	0
Profitability	Action	0.99261	0.990263	0.994956	0.001197	829.1457	0

Source: Author (2023)

Table 8 shows the standardized coefficients (factor loadings) for the items on the latent variables (LV). The factor loadings ranges from 0.98 to 1, suggesting that the level of relationship was significantly adequate. These standardized factor loadings are robust values, meaning that they are insensitive to non-normality problems.

The Structural Equation Model for The Study (SEM*)*

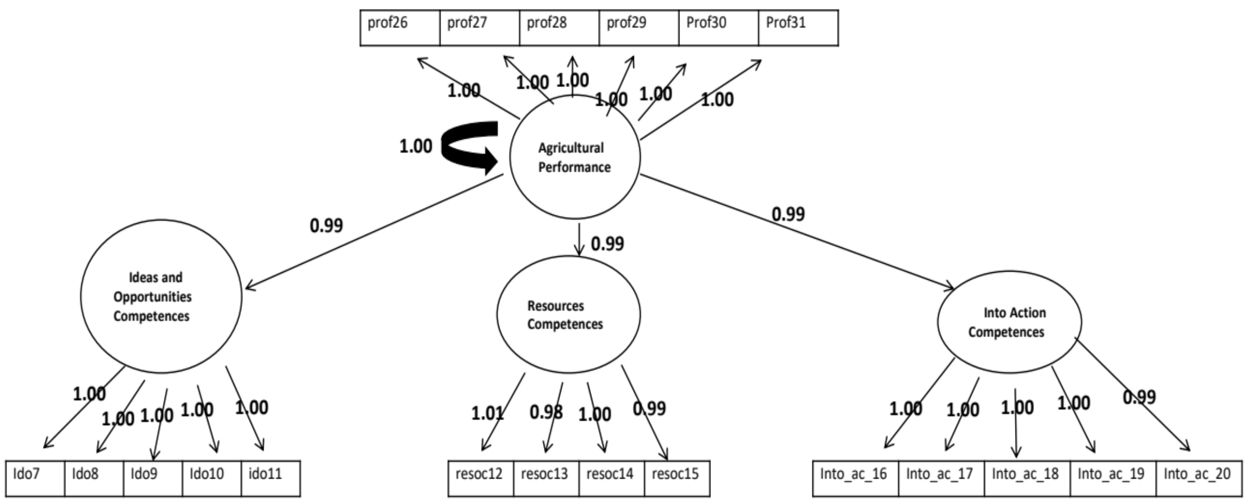

Figure 2 : The Structural Equation Model (SEM)

Source: Author (2023)

The structural equation modeling is able to determine relationships and to suggest a general fit between the observed data and the research model. The fit indices for the structural model were satisfactory. The factor loadings range from 0.98-1 as shown on Figure 2 suggesting that the level of relationship was significantly adequate. This implies that a unit increase in each variable results in a matching increase in the predictive capability of entrepreneurial competences to improve agricultural performance.

Conclusion And Recommendations

The Effect of Ideas and Opportunities Competence Area on Agricultural Performance.

The authors conclude that from the results, farmers who had a high exhibition or possession of idea and opportunity competencies had a higher agricultural performance score. The authors conclude that these farmers are likely to use their imaginations, identify opportunities, develop creative ideas, work towards a vision, and make the most of the opportunities, thereby improving their agricultural performance.

The authors therefore proffer that the farmers must be able to seize opportunities and create value by utilizing the existing landscape. They should identify their needs and have the ability to mitigate challenges. They should be innovative and creative in their approach to farming, and have the ability to combine knowledge and innovation to achieve satisfactory agricultural performance. They need to be visionary by being able to see into the future (imagination) and transform that vision into ideas, assess its potential, and gravitate towards maximization of the idea. Farmers must embrace ethical approaches and be disciplined to adopt responsible practices.

The conclusion is corroborated and confirmed by empirical evidence from other studies that show that there is a significant effect of ideas and opportunities competences and their sub-competences or specific indicators on business performance. (Adeyeye et al., 2019; Alvarez & Busenitz, 2001; Fong et al., 2018; Mujanah et al., 2021; Munizu & Hamid, 2018; Ng'aru, 2019; Syam et al., 2020; Ramli et al., 2019 & Van Stel et al., 2021).

The Effect of Resources Competences Area on Agricultural Performance.

The authors conclude that from the results, farmers who exhibit high resource competencies scored higher on agricultural performance because of core competencies in this cluster, such as belief in themselves against all odds, a high level of focus, the ability to manage limited resources, capacity for financial knowledge, and the ability to foster inspiration in the team.

The authors proffer that farmers should practice self-belief and continuous improvement by evaluating their strengths and weaknesses. They should stay focused, patient, and resilient against adversity and challenges. Farmers must make the scarce resources and continue to acquire skills that they are deficient in so as to manage their competences. The authors conclude that farmers need to acquire financial skills to improve their capacity to measure and assess the cost of financial decisions. Farmers need to be able to 'sell' their ideas to external stakeholders in order to obtain resources support. To achieve this, they must develop communication and negotiation skills to entice and inspire stakeholders to grant support.

The conclusion is corroborated and confirmed by empirical evidence from other studies that show a significant effect of resource competences and their sub competences or specific indicators on business performance. (Fauzi et al, 2018; Fonger, 2017; Hidaya et al, 2013; Machmud & Sidharta, 2016; Maluda & Alias, 2022; Mamum & Ali Fazali, 2018; Msuga et al., 2008; Mujuru, 2014; Ng'aru, 2019; Riana, 2015; Tindika, 2019; Ul Haq & Iqbal, 2022); Usama & Yusoff, 2019).

The Effect of Into Action Competences Area on Agricultural Performance.

The authors conclude that from the results, farmers who exhibited a higher score on action competencies showed improved farm performance. This is due to inherent competencies in this cluster, such as the drive to take on initiatives, organizational skills, teamwork, and continuous improvement due to learning from past experiences.

Farmers must be self-starters and goal-getters by initiating projects independently. There is a need for sound planning with set goals and objectives, so that they remain focused. The said plans and objectives must be adapted to a changing environment while maintaining the goal. Farmers should be decisive in their activities and have structures or support staff to reduce the risk of being overwhelmed or failing. Teamwork must be emphasized as a necessity, and cooperation with fellow farmers will lead to shared ideas, innovations, and strategies that will improve agricultural performance. Farmers should not shy away from learning from their own experience or failures of themselves or others, as there is a huge scope for value creation through learning.

The results are corroborated and confirmed by empirical evidence from other studies that show a significant effect of action competences and their subcompetences or specific indicators on business performance. ((Amoako & Boateng, 2022; Bergevoet et al., 2004; Eschker et al., 2017; Nasir & Chellakan, 2020; Karel et al., 2013; Ansar, 2028; Sandada et al., 2014; Staniewski, 2016; Vaskova, 2007)

The Impact of The Combined Effect of Entrepreneurial Competence Areas on Agricultural Performance.

The authors conclude that from the results, the three classes of entrepreneurial competence significantly predicted improved agricultural performance. This means that a combination of all entrepreneurial competences working in synergy, intersection, and overlap at some points would contribute to an improvement in agricultural performance.

The conclusion is corroborated and confirmed by empirical evidence from other studies that show a predictive effect of combined entrepreneurial competences and their sub-competences or specific indicators of business performance. (Abaho et al., 2016; Kamuri, 2023; Nasir & Chellakan, 2020; Pranowo et al., 2020; Sakib et al., 2022; Sumawidjaja et al., 2019)

The Direct or Indirect Effect of Entrepreneurial Competence Areas On Agricultural Performance.

The authors conclude that since the model suggested that the data fit, this then showed that the relationship was adequate. This implies that in an ideal setup, when all variables are combined in synergy, they can act transversally to any farm class, and any unit increase in each of the variables will result in a matching increase in the predictive capability of entrepreneurial competences to improve agricultural performance.

The authors conclude that the results illustrate that improving agricultural performance in the Zimbabwean farming context can be achieved by increasing entrepreneurial competence among farmers. This can be achieved by intensive training.

Recommendations

This research highlights the importance of policy planners and stakeholders, such as contractors, to explore and pay attention to the entrepreneurial competences of farmers who are beneficiaries of government or private schemes. The Government of Zimbabwe can wean farmers from current input schemes, such as the Presidential Input Scheme, to foster a culture of a business approach to farming. The subsidies and inputs traditionally doled out annually can gradually be eased to reduce shocks to the vulnerable and to screen off undeserving beneficiaries. Alternatively, the Presidential Inputs Scheme can be modified to a loan scheme whereby beneficiaries are expected to pay back for the inputs. This can catalyse the morphing of the scheme into a revolving fund, thus reducing the drain on the fiscus. Research by Muponda (2012) recommended that the Government of Zimbabwe should desist from subsidizing funds to micro-enterprises and opt for the activation of an enabling environment whereby recurrent market failures are rectified, as this will spur private equity players to come on board. While this research focused on light industrial micro-enterprises, the recommendation resonates with the author's assertion. A business approach that safeguards against market failures remains an ideal recommendation by the authors, and this will cultivate the development of a performance-based approach if inputs are not regarded as freebies.

Finally, the Government of Zimbabwe can identify a pool of farmers per province to be trained in entrepreneurial competences and be supported with adequate capital in specific agricultural activities where their provinces enjoy a competitive advantage over others and be monitored so as to build a business culture for agriculture.

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