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Editorial Note: Journal of Technological Sciences

It is my pleasure to welcome you to the first issue of the Journal of Technological Sciences for 2025. The journal continues to stick to its technological inclination. This issue covers four main domains, namely engineering sciences, mathematics and modelling, animal health and food security. The articles cover a balance between original research and reviewed work and bring to the fore exciting recent findings in the four scientific domains.

The mathematics articles tease the issues of Linear Regression (LG), a statistical approach that is widely used in the scientific purviews. Our readers will find this peace valuable as it gives a snap shot of the general dos and don'ts regarding the use of LG. Another exciting piece exhaustively details the approaches and application of actuarial modelling to life insurance methodologies. The article examines in detail the mathematical methodologies that our readers will find handy and would consider as a major reference point.

Our issue also covers the areas of animal health and food security. Two articles touch on the highly important topics on nutrition and health and including underutilized crops such as sorghum and baobab. We are excited to cover these important crops that have remained under-utilized in sub-Saharan Africa but are slowly gaining prominence.

I hope this mix of articles will bring some refreshing perspectives more so as we now consider the interdisciplinary nature of research domains and the need to expand our worlds of views beyond single disciplines. I wish our readers an exciting engagement with articles in this issue.

Editor in Chief

Professor Robert Musundire

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Linear Regression in the Spotlight: From Statistical Staple to Misused Tool

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Abstract

This article explores the application, assumptions, and frequent misuses of linear regression analysis in research, particularly within the business, social sciences and medical fields. While linear regression remains one of the most widely used and accessible statistical tools due to its simplicity and interpretability, it is often misapplied, especially when researchers overlook the foundational assumptions required for valid inferences. The paper reviews the key assumptions of linearity, normality, homoscedasticity, and independence of errors, and discusses the appropriate use of linear regression in descriptive, predictive, and causal research. Through a critical review of published studies and an empirical analysis of customer satisfaction data from Kaggle, the article identifies common violations, including the inappropriate modelling of discrete and ordinal dependent variables, unjustified covariate adjustments, and misinterpretation of regression coefficients. Residual plots and diagnostic tests further reveal that linear regression is frequently applied where it is not suitable, leading to misleading conclusions. The study concludes with practical recommendations to improve statistical literacy and rigor among researchers, emphasizing the importance of involving statisticians and aligning statistical instruction with domain-specific research contexts.

Key words: Residual, Autocorrelation, Homoscedasticity, Linearity, Regression.

Introduction

Linear Regression is a commonly employed statistical technique across different fields to model the relationship between a dependent variable and one or more independent variables (Montgomery et al., 2012). In Economics, it is notably used to examine the link between consumer spending and personal income, while in Finance, it helps predict financial risks and stock prices. In Healthcare, linear regression is utilized to analyse relationships between variables such as age and blood pressure. Additionally, in business, effective marketing strategies are crucial for success, and linear regression aids in optimizing these strategies and forecasting sales based on advertising expenditures. Linear regression is extensively utilized in Environmental Science to examine how factors such as rainfall, temperature, and fertilizer affect crop yield. In Hydrology, it helps identify relationships between variables like rainfall and water table depth. Various sports employ linear regression to analyse performance metrics. In Real Estate, it is used to forecast house prices based on factors like location, square footage, and number of rooms. Additionally, the Social Sciences rely on linear regression for preliminary data analysis and predicting future trends.

Regression analysis helps determine how changes in one variable such as price can influence another, like sales (Leffondré et al., 2014). The technique comes in many forms that include linear, logistic, ordinal, multinomial, ridge, Lasso, hedonic and Gompertz models.

The method is perhaps the most commonly used form of statistical analysis and is invaluable when making a large number of business and economic decisions (Nwachukwu et al 2000). In areas such as the social and behavioural sciences, medicine and public health, linear regression, in particular, stands out as one of the most widely used analytical tools (Darlington & Hayes, 2017). One of the reasons for linear regression's wide spread use is that there are several natural phenomenal laws that can be captured by it.

The use of linear regression models is generally justified, provided particular assumptions are satisfied. While some statistical techniques are complex and require specialized knowledge, others are more accessible (Mehta, 2023). Linear regression stands out as one of the simplest, hence most commonly used method, which explains why it features prominently in a vast number of research studies. Allen, M. P. (2004) encourages researchers to employ linear regression analysis because its linear functional form is simpler than most mathematical equations.

Regardless of it being the most widely used technique, linear regression has moved from being a statistical staple to a misused tool. This article examines a variety of situations in which the technique is misused. The remaining part of the paper looks at Linear Regression Analysis assumptions, uses of linear regression, misuses of linear regression, methodology, data analysis, findings, conclusion and recommendations, in that order.

Linear Regression Analysis assumptions

i. **Linearity:**
The core assumption of linear regression is that the relationship between the independent variable(s) and the dependent variable is a straight line. This implies that a change in the dependent or response variable due to one unit change in independent or predictor variable is constant, regardless of the value of the predictor variable. In multiple regression, this linear relationship should exist between the response variable and each of the predictor variables. This linearity assumption is stressed by Hadi and Chatterjee (2006).

ii. **Residual Expectation**
$\boldsymbol{E\{e_i\} = 0}$ **for all** ***i.*** The expected value of the errors is zero. Suppose there is a number of observations with the same value of the independent variable. If the relationship between the dependent variable and this independent variable is exact then all the observations mentioned above have the same value of the dependent variable. Each residual, which is the deviation of the estimated value from the observed value, is zero hence the expectation is zero as stated. Alternatively, if the relationship is statistical, this assumption implies that the deviations are distributed with both positive and negative values, balancing out so that their sum, and therefore their expected value, is zero.

iii. **Homoscedasticity**
$\boldsymbol{Var\{e_i\} = \sigma^2}$ **for all** ***i.*** The variance of the errors is constant. This assumption suggests that because there are multiple residuals for each value of the independent variable, there is an associated variance, and this variance remains constant across all values of the independent variable.

iv. **Autocorrelation**
$\boldsymbol{\mathrm{Cov}(e_i, e_j) = 0}$ **for** $\boldsymbol{i \neq j}$. The errors are uncorrelated to each other. When we talk about uncorrelated errors in the context of regression, we mean that the covariance of the residuals of different observations is zero.

v. **Normality**
$\boldsymbol{\varepsilon \sim N(0, \sigma^2)}$. The errors are normally distributed. This implies that the errors are symmetrically distributed around zero, with no skewness or kurtosis.

In order for regression analysis to generate valid results the above assumptions must be satisfied.

Uses of Linear Regression

Linear regression analysis is a powerful statistical tool that can be used for descriptive, predictive, and causal research. Below is a detailed explanation of how it is applied in each of these types of research, along with concrete examples:

Descriptive Purpose

A linear regression model is said to answer a descriptive question if it seeks to provide a broad characterization of populations or subpopulations (in the latter case, perhaps with the aim of describing the difference between subpopulations (Carlin and Moreno-Betancur 2024). The model describes the strength and direction of relationships between variables, without implying causation. The focus of such research is to provide summary statistics such as means and standard deviations of continuous variables along with percentage breakdowns into key categories of interest (Carlin and Moreno-Betancur 2024). As an example, a researcher may want to explore the relationship between hours studied and examination scores among university students. The corresponding linear regression model is:

$$\text{Examination Score} = \beta_0 + \beta_1(\text{Hours Studied}) + \varepsilon$$

Where β_1 is the change in examination score per unit change in hours studied. This gives a clear picture of how strongly the two variables are related. Descriptive regression is often exploratory, it tells us what is happening, not why or what will happen next.

Predictive Research

In predictive research, linear regression helps build a model that can be used to predict the value of a dependent variable based on one or more independent variables. Prediction problems invariably involve multiple predictors and seek to develop an algorithm (i.e. in our usage, a procedure) for reliably forecasting the value of Y for individuals for whom only the values of the *X*'s are available (Carlin and Moreno-Betancur 2024). An insurance company, for example, wants to predict a client's car insurance premium based on age, driving and car type. The linear regression model is:

$$\text{Premium} = \beta_0 + \beta_1(\text{Age}) + \beta_2(\text{experience}) + \beta_3(\text{Car TYPE}) + \varepsilon$$

The model is developed on historical data. Once developed, it can be used to predict the premium for a new client. The model tells us how each factor contributes to the predicted premium. Predictive regression focuses on what will happen or estimating unknowns, using patterns in existing data.

Causal Research

Causal research aims to establish cause-and-effect relationships, often using techniques like controlled experiments, instrumental variables, or difference-in-differences within a regression framework to address confounding factors. These studies seek to answer a "What if…" question. Such questions are answered, ideally, by experimentation. However, regression modelling through observational data is often used. A policymaker who wants to know if increasing the minimum

wage causes a change in employment levels may build the following model: The simple linear regression model is:

$$\text{Employment Rate} = \beta_0 + \beta_1(\text{Minimum Wage})) + \varepsilon$$

Other variables (e.g., economic gross domestic product growth, industry type) could influence employment. To control for their effect, we could use a more controlled regression (e.g., include control variables, fixed effects, or natural experiments) to isolate the causal impact of minimum wage on employment. An improved model is as follows:

$$\text{Employment Rate} = \beta_0 + \beta_1(\text{Minimum Wage})) + \beta_1(\text{GDP Growth}) + \alpha_i + \delta_t + \varepsilon_{it}$$

Causal regression is about answering "what happens if we change X?" it requires careful design to avoid misleading conclusions.

Misuses of Linear Regression

Many applications of regression analysis in the medical and health research literature lack clarity of purpose and exhibit misunderstanding of key concepts. Linear regression analysis can be a very effective way to model data as long as the assumptions being made are true, but if they are violated least squares can potentially lead to misleading results (Chatterjee and Simonoff, 2013). The technique is suited for a dependent variable which is quantitative and continuous.

Pearl (2000) asserts that while linear regression can reveal relationships between variables, misinterpretation may result in incorrect causal conclusions, highlighting the necessity of distinguishing correlation from causation. Hastie et al. (2009) address the problem of over fitting, which arises when too many predictors are used, and emphasize the need to balance model complexity with the ability to generalize to new data. Belsley et al. (1980) stress the critical nature of verifying the assumptions of linear regression which are linearity, independence, and homoscedasticity since neglecting these can lead to invalid conclusions and misleading outcomes. Harlow and Mulaik (2014) criticize the excessive dependence on R-squared as the only indicator of model fit, noting that it can lead to misguided conclusions about predictive accuracy and overall model quality. They argue that R-squared fails to give a comprehensive view of model fit, which can be deceptive. Wright (1934) highlights the risks associated with using linear regression predictions outside the data's range, stressing that extrapolation can result in considerable errors and inaccurate forecasts.

Belsley (1991) points out that multi-collinearity can increase standard errors and produce misleading coefficient estimates, complicating the evaluation of individual predictors' effects. Steyerberg et al. (2010) stress the importance of model validation to ensure reliability, noting that misuse frequently happens when models are not evaluated on independent datasets.

Carlin and Moreno-Betancur (2024) examined 57 papers published in three leading journals of clinical research: *Pediatrics*, *Neurology* and *BMJ Open* in June 2022. (The journals were selected from top 20 most influential medical journals. 36 of the papers used linear regression. Among

these papers, 25 (69%, or 44% of all papers) exhibited a type of misuse of regression along the lines that we have identified in the table below. 10 papers applied multiple regression to ill-posed questions. Frequent misuse of regression, such as inadequately justified "adjustment for covariates" and erroneous interpretation of estimated coefficients was observed. Table 1 was generated from that data by Carlin and Moreno-Betancur (2024).

Table 1: Research classification and challenges faced by Researchers

Type of research question	N	**Problems found**	Types of Problems
Descriptive	5	3	no justification for adjustment.
Predictive	7	4	inappropriate model developed, also interpretation of coefficients.
Causal	14	8	Univariable, ignoring confounding, unclear about confounding adjustment, problems in method used to identify adjustment set.
Vague/unclear	10	10	all risk factor identification and version of type 2 fallacy.
Total	36	25	

Papers using regression analysis (36 of a total of 57 reviewed) in the 3 journals (June 2022), classified according to the purpose (type of research question) underlying the analysis.

In business and social sciences, linear regression is frequently used to model qualitative data. Researchers in these fields often mistakenly believe that assigning numerical codes to qualitative variables effectively transforms them into quantitative data. A common example of this practice is the modelling of customer satisfaction, a qualitative construct, using linear regression. Customer satisfaction reflects how pleased customers are with their overall experience and is typically assessed through questionnaires. These questionnaires contain opinion-based statements, with responses ranging from "strongly disagree" to "strongly agree," which are then coded numerically from 1 to 5.

In such studies, customer satisfaction is treated as the dependent variable, while factors like price fairness, service quality and product quality, also measured on 5-point Likert scales, are used as independent variables. This approach was observed in seven articles from journals published in the years 2010, 2011, 2018, 2022 (two articles), and 2023 (two articles). Notably, the results of these studies were often reported without meaningful interpretation. Researchers seem to overlook the fact that regression is not merely a model-fitting tool but a method for answering specific research questions. Concerns about the validity of results are largely ignored, and the fundamental assumptions of regression, namely, linearity, independence, homoscedasticity and normality are often disregarded altogether.

Some published articles from these fields have objectives whose achievement has nothing in line with regression analysis. However, because regression analysis is the only tool that is readily available for most of these researchers, regression models are run and results are adopted.

Methodology

Articles on uses and misuses of linear regression were studied. Seven articles that utilized regression analysis to model customer satisfaction were examined. This was meant for establishing the scale on which customer satisfaction was measured. The study aimed at revealing misuses of linear regression analysis.

Five datasets in which customer satisfaction served as the dependent variable were downloaded from Kaggle. Of these, one had age, gender, country, income, product quality, service quality, purchase frequency, feedback score, and loyalty level as independent variables. A scrutiny of the types of the variables, especially the dependent variables, in the study was carried out.

Since Linear regression models are designed for continuous dependent variables, modelling other types of dependent variables is a violation of this important condition. Linear regression assumptions were checked using residual plots to ensure model validity. Key assumptions include linearity, normality of errors, independence of errors, and homoscedasticity.

Data Analysis

The analysis looked mainly at determining when linear regression is misused. Jamovi software was used to generate the tables and plots that follow. The Kaggle dataset that had customer satisfaction as the dependent variable and age, gender, country, income, product quality, service quality, purchase frequency, feedback score, and loyalty level as independent variables was used in the generation of theses plots and tables.

Table 2: Correlation Matrix

		Product-Quality	Service-Quality	Feedback-Score	Loyalty-Level	Age	Income	Satisfaction
Product-Quality	r_s	1.00						
	p-value							
Service-Quality	r_s	0.005	1.00					
	p-value	0.307						
Feedback-Score	r_s	-0,010	0.000	1.00				
	p-value	0.050	0.969					
Loyalty-Level	r_s	0.000	-0.006	-0.001	1.00			
	p-value	0.999	0.233	0.841				
Age	r_s	-0.009	-0.005	0.003	-0.006	1.00		
	p-value	0.071	0.342	0.608	0.243			
Income	r_s	-0.002	0.005	-0.004	-0.006	0.000	1.00	
	p-value	0.753	0.314	0.396	0.224	0.985		
Satisfaction	r_s	0.542	0.547	-0.009	-0.006	0.156	0.242	1.00
	p-value	<0.001	<0.001	0.063	0.287	<0.001	<0.001	

The matrix in table 2 was meant for checking multicollinearity. It is evident from the matrix that there was no multicollinearity among the independent variables. Product-quality, service-quality, age and income were significantly correlated to satisfaction.

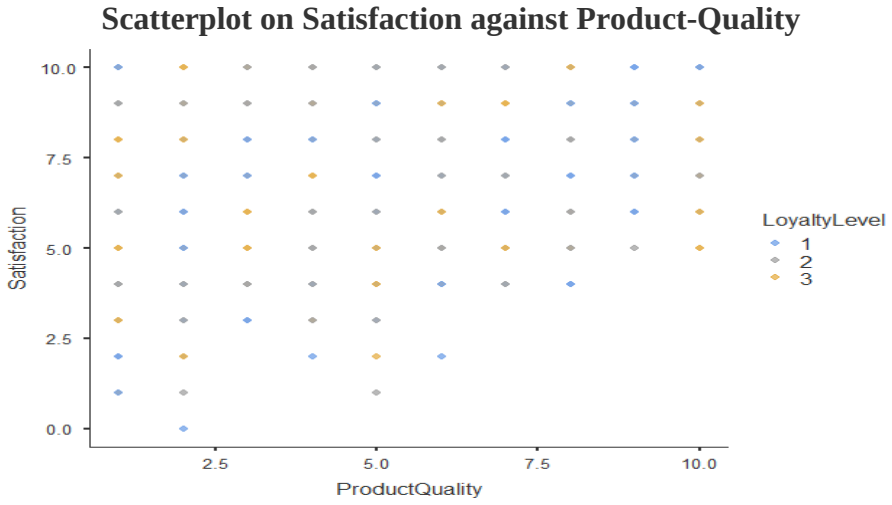

Figure 1

Figure 1 is a scatterplot on Satisfaction against product-quality, grouped by loyalty-level. Although the data satisfied the multicollinearity assumption, the linearity assumption is violated here. It is clear that there is no linear relationship between satisfaction and product-quality. This, in addition to the dependent variable being non-continuous, makes linear regression unsuitable.

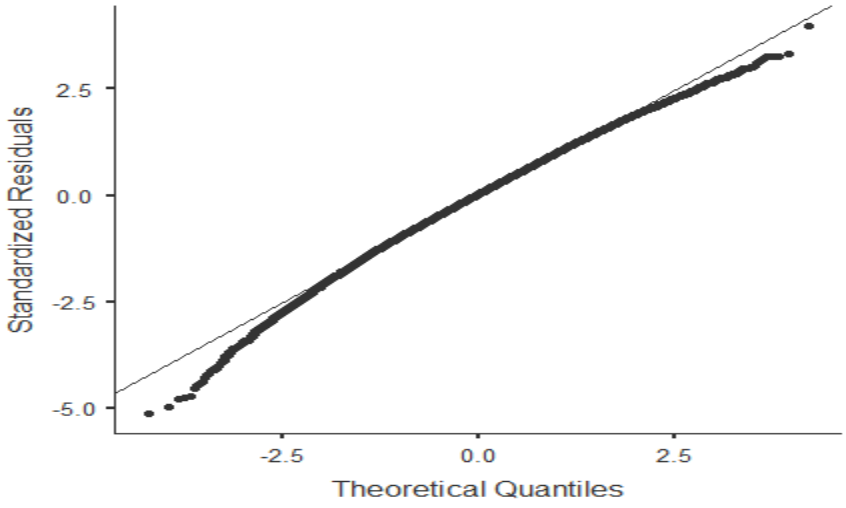

Figure 2

The Q-Q plot in figure 2 shows that the residuals are approximately normally distributed generally, especially around the centre where the points closely follow the line, supporting the normality assumption in that region. There are, however, noticeable deviations in the tails where the points fall away from the line, suggesting potential skewness. The slight deviations from the line indicate mild outliers or non-normal errors.

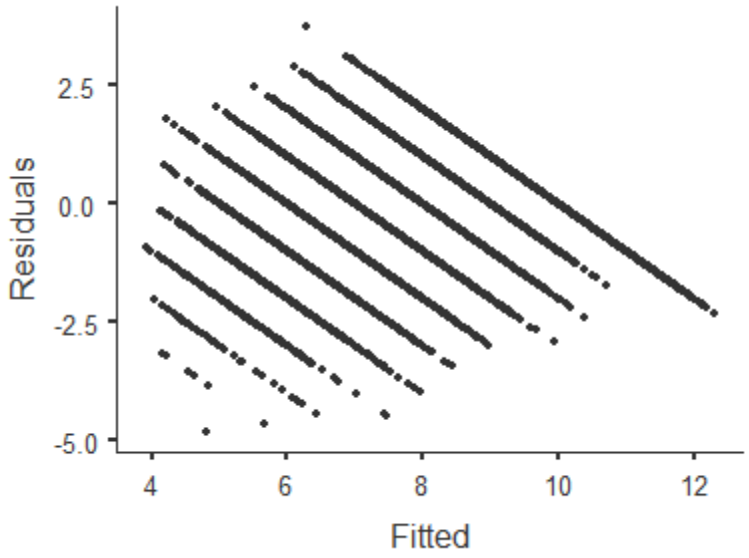

Figure 3

Figure 3 is a residuals-fitted plot which is meant for testing for a number of assumptions that include the homogeneity of variance assumption. The residuals are arranged in a very regular, diagonal banded pattern. The spread of residuals decreases as fitted values increase. This is not typical of good residual plots as these residuals are expected to be randomly scattered around zero. The structured residuals suggest that the model violates the linearity, independence and homoscedasticity assumptions. It may also indicate the presence of ordinal or discrete outcome values, like count data, where residuals naturally cluster in patterns. This plot suggests that a linear regression model is not appropriate for the dataset.

Jamovi software was also used to run linear regression models with each of four other Kaggle datasets on customer satisfaction. For all the datasets, the scatter-plots

Findings

The reviewed articles revealed that the requirement for the dependent variable to be continuous is often overlooked, with researchers mistakenly applying linear regression, not only to discrete but also to ordinal data. Additionally, it was observed that many researchers appear unaware of the assumptions underlying least-squares regression and therefore fail to verify their validity. A lack of familiarity with alternative methods to least-squares regression when assumptions are violated was also noted. Misinterpretation of regression coefficients emerged as another common challenge faced by researchers.

Conclusion

Linear regression remains one of the most widely used and accessible statistical tools across various disciplines due to its simplicity and interpretability. When properly applied, it offers powerful insights for descriptive, predictive, and causal analysis. However, this article highlights

a critical and growing concern: the frequent misuse of linear regression, particularly in fields such as health research, business, and the social sciences. Common errors include applying the model to inappropriate types of data, especially non-continuous dependent variables, failing to test key assumptions, and interpreting results without contextual understanding. The data analysis presented further demonstrates that when foundational assumptions such as linearity, homoscedasticity, normality, and independence are violated, the validity of the results is compromised. The findings underscore the urgent need for researchers to treat regression not just as a model-fitting procedure, but as a question-driven analytical tool that demands careful model selection, assumption checking, and critical interpretation. Without such rigor, the risk of drawing invalid conclusions increases, ultimately undermining the reliability of scientific and applied research.

Recommendations

The following recommendations were made:

i. Advanced statistics courses focusing on statistical issues and data analysis should be incorporated into both taught and research-based Master's and Doctoral programmes.

ii. At least one of the research supervisors at master's and doctoral levels should involve a Statistician from the onset through to the completion of the study.

iii. Reviewers of journals should have an understanding of the basics of statistics so that articles that do not conform to appropriate statistical analysis techniques are not accepted.

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A Novel Analytical Technique of Estimating Whole Life Insurance Benefits Payable Multiple Times Per Period of Insurance

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Abstract

The deepest form of actuarial estimation problems remains the subject of classical life insurance methodologies. A life insurance contract provides the payment of a defined sum assured contingent upon the death of an insured life. Although in practice, death benefits is payable as soon as death claim is advised and the legal requirement is completed, it is necessary to examine death benefits which are paid at the end of policy anniversary of death, that is on the first policy anniversary of effecting the policy after death. When the frequency of payments of an mthly life insurance benefit scheme is infinite, the resulting life insurance function becomes continuously payable momentarily throughout the year so that the total annual payment is equivalent to 1. This admittedly artificial phenomenon has marked consequences in classical life contingency applications and at the same time important as an estimation of benefits payments made weekly or monthly in life insurance benefit program. Consequently, the approximation in the form most suitable for this purpose will be based on Bernoulli power series. In this paper, the objective is to construct analytical expressions for whole life insurance functions payable at different frequencies where the resulting expression represents an adjustment to the yearly formula. Unless an analytical expression for the survival function at age x is defined, approximation will be required to evaluate this expressions. From the results obtained, we confirm asymptotically that $\lim_{K\to\infty} A_x^{(K)} = \overline{A}_x$.

Keywords: Estimation problems, policy anniversary, death benefits, Bernoulli power series, survival function

Introduction

A difficulty level in evaluating life insurance functions from their respective actuarial present values where a life insurance scheme has been incepted under continuous setting is that the probability of survival function for a life aged x may not have an explicit representation. In addition, the derivative of the governing force of mortality may not even exist everywhere. Undoubtedly, there is a gap between the numerical estimations and analytical derivations of life insurance functions. This accounts for the reason why moderate actuarial estimation is required to address complex issues identified in theory to enable us generate closed form expressions which serve as a reference point in a more complex mortality scenario.

Therefore, the theory of estimation is of crucial significance for life insurers to remain solvent and meet the needs of all parties to the business especially the policyholders and stakeholders. A life insurance is a contractual agreement under which the insurer having received premiums from the insured legally accepts a risk from the insured by agreeing to pay benefit contingent on the occurrence of a specified uncertain future event. In Hoem (1969), Hoem (1988), Christiansen (2008) and Christiansen, (2010), the policies are usually long term contracts where the benefit is defined at inception and are underwritten to cover mortality and longevity risks or have embedded savings structure. A typical life insurance is the whole life insurance scheme where the benefit is paid irrespective of the time of death of the insured (Bowers, Gerber, Hickman, Jones, Nesbitt, 1997); Dickson, Hardy & Waters, 2013).

According to Cox, Ingersoll and Ross (1985), Hacaritz, Kleinow and Macdonald (2024), the projection of future cash flows under a life insurance scheme evolves as a result of the requirements to develop key actuarial assumptions in form of technical bases for pricing and satisfying valuation conditions. Following observations in Steffensen (2000), the actuarial assumptions are developed in respect of future interest rates to discount cash flows to the present. Following Sundt and Teugels (2004), the actuarial bases are derived in accordance with future rates of mortality and future expenses as well as basis set in the policy to target profit.

In the classical insurance domain, a level of safety margins is defined when applying the actuarial basis by setting the interest rate below the market level so that a safety margin is built into the mortality rates. Ramlau-Hansen (1988), Ramlau-Hansen (1990) and Linnemann (1993) argue that although life insurers offer various types of life insurance products, safety margins could differ consistent with the kind of policy underwritten. The inclusion of margins is to ensure that on the average, profit emerges over time.

The benefit payment functionally depends on the time of death of the insured or on his survival at a predetermined term. The actuarial methodologies adopted in modelling the uncertainties within the duration of an insured's future lifetime is to consider the remaining lifetime random variable of such life.

The future lifetime of a life aged x is defined by the continuous random variable T_x and the age at death is represented by $T_x + x$ .The cumulative distribution function of T_x applied in computing probabilities of death at time t is given by

$$F_{T_x}(s) = P(T_x \leq s) =_s q_x \tag{1}$$

while the complementary function is defined as

$$S_{T_x}(s) = 1 - F_{T_x}(s) = P(T_x > s) =_s p_x \tag{2}$$

To calculate probabilities at different ages given that a life survives to that age some years later using T_x; $x \geq 0$, it is assumed that

$$F_{T_x}(s) = P(T_x \leq s) = {}_s q_x = P(T_0 \leq x+s | T_0 > x) \tag{3}$$

for all $x \geq 0$ and T_0 is the future lifetime of a newborn. From the axioms of conditional probability, we have

$$F_{T_x}(s) = P(T_x \leq s) = \frac{P(x < T_0 \leq x+s)}{P(T_0 > x)} = \frac{{}_{x+s}q_0 - {}_x q_0}{{}_x p_0} \tag{4}$$

$${}_s q_x + {}_s p_x = 1 \tag{5}$$

the consistency condition for the survival probability requires that

$${}_{x+s} p_0 = ({}_x p_0)({}_s p_x) \tag{6}$$

Consequently, following observations in Dickson et al. (2013), the survival probability of a new born surviving to age $x+s$ is the product of the survival probability from birth to age x and the survival probability from age x to age $x+s$.

An important aspect of mortality is the force of mortality for (x) defined by

$$\mu_x = \lim_{\Delta \to 0} \frac{{}_\Delta q_x}{\Delta} = \lim_{\Delta \to 0^+} \left(\frac{1 - {}_\Delta p_x}{\Delta} \right) \tag{7}$$

defining the relationship between the integrated hazard function and survival probability defined by ${}_s p_x = \exp\left(-\int_0^s \mu_{x+s} ds \right)$ (8)

The force of mortality is the instantaneous mortality measure on a life aged x. Within a short interval of time Δ, it is assumed that $\Delta \times \mu_x = {}_\Delta q_x$

The death density function of the future lifetime T_x is obtained as follows.

$$f_{T_x}(s) = \frac{d}{ds}({}_sq_x) = \frac{d}{ds}(-{}_sp_x) = (\mu_{x+s})({}_sp_x) \tag{9}$$

Following Dickson et al. (2013), we obtain an important formula that relates the future lifetime distribution function in terms of the survival function and the force of mortality

$${}_sq_x = \int_0^s {}_sp_x\mu_{x+s}ds \tag{10}$$

Under a life insurance policy, the payment of the benefit by the insurer and the payment of the premium by the insured can either be in the form of a single amount or a life contingent annuity. Lump sum premiums are paid at the beginning of the policy to guarantee risk coverage. The life contingent single benefits and the life contingent annuities depend on the time of death of the policyholder.

Following Anggraeni, Rahmadani, Utama and Handayani. (2023), the valuation of these types of benefits and annuities is essential for the computation of premiums and examination of policy values. The life contingent single benefit is a function of the time of death that is modelled as a random variable. Its present value depends on the chosen actuarial basis. For different actuarial bases, the distribution of the present value can be derived while its actuarial present value and other moments can equally be obtained.

The present value function of a whole life insurance function is given by $e^{-\delta T_x}$ while its actuarial present value is

$$\overline{A}_x = \int_0^{\Omega-x} e^{-\delta s}({}_sp_x)\mu_{+s}ds \tag{11}$$

Cash flows could occur during the fraction of a year, as for example monthly or quarterly. Considering a fraction of a year $\frac{1}{n};\quad n \geq 1$, where n can be 12 or 4 corresponding to months or quarters and defining the curtate future lifetime random variable as

$$K_x^{(n)} = \frac{1}{n}\lfloor nT_x \rfloor \tag{12}$$

where $\lfloor . \rfloor$ is the floor function. In this case, the contingent single benefits can be obtained in discrete time at that fraction of the year where $v = \frac{1}{1+i}$ and ${}_{\frac{k}{n}|\frac{1}{n}}q_x$ is the probability probability that the life aged x survives $\frac{k}{n}$ years and then dies in the next $\frac{1}{n}$ years. The present value function of whole life insurance function is given by $v^{K_x^{(n)}+\frac{1}{n}}$ while its actuarial present value is

$$A_x^{(n)} = \sum_{k=0}^{\Omega=x-1}\left(v^{\frac{k+1}{n}}\right)\left({}_{\frac{k}{n}|\frac{1}{n}}q_x\right) \tag{13}$$

Methodology

When life assurance product is designated as $A_x^{(K)}$, then 1 unit of benefit should be paid $\frac{1}{K}$ of year after insurance period s where s is increased at intervals of $\frac{1}{K}$ within $0 \leq s < \Omega$. As $K \to \infty$, $A_x^{(K)} \to \bar{A}_x$. We then apply Euler–Maclaurin model on the kthly payable whole life insurance benefit $A_x^{(K)}$ to obtain $\bar{A}_x$. We define the following nomenclature consistent with Bowers et al., 1997) as follows

Let $\frac{d}{ds}$ define the differential operator.

Δ_1 be the differencing at interval s of 1

$\Sigma^{(1)} = \Sigma$ be the summation operator at interval of 1 to infinity

$\Sigma^{(K)}$ be the summation operator at interval of $\frac{1}{K}$ that is $\left\{0, \frac{1}{K}, \frac{2}{K}, \frac{3}{K}, ..., \frac{K-1}{K}, 1, \frac{K+1}{K}, ...\right\}$ to infinity

δ is the differencing operator in the interval $\frac{1}{K}$

$$\left(1+\Delta\right) = \left(1+\delta\right)^{K} = \exp\left(\frac{d}{ds}\right) \tag{14}$$

Obtaining $\frac{1}{\delta}$ in (14) we obtain

$$K\sum^{(k)} = \frac{1}{\delta} = \left[e^{\frac{1}{K}\frac{d}{ds}} - 1\right]^{-1} \Rightarrow \sum^{(k)} = \frac{1}{K\delta} = \frac{1}{K}\left(\frac{1}{\delta}\right) = \frac{1}{K}\left[e^{\frac{1}{K}\frac{d}{ds}} - 1\right]^{-1} \tag{15}$$

Observe that

$$\frac{\frac{1}{K}\frac{d}{ds}}{\left(e^{\frac{1}{K}\frac{d}{ds}} - 1\right)} = \sum_{n=0}^{\infty} B_n \times \left\{\frac{\left(\frac{1}{K}\right)\frac{d^n}{ds^n}}{n!}\right\} \tag{16}$$

where B_n are the Bernoulli numbers

$$\begin{aligned}\frac{\frac{1}{K}\frac{d}{ds}}{\left(e^{\frac{1}{K}\frac{d}{ds}} - 1\right)} &= \frac{B_0}{0!}\left(\frac{d}{Kds}\right)^{0} + \frac{B_1}{1!}\left(\frac{1}{K}\frac{d^1}{ds^1}\right) + \frac{B_2}{2!}\left(\frac{1}{K}\frac{d^2}{ds^2}\right) + \frac{B_3}{3!}\left(\frac{1}{K}\frac{d^3}{ds^3}\right) + \frac{B_4}{4!}\left(\frac{1}{K}\frac{d^4}{ds^4}\right) \\ &+ \frac{B_5}{5!}\left(\frac{1}{K}\frac{d^5}{ds^5}\right) + \frac{B_6}{6!}\left(\frac{1}{K}\frac{d^6}{ds^6}\right) + ... + \frac{B_r}{r!}\left(\frac{1}{K}\frac{d^r}{ds^r}\right)\end{aligned} \tag{17}$$

Let

$$y = \frac{1}{K}\frac{d}{ds} \tag{18}$$

$$B_r = \left[\frac{d^m}{dy^m} \left(\frac{y}{e^y - 1} \right) \right]_{y=0} \tag{19}$$

$$B_0 = \lim_{y \to 0} \left(\frac{y}{e^y - 1} \right) = \lim_{y \to 0} \left(\frac{1}{e^y} \right) = 1 \tag{20}$$

$$B_1 = \lim_{y \to 0} \frac{d}{dy} \left(\frac{y}{e^y - 1} \right) = \lim_{y \to 0} \left(\frac{e^y - 1 - ye^y}{\left(e^y - 1 \right)^2} \right) = \lim_{y \to 0} \left(\frac{e^y - ye^y - e^y}{2\left(e^y - 1 \right)} \right) = \lim_{y \to 0} \left(\frac{-ye^y}{\left(2e^y - 2 \right)} \right)$$
$$= \lim_{y \to 0} \left(\frac{-ye^y - e^y}{2e^y} \right) = \lim_{y \to 0} \left(\frac{-y - 1}{2} \right) = \frac{-1}{2} \tag{21}$$

$$e^y = 1 + y + \frac{y^2}{2!} + \frac{y^3}{3!} + \frac{y^4}{4!} + \frac{y^5}{5!} \ldots \tag{22}$$

Subtracting 1 from both sides (22)

$$e^y - 1 = y + \frac{y^2}{2!} + \frac{y^3}{3!} + \frac{y^4}{4!} + \frac{y^5}{5!} \ldots \tag{23}$$

Dividing both sides by y , we obtain

$$\frac{e^y - 1}{y} = 1 + \frac{y}{2!} + \frac{y^2}{3!} + \frac{y^3}{4!} + \frac{y^4}{5!} \ldots \tag{24}$$

$$\text{Let } U = \frac{y}{2!} + \frac{y^2}{3!} + \frac{y^3}{4!} + \frac{y^4}{5!} + \ldots \tag{25}$$

$$\frac{e^y - 1}{y} = 1 + U \tag{26}$$

Now observe that the half-angle hyperbolic cotangent function is given by

$$\frac{y}{2} \coth \frac{y}{2} = \frac{y}{2} \frac{e^{\frac{y}{2}} + e^{-\frac{y}{2}}}{e^{\frac{y}{2}} - e^{-\frac{y}{2}}} = \frac{y}{2} \frac{e^{-\frac{y}{2}}}{e^{-\frac{y}{2}}} \frac{e^y + 1}{e^y - 1} = \frac{y}{2} \left(\frac{e^y - 1}{e^y - 1} + \frac{2}{e^y - 1} \right) = \frac{y}{2} + \frac{y}{2} \frac{2}{e^y - 1} = \frac{y}{2} + \frac{y}{e^y - 1} \tag{27}$$

This is the reciprocal of both sides of (24) and is defined in terms of hyperbolic cotangent.

hence

$$\frac{y}{2} \coth \frac{y}{2} - \frac{y}{2} = \frac{y}{e^y - 1} \tag{28}$$

By definition,

$$\frac{y}{2}\coth\frac{y}{2}=\frac{y}{2}\frac{\cosh\frac{y}{2}}{\sinh\frac{y}{2}}=\frac{\frac{e^{\frac{y}{2}}+e^{-\frac{y}{2}}}{2}}{\frac{e^{\frac{y}{2}}-e^{-\frac{y}{2}}}{2}}=\frac{e^{\frac{y}{2}}+e^{-\frac{y}{2}}}{e^{\frac{y}{2}}-e^{-\frac{y}{2}}} \tag{29}$$

Expanding the bottom bracket and simplify

$$\frac{y}{2}\coth\frac{y}{2}=$$

$$\left(\frac{y}{2}\right)\left(\frac{\begin{array}{l}1+\frac{1}{1!}\left(\frac{y}{2}\right)^1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots\\ +1+\frac{1}{1!}\left(-\frac{y}{2}\right)^1+\frac{1}{2!}\left(-\frac{y}{2}\right)^2+\frac{1}{3!}\left(-\frac{y}{2}\right)^3+\frac{1}{4!}\left(-\frac{y}{2}\right)^4+\frac{1}{5!}\left(-\frac{y}{2}\right)^5+\left(-\frac{y}{2}\right)^6+\ldots\end{array}}{\begin{array}{l}1+\frac{1}{1!}\left(\frac{y}{2}\right)^1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots+\\ -\left(1+\frac{1}{1!}\left(-\frac{y}{2}\right)^1+\frac{1}{2!}\left(-\frac{y}{2}\right)^2+\frac{1}{3!}\left(-\frac{y}{2}\right)^3+\frac{1}{4!}\left(-\frac{y}{2}\right)^4+\frac{1}{5!}\left(-\frac{y}{2}\right)^5+\frac{1}{6!}\left(-\frac{y}{2}\right)^6+\ldots\right)\end{array}}\right) \tag{30}$$

$$\frac{y}{2}\coth\frac{y}{2}=$$

$$\left(\frac{y}{2}\right)\left(\frac{\begin{array}{l}1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots+1+\frac{1}{2!}\left(-\frac{y}{2}\right)^2+\frac{1}{4!}\left(-\frac{y}{2}\right)^4+\left(-\frac{y}{2}\right)^6+\ldots\end{array}}{\begin{array}{l}1+\frac{1}{1!}\left(\frac{y}{2}\right)^1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots+\\ -1-\frac{1}{1!}\left(-\frac{y}{2}\right)^1-\frac{1}{2!}\left(-\frac{y}{2}\right)^2-\frac{1}{3!}\left(-\frac{y}{2}\right)^3-\frac{1}{4!}\left(-\frac{y}{2}\right)^4-\frac{1}{5!}\left(-\frac{y}{2}\right)^5-\frac{1}{6!}\left(-\frac{y}{2}\right)^6-\ldots\end{array}}\right) \tag{31}$$

$$\frac{y}{2}\coth\frac{y}{2}=$$

$$\left(\frac{y}{2}\right)\left(\frac{1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots+1+\frac{1}{2!}\left(-\frac{y}{2}\right)^2+\frac{1}{4!}\left(-\frac{y}{2}\right)^4+\left(-\frac{y}{2}\right)^6+\ldots}{\frac{1}{1!}\left(\frac{y}{2}\right)^1+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\ldots+\frac{1}{1!}\left(\frac{y}{2}\right)^1+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{5!}\left(\frac{y}{2}\right)^5-\ldots}\right) \quad (32)$$

$$\frac{y}{2}\coth\frac{y}{2}=\left(\frac{y}{2}\right)\left(\frac{2+2\times\frac{1}{2!}\left(\frac{y}{2}\right)^2+2\times\frac{1}{4!}\left(\frac{y}{2}\right)^4+2\times\frac{1}{6!}\left(\frac{y}{2}\right)^6+\ldots}{2\times\frac{1}{1!}\left(\frac{y}{2}\right)^1+2\times\frac{1}{3!}\left(\frac{y}{2}\right)^3+2\times\frac{1}{5!}\left(\frac{y}{2}\right)^5+\ldots}\right) \quad (33)$$

Dividing the numerator and denominator of the right hand side by 2 simplifies to

$$\frac{y}{2}\coth\frac{y}{2}=\left(\frac{y}{2}\right)\left(\frac{1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\frac{1}{8!}\left(\frac{y}{2}\right)^8+\frac{1}{10!}\left(\frac{y}{2}\right)^{10}+\ldots}{\left(\frac{y}{2}\right)+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\frac{1}{7!}\left(\frac{y}{2}\right)^7+\frac{1}{9!}\left(\frac{y}{2}\right)^9+\frac{1}{11!}\left(\frac{y}{2}\right)^{11}+\ldots}\right) \quad (34)$$

$$\frac{y}{2}\coth\frac{y}{2}=\left[1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\frac{1}{8!}\left(\frac{y}{2}\right)^8+\frac{1}{10!}\left(\frac{y}{2}\right)^{10}\right]\times$$

$$\left(\frac{\left(\frac{y}{2}\right)}{\left(\frac{y}{2}\right)+\frac{1}{3!}\left(\frac{y}{2}\right)^3+\frac{1}{5!}\left(\frac{y}{2}\right)^5+\frac{1}{7!}\left(\frac{y}{2}\right)^7+\frac{1}{9!}\left(\frac{y}{2}\right)^9+\frac{1}{11!}\left(\frac{y}{2}\right)^{11}+\ldots}\right) \quad (35)$$

Dividing the numerator and denominator in (35) by $\frac{y}{2}$, we obtain

$$\frac{y}{2}\coth\frac{y}{2}=\left(1+\frac{1}{2!}\left(\frac{y}{2}\right)^2+\frac{1}{4!}\left(\frac{y}{2}\right)^4+\frac{1}{6!}\left(\frac{y}{2}\right)^6+\frac{1}{8!}\left(\frac{y}{2}\right)^8+\frac{1}{10!}\left(\frac{y}{2}\right)^{10}\right)$$

$$\times\left(\frac{1}{1+\frac{1}{3!}\left(\frac{y}{2}\right)^2+\frac{1}{5!}\left(\frac{y}{2}\right)^4+\frac{1}{7!}\left(\frac{y}{2}\right)^6+\frac{1}{9!}\left(\frac{y}{2}\right)^8+\frac{1}{11!}\left(\frac{y}{2}\right)^{10}+\ldots}\right) \quad (36)$$

$$\frac{1}{1+U}=1+\left(-U\right)+\left(-U\right)^{2}+\left(-U\right)^{3}+\left(-U\right)^{4}+\left(-U\right)^{5}+... \tag{37}$$

$$\begin{aligned}\frac{y}{2}\coth\frac{y}{2}&=\left(1+\frac{1}{2!}\left[\frac{y}{2}\right]^{2}+\frac{1}{4!}\left[\frac{y}{2}\right]^{4}+\frac{1}{6!}\left[\frac{y}{2}\right]^{6}+\frac{1}{8!}\left[\frac{y}{2}\right]^{8}+\frac{1}{10!}\left[\frac{y}{2}\right]^{10}\right)\\&\times\left\{\begin{array}{l}\left[1-\left(\frac{1}{3!}\left[\frac{y}{2}\right]^{2}+\frac{1}{5!}\left[\frac{y}{2}\right]^{4}+\frac{1}{7!}\left[\frac{y}{2}\right]^{6}+\frac{1}{9!}\left[\frac{y}{2}\right]^{8}+...\right)\right]\\+\left(\frac{1}{3!}\left[\frac{y}{2}\right]^{2}+\frac{1}{5!}\left[\frac{y}{2}\right]^{4}+\frac{1}{7!}\left[\frac{y}{2}\right]^{6}\right)^{2}-\left(\frac{1}{3!}\left[\frac{y}{2}\right]^{2}+\frac{1}{5!}\left[\frac{y}{2}\right]^{4}\right)^{3}+\left(\frac{1}{3!}\left[\frac{y}{2}\right]^{2}\right)^{4}\end{array}\right\}+O\left(y^{10}\right)\end{aligned} \tag{38}$$

After simplifying this equation, we obtain

$$\frac{y}{2}\coth\frac{y}{2}=1+\left(\frac{1}{6}\right)\frac{y^{2}}{2!}+\left(-\frac{1}{30}\right)\frac{y^{4}}{4!}+\left(\frac{1}{42}\right)\frac{y^{6}}{6!}+\left(-\frac{1}{30}\right)\frac{y^{8}}{8!}+... \tag{39}$$

Observe here that the there is no term containing y^{1} in equation (39)

But

$$\begin{aligned}\frac{y}{\left[e^{y}-1\right]}&=\sum_{m=0}^{\infty}\left(\frac{B_{m}}{m!}\right)y^{m}=\left(\frac{B_{0}}{0!}\right)y^{0}+\left(\frac{B_{1}}{1!}\right)y^{1}+\left(\frac{B_{2}}{2!}\right)y^{2}+\left(\frac{B_{3}}{3!}\right)y^{3}+\left(\frac{B_{4}}{4!}\right)y^{4}+\left(\frac{B_{5}}{5!}\right)y^{5}\\&+\left(\frac{B_{6}}{6!}\right)y^{6}+\left(\frac{B_{7}}{7!}\right)y^{7}+\left(\frac{B_{8}}{8!}\right)y^{8}+\left(\frac{B_{9}}{9!}\right)y^{9}+...\end{aligned} \tag{40}$$

Since there is no term containing y^{1} in equation (39) we must add $\left(-\frac{y}{2}\right)$ from both sides

$$\frac{y}{2}\coth\frac{y}{2}-\left(\frac{1}{2}\right)\frac{y}{1!}=-\left(\frac{1}{2}\right)\frac{y}{1!}+1+\left(\frac{1}{6}\right)\frac{y^{2}}{2!}+\left(-\frac{1}{30}\right)\frac{y^{4}}{4!}+\left(\frac{1}{42}\right)\frac{y^{6}}{6!}+\left(-\frac{1}{30}\right)\frac{y^{8}}{8!}+... \tag{41}$$

Comparing co-efficient of powers of y in equations (39) and (40), we have

$$\begin{aligned}&\frac{B_{0}}{0!}=1;\frac{B_{1}}{1!}=-\frac{1}{2\times1}=-\frac{1}{2};\frac{B_{2}}{2!}=\frac{1}{12};\frac{B_{3}}{3!}=0;\frac{B_{4}}{4!}=-\frac{1}{720};\frac{B_{5}}{5!}=0;\frac{B_{6}}{6!}=-\frac{1}{30240};\\&\frac{B_{8}}{8!}=\frac{1}{30\times40,320}\end{aligned} \tag{42}$$

The odd Bernoulli numbers all vanishes except B_1 that is $B_{2r-1}=0$ for $r\geq 2$. We use the symbol

$\left(\frac{1}{K}\frac{d}{ds}\right)^n$ to mean $\left(\frac{1}{K}D\right)^n$ where $D^n=\frac{d^n}{ds^n}$

$$\frac{\frac{d}{Kds}}{\left[e^{\frac{1}{K}\frac{d}{ds}}-1\right]}=\frac{1}{0!}\left(\frac{d}{Kds}\right)^0-\frac{1}{2}\left(\frac{d}{Kds}\right)^1+\frac{1}{12}\left(\frac{d}{Kds}\right)^2-\frac{1}{720}\left(\frac{d}{Kds}\right)^4+\frac{1}{30240}\left(\frac{d}{Kds}\right)^6 \\ -\frac{1}{1209600}\left(\frac{d}{Kds}\right)^8+\frac{1}{47900160}\left(\frac{d}{Kds}\right)^{10} \tag{43}$$

Dividing throughout by $\frac{d}{Kds}$

$$\frac{1}{\frac{d}{Kds}}\frac{\frac{d}{Kds}}{\left[e^{\frac{1}{K}\frac{d}{ds}}-1\right]}=\frac{\frac{1}{0!}\left(\frac{d}{Kds}\right)^0}{\frac{d}{Kds}}-\frac{1}{2}+\frac{1}{12}\left(\frac{d}{Kds}\right)^1-\frac{1}{720}\left(\frac{d}{Kds}\right)^3 \\ +\frac{1}{30240}\left(\frac{d}{Kds}\right)^5-\frac{1}{1209600}\left(\frac{d}{Kds}\right)^7+\frac{1}{47900160}\left(\frac{d}{Kds}\right)^9 \tag{44}$$

$$K\sum{}^{(K)}=\frac{1}{\frac{d}{Kds}}\frac{\frac{d}{Kds}}{\left[e^{\frac{1}{K}\frac{d}{ds}}-1\right]} \tag{45}$$

$$K\sum{}^{(K)}=\frac{1}{\frac{d}{Kds}}-\frac{1}{2}+\frac{1}{12}\left(\frac{d}{Kds}\right)^1-\frac{1}{720}\left(\frac{d}{Kds}\right)^3 \\ +\frac{1}{30240}\left(\frac{d}{Kds}\right)^5-\frac{1}{1209600}\left(\frac{d}{Kds}\right)^7+\frac{1}{47900160}\left(\frac{d}{Kds}\right)^9 \tag{46}$$

$$\sum^{(K)} = \frac{1}{\left(\frac{K}{1}\times\frac{d}{Kds}\right)} - \frac{1}{2K} + \frac{1}{12K}\left(\frac{d}{Kds}\right)^1 - \frac{1}{720K}\left(\frac{d}{Kds}\right)^3 + \frac{1}{30240K}\left(\frac{d}{Kds}\right)^5 - \frac{1}{1209600K}\left(\frac{d}{Kds}\right)^7 + \frac{1}{47900160K}\left(\frac{d}{Kds}\right)^9 \quad (47)$$

Note that $\left(\frac{d}{ds}\right)^n = D^n = \frac{d^n}{ds^n}$ and substituting $K = 1$ in (47)

$$\sum^{(1)} = \frac{1}{\left(\frac{d}{ds}\right)} - \frac{1}{2} + \frac{1}{12}\left(\frac{d}{ds}\right)^1 - \frac{1}{720}\left(\frac{d}{ds}\right)^3 + \frac{1}{30240}\left(\frac{d}{ds}\right)^5 - \frac{1}{1209600}\left(\frac{d}{ds}\right)^7 + \frac{1}{47900160}\left(\frac{d}{ds}\right)^9 \quad (48)$$

$$\sum^{(K)} - \sum^{(1)} = \frac{1}{K\frac{d}{Kds}} - \frac{1}{2K} + \frac{1}{12K^2}\left(\frac{d}{ds}\right)^1 - \frac{1}{720K^4}\left(\frac{d}{ds}\right)^3 + \frac{1}{30240K^6}\left(\frac{d}{ds}\right)^5 - \frac{1}{1209600K^8}\left(\frac{d}{ds}\right)^7 + \frac{1}{47900160K^{10}}\left(\frac{d}{ds}\right)^9 - \frac{1}{\left(\frac{d}{ds}\right)} + \frac{1}{2} - \frac{1}{12}\left(\frac{d}{ds}\right)^1 + \frac{1}{720}\left(\frac{d}{ds}\right)^3 - \frac{1}{30240}\left(\frac{d}{ds}\right)^5 + \frac{1}{1209600}\left(\frac{d}{ds}\right)^7 - \frac{1}{47900160}\left(\frac{d}{ds}\right)^9 \quad (49)$$

$$\sum^{(K)} - \sum^{(1)} = \frac{1}{K\frac{d}{Kds}} - \frac{1}{\left(\frac{d}{ds}\right)} + \frac{1}{2} - \frac{1}{2K} + \frac{1}{12K^2}\left(\frac{d}{ds}\right)^1 - \frac{1}{12}\left(\frac{d}{ds}\right)^1 + \frac{1}{720}\left(\frac{d}{ds}\right)^3 - \frac{1}{720K^4}\left(\frac{d}{ds}\right)^3 + \frac{1}{30240K^6}\left(\frac{d}{ds}\right)^5 - \frac{1}{30240}\left(\frac{d}{ds}\right)^5 + \frac{1}{1209600}\left(\frac{d}{ds}\right)^7 - \frac{1}{1209600K^8}\left(\frac{d}{ds}\right)^7 + \frac{1}{47900160K^{10}}\left(\frac{d}{ds}\right)^9 - \frac{1}{47900160}\left(\frac{d}{ds}\right)^9 \quad (50)$$

$$\sum^{(K)} - \sum^{(1)} = \frac{K-1}{2K} + \frac{1-K^2}{12K^2}\left(\frac{d}{ds}\right)^1 + \frac{K^4-1}{720K^4}\left(\frac{d}{ds}\right)^3 + \frac{1-K^6}{30240K^6}\left(\frac{d}{ds}\right)^5 + \frac{K^8-1}{1209600K^8}\left(\frac{d}{ds}\right)^7 + \frac{1-K^{10}}{47900160K^{10}}\left(\frac{d}{ds}\right)^9 \tag{51}$$

We insert the function $\frac{C_{x+s}}{D_x}$ in (51) throughout as follows

$$\sum^{(K)}\left(\frac{C_{x+s}}{D_x}\right) - \sum^{(1)}\left(\frac{C_{x+s}}{D_x}\right) = \frac{K-1}{2K}\left(\frac{C_{x+s}}{D_x}\right) + \frac{1-K^2}{12K^2}\left(\frac{d}{ds}\frac{C_{x+s}}{D_x}\right)^1 + \frac{K^4-1}{720K^4}\left(\frac{d}{ds}\frac{C_{x+s}}{D_x}\right)^3 + \frac{1-K^6}{30240K^6}\left(\frac{d}{ds}\frac{C_{x+s}}{D_x}\right)^5 + \frac{K^8-1}{1209600K^8}\left(\frac{d}{ds}\frac{C_{x+s}}{D_x}\right)^7 + \frac{1-K^{10}}{47900160K^{10}}\left(\frac{d}{ds}\frac{C_{x+s}}{D_x}\right)^9 \tag{52}$$

Since the integral $\bar{A}_x = \int_0^\infty e^{-\delta s}\mu_{x+s}\left({}_sP_x\right)ds$ is difficult to solve by direct integration, we first obtain the derivatives of the *discounted death* function C_{x+s} in equation (52) and thereafter estimate the whole life insurance $\bar{A}_x$. Both the discounted deaths and number of deaths are defined as follows

$$C_x = d_x v^{x+1}; \quad d_x = l_x - l_{x+1} \tag{53}$$

where $C_x \in \mathbf{C}^n$ and C_x is the discounted deaths. Replacing x by $x+s$ in (53)

$$C_{x+s} = v^{x+1+s}d_{x+s} = e^{(\ln v)(x+1+s)}d_{x+s} \tag{54}$$

The number of death cases at age $x+s$ is given by

$$d_{x+s} = \left(l_{x+s} - l_{x+1+s}\right) \tag{55}$$

$$C_{x+s} = v^{x+1+s}d_{x+s} = \exp\left[\left(\ln v\right)\left(x+1+s\right)\right]d_{x+s} = \left(l_{x+s} - l_{x+1+s}\right)\times\exp\left[\left(\ln v\right)\left(x+1+s\right)\right] = \left(l_{x+s}\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right] - l_{x+1+s}\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\right) \tag{56}$$

Finding the difference between omega age $\Omega = \infty$ and age 0, we have

$$\left[C_{x+s}\right]_0^{\Omega} = \left[C_{x+s}\right]_{s=\Omega} - \left[\ _{C_{x+s}}\right]_{s=0} = -e^{(\ln v)(x+1)}d_x = -e^{(-\delta)(x+1)}d_x = -v^{x+1}d_x = -C_x \tag{57}$$

where Ω is the limit of life

$$\Omega = Sup\left\{\zeta \in \mathbf{R}^{+} \middle| F_{T_x}(\zeta) \le 1\right\} \tag{58}$$

Differentiating (56) with respect to s once and observing that

$$\frac{d}{ds}l_{x+s} = -\mu_{x+s}l_{x+s} \tag{59}$$

$$\begin{aligned}&\frac{d}{ds}C_{x+s} = \frac{d}{ds}\left[\left(l_{x+s} - l_{x+1+s}\right)\times\exp\left\{\left(\ln v\right)\left(x+1+s\right)\right\}\right] = \\ &+\left(l_{x+s} - l_{x+1+s}\right)\frac{d}{ds}\exp\left[\left(\ln v\right)\left(x+1+s\right)\right] + \exp\left[\left(\ln v\right)\left(x+1+s\right)\right]\frac{d}{ds}\left(l_{x+s} - l_{x+1+s}\right)\end{aligned} \tag{60}$$

$$\begin{aligned}&\frac{d}{ds}C_{x+s} = \left(l_{x+s} - l_{x+1+s}\right)\left(\ln v\right)\exp\left[\left(\ln v\right)\left(x+1+s\right)\right] \\ &-\exp\left[\left(\ln v\right)\left(x+1+s\right)\right]\left[\mu_{x+s}l_{x+s} - \mu_{x+1+s}l_{x+1+s}\right]\end{aligned} \tag{61}$$

$$\begin{aligned}&\frac{d}{ds}C_{x+s} = d_{x+s}\left(\ln v\right)\exp\left[\left(\ln v\right)\left(x+1+s\right)\right] \\ &-\exp\left[\left(\ln v\right)\left(x+1+s\right)\right]\left[\mu_{x+s}l_{x+s} - \mu_{x+1+s}l_{x+1+s}\right]\end{aligned} \tag{62}$$

$$\begin{aligned}&\frac{d}{ds}C_{x+s} = \left(\ln v\right)\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\times d_{x+s} - \exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+s}l_{x+s}\right) \\ &+\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+1+s}l_{x+1+s}\right)\end{aligned} \tag{63}$$

$$\begin{aligned}\left[\frac{d}{ds}C_{x+s}\right]_0^{\Omega} = &\begin{bmatrix}\left(\ln v\right)\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\times d_{x+s} - \exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+s}l_{x+s}\right) \\ +\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+1+s}l_{x+1+s}\right)\end{bmatrix}_{s=\Omega} \\ -&\begin{bmatrix}\left(\ln v\right)\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\times d_{x+s} - \exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+s}l_{x+s}\right) \\ +\exp\left[\left(\ln v\right)\times\left(x+1+s\right)\right]\left(\mu_{x+1+s}l_{x+1+s}\right)\end{bmatrix}_{s=0}\end{aligned} \tag{64}$$

$$\left[\frac{d}{ds}C_{x+s}\right]_0^{\Omega} = -\begin{bmatrix}\left(\ln v\right)\exp\left[\left(\ln v\right)\times\left(x+1\right)\right]\times d_x - \exp\left[\left(\ln v\right)\times\left(x+1\right)\right]\left(\mu_x l_x\right) \\ +\exp\left[\left(\ln v\right)\times\left(x+1\right)\right]\left(\mu_{x+1}l_{x+1}\right)\end{bmatrix} \tag{65}$$

Taking the second derivative using (63) and noting that

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)\frac{d}{ds}C_{x+s} + \frac{d}{ds}\left[\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right)\right] - \frac{d}{ds}\left[\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right)\right] \tag{66}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)\begin{bmatrix}(\ln v)C_{x+s} + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right)\\ -\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right)\end{bmatrix} + \left(\frac{d}{ds}l_{x+s}\right)\frac{d}{ds}\exp\left[(\ln v)\times(x+1+s)\right] + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d}{ds}\left(\frac{d}{ds}l_{x+s}\right) - \left(\frac{d}{ds}l_{x+1+s}\right)\frac{d}{ds}\exp\left[(\ln v)\times(x+1+s)\right] - \exp\left[(\ln v)\times(x+1+s)\right]\frac{d}{ds}\left(\frac{d}{ds}l_{x+1+s}\right) \tag{67}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)\begin{bmatrix}(\ln v)C_{x+s} + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right)\\ -\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right)\end{bmatrix} + (\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right) + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}l_{x+s}\right) - (\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right) - \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}l_{x+1+s}\right) \tag{68}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right) - 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right) + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}l_{x+s}\right) - \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}l_{x+1+s}\right) \tag{69}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+s}\right) - 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}l_{x+1+s}\right) + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}\left(l_{x+s} - l_{x+1+s}\right) \tag{70}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\frac{d}{ds}(l_{x+s} - l_{x+1+s}) + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}(l_{x+s} - l_{x+1+s}) \tag{71}$$

$$\frac{d^2}{ds^2}C_{x+s} = (\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\frac{d}{ds}d_{x+s} + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}d_{x+s} \tag{72}$$

$$\left[\frac{d^2}{ds^2}C_{x+s}\right]_0^{\Omega} = \left[\begin{array}{l}(\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}d_{x+s}\right) \\ + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}d_{x+s}\end{array}\right]_{s=\Omega} - \left[\begin{array}{l}(\ln v)^2 C_{x+s} + 2(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}d_{x+s}\right) \\ + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}d_{x+s}\end{array}\right]_{s=0} \tag{73}$$

$$\left[\frac{d^2}{ds^2}C_{x+s}\right]_0^{\Omega} = -\left[\begin{array}{l}(\ln v)^2 C_x + 2(\ln v)\exp\left[(\ln v)\times(x+1)\right]\left(\frac{d}{dx}d_x\right) \\ + \exp\left[(\ln v)\times(x+1)\right]\frac{d^2}{dx^2}d_x\end{array}\right] \tag{74}$$

The first term will be zero because both C and d are all functions of l_{x+s} which also vanishes at

$$s = \Omega \quad ;\left[\frac{d}{ds}d_{x+s}\right]_{s=0} = \frac{d}{dx}d_x \tag{75}$$

Taking the third derivative

$$\frac{d^3}{ds^3}C_{x+s} = (\ln v)^2\frac{d}{ds}C_{x+s} + 2(\ln v)\frac{d}{ds}\left[\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}d_{x+s}\right)\right] + \frac{d}{ds}\left[\exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}d_{x+s}\right] \tag{76}$$

$$\frac{d^3}{ds^3}C_{x+s} = (\ln v)^2 \begin{Bmatrix} (\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\times d_{x+s} - \exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+s}l_{x+s}) \\ +\exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+1+s}l_{x+1+s}) \end{Bmatrix}$$
$$+2(\ln v)\left\{\left(\frac{d}{ds}d_{x+s}\right)\frac{d}{ds}\exp\left[(\ln v)\times(x+1+s)\right] + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}d_{x+s}\right)\right\} \quad (77)$$
$$+\left[\frac{d^2}{ds^2}d_{x+s}\times\frac{d}{ds}\exp\left[(\ln v)\times(x+1+s)\right] + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^3}{ds^3}d_{x+s}\right]$$

$$\frac{d^3}{ds^3}C_{x+s} = (\ln v)^2 \begin{Bmatrix} (\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\times d_{x+s} - \exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+s}l_{x+s}) \\ +\exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+1+s}l_{x+1+s}) \end{Bmatrix}$$
$$+2(\ln v)\left[\left(\frac{d}{ds}d_{x+s}\right)(\ln v)\exp\left[(\ln v)\times(x+1+s)\right] + \exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}d_{x+s}\right)\right] \quad (78)$$
$$+\left[(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\frac{d^2}{ds^2}d_{x+s} + \exp\left[(\ln v)\times(x+1+s)\right]\frac{d^3}{ds^3}d_{x+s}\right]$$

$$\frac{d^3}{ds^3}C_{x+s} = (\ln v)^2 \begin{Bmatrix} (\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\times d_{x+s} - \exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+s}l_{x+s}) \\ +\exp\left[(\ln v)\times(x+1+s)\right](\mu_{x+1+s}l_{x+1+s}) \end{Bmatrix}$$
$$+2(\ln v)^2\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d}{ds}d_{x+s}\right) + 3(\ln v)\exp\left[(\ln v)\times(x+1+s)\right]\left(\frac{d^2}{ds^2}d_{x+s}\right) \quad (79)$$
$$+\exp\left[(\ln v)\times(x+1+s)\right]\frac{d^3}{ds^3}d_{x+s}$$

$$\left[\frac{d^3}{ds^3}C_{x+s}\right]_0^{\Omega}=\left[\begin{array}{l}(\ln v)^2\left\{\begin{array}{l}(\ln v)e^{(\ln v)(x+1+s)}\times d_{x+s}-e^{(\ln v)(x+1+s)}\left(\mu_{x+s}l_{x+s}\right)\\+e^{(\ln v)(x+1+s)}\left(\mu_{x+1+s}l_{x+1+s}\right)\end{array}\right.\\+2(\ln v)^2 e^{(\ln v)(x+1+s)}\left(\frac{d}{ds}d_{x+s}\right)+3(\ln v)e^{(\ln v)(x+1+s)}\left(\frac{d^2}{ds^2}d_{x+s}\right)\\+e^{(\ln v)(x+1+s)}\frac{d^3}{ds^3}d_{x+s}\end{array}\right]_{s=\Omega}$$

$$-\left[\begin{array}{l}(\ln v)^2\left\{\begin{array}{l}(\ln v)e^{(\ln v)(x+1+s)}\times d_{x+s}-e^{(\ln v)(x+1+s)}\left(\mu_{x+s}l_{x+s}\right)\\+e^{(\ln v)(x+1+s)}\left(\mu_{x+1+s}l_{x+1+s}\right)\end{array}\right.\\+2(\ln v)^2 e^{(\ln v)(x+1+s)}\left(\frac{d}{ds}d_{x+s}\right)+3(\ln v)e^{(\ln v)(x+1+s)}\left(\frac{d^2}{ds^2}d_{x+s}\right)\\+e^{(\ln v)(x+1+s)}\frac{d^3}{ds^3}d_{x+s}\end{array}\right]_{s=0} \tag{80}$$

$$\left[\frac{d^3}{ds^3}C_{x+s}\right]_0^{\Omega}=-\left\{\begin{array}{l}(\ln v)^2\left\{\begin{array}{l}(\ln v)e^{(\ln v)(x+1)}\times d_x-e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\+e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{array}\right.\\+2(\ln v)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3(\ln v)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\+e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{array}\right\} \tag{81}$$

summing up the discounted death from zero to the limit of life Ω, we have

$$\frac{1}{D_x}\sum_{S=0}^{\Omega}{}^{(K)}C_{x+s}=\frac{1}{D_x}\sum_{S=0}^{\Omega}C_{x+s}+\frac{K-1}{2K}\left[\frac{C_{x+s}}{D_x}\right]_{s=0}^{\Omega}+\frac{\left(1-K^2\right)}{12K^2}\left[\frac{1}{D_x}\frac{d}{ds}C_{x+s}\right]_{s=0}^{\Omega}$$
$$+\frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_x}\frac{d^3}{ds^3}C_{x+s}\right]_{s=0}^{\Omega} \tag{82}$$

substituting for the derivatives in (82) but ignoring higher order derivatives than 3 gives

$$\frac{1}{D_x}\sum_{S=0}^{\Omega}{}^{(K)}C_{x+s}=\frac{1}{D_x}\sum_{S=0}^{\Omega}C_{x+s}-\frac{K-1}{2K}\left[\frac{C_x}{D_x}\right]$$
$$-\frac{\left(K^2-1\right)}{12K^2}\left[\frac{1}{D_x}\left\{\begin{matrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x-e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\+e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{matrix}\right\}\right]$$
$$-\frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_x}\left\{\begin{matrix}\left(\ln v\right)^2\left\{\begin{matrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x-e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\+e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{matrix}\right\}\\+2\left(\ln v\right)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3\left(\ln v\right)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\+e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{matrix}\right\}\right] \tag{83}$$

Following definition in Bowers et al. (1997), the discrete whole life insurance whose benefit is payable at the end of the next anniversary period is defined as

$$A_x=\frac{1}{D_x}\sum_{s=0}^{\Omega}C_{x+s} \tag{84}$$

Consequently, the K-thly life insurance benefit is given as

$$A_x^{(K)}=\frac{1}{D_x}\sum_{S=0}^{\Omega}{}^{(K)}C_{x+s} \tag{85}$$

$$A_x^{(K)}=A_x-\frac{K-1}{2K}\left[\frac{C_x}{D_x}\right]-\frac{\left(K^2-1\right)}{12K^2}\left[\frac{1}{D_x}\left\{\begin{matrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x-e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\+e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{matrix}\right\}\right]$$
$$-\frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_x}\left\{\begin{matrix}\left(\ln v\right)^2\left\{\begin{matrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x-e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\+e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{matrix}\right\}\\+2\left(\ln v\right)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3\left(\ln v\right)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\+e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{matrix}\right\}\right] \tag{86}$$

$$A_{x+1}^{(K)} = A_{x+1} - \frac{K-1}{2K}\left[\frac{C_{x+1}}{D_{x+1}}\right] - \frac{\left(K^2-1\right)}{12K^2}\left[\frac{1}{D_{x+1}}\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+2)} \times d_{x+1} - e^{(\ln v)(x+2)}\left(\mu_{x+1}l_{x+1}\right)\\ +e^{(\ln v)(x+2)}\left(\mu_{x+2}l_{x+2}\right)\end{Bmatrix}\right]$$
$$-\frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_{x+1}}\begin{Bmatrix}\left(\ln v\right)^2\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+2)} \times d_{x+1} - e^{(\ln v)(x+2)}\left(\mu_{x+1}l_{x+1}\right)\\ +e^{(\ln v)(x+2)}\left(\mu_{x+2}l_{x+2}\right)\end{Bmatrix}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+2)}\left(\frac{d}{dx}d_{x+1}\right)+3\left(\ln v\right)e^{(\ln v)(x+2)}\left(\frac{d^2}{dx^2}d_{x+1}\right)\\ +e^{(\ln v)(x+2)}\frac{d^3}{dx^3}d_{x+1}\end{Bmatrix}\right] \quad (87)$$

$$A_{x+2}^{(K)} = A_{x+2} - \frac{K-1}{2K}\left[\frac{C_{x+2}}{D_{x+2}}\right] - \frac{\left(K^2-1\right)}{12K^2}\left[\frac{1}{D_{x+2}}\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+3)} \times d_{x+2} - e^{(\ln v)(x+3)}\left(\mu_{x+2}l_{x+2}\right)\\ +e^{(\ln v)(x+3)}\left(\mu_{x+3}l_{x+3}\right)\end{Bmatrix}\right]$$
$$-\frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_{x+2}}\begin{Bmatrix}\left(\ln v\right)^2\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+3)} \times d_{x+2} - e^{(\ln v)(x+3)}\left(\mu_{x+2}l_{x+2}\right)\\ +e^{(\ln v)(x+3)}\left(\mu_{x+3}l_{x+3}\right)\end{Bmatrix}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+3)}\left(\frac{d}{dx}d_{x+2}\right)+3\left(\ln v\right)e^{(\ln v)(x+3)}\left(\frac{d^2}{dx^2}d_{x+2}\right)\\ +e^{(\ln v)(x+3)}\frac{d^3}{dx^3}d_{x+2}\end{Bmatrix}\right] \quad (88)$$

Result

As an immediate consequence from the results obtained in equation (86), we can take the limit as K tends to infinity in (86), we obtain the continuous whole life insurance. Following Neil (1979), $\lim_{K\to\infty} A_x^{(K)} = \overline{A}_x$ and consequently,

$$\lim_{K\to\infty} A_x^{(K)} =$$

$$\lim_{K\to\infty} A_x - \lim_{K\to\infty} \frac{K-1}{2K}\left[\frac{C_x}{D_x}\right] - \lim_{K\to\infty} \frac{\left(K^2-1\right)}{12K^2}\left[\frac{1}{D_x}\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{Bmatrix}\right]$$

$$-\lim_{K\to\infty} \frac{\left(K^4-1\right)}{720K^4}\left[\frac{1}{D_x}\begin{Bmatrix}\left(\ln v\right)^2\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{Bmatrix}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3\left(\ln v\right)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\ +e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{Bmatrix}\right] \tag{89}$$

$$\lim_{K\to\infty} A_x^{(K)} = \lim_{K\to\infty} A_x - \lim_{K\to\infty} \frac{1-\frac{1}{K}}{2}\left[\frac{C_x}{D_x}\right]$$

$$-\lim_{K\to\infty} \frac{\left(1-\frac{1}{K^2}\right)}{12}\left[\frac{1}{D_x}\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{Bmatrix}\right]$$

$$-\lim_{K\to\infty} \frac{\left(1-\frac{1}{K^4}\right)}{720}\left[\frac{1}{D_x}\begin{Bmatrix}\left(\ln v\right)^2\begin{Bmatrix}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{Bmatrix}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3\left(\ln v\right)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\ +e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{Bmatrix}\right] \tag{90}$$

$$\overline{A}_x = A_x - \frac{1}{2}\left[\frac{C_x}{D_x}\right] - \frac{1}{12}\left[\frac{1}{D_x}\begin{Bmatrix}(\ln v)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}(\mu_x l_x)\\ +e^{(\ln v)(x+1)}(\mu_{x+1}l_{x+1})\end{Bmatrix}\right]$$
$$-\frac{1}{720}\left[\frac{1}{D_x}\begin{Bmatrix}(\ln v)^2\begin{Bmatrix}(\ln v)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}(\mu_x l_x)\\ +e^{(\ln v)(x+1)}(\mu_{x+1}l_{x+1})\end{Bmatrix}\\ +2(\ln v)^2 e^{(\ln v)(x+1)}\left(\frac{d}{dx}d_x\right)+3(\ln v)e^{(\ln v)(x+1)}\left(\frac{d^2}{dx^2}d_x\right)\\ +e^{(\ln v)(x+1)}\frac{d^3}{dx^3}d_x\end{Bmatrix}\right] \quad (91)$$

This is the continuous whole life insurance for a life aged x

Furthermore, from the results obtained in equation (86), we can value an increasing whole life insurance as the aggregate of the deferred whole life insurance schemes with deferred periods $0,1,2,3,...$ years and the sum is unity so that the death benefits in the rth year becomes $(r+1)$. This reasoning applies irrespective of whether the death benefits is payable at the moment of death or at the end of the $\frac{1}{K}th$ year of death or at the end of year of death.

$$\left(IA^{(K)}\right)_x = \begin{Bmatrix} A^{(K)1}{}_{x:\overline{1}|} & + & {}_1p_x(1+i)^{-1}A^{(K)1}{}_{x+1:\overline{1}|} & + & {}_2p_x(1+i)^{-2}A^{(K)1}{}_{x+2:\overline{1}|} & + & .... \\ & + & {}_1p_x(1+i)^{-1}A^{(K)1}{}_{x+1:\overline{1}|} & + & {}_2p_x(1+i)^{-2}A^{(K)1}{}_{x+2:\overline{1}|} & + & ... \\ & & & + & {}_2p_x(1+i)^{-2}A^{(K)1}{}_{x+2:\overline{1}|} & + & ... \\ & & & & & + & ... \\ & & & & & + & ... \end{Bmatrix} \quad (92)$$

Now consider each row, we have

$$\left(IA^{(K)}\right)_x = A_x^{(K)} +_1 p_x(1+i)^{-1}\left(A^{(K)1}{}_{x+1:\overline{1}|} +_1 p_{x+1}(1+i)^{-1}A^{(K)1}{}_{x+2:\overline{1}|} +_2 p_{x+1}(1+i)^{-2}A^{(K)1}{}_{x+3:\overline{1}|} +...\right)$$
$$+_2 p_x(1+i)^{-2}\left(A^{(K)1}{}_{x+2:\overline{1}|} +_1 p_{x+2}(1+i)^{-1}A^{(K)1}{}_{x+3:\overline{1}|} +_2 p_{x+2}(1+i)^{-2}A^{(K)1}{}_{x+4:\overline{1}|} +...\right)+... \quad (93)$$

$$\left(IA^{(K)}\right)_x = A_x^{(K)} +_1 p_x(1+i)^{-1}A_{x+1}^{(K)} +_2 p_x(1+i)^{-2}A_{x+2}^{(K)} \quad (89)$$

$$\left(IA^{(K)}\right)_x = \left\{ \begin{array}{l} A_x - \dfrac{K-1}{2K}\left[\dfrac{C_x}{D_x}\right] - \dfrac{\left(K^2-1\right)}{12K^2}\left[\dfrac{1}{D_x}\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{array}\right\}\right] \\ -\dfrac{\left(K^4-1\right)}{720K^4}\left[\dfrac{1}{D_x}\left\{\begin{array}{l}\left(\ln v\right)^2\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+1)}\times d_x - e^{(\ln v)(x+1)}\left(\mu_x l_x\right)\\ +e^{(\ln v)(x+1)}\left(\mu_{x+1}l_{x+1}\right)\end{array}\right\}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+1)}\left(\dfrac{d}{dx}d_x\right)+3\left(\ln v\right)e^{(\ln v)(x+1)}\left(\dfrac{d^2}{dx^2}d_x\right)\\ +e^{(\ln v)(x+1)}\dfrac{d^3}{dx^3}d_x\end{array}\right\}\right] \end{array}\right\}$$

$$+{}_1p_x\left(1+i\right)^{-1}\left\{ \begin{array}{l} A_{x+1} - \dfrac{K-1}{2K}\left[\dfrac{C_{x+1}}{D_{x+1}}\right] - \dfrac{\left(K^2-1\right)}{12K^2}\left[\dfrac{1}{D_{x+1}}\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+2)}\times d_{x+1} - e^{(\ln v)(x+2)}\left(\mu_{x+1} l_{x+1}\right)\\ +e^{(\ln v)(x+2)}\left(\mu_{x+2}l_{x+2}\right)\end{array}\right\}\right] \\ -\dfrac{\left(K^4-1\right)}{720K^4}\left[\dfrac{1}{D_{x+1}}\left\{\begin{array}{l}\left(\ln v\right)^2\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+2)}\times d_{x+1} - e^{(\ln v)(x+2)}\left(\mu_{x+1} l_{x+1}\right)\\ +e^{(\ln v)(x+2)}\left(\mu_{x+2}l_{x+2}\right)\end{array}\right\}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+2)}\left(\dfrac{d}{dx}d_{x+1}\right)+3\left(\ln v\right)e^{(\ln v)(x+2)}\left(\dfrac{d^2}{dx^2}d_{x+1}\right)\\ +e^{(\ln v)(x+2)}\dfrac{d^3}{dx^3}d_{x+1}\end{array}\right\}\right] \end{array}\right\}$$

$$+{}_2p_x\left(1+i\right)^{-2}\left\{ \begin{array}{l} A_{x+2} - \dfrac{K-1}{2K}\left[\dfrac{C_{x+2}}{D_{x+2}}\right] - \dfrac{\left(K^2-1\right)}{12K^2}\left[\dfrac{1}{D_{x+2}}\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+3)}\times d_{x+2} - e^{(\ln v)(x+3)}\left(\mu_{x+2} l_{x+2}\right)\\ +e^{(\ln v)(x+3)}\left(\mu_{x+3}l_{x+3}\right)\end{array}\right\}\right] \\ -\dfrac{\left(K^4-1\right)}{720K^4}\left[\dfrac{1}{D_{x+2}}\left\{\begin{array}{l}\left(\ln v\right)^2\left\{\begin{array}{l}\left(\ln v\right)e^{(\ln v)(x+3)}\times d_{x+2} - e^{(\ln v)(x+3)}\left(\mu_{x+2} l_{x+2}\right)\\ +e^{(\ln v)(x+3)}\left(\mu_{x+3}l_{x+3}\right)\end{array}\right\}\\ +2\left(\ln v\right)^2 e^{(\ln v)(x+3)}\left(\dfrac{d}{dx}d_{x+2}\right)+3\left(\ln v\right)e^{(\ln v)(x+3)}\left(\dfrac{d^2}{dx^2}d_{x+2}\right)\\ +e^{(\ln v)(x+3)}\dfrac{d^3}{dx^3}d_{x+2}\end{array}\right\}\right] \end{array}\right\}$$

Discussion

The derived models generalize and unify existing actuarial formulations by incorporating an analytically rigorous estimation technique which extends beyond the traditional commutation functions approaches. However, the closed-form expression derived captures payment frequencies greater than one such as semi-annual, quarterly and monthly, resolving the problems of estimating

act present values under non-annual payment assumptions. The Euler-Maclaurin expansion offers a smooth estimation to the sum of discounted probabilities over finely divided intervals, ensuring higher accuracy compared to the standard actuarial linear interpolation methods (uniform distribution of death assumption). The continuous whole life model derived through the Euler-Maclaurin series accommodates the limiting behavior of frequent payments as the interval tends to infinity. The resulting expression provides a tractable actuarial model, closely aligned to the analytical underpinnings of continuous-time life insurance mathematics and offers a basis for analytic comparison against more discretized methods.

The model for increasing whole life insurance, where the benefit due increases linearly over time, is particularly worrisome due to its analytical intractability. The application of the Euler-Maclaurin series enhances a tractable estimation to what would otherwise involve recursive methods. The derived expressions provides both analytical insight for practical opportunities application in product pricing and reserve estimation in life insurance products developments with benefit innovation characteristics.

Although market data is unavailable for direct numerical validation, the theoretical correctness of the results is supported by their derivation from the first principles and their internal consistency when compared with linear interpolation. For instance, when simplified under certain constraints (e.g. constant force of mortality or annual payments), the new models reduce to classical results, thereby reinforcing their validity.

The basic contribution of this paper lies in the derivation of these expressions and in demonstrating that the Euler-Maclaurin series, traditionally applied in numerical and analytical mathematics, can be efficiently deployed to the domain of actuarial mathematics for deriving advanced life insurance models. This analytical innovation widens the theoretical depth available to actuaries and lays the foundation for further research in estimating life contingency functions under complex payment and benefit structures.

Implications and Adequacy of the Derived Expressions

The implication of these results lies in their ability to enhance both the precision and computational efficiency of life insurance valuation. The multi-payment frequency model accounts for more realistic premium payment frameworks (monthly, quarterly or weekly), which are common in practice. Traditional actuarial models usually depend on estimations such as uniform distribution of deaths assumptions which assume annualized payments, leading to discrepancies. The closed-form expressions derived here eliminates the need for such estimations and aligns the model more closely with actual insurance contracts.

The continuous life insurance model provides exact limiting conditions of the discrete formulations, accommodating the behavior of infinitesimally small payment intervals. This is especially important in theoretical analyses, reserve computations under Solvency II or IFRS 17 frameworks, and in high-precision pricing conditions. The increasing whole life insurance model enables valuation of products where benefits increase linearly over time, which are commonly applied to hedge inflation. In the past, such products usually employed iterative numerical methods. The availability of a closed-form expression markedly ease-out implementation and sensitivity analysis.

Collectively, these tools provide enough and highly accurate technique for estimating the actuarial present value for different whole life insurance products, especially in theoretical or high-precision

computational frameworks. By eliminating the need for summation over life contingency functions or numeric integration, they enhance the speed and reproducibility of actuarial computations.

Evidence Supporting the Adequacy of the Derivations

Although empirical validation using real-world mortality data and interest rate data were not conducted due to data unavailability, different lines of theoretical evidence support the validity and adequacy of the models. The analytical rigour involved in the derivations were based on the Euler-Maclaurin formula, which is a well-established technique of estimating sums by integrals with quantifiable error bounds. This lends analytical robustness to the expressions. In particular cases, such as annual payments, constant force of mortality or zero benefit escalation, the derived models reduce exactly to well-known classical actuarial expressions. This consistency strongly validates the generalizations proposed. The Euler-Maclaurin series provides known error bounds under certain smoothness conditions of the mortality laws and interest functions. Consequently, the models maintain a high level of accuracy even when data were not explicitly available, provided that assumptions on smoothness hold. Symbolic and numerical comparisons under hypothetical or constructed mortality laws will prove that the new models behave consistently with established theoretical expectations (e.g., actuarial present values increase with age and benefit size, and decrease with higher discount rates)

Conclusion

Life insurance estimations are essential based on two major reasons. The first reason evolves from the gap between the numerical estimations and analytical analysis. While numerical analysis sheds light on specified mortality scenarios, analytical techniques consider important properties and behaviour in general cases. This includes the asymptotic behaviour of mortality functions as the specified period of payment of benefits become large or infinitesimally small. The second reason concerns the challenge of implementing the approximation schemes. This paper therefore contributes in both directions as the results evince good understanding of such estimation procedures. Consequently, we investigate the effect of the Bernoulli power series on the behaviour of whole life insurance function in the long run. This method is important because we can generate a closed form expression which serves as a reference point in a more complex mortality scenario. The valuation of a life insurance policy still in force at any time $s;\ \ 0<s<\infty$ is essential to assess the solvency of the business. Since life insurance policy is essentially a long-term contract where the insurer accepts risk from the insured by receiving premiums and paying benefit when the contingent future event happens, we need to predict future events based on estimation. Therefore, some assumptions have to be made in respect of the variables of interest defined as the actuarial basis because life insurance policies depend on death or survival of the insured life in line with the economic and financial environment as premiums have to be invested to pay future benefits and on any other variables considered in the contract. However, with the emerging and sophistication of financial market in connection to the securitization of life insurance risk as an option in downplaying the traditional exchange of risk through reinsurance contracts, it becomes necessary to employ finance principles for the computation of life insurance premiums. Future work may include numerical validation of the models once suitable mortality and financial data become available, as well as extensions to incorporate stochastic interest rates or mortality improvements. Nevertheless, the results achieved here represent a significant theoretical advancement and contribute novel insights to the body of actuarial literature.

Recommendation

Insurance business is a risky business in terms of benefits paid out. In order to protect the life insurers from one-off pay out, the above model can be employed to compute the insured's benefits as agreed to, in the policy conditions.

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Developments in Nuclear Energy Power Plants-A Review

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ABSTRACT

The paper posits that nuclear energy is energy from the nucleus of atoms that binds neutrons and protons together and can be released by bombardment and can be exploited for electricity generation. The paper reviews literature on nuclear power plants and positions it as a viable substitute for replacing fossil fuel generation in order to avoid and avert emission of greenhouse gases which results in global warming and consequent climate change. The paper defines nuclear power and describes how nuclear power stations operate.

The paper also describes the disadvantages and advantages of nuclear electricity generation. It compares nuclear power plants with fossil, solar and wind power plants. The paper says current nuclear power plants are mainly based on nuclear fission as nuclear fusion is still in experimental stage. Nuclear fission particularly of uranium-235 is a mature technology. If successful, nuclear fusion will provide electricity for thousands of years as nuclear fusion material are plenty whereas nuclear fission material is scarce, depletable and estimated to continue to last for the next 50 years only. The paper posits that nuclear power stations need less geographical space than solar or wind energy power stations per given MW output.

The paper concludes by recommending nuclear power stations for countries like Zimbabwe with energy shortfalls.

Introduction

Nuclear energy is a realistic option for decisively replacing fossil fuel generation and hence curb greenhouse gas emission and climate change (Fernandez-Arias et al (2020)). The expected phasing down of fossil fuel power plants in the next decade is anticipated to witness an increase or surge in the numbers of nuclear power stations. According to Hashemian (2011) nuclear power plants can operate upto 60 years or more. According to Zinkle and Was (2013), power generation mainly from fossil fuel is responsible for 66 % of greenhouse gas emissions worldwide. Brook et al. (2014) says that there is a compelling need to convert fossil fuel power plants to nuclear fission plants. Wind and solar electricity generation are intermittent, variable and unpredictable and need to operate in conjunction with nuclear power plants. According to Mathew (2022), nuclear fusion can provide unlimited, clean, safe and affordable energy but unfortunately is still at experimental stage. According to National Geographic Society Education (2024), nuclear energy is the energy in the nucleus or core of an atom, which can be exploited for electricity production and generation in nuclear power plants. The mentioned energy requires first to be emitted or let loose from the atom's nucleus. National Geographic defines an atom as small entities that make up all matter in the universe and unites entities such as protons and neutrons i.e. kept together in the atom's nucleus by binding energy. There exists huge amount of energy in the atom's dense nucleus (National Geographic Society Education (2024)).

According to ForoNuclear (2024), atoms are the smallest particles into which a chemical element can be divided and still maintain its properties. An atom consists of its core or nucleus consisting of neutrally charged neutrons and positively charged protons. Circulating around the nucleus are negatively charged electrons in various shells. The force that binds the nucleus even overcoming the electrostatic repulsive forces of one proton against another is called nuclear force or nuclear

power. ForoNuclear says that nuclear energy is power normally resident in the core or nucleus of an atom. ForoNuclear (2024), says that the mass of the nucleus is less than the sum of the mass of its parts. The disparity between the mass of the nucleus and the mass of its components is termed mass defect (m) and the energy that binds the components is calculated from Einstein Equation

E=(m)c^2 , where c=light's speed

According to International Atomic Energy Agency (2024), the energy in the nucleus of an atom can be emitted in two ways (1) nuclear fission –when nuclei of atoms split into several parts and (2) nuclear fusion –when nuclei fuse together. Production of energy through nuclear fission is mature and to produce electric energy through nuclear fusion is still at Research and Design phase.

According to National Geographic Society Education (2024), a series of machines which can control or regulate nuclear fission to generate electricity is called a nuclear reactor or nuclear power plant. The pellets of uranium-235 are the fuel employed in nuclear reactors to result in nuclear fission. The atoms of uranium are compelled to break apart in nuclear reactors and release products of fission. Products of fission force the splitting of other uranium atoms initiating a chain reaction. The power from this chain reaction generates thermal energy. Water, which is normally the reactor's cooling agent is heated by the thermal energy created from nuclear fission. Other reactors employ liquid metal or molten salt as cooling agent.

The steam that is produced under pressure by the nuclear fission is heated up to produce rotation of the turbine-generator set thereby producing electricity.

According to National Geographic Society Education (2024), rods of material known as nuclear Poisson can adjust how much electricity is produced. Xenon element is an example of nuclear Poisson material that absorb products of nuclear fission. If more rods of the nuclear poisson are available during the dynamics of the chain reaction, the less speed and the more restricted the chain reaction. Removing the rods will facilitate a faster chain reaction and produce more heat and therefore more electricity.

According to Britannica (2024), nuclear power is electricity generated by power plants that derive their heat from fission in a nuclear reactor. The role of a boiler is played by the reactor.
Nuclear power provides approximately 15 % of the world's electricity according to Britannica (2024).
ForoNuclear(2024) says that nuclear fission and nuclear fusion are the two major types of nuclear reactors.

When light weight atoms have nuclei that are combined to result in a stable and heavier atom nuclear fusion releases energy e.g. two hydrogen atoms are combined to create one helium atom as what happens in the sun. Nuclear fusion is the source of heat from the sun. It is still at experimental stage here on earth.

Nuclear fission occurs when heavy atoms' nuclei are bombarded with neutrons and decompose into smaller and lighter nuclei emitting energy that normally keeps their protons and neutrons together and releasing three or two neutrons. According to ForoNuclear (2024), these can then subsequently produce more fissions by interacting with new heavy nuclei that will emit new

neutrons and so on such that a chain reaction sustains itself. ForoNuclear (2024) calls this multiplying effect 'nuclear fission chain reaction'.
According to Britannica (2024), in nuclear fission the nucleus of an atom such as that of plutonium or uranium breaks up into two lighter nuclei of approximately equal mass. The process may be spontaneous in some cases or induced by the excitation or bombardment of the nucleus with a variety of particles (e.g. neutrons, protons, deuterons or alpha particles) or with electromagnetic radiation in the form of gamma rays (Britannica (2024)). A huge amount of energy is emitted in the process. A tiny uranium pellet the size of a peanut has potential to produce as much power as 800kg of coal according to EDF website (2024).

The huge amount of thermal energy produced during the chain reaction of nuclear fission is exploited by nuclear power plants to produce electricity via steam production.

To start the process of fission reaction, normally radium, polonium, beryllium or other alpha emitter are used. Alpha particles emanating from the disintegration results in the ejection or release of neutrons from beryllium as it transforms into carbon-12.

WHAT IS NUCLEAR FISSION?

Nuclear fission is a reaction whereby the nucleus of a heavy atom splits or fragments into two or more tinnier nuclei releasing energy in the process. A uranium-235 atom fragments into two smaller nuclei e.g. barium nucleus and krypton nucleus and two or more neutrons when bombarded by a neutron. (International Atomic Energy Agency (2022)). Other nearby uranium-235 atoms are hit by these extra neutrons and this will result in it the further splitting to produce additional neutrons thus providing a multiplying effect resulting in a chain reaction during a split of a second.in the process (International Atomic Energy Agency (2022)).

During every time that the reaction above happens, there occurs a release of radiation and thermal energy. Thermal energy can be transformed into electric energy in an identical manner to coal power generation.

According to National Geographic Society Education (2024), nuclear energy can also be generated through nuclear fusion or fusing or joining together of atoms e.g. in the sun where hydrogen atoms fuse to form helium atoms.

DESCRIPTION OF THE FUNCTIONALITY OF A NUCLEAR POWER STATION

Nuclear reactors and their equipment inside nuclear power plants has inside them and regulate the chain reaction normally powered by uranium-235 to generate thermal energy via fission. The thermal energy produced heats the cooling agent in the reactor which is normally water. This water vapor is subsequently directed to rotate the turbine-generator set directly or through a gearbox to generate electric energy.

Mineral Extraction, Enrichment and Getting Rid Of Uranium

Uranium is a substance or element that is found in rocks almost everywhere in the world. It has several isotopes. Two isotopes of uranium which are primordial are uranium238 and uranium-235. Uranium-238 constitute the majority of uranium found inside planet earth and uranium-238 cannot produce fission reactions like uranium-235 which contribute less than one % of all uranium in the world. According to National Geographic Society Education (2024), the frequently used fuel to generate nuclear energy is uranium due to the fact that uranium atoms split apart easily comparatively. According to TEPCO (2024), uranium-235 acts as a fuel for nuclear power plants. TEPCO (2024) says that naturally occurring uranium has only approximately 0.7 % uranium-235 which needs concentration of this ratio to about 2 % or 4 %. It is then baked into pellets after undergoing various processes. TEPCO (2024) says that the pellets have an approximate diameter and height of 1 cm each.

To make naturally occurring uranium more readily undergo fission, it is imperative that we increase the quantity of uranium-235 within a given sample via a process known as enrichment of uranium. Uranium needs to get extracted from other minerals after it is mined.

The following generation after the current generation of nuclear power stations will produce far less nuclear waste compared to today's reactors (Galindo (2022)). They could be under construction by 2030.

According to ForoNuclear (2024), the most common uses of nuclear power is electricity production although it has many applications in sectors such as medicine, hydrology, agriculture and food, mining, industry, art, the environment, space exploration and cosmology.

According to Gov.UK (2024), a recent report by the U.N. Economic Commission, it is impossible to meet the World's climate change targets if nuclear technologies are excluded from future efforts of the de-carbonization of the power industry.

According to National Geographic Society Education (2024), nuclear material such as uranium and plutonium are also used to make nuclear weapons.

DISCOVERY

In 1911, Ernest Rutherford discovered the core of atoms called the nucleus soon after observing and studying α particles released by atoms. The neutrons were discovered by James Chadwick and its reaction dynamics were done by Jolliot Currie couple. Friz Strassman and Otto Hahn found out reactions of fission in 1939. Enrico Fermi is given the credit of developing the chain reaction. A nuclear power station is also called an atomic power plant. The source of thermal energy in nuclear reactors are atoms and hence the name. Heat is employed to produce steam that turns or rotates a steam turbine-generator set to generate electricity.

According to ForoNuclear (2024), the water for cooling is obtained from the sea, river or lake and exploited for liquefying the water vapor contained in the condenser. ForoNuclear (2024) highlights the components of a Nuclear power plant as follows: -

- Uranium-235 fuel ore
- Reactor vessel
- Pressurizer
- Control rods or control bars
- Vapor generators
- Containment building-normally a meter-thick concrete and steel structure
- Turbine
- Alternator or generator
- Transformer
- Cooling tower
- Condenser.

According to ForoNuclear (2024), the main components of a Nuclear Reactor are as follows: -

1. **Fuel**-normally the dioxide of enriched uranium 235. Employed as a source of heat and also at the same time as a source of neutrons needed to sustain the chain reaction of uranium. Uranium dioxide is in a solid state in cylindrical pellet form encapsulated into metallic rods a few meters long (ForoNuclear (2024)). According to World Nuclear Association (2024), fuel is normally uranium oxide pellets tubes configured as fuel rods. These rods are configured in assemblies of fuel in the reactor.
2. **Moderator Water**- Water retards the fast neutrons produced by the fission chain reaction, which results in new nuclear fissions and sustainability of the reaction which is in a form of a chain. According to World Nuclear Association (2024), the moderator is normally water but maybe graphite.
3. **Cooling water**-The same water that is used as a type of moderator now also functions as a heat extractor which heat is produced by nuclear fission of the fuel which is uranium-235.
4. **Control rods**- They are the regulating entities within the reactor. The control rods behave in the absorption of neutrons. These rods are manufactured from indium-cadmium or boron carbide and facilitates constant control of the neutron population whilst keeping the reactor stable (Foronuclear (2024)). They also enable the stopping of the chain reaction whenever necessary. According to World Nuclear Association (2024), control rods are normally made from boron, hafnium and cadmium to regulate reaction rate or even to halt it.
5. **Shielding** –according to Foronuclear (2024), they prevent leakage of radiation and neutrons from inside the reactor to outside. The shielding is normally made up of lead, steel or concrete.
6. **Safety Considerations**-all power stations of the nuclear type incorporate many safety schemes for preventing the leakage of the radioactive material to the surroundings. These schemes also comprise of including the 'containment building' as part of the design.

ForoNuclear (2024), says that nuclear power generates heat through nuclear fission chain reactions in the nuclear reactor vessel which heats water to produce superheated steam under pressure which is used to rotate or spin a turbine-generator set and the generator produces electricity.

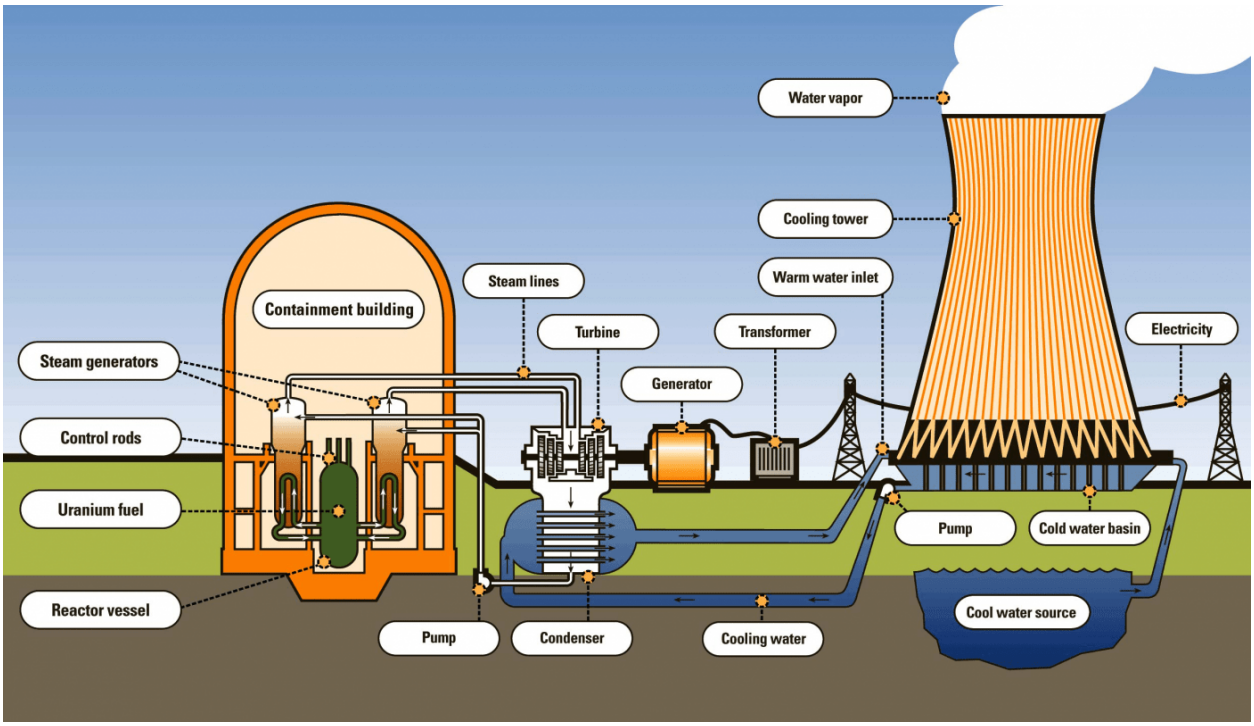
One of the major components of a nuclear power station is the nuclear reactor. It normally includes uranium which is the atomic and nuclear fuel. Its system is able to initiate, sustain or even halt the nuclear chain reaction in a control system or regulated manner. A nuclear power station operates in an identical manner to a conventional coal power plant except that the nuclear reactor with uranium fuel replaces the coal fuel as a heat source. Heat is obtained from the nuclear fuel which is uranium 235 through a chain reaction. The heat is employed to raise the temperature of water under elevated temperatures and elevated pressure conditions until it turns to water vapor. The water vapor rotates a turbine-generator set which converts rotational mechanical energy to electricity.
Inside the reactors construction materials encounter stress, corrosion and radiation

TYPES OF REACTORS (Fernandez-Arias et al. (2020)

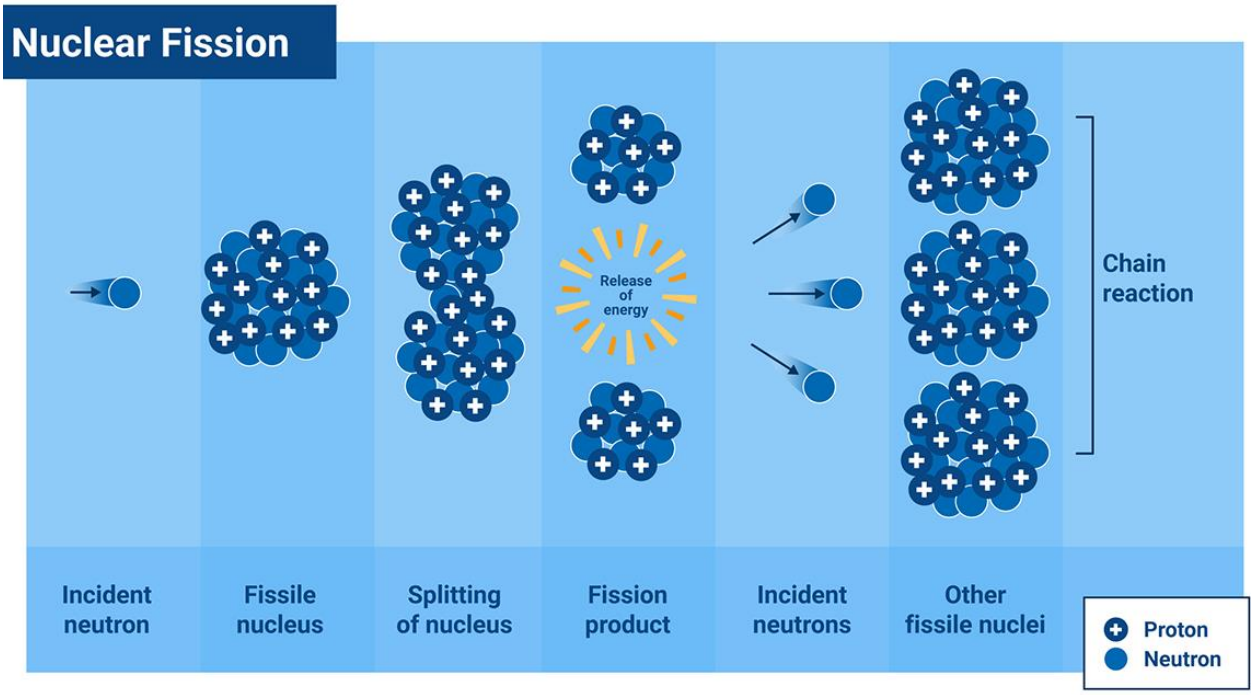
- Pressurized Water reactors(PWR)-two thirds of installed output capacity in the world
- Boiling Water Reactors(BWR)-twenty-one percent of installed capacity
- Pressurized Heavy Water Reactors (PHWR)-fourteen percent of installed output capacity
- Gas Cooled reactors-5 % of installed capacity

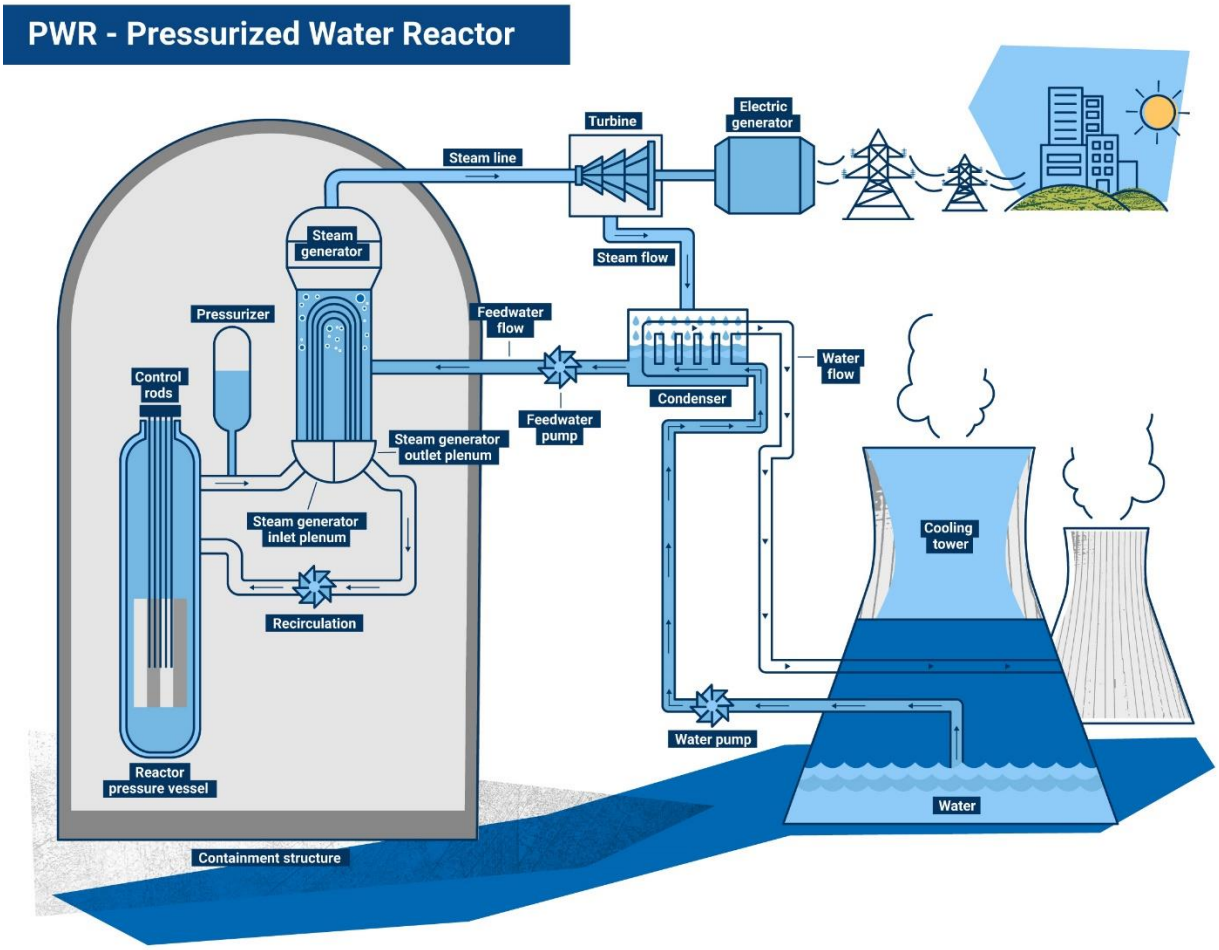
Two frequently used kinds of nuclear reactors are: -

- Pressurized Water Reactor (PWR) and
- Boiling Water Reactor (BWR) and

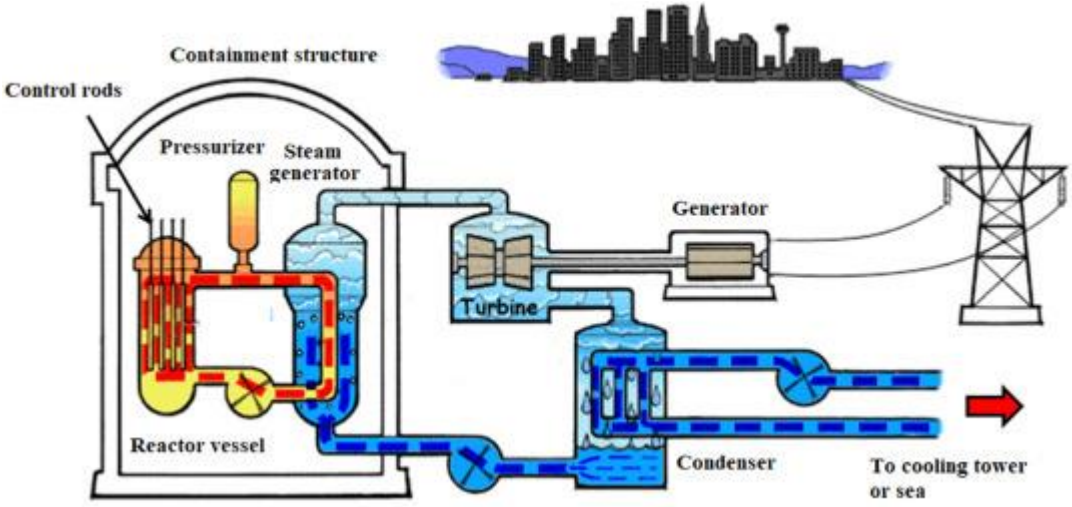


URANIUM DIOXIDE NUCLEAR FUEL




PWR - Pressurized Water Reactor
Turbine
Electric generator
Steam line
Steam generator
Steam flow
Pressurizer
Feedwater flow
Water flow
Control rods
Condenser
Feedwater pump
Steam generator outlet plenum
Steam generator inlet plenum
Cooling tower
Recirculation
Water pump
Reactor pressure vessel
Water
Containment structure

PRESSSURIZED WATER COOOLED NUCLEAR REACTOR



OPERATIONS OF A PRESSURIZED WATER REACTOR

It must be remembered that nuclear fission involves heavy atoms' nuclei being hit by neutrons which then disintegrate into lighter and smaller nuclei. They emit heat energy in this process from the energy that binds protons and neutrons composing them and emit two or three neutrons. More fission is produced as they interact again with new heavy nuclei which subsequently release fresh and new neutrons etc. in such a manner that there is sustenance of the reaction by the process itself. The chain reaction of nuclear fission is the multiplying effect. Pressurized Water reactors are the most widely deployed technologies in the world of nuclear power plants (Fernandez-Arias et al. (2020). According to Zinkle and Was (2013), pressurized water in the primary circuit enters the reactor core at 275 ^{O}C and has a core exit temperature of 325 ^{O}C. Low alloy or low carbon steel is employed to construct boundary of pressure components (pressurizer, reactor pressure vessel, condenser, turbine, steam lines and steam generator). Austenitic stainless steels make the core structural materials and also as cladding material inside of the reactor pressure vessel and pressurizer according to Zinkle and Was (2013). Nickel-based alloys make springs and fasteners.

According to Mathew (2022), water cooled reactors have been the major source of nuclear energy in the 20th century.

Was et al. (2019), says that materials for future nuclear power plants will need to operate under more extreme conditions of higher temperature and corrosive environment.

What differentiates Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR) is that Boiling Water Reactors comprises of one water circuit crafted for boiling to happen in the centre with directly flowing steam to the turbine blades which removes the need for pressurizer and steam generator that exists in Pressurized Water Reactors (Zinkle and Was (2013)). The operating temperature for both are comparable about 300 ^{O}C with comparable radiation environment and stress. According to Zinkle and Was (2013), the major difference is the zirconium alloys which is

employed as fuel rod cladding, with BWR fuel cladding optimized for resistance to hydrogen absorption in the low potential environment of the core.

Pressurized heavy water reactors are also in high use word-wide. It employs heavy water as the primary coolant and controller passing thermal energy to light water through a steam generator

5 STEPS THROUGH WHICH A NUCLEAR POWER STATION WORKS

1. Uranium nuclear fission occurs in the nuclear reactor vessel. This emits large quantities of heat energy that raises the temperature of the water coolant that circulates at very huge pressures. The primary circuit transports water through to a heat exchanger also called steam generator which produces water vapor. According to World Nuclear Association (2024), temperatures of approximately 325 ^{O}C is reached by water in the reactor and need to be kept below 150 times atmospheric pressure to avoid a situation where it would boil.
2. A secondary circuit transports this steam to a turbine-generator set.
3. The vanes or blades of the turbine rotate the turbine-generator set and rotational kinetic energy is converted to electricity by the generator or alternator.
4. After the steam passes through the turbine's blades, it is passed on to a condenser for cooling so that it becomes water liquid again.
5. According to ForoNuclear (2024), this water is then subsequently carried to the steam generator so that it becomes steam again inside a closed circuit.

According to TEPCO (2024), condensers are used to cool the steam after it has been exploited to spin the turbine and return it to water. TEPCO (2024) further says that condensers have 40 000 to 50 000 cooling pipes having a thickness of about 3 cm via which seawater flows, functioning to make the steam cool as the seawater never mixes with the hot steam. In addition, condensers help to enhance turbine efficiency because converting steam to water reduces the volume, forming a high vacuum which results in enhanced steam flow.

The cooling towers cools the steam.

The nuclear fission chain reactions can be started, sustained and stopped in the nuclear reactor in a regulated and determined way. There is enough capability to extract thermal energy from the nuclear reactor vessel.
According to Britannica (2024), a typical nuclear power plant has a generating capacity of nearly one gigawatt (GW) of electricity.

The major part in a nuclear power station is called the reactor that is the location that houses the uranium nuclear fuel.

According to Britannica (2024), the busbar costs of a nuclear power plant are sensitive to construction costs and interest rates. Stricter laws and carbon taxes on carbon pollution could definitely raise costs of running coal power plants and make nuclear generation more competitive.

ADVANTAGES OF NUCLEAR GENERATION

1. It is highly efficient- a tiny amount of nuclear fuel is needed to produce lots of electricity (BBC Bitesize (2024)).
2. Nuclear is a carbon-free electric energy source and can limit the emission of greenhouse gases. Nuclear power stations produce low carbon unlike gas, oil and coal power stations. They do not emit CO_2 during operational activities and they are critical in satisfying the goals of climate change.
3. It can be used as a supply to base load and is important for energy security. Nuclear power plants produce electricity 24/7
4. Its output can accurately be predicted
5. Britannica (2024) highlights that the cost of nuclear fuel is substantially less than the cost of fossil fuel per kilowatt-hour of electricity generated due to enormous energy content of each unit of nuclear fuel compared to fossil fuel.
6. According to Chu (1982), nuclear electricity generation is not only safe and reliable but also highly economical. It has low ongoing running costs and produces reliable electricity. Running costs are small once set up.
7. Nuclear energy is a carbon-free, renewable and clean source of energy.
8. Do not radically change the surroundings
9. Can be constructed in rural and urban areas according to National Geographic Society Education (2024)).
10. Nuclear power plants can produce more energy with less fuel compared to any other technology today and use very little fuel (Climate Portal (2024).
11. Has the highest capacity factor
12. Cleaner than fossil fuel
13. Plants need less maintenance

DISADVANTAGES OF NUCLEAR POWER

1. Danger of radioactive leaks-i.e. safety risks to humans, flora and fauna. The byproducts of nuclear generation are radioactive. According to National Geographic Society Education (2024), radioactive material is very toxic and causes risk of cancer, bone decay, blood diseases and causes burns. The products of radioactive waste lasts for a long time. Radioactive waste may pollute the groundwater in the soil that will be close to the plant posing risk to people or organisms in the area.
2. Costly-The maintenance and operational costs of nuclear power stations are above those for coal fuel stations due to complexity of nuclear generation stations and legal issues which pop-up during the station's operational activities.
3. Disposal of radioactive waste is a challenge which is risky to the environment and general public -geological disposal.
4. Danger of the development of nuclear weapons
5. During the occurrence of an accident, nuclear generation plants could be considered the most dangerous plants due to radioactive activities. It could result in harmful outcomes passed on from one generation to another over a large geographical area. Nuclear power stations must therefore be crafted and designed securely and robustly.

6. Can be used to manufacture nuclear weapons
7. Constructing nuclear reactors need or demands a high level of technological prowess and therefore only regions which will have pended their signature to the Nuclear-non-Proliferation Treaty could have access to uranium or plutonium that they require according to National Geographic Society Education (2024)). Because of the reasons above, majority of nuclear stations are in the developed world.
8. Need huge upfront investment –Nuclear power plants are highly expensive and complex to build (Greenpeace (2024)).
9. Nuclear fuel is not renewable and is a finite resource of energy (BBC Bitesize (2024))
10. Very high setup costs. Takes many years to construct.
11. Nuclear power plants are favorite targets to terrorist attack and sabotage.
12. The uranium in the world may run out in approximately 50 years

According to Koning and Rochman (2008), if nuclear generation is to be successful as a sustainable energy source, 5 crucial issues require to be addressed: -

1. Safety Issues
2. Inhibition of Proliferation
3. Production of minimum radioactive material waste
4. Access to natural resources e.g. uranium-235
5. Economic competitiveness

The interactions between particles normally neutrons and uranium-235 nuclei results in radioactivity, decay heat and finally electricity generation.

USES OF NUCLEAR ENERGY

- Electricity production
- Medical purposes to help in control of the proliferation of illnesses, in disease treatment or diagnosis.
- Energizes greatly ambitious exploration missions in space.

Reasons for the Opposition of Nuclear Energy by Environmentalists and Governments (Brook et al (2014):

- Unsafe
- Connection to the spread of nuclear weapons
- Uneconomic
- Unsuitable

According to Brook et al. (2014) sustainable means meeting current needs without compromising the ability of future generations to meet their own needs. There is need for sustainable use of uranium-235 resources if electricity production is limited to only nuclear fission.

According to World Nuclear Association (2024) 70% of electric power in France comes from nuclear generation. 50% of electricity in Ukraine, Slovakia, Belgium and Hungary comes from nuclear power and zero percent (0%) in Zimbabwe.

According to Britannica (2024), the first nuclear power plants were built in the 1960s. National Grid ESO (2024) says that the pioneering nuclear power generation plant on planet earth was built in Great Britain in 1956. They were prototypes that enabled the laying of groundwork for the construction of better energy reactors that were to follow. More than 400 nuclear reactors in the year 2012 were operational in 30 countries worldwide. Britannica (2024) says that the United States has the largest nuclear power industry with more than 100 reactors followed by France with more than 50.

According to World Nuclear Association website (2024), the first commercially operated nuclear plant began operational activities in the 1950s. Nuclear energy contribute 10 % of the world's electricity from about 440 power reactors according to World Nuclear Association website (2024), but Zinkle and Was (2013) puts the contribution from nuclear energy worldwide at 13 % and Mathew (2022) puts it at 11 % of global electricity generation. It is a dependable source of baseload electricity. According to Fernandez-Arias et al. (2020), as of 2020 there were 447 nuclear reactors operating in the world. Thirty-one (31) countries (plus Taiwan) have operational nuclear power plants. Commercial nuclear power industry began in the 1960s. According to National Geographic Society Education (2024), by 2011 the contribution to electricity generation from nuclear power plants was 15 % of total and nations such as France, Slovakia and Lithuania produce almost all of their electricity from nuclear power plants (National Geographic Society Education (2024)).

According to Koizumi and Morooko (2023), the history of nuclear electricity generation began with the discovery of radioactivity by Becquerel in 1896. The first production of electric power using nuclear worldwide occurred in the year 1951 in Idaho U.S.A at EBR-1

According to Fernandez-Arias et al. (2020), nuclear power plants were initially designed for a lifespan of 40 years which can be extended to 60 years and construction and commissioning period is 68 months (i.e. about 6 years).

According to Mathew (2022), New Innovations in Nuclear Energy include the following: -

1. Developments in big reactors
2. Emerging technological breakthroughs like small modular reactors or advanced fuel
3. Engineering advances in prolonging life span of existing nuclear reactors
4. Improved management of waste
5. New innovations and discoveries in materials

The demonstration of fusion reactors has been done successfully. According to Mathew (2022), the world's largest fusion reactor facility called ITER is at an advanced stage of construction to demonstrate the scientific and technological success of the fusion energy research for commercial production. The advantage is that fusion materials which is the fuel is accessible easily and widely available. Mathew (2022), says that it is believed that fusion energy is the pathway to energy security for thousands of years.

According to Mathew (2022), fusion reactor technology is very complex but promises unlimited energy potential. For reactions involving fusion to occur, there is need for collisions to happen

between the atomic nuclei which could only occur at elevated temperatures surpassing millions of degrees Celsius (Mathew (2022)).

Conclusions

Supply inadequacy and rampant load shedding in countries like Zimbabwe, calls for innovation in electricity generation methods. There in need for Nationally ventilating knowledge of alternative generation methods to coal.

Nuclear energy generation will be quite exciting for countries like Zimbabwe who are not yet members of the nuclear club. There is information that there are uranium deposits in Kanyemba area which have not yet been exploited. There are also uranium claims in Shamva in Zimbabwe according to a geologist who is a Director in the Ministry of Mines in Zimbabwe. The risks of nuclear leakages and diseases like cancer that radioactive material causes also acts as a deterrent. Care has to be taken if Zimbabwe is keen in joining the nuclear club. Since nuclear power stations are linked to nuclear weapons proliferation, there is need for commitment on the part of Zimbabwe to only use nuclear energy for powering our industries and not for producing nuclear weapons.

There is also need for studies in uranium-235 enrichment which is a critical step in effective and efficient nuclear power generation in Zimbabwe.

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DETERMINATION OF FUNCTIONAL GROUPS AND NUTRIENTS IN A LOCAL READY- TO -USE SUPPLEMENTARY FOOD BY FOURIER TRANSFORM INFRARED SPECTROSCOPY

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Abstract

Development of new functional foods must ensure presence of adequate nutrients to mitigate acute malnutrition. This study consists of an innovative approach for simultaneous detection of chemical bonds and organic content such as carbohydrates, fibres, lipids, and proteins of a local Ready-to-Use Supplementary Food (RUSF) by Fourier transform infrared (FTIR) spectroscopy and proximate analysis techniques. The RUSF was prepared by mixing peanut butter with soy bean oil into thin slurry. Icing sugar, baobab powder, extruded sorghum powder, and extruded soy meal powder were added into the peanut butter- soy bean oil slurry and thoroughly blended a the peanut butter making machine until a brown thick RUSF paste was produced. The RUSF was thoroughly mixed and a sample enough to cover the diamond crystal on the FTIR was placed onto the diamond crystal after zeroing the machine by scanning the air at mid-infrared region (4000-400 cm^{-1}). Obtained experimental FTIR wave numbers and literature-based wave ranges were used to assign chemical bonds and identify nutrients in the local RUSF. The proximate analysis fat content by Analysis of Association of Official Analytical Chemists (AOAC) Soxhlet method (AOAC, 2016), protein content using the VELPA SCIENTIFICA automatic distillation and titration system (Model UDK159), carbohydrate content through the carbohydrate by difference method (AOAC, 2004), and moisture by Adams analyser. FTIR analysis detected various different functional groups like amine groups, quinones, alcohols, aliphatic amines, alkanes, alkenes, alkyl halides, carboxylic acids, esters, ethers, ketones, peroxides, nitro compounds, phenols, and triglycerides. Carbohydrates, fibres, lipids, proteins, and water were detected by both FTIR and proximate analysis. This research underscored the potential of FTIR spectroscopy and proximate analysis as tools for rapid assessment and identification of nutrients in food science. This study concluded that the RUSF contained nutrients that could reduce and manage malnutrition and non-communicable diseases.

Key words: Fourier Transform Infrared, mid infrared spectroscopy, functional group$_3$, moderate acute malnutrition, Ready-to-Use Supplementary Food

Introduction

Ready-to-Use Supplementary Food (RUSF) refers to large-quantity lipid-based nutrient supplements for treatment of moderate acute malnutrition. RUSFs are fortified with micronutrients. They contain essential fatty acids and quality protein to ensure that a child's nutritional needs are met. RUSFs are advantageous as they do not require additional water or fuel to cook the product and they have low microbial count and longer shelf life. These products are available in different packaging options such as porches, sachets, and plastic jars with lids. These products include Plumpy Sup, eeZee RUSF, Nutributter, Plumpy Doz, Plumpy Doz- corn formula, Plumpy Up, Plumpy Soy, Growell Child, Gowell Mum, Plumpy Sup, Plumpy Sup corn formula, Plumpy Mum, and eeZee cup (Nutriset, 2014). RUSFs are supposed to be modifiable, low cost, palatable, safe, and nutrient dense for prevention or treatment of acute malnutrition (Manary, 2006). RUSFs consist of peanut butter, milk powder, vegetable oil, sugar, vitamins, and minerals. RUSFs contain all the energy and nutrients required to facilitate rapid catch-up growth especially in treatment of children from 6 months to 23 months with moderate acute malnutrition, appetite, and without medical complications. Some of the commercially available products are packaged in individual sachets that provide 500 kcal per sachet. It is used as is without any other processing. After being opened, the sachet can be used throughout the day.

Many local RUSFs were developed in the world using local nutrient dense ingredients such as legumes, fruits, and vegetables, which contain lots of carbohydrates, fats, and fatty acids, proteins, minerals, phytochemicals, and vitamins. It is necessary to analyse such RUSFs to determine if all these organic compounds still exist in the RUSF matrix. Zimbabwe has plenty of nutrient dense and medicinal plants which could be utilised as valuable ingredients for production of several traditional and modern functional foods.

Fourier transform infrared (FTIR) spectroscopy is an essential analytical technique for characterisation of samples in the forms of fibres, films, gases, liquids, pastes, powders, and solutions (Nandiyanto *et al*, 2019). FTIR is an essential tool for simultaneous determination of organic components, including chemical bonds, as well as organic content such as carbohydrates, lipids, and proteins (Nandiyanto *et al*., 2019).

During infrared spectroscopy, infrared radiation is passed through a sample. Some of the infrared radiation is absorbed by the sample while some of it is passed through (transmitted). The outcome is a spectrum that represents the molecular absorption and transmission that creates a fingerprint of the sample. Each sample has unique molecular structure such that two molecular structures with unique combination of atoms do not produce the exact same infrared spectrum. An infrared spectrum represents a unique fingerprint of a sample with absorption peaks corresponding to the frequencies of vibrations between the bonds of the atoms making up the material. The FTIR spectrum can be obtained by the result of absorption versus wave number or transmission versus wave number data. The Infrared spectrum is divided into three wave regions, namely, the far-IR spectrum (<400cm-1), the mid- IR spectrum (400-4000cm^{-1}), and the near-IR spectrum (4000-13000cm^{-1}) but the mid-IR spectrum is used most frequently in sample analysis (Nandiyanto *et al.,* 2019). FTIR can identify unknown materials, determine the quality and consistency of a sample and can determine the quantity of components in a mixture (Nurwahidah *et al*., 2019). Fourier transform infrared spectroscopy – attenuated total reflectance (FTIR–ATR) analysis allows for the identification of the position, intensity, and shape of infrared peaks,[17] which can reveal chemical bonds and quantify chemical structures of macromolecules such as carbohydrates, lipids, fiber, moisture, bioactive compounds, antinutrients, and other compounds of interest. FTIR can provide compositional information in terms of carbohydrates, fat, moisture, and protein content in foods (van de Voort, 1992). Identification of molecules and nutrients in unknown substances is supported by Messerschmidt and Harthcock (1988), who stated that over the last 100-plus years a great number of infrared spectra have been measured, and the peak positions of known molecules derived from these spectra can be used to identify the molecules in an unknown sample.

Despite the widespread use of FTIR in Food Science researches, there's a pronounced research gap concerning its application in detecting nutrition composition of foods. Conventional methods, such as proximate analysis, although accurate, require longer time and more labor that makes them less feasible for large-scale or rapid analyses. Such limitations necessitate the urgency need for innovative, efficient techniques that can offer both accuracy and speed (Sirega *et al.,* 2024). This study aims to devise a rapid and reliable method for detecting local RUSF's proximate contents using Fourier Transform Infrared (FTIR) spectroscopy integrated with proximate analysis.

There are plenty of molecular fragments considered to be functional groups attached to organic structures or backbones, for example, -C-X, i.e., the halogens (X=F, CL, Br, and I), hydroxy (X=OH), oxy or ether (X=OR, where R = alkyl), and amino (X=NH2, =NH or ΞN). With the exception of carbonyl functionality, these three basic functional groups cover most of the common occurrences in simple organic compounds (Coates, 2000). The infrared spectrum is effective in diagnostics which makes it possible to differentiate functional group structures for primary, secondary, and tertiary aromatic amines (Coates, 2000). Carbonyl compounds are chemically important and essential in the interpretation of the entire spectrum as they define two related families of organic compounds called aldehydes ad ketones

The C=O absorption is one of the most characteristic in the entire spectrum. In essence, the ketone is considered the root compound, with the aldehyde being a unique case where the carbonyl group is terminal and only has one substituent, the other being a single hydrogen atom. All other carbonyl compounds are derived from the base ketone structure where one or both alkyl (or aryl) substituents are replaced by another functionality, e.g., from a single hydroxy group like in carboxylic acids, to two ether groups, as in the case of an organic carbonate (Coates, 2000). Thiols and thio-substituted compounds can be diagnosed by FTIR. Thiols and thio-substituted compounds are direct analogs of the equivalent oxygenated compounds such as alcohols and ethers (Coates, 2000).

The objectives of this study included the determination of the chemical bonds and functional groups in the local RUSF by FTIR spectroscopy and proximate analysis in order to detect and identify nutrients in the local RUSF. There was need to determine the proximate profile of RUSF by detecting key nutrients such as carbohydrates, fats, fibre, moisture, and proteins through their characteristic spectral signatures.

According to our knowledge, this is the first systematic diagnosis and collection of typical unique frequencies for a local RUSF manufactured from local Zimbabwean ingredients. The analysis results were compared with official published literatures to assign chemical bonds, absorption frequencies, functional groups, and identify organic nutrients in the local RUSF. The nutrients were found to be suitable for managing and curing acute malnutrition in humans.

Materials and methods

A local RUSF was developed from local Zimbabwean ingredients and analysed for presence of carbohydrates, fibre, fats, moisture, and proteins by FTIR and proximate analysis techniques. Soy beans were sampled by the snowball method and bought from farmers in Mazowe district, Mashonaland Central in Zimbabwe and extruded using a single screw extruder in Harare. The soy beans extrudates were ground into fine soy bean powder by a hammer meal in Harare. Produced soy meal powder was packed in an air tight plastic container for later use. Red sorghum was sampled by the snowball method and bought from farmers in Guruve district, Mashonaland Central in Zimbabwe and extruded using a single screw extruder in Harare. The sorghum extrudates were ground into fine sorghum powder in a hammer mill in Harare. Produced sorghum powder was packed in an air tight plastic container for later use. Baobab powder was randomly purchased from local villagers in Lower Guruve and placed in air tight containers for later production of the local RUSF. Peanut butter, icing sugar, and soy bean oil were purchased form OK supermarket in Harare. All ingredients were stored at ambient temperature prior to local RUSF production.

Peanut butter, baobab, icing sugar, extruded soy meal, extruded sorghum powder, and soy bean oil were used to manufacture the peanut-based RUSF paste. The RUSF was prepared by mixing peanut butter with soy bean oil into thin slurry in a peanut butter making machine. Icing sugar, baobab powder, extruded sorghum mealie meal, and extruded soy meal powder were mixed and added to the peanut butter- soy bean oil slurry and thoroughly blended by the peanut butter making machine until a brown thick nutrient rich RUSF paste was formed. The RUSF paste was packed in plastic jars with lids for storage and analysis.

The RUSF's functional groups were detected using Fourier Transform Infrared (FTIR) spectroscopy (Perkin Elmer, UATR TWO, Massachusetts, USA). The FTIR spectra were obtained using a Two FTIR interfaced with an ATR sampling accessory that had a single bounce diamond crystal. A spectrum in the absorbance mode was obtained by measuring from $4000cm^{-1}$ to $400cm^{-1}$ through accumulation of 64 scans at a spectral resolution of $4cm^{-1}$. The FTIR instruments use a HeNe laser as an internal wavelength calibration standard (referred to as the Connes Advantage) which means that the instruments are self -calibrating and do not need to be calibrated by the user (Nurwahidah *et al.,* 2019). Air was scanned without a sample on the diamond crystal as the reference background spectrum before each RUSF sample measurement. Enough RUSF paste to

cover the diamond crystal was deposited onto the diamond crystal to obtain the spectrum. All spectra were processed by PerkinElmer Spectrum TM software (version 5.2.1), Massachusetts, USA). Characteristic absorption band number and their functional groups were detected. FTIR identified the types of chemical bonds and functional groups present in the local RUSF. Spectral features present were strictly due to the sample. The wavelength of the light absorbed was the salient feature associated with chemical bonds as observed in the annotated spectrum. Interpretation of the infrared absorption spectrum determined the chemical bonds in the local RUSF paste. The report was generated using a template that included the spectrum and data base referral results. Obtained transmittance spectra and absorption band numbers were compared with published standard references in literature to identify chemical bonds, functional groups, and nutrients in the local RUSF in table 1.

The proximate composition of the macronutrients protein, lipids, dietary fiber, and moisture of local RUSF was measured according to the methods proposed by the AOAC (Association of Official Analytical Chemists, 2000; 2005; 2016) and the carbohydrate content was estimated by difference.

The moisture analyser (Adams, Model PMB53, South Africa) was used to determine moisture content of the RUSF. The sample was placed onto the moisture analyzer scale and the weight was recorded. The heater automatically switched on and the heat supplied vaporized water from the samples. When moisture content stabilised, the moisture analyzer indicated the percentage moisture content on the analyzer's screen. Moisture measurement was based on thermos-gravimetric principles according to weight loss of the sample due to heating. Drying temperature was pegged at 105 ^{O}C with constant temperature drying. The moisture content was recorded using the same method for all samples.

The protein content was determined using VELPA SCIENTIFICA automatic distillation and titration system (Model UDK159), method number 7. One gram of the RUSF was weighed in three digestion tubes and two tablets of catalyst CT0006650 were added into each test tube followed by 12 ml of concentrated sulphuric acid. The test tubes were shaken gently and placed into the digestion block (Velpa Scientifica, model UDK159) at 420 ^{O}C for 60minutes for heating and digestion. The test tubes were left to cool to 50 ^{O}C - 60 OC.

Distillation and titration of the digested samples were carried out by the automatic distillation unit (Velpa Scientifica, model UDK159). The distilled water used for dilution per sample was 50 ml: 30 ml boric acid and 50 ml sodium hydroxide. Hydrochloric acid was used as the titrant. The volume of titrant and the protein content were displayed on the machine screen and recorded.

To measure the fat content of the RUSF samples, AOAC Soxhlet method (AOAC, 2016) was used. Crude fat determinations were done using Soxhlet apparatus (Simtronics, India) based on the Soxhlet extraction method. Borosilicate quick-fit round bottomed flasks (500 ml) were cleaned with detergent and 300 ml of clean water. The flasks were rinsed with warm distilled water and then 99.99 % ethanol and dried in a pre-heated air circulating box oven (Scientific, Model 279D, South Africa), at 110 ^{0}C to a constant weight. Samples of 15 g were weighed and placed into a muslin extraction thimble and covered with glass wool. These were inserted into the extraction column with the condenser connected to running cold tape water. Approximately 500 ml of pet ether solvent was added into the round bottomed quick-fit flask. An electro-thermal heating mantle set at 70 ^{0}C heated the flask for 3 hours. Evaporated solvent was cooled by running cold tape water in the condenser and refluxed back into the quick-fit round bottomed flask. After extraction, the extraction thimble was removed and the flask was placed in a water bath at 70 ºC to evaporate the petroleum ether. The sample was dried in an air circulating box oven (Scientific, Model 279, South Africa) at 105 ºC for 30 minutes cycles to remove residual solvent and re-weighing until the sample weight was constant. The flask with the sample was cooled in a desiccator and weighed on an analytical balance (Adams, Model PW54, and South Africa). The weight of the fat was expressed as the percent of the initial sample using the equation below:

$$\text{Crude fat (\%)} = \frac{\text{Weight of extracted fat sample}}{\text{Weight of sample}} \times 100$$

The carbohydrates in the local RUSF were determined by the difference method. The sum of the percentages of ash, fat, moisture, and protein were deducted from the total weight of the sample. The equation below was used:

Carbohydrate (%) = [100 - (Moisture (%) + Ash (%) + Fibre (%) +Fat (%) +Protein (%)] (AOAC, 2004).

The method of Association of Official Analytical Chemists (AOAC, 2000 with modifications) was used to determine the crude fibre of the RUSF. Samples were defatted by the Soxhlet process and placed into a 500 ml borosilicate round bottomed flask containing 1.0 g of porcelain boiling chips. A volume of 200 ml of boiling 1.25 % (v/v) sulphuric acid was added and the flask was quickly placed onto a hot heating mantle and then connected to a condenser with running cold tape water. Contents in the flask were boiled for 3 minutes and then allowed to digest through reflux for 30 minutes. The digested sample was filtered through a very fine cloth and subsequently washed with hot distilled water three times to remove acidity. The sample was washed back into the conical flask using 200 ml of 1.25 % (w/v) sodium hydroxide solution. A condenser was connected to the round bottomed flask on the heating mantle and permitted to reflux for 30 minutes. The sample was filtered on a fine cloth by washing with distilled water to remove alkalinity. The residue was transferred into a clean and dry porcelain crucible with a spoon end spatula. Remaining pieces of the sample were washed into the crucible by using 50 ml of ethanol. The crucible containing the sample was dried in a box an air circulating oven (Scientific, Model 279, and South Africa) at 110 ^{O}C for 6 hours until a constant weight was achieved on an analytical balance. The contents in the crucible were ignited in a pre-heated muffle furnace (Scientific, Model283B, South Africa) at 650 ^{O}C for 30 minutes and allowed to cool in a desiccator. The cool sample was weighed and the difference in weight between the ashed samples and the digested samples was considered as the crude fibre content (Southgate, 1969). Ash content was calculated using he equation below:

$$\text{Crude fibre (\%)} = \frac{\text{weight after ignition}}{\text{Weight of sample}} \times 100$$

Results

All FTIR absorption band numbers represent the chemical groups of the components present in the local RUSF. The table shows that some low to medium absorption band numbers lie in the region of 600 cm^{-1}–1800 cm^{-1} and this region is the finger print region of macronutrients. Absorption band numbers around 1680 cm^{-1} – 1770 cm^{-1} belong to the C═O band that is assigned to lipids and carbohydrates (Hong *et al*., 2021). For protein analysis, the determination of the secondary structure of this macronutrient was mainly based on the analysis of the amide I band between 1700 cm^{-1} and 1600 cm^{-1}.

Table 1. FTIR analysis data and interpretation of a local RUSF.

Peak number	Absorption Frequency X(cm^{-1})	Y (% T)	Group Frequency (cm^{-1})	Bond	Functional group
1	3314.83	95.22	3200-3570	O-H stretch	Alcohol, hydroxy groups
2	3008.14	92.66	3000-3100	C-H symmetric stretch	Alkene
3	2923.28	59.80	2935-2915	C-H stretch, asymmetric	Alkene
4	2853.57	70.34		C-H stretch	Alkane
5	1744.26	59.06	1670-1820	C= O stretching	Ester carbonyl of triglycerides
5	1744.26	59.06	1725-1750	C=O stretching	Ester
6	1650.44	89.99	1620-1680	C=C / HOH	Alkene/ water
8	1650.44	89.99	1590-1650	N-H bend	Primary/ secondary amino
9	1650.44	89.99	1600-1650	C=C stretch	Conjugate ketone or quinone
7	1537.44	92.94	1400-1600	C=C stretch	Aromatic compound – diketones
8	1460.75	81.43	1515-1560	N-O stretch	Nitro compounds, nitrosamine
9	1376.98	85.79	1350-1480	C-H bending symmetric	Phenol/ tertiary alcohol
9	1376.98	85.79	1345-1385	N-O stretch	Nitro compounds
10	1235.83	80.26	1000-1300	C-O stretch	Alcohols, Aromatic ethers, Alkyl aryl ether
11	1159.29	67.96	1159-1164	C-O stretch	Ester, Tertiary alcohol
11	1159.29	67.96	1130-1190	C-N stretch	Secondary amine

12	1068.18	70.53	1080-1360	C-N stretch	Amine
12	1068.18	70.53	1050-1150	C-O- stretch	Alcohols, Ethers, carboxylic acids
12	1068.18	70.53	1020-1090	C-N stretch	Alcohols, Ethers, carboxylic acids
13	1052.34	71.89	1020-1090	C-O stretch	Primary alcohol, alkyl - substituted ether
14	989.90	73.02	980-960	CH=CH trans	Primary alcohol, alkyl - substituted ether
15	909.16	81.90	890-915	C-H out of plane bend	Aromatic ring.
16	867.16	85.66	820-890	C-O-O stretch	Peroxides, Alkenes
17	721.15	75.29	600-800	C-CL, C-H rocking	Peroxides, Alkenes
18	521.86	71.76	500-600	C-I stretch	Peroxides, Alkenes
19	471.38	72.19	470-500	S-S stretch	Peroxides, Alkenes

The spectrum of the local RUSF is presented in figure 1. Different absorption band numbers and absorbances showed presence of various bonds and functional groups in the local RUSF. Distinct absorption band numbers of the local RUSF absorption frequencies were compared with reference literature by Coates (Coates, 2000). These were used to assign functional groups and identify bonds and nutrients in the local RUSF.

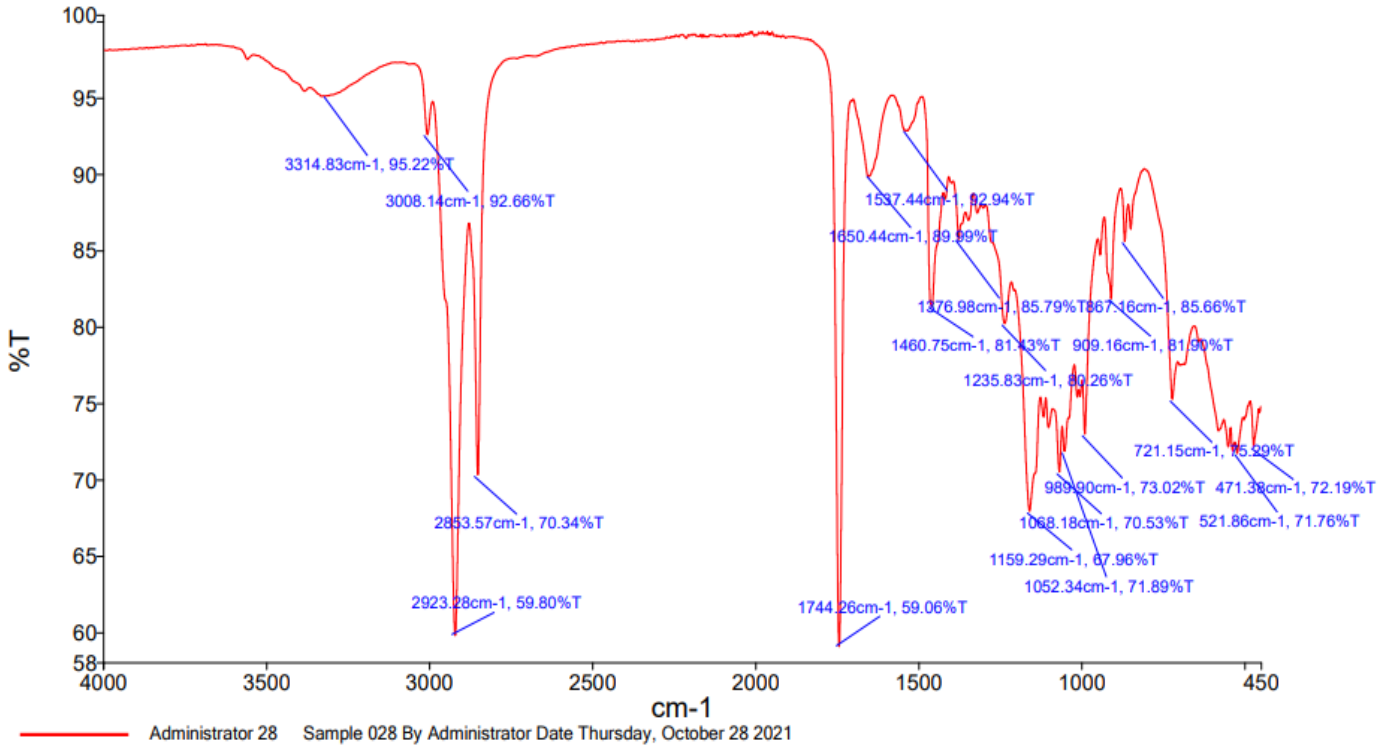

Figure 1. FTIR spectrum of the local RUSF scanned at infra region 4000-450 cm^{-1}. (PerkinElmer Spectrum IR Version 10.6.2).

The local RUSF produced 19 distinct absorption band numbers as indicated by figure 1. Absorption band number 3314.83 cm^{-1} showed presence of O-H stretch of alcohol and *hydroxyl* groups. Absorption band number 3008.14 cm^{-1} represented C-H symmetric stretch of alkenes and 2923.28cm^{-1} corresponded to C-H stretch and symmetric bonds of an alkene. Absorption band number 2853.57 cm^{-1} showed the presence of C-H stretch and symmetric C-H bonds of an alkane. The 1744.26 cm^{-1} absorption band number indicated C=O stretch of esters. Absorption band number 1650.44 cm^{-1} revealed the N-O stretch bonds of an alkane and O-H stretch bond of water. It also had N-H bend of primary and secondary amino groups as well as C=C bonds of conjugate ketone or quinone. Absorption band number 1537.44cm^{-1} represented C=C stretch bonds of aromatic compounds called diketones and 1460.75cm^{-1} absorption band number corresponded to N-O stretch bonds of nitrosamine nitro compounds. The 1376.98cm^{-1} absorption band number represented C-H symmetric bonds of phenol and tertiary alcohols and N-O nitro stretch bonds of nitro compounds.

Absorption band number 1235.83 cm^{-1} showed the presence of C-O stretch and symmetric C-H bonds of alcohols, aromatic ethers, and alkyl aryl ethers. Absorption band number 1159.29cm^{-1} represented C-O stretch bonds of esters and tertiary alcohol and C-N stretch bonds of Secondary amines. Absorption band number 1068.18cm^{-1} represented C-O stretch bonds of alcohols, ethers, and carboxylic acids and C-N stretch bonds of amines and secondary amines. The absorption band number 1052.34cm^{-1} indicated C-O stretch bonds of primary alcohol and alkyl -substituted ethers. Absorption band number 989.90cm^{-1} showed presence of CH=CH stretch bonds of alkenes. Absorption band number at 909.16cm^{-1} showed presence of C-H out of plane bend bonds of aromatic rings. Absorption band number 867.16 cm^{-1} represented C-O-O stretch bonds of alkenes and peroxides while absorption band number 721.15cm^{-1} corresponded to C-H rocking bonds of aliphatic compounds and C-CL bonds of alkyl halides. Absorption band number 521.86cm^{-1} showed presence of C-I bonds of aliphatic iodo- compounds while absorption band number 471.386 cm^{-1} indicated the presence of S-S bonds of polysulfides, alkenes, and alkyl halides. FTIR analysis showed the presence of different functional groups such as carboxylic acids, aromatics, alkanes, alcohols, phenols, aliphatic amines, alkenes, and primary as well as secondary amine groups in the local RUSF.

Table 2. Proximate results of the local RUSF

Analytical parameter	**Result**
Moisture (g/100 g)	2.4 ± 0.13
Carbohydrates (g/100 g)	44.7 ± 1.02
Proteins (g/100 g)	15.5 ± 0.14
Fat (g/100 g)	31.2 ± 0.09
Crude fibre (g/100 g)	2.2 ± 0.06

The proximate analysis of the local RUSF showed that the local RUSF prototype contained carbohydrates, crude fibre, fats, proteins, and moisture.

Discussion

Spectroscopy methods with physicochemical tests allow for rapid and reliable identification of macronutrients and bioactive compounds. FTIR spectral analysis can diagnose presence of many functional groups. Detectable groups include aldehydes (H–C=O: C–H stretch), alkenes(–C=C– stretch), alcohols, carboxylic acids, esters, and ethers (C–O stretch), aromatics (C–C stretch in–ring), carboxylic acids (C=O stretch) or (O–H bend), carbonyls (C=O stretch), primary and secondary amines (N–H wag), carbohydrates, polysaccharides, and nitrates (Muruganantham *et al.,* 2009). In other studies, functional groups like alcohols, alkanes, alkene, alkyl halides, alkynes, amines, aromatic compounds, ether, nitrile, and nitro compounds were diagnosed by FTIR spectroscopy by Pongpiachan (Pongpiachan, 2014). Ragavendran (Ragavendran *et al.,* 2011) analysed leaf extract of Aerva lantana by FTIR and found functional groups of amines, carboxylic acids, halogens, polysaccharides, organic hydrocarbons, and sulphur derivatives in the extract display. This shows that FTIR is an essential tool that can produce individual unique spectrum according to unique chemical bonds in each sample and different functional groups would not produce similar spectra. This means that FTIR can be used to identify unknown materials, determine quality of a sample, and determine the number of components in a mixture (Nurwahidah *et al., 2019*) which is important in food and medicinal product development. Detection and characterisation of constituents of functional foods is essential in medicinal foods research such as the local RUSF.

Obtained experimental wave number and literature-based wave ranges were used to assign chemical bonds and to identify nutrients in the local RUSF. Experimental wave number 1159.29 cm^{-1} and literature range of 1159 cm^{-1} to 1164 cm^{-1} were used to assign C-O bonds of carbohydrates and proteins and C-OH groups of serine, threonine, and tyrosine residues of cellular proteins. Possible nutrient type was collagen and protein (serine, threonine, and tyrosine) (Fung *et al.,* 1996). This concurred with Yang (Yang *et a*l., 2005) who stated that C-O bonds from the stretching mode of C-OH groups represented serine, threosine, and tyrosine of proteins. The -C-O-C was assigned to cellulose and polysaccharides (Shetty *et al.,* 2006). This showed that the local RUSF had both carbohydrates and proteins that could fight protein- energy malnutrition and the polysaccharides

provided some fibre to fight constipation. This qualified the local RUSF as an important potential functional food to reduce malnutrition in Zimbabwe.

Experimental wave number 1235.83 cm^{-1} and literature range of 1230 cm^{-1} to 1238 cm^{-1} were used to assign the overlapping of the protein amide iii and the nucleic acid phosphate (PO2-) vibration that is composed of amide iii and phosphate vibration of nucleic acids (Chiriboga *et al*., 1998).

The fingerprint FTIR spectroscopy absorption bands of proteins are the stretching vibration of amide I and amide II (Brauner *et al.,* 2005). The former is attributed to C=O and ring stretching vibration in the range of 1690–1600 cm^{-1}, and the latter is attributed to C–N stretching vibrations in the range of 1600–1500 cm^{-1}. This supported by experimental wave number 1650.44 cm^{-1} and literature range of 1649 to 1652 cm^{-1} that were used to assign the unordered random coils and turns of amide I where protein was the nutrient present (Eckel *et al*., 2001). This observation is supported by the fact that pure soy protein isolate has typical infrared absorption bands at 1636 cm^{-1} to 1680 cm^{-1} and 1533 cm^{-1} to 1559 cm^{-1} that are attributed to the -NH- bonds of amide i at 1640 cm^{-1} and at 1550 cm^{-1} for amide ii in peptides bonds forming the backbone of proteins. The absorption band at 1241 cm^{-1} to 1472 cm^{-1} was attributed to the C=O and C-N stretching and N-H bending of amide iii vibrations (Su *et al*., 2008). This concurs with the observations that the bands observed in rice at 1250 cm-1 and 1360 cm^{-1} corresponded to the amide-III protein band ranges, as referenced in previous studies of rice, (Ji *et al.*, 2020; Wei *et al.*, 2021) and the C–N stretching mode of proteins (Coates, 2002). Wave numbers 1650.44 cm^{-1} and 1235.83 cm^{-1} showed that the local RUSF contained some soy proteins from the extruded soy meal powder that was used in the local RUSF formulation. Proteins were confirmed to be 15.5 ± 0.14 g/100 g by proximate analysis (Masheka *et al.,* 2023) in the local RUSF. Proteins are essential for prevention of protein- energy malnutrition.

Esters in the local RUSF were associated with experimental wave number 1744.26 cm^{-1} and literature range of 1744 cm^{-1} to 1750 cm^{-1} were used to assign the ester group(C=O) vibration of triglycerides and the possible nutrient type assumed was fat (Wu *et al.,* 2001). This agreed with the carbonyl ester triglycerides obtained from the RUSF FTIR spectrum. It can be concluded that the RUSF contained some fats that can supply some energy and could be the source of essential polyunsaturated linoleic fatty acids that cannot be produced by the human body.

The vibrations of $-CH_3$, the deformation of $-CH_2$, and the C═O bond (Reigar *et al.,* 2024) were associated with lipids. These agreed with a previous research that showed that experimental wave number 2853.7 cm^{-1} and literature range of 2853 cm^{-1} to 2860 cm^{-1} was used to assign the CH_2 bond of lipids. The asymmetric CH_2 stretching mode of the methylene chains was found in membrane lipids and the assumed possible nutrient type was fat (Fung *et al*., 1996). The presence of fats was supported by experimental wave number 2923.28 cm^{-1} and literature range of 2923 cm^{-1} to 2930cm^{-1} that were used to assign the C-H stretching bends in malignant and normal tissues and the assumed possible nutrient type was fat (Wu *et al*., 2001). In addition, the availability of fats in the local RUSF was confirmed to be 31.2 ± 0.09 g/ 100 g by proximate analysis (Masheka *et al*., 2023).

A broad absorption band in the range of between 3650 cm^{-1} and 3250 cm^{-1} indicated the presence of hydrogen bonds. This band confirmed the existence of hydrate (H_2O), hydroxyl (- OH), ammonium, or amino group. The hydroxyl compound was followed by the presence of spectra at frequencies of 1600 cm^{-1} to 1300 cm, 1200 cm^{-1} to 1000 cm and 800 cm^{-1} to 600 cm^{-1} that confirmed the presence of water **(**Coates, 2000**)** in the local RUSF. Previous studies showed that water molecules, being infrared-active, exhibit absorption in two distinct regions, approximately 1300 cm^{-1} −2000 cm^{-1} and 3500 cm^{-1} −4000 cm^{-1}. The analysis pinpointed several regions associated with moisture content, including 640 cm^{-1}, 710 cm^{-1}, 860 cm^{-1}, 940 cm^{-1}, and numerous regions around 1200 cm^{-1} −1800 cm^{-1} (particularly 1630 cm^{-1}). (Troen *et al*., 2020) The results for 1630 cm^{-1} align well with Nesakumar et al. that assigned 1637 cm^{-1} to the moisture (Nesakumar *et al.,* 2018). Presence of water concurs with the proximate analysis of the local RUSF where moisture was found to be below 2.5 % (Masheka *et al*., 2023). Low moisture increased the shelf life of the local RUSF due to low water activity.

This innovative application for quantifying proximate composition of the local RUSF using FTIR holds promise for versatile applications in agriculture, dietary guidance, and the advancement of nutritional research as well as contributing to enhancing our understanding of FTIR spectra in the context of macronutrients. Understanding the nutrient composition helps the community make informed dietary choices. Knowledge of the health benefits associated with the identified nutrients in the local RUSF can encourage the use of the supplementary food. Knowledge about the value

of local ingredients in nutrition encourages promoting local food products supply chains, strengthens community resilience, supports and improves the livelihoods of local farmers. The results of this research enhance provision of information on the nutrient content of the local RUSF to educate the community about its health benefits and promote its use as a dietary supplement. Future research endeavors can leverage this approach for a broader spectrum of food samples and nutritional components, expanding FTIR spectrometry applicability and impact in the field of food quality control, nutritional studies, and culinary arts. The FTIR analysis provided valuable insights into the nutritional profile of the new supplementary food, for example, FTIR was used to investigate the relationship between nutrition and protein structure in food (Deng et al., 2020) and guide the treatment of food to maintain the nutrition... By sharing this information, we can empower the community to enhance their diets with locally available, nutrient-rich foods.

Conclusion

This study showcases the potential of FTIR spectroscopy coupled with proximate analysis as robust tools for rapid and accurate assessment techniques to detect nutrients in the local RUSF. FTIR spectroscopy is a quick analytical technique that confirmed the presence of key functional groups in foods such as aromatics, alkanes, alcohols, phenols, aliphatic amines, alkenes, amine groups, carboxylic acids, ethers, and esters in the local RUSF. FTIR in conjunction with the proximate analysis detected carbohydrates, fibres, lipids, and proteins in the local RUSF. This showed that the local RUSF had both carbohydrates and proteins that could fight protein- energy malnutrition and the polysaccharides provided some fibres that could reduce constipation. All detected nutrients qualified the local RUSF as a potentially good functional food that can be utilised to reduce moderate acute malnutrition**.** This research underscores the potential of FTIR spectroscopy and proximate analysis as rapid and accurate proximate assessment in food science and culinary arts.

Conflict of interest

The authors declare that there is no conflict of interest reported in this work.

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Mushroom fly pest incidence in four button mushroom (*Agaricus bisporus*) production centres of Zimbabwe-An exploratory study

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ABSTRACT

Mushroom fly pests are a serious deterrent to many wood-be button mushroom producers in Zimbabwe due to their yield and quality degrading damage. Mushroom fly ubiquity is exacerbated by conducive environmental factors, arguably the rampant food and fruit waste disposal in the environment. Although modest fly pest management methods are available, expensive methods are employed to contain pest spread and the subsequent damage they cause. The aim of this exploratory study was to investigate prevalence, infestation sources, damage, seasonal severity and control methods for mushroom fly pests on button mushroom farms in four production centres of the crop. A farmer survey was conducted using a postal questionnaire to farmer respondents using a mobile phone-integrated application. This study found that sciarid and phorid fly attack button mushroom crop starting at the early spawn running phase through to the second crop flush with rapid population build up if uncontrolled. The infestations were found to be high across four surveyed sites with greatest infestations coinciding with the rainy season. Mushroom fly incidence and the damage to button mushroom were not explained by location or farmer experience, making these two variables insignificant in constructing a predictive model for the resultant fly pest incidence or crop losses experienced. Hence production practices need to be re-evaluated to develop sustainable methods of managing mushroom fly incidence and novel methods such as fly repellents, baiting or manipulation of the mating mechanisms and overwintering disruption have to be explored. From this study we found three species of mushroom fly as significant button mushroom pests in the studied areas and hence appropriate pest management measures must be taken to protect the crop to enable good quality and yield. Such adopted pest management methods will go a long way in promoting and sustaining standard agro-ecological principles.

***Keywords*:** mushroom fly, incidence, crop damage, spawn running, pinning, Agaricus bisporus, pest management

Introduction

White button mushroom cultivation began earnestly in the 1990s in Zimbabwe. Since then, the area and seasonal space under the crop has grown as demand continues to rise, complementing its oyster mushroom counterpart on the urban and catering industry market and a variety of wild

mushrooms mainly consumed in rural markets (Mlambo & Maphosa, 2022; Chitamba et al., 2012). Button mushroom has helped in satisfying specialty markets in hotels, restaurants, and hospitals and among tourists from mycophillic cultures elsewhere such as continental Europe, China and Japan (Peintner et al., 2013). Although white button mushroom growers worldwide have significantly contributed to global food security, in Zimbabwe the bulk of this sector remains largely constrained by pest affliction (Navarro, 2020). Quite a few pests have been reported through oral and undocumented discourses. Hence it has until now remained unclear what pests are of significant economic importance as experienced by button mushroom growers in Zimbabwe. This paucity of knowledge has been exacerbated by a presumed culture of secrecy in developments within the mushroom farming sector of Zimbabwe, which is relatively unregulated by the state. Thus, for Zimbabwe, the real significance of pest problems in white button mushroom production has not received any significant research attention.

World-wide, several button mushroom pests, the majority being insects, have been studied extensively with corresponding pest management methods developed (Lee et al., 2022; Shamshad, 2010; Sharma et al., 2021). Topping the groups of button mushroom pests are members of Diptera order, mites, springtails and a variety of beetles (Kakraliya, 2022). Among these pests, the most frequently encountered are sciarid flies (Diptera: Sciaridae) *viz*. *Lycoriella ingenua*, *L. auripila, L. agarici, Sciara multiselta, S. agaris, Bradysia paupera, B. tritici,* and *S. orientalis*; Cecid flies (Diptera: Cecidomyiidae) including *Mycophila speyeri*, *M. borresi*, *Heteropeza pygmaea* and phorid fly (Diptera: Phoridae): *Megaselia nigra, M. sandhui, M. halterata,* and Springtails (*Seira iricolor*), mites eg. *Microdispus lambi*, beetles e.g. *Cyllodes indicus*, *Scaphisoma nigrofasciatum*, *Staphylinus* sp. and *Spondotriplax pallidipes* (Lee et al., 2022; Kumar et al., 2022; Coles et al., 2021; Sharma et al., 2021; Kakraliya & Kumawat, 2022; Navarro, 2020; Sharma et al., 2019). The sciarid fly, *Lycoriella*, is by far the most serious and most ecologically widespread arthropod pest of button mushroom worldwide (Lee et al., 2016; Andreadis et al., 2016; Marques et al., 2021). The most reported damage experienced on button mushrooms is by the phorid fly *Megaselia halterata* in Spain, leading to 10 to 40% yield loss if uncontrolled (Navarro, 2020) while in India sciarids, cecids and phorids are reported to have caused 17-26%, 26-33% and 46% yield loss respectively when uncontrolled (Limbule et al., 2021). Furthermore, *Lycoriella ingenua* is known to vector green mold (*Trichoderma aggressivum*) spores, mushroom mites and nematodes (Lee et al., 2022; Coles et al., 2021; Limbule et al., 2021) and also transmits the mushroom pathogenic

fungus *Trichoderma aggressivum* Samuels & W Gams (Mazin et al., 2017) while its larvae feed on and destroy both the mushroom mycelium and the compost (Shamshad,2010). Apart from the shortened life cycle of around 20 days and their capacity to oviposit large numbers of eggs, some cecid species have been reported to be paedogenetic, hence their enhanced fungivory fitness (Rijal et al., 2021; Jaiswal & Kumar, 2020). To mitigate potential damage, the most effective control methods developed to date rely on hygiene as the first line of defence, quarantine of affected crops and chemical control often used sparingly on commercial farms as backup counter-pest measures (Gill and Allan, Accessed 7 July 2025).

Use of chemical pesticides such as paralyzing pyrethroids, growth regulating cyromazine, and botanicals, neem oil and horticultural oil in mushroom production, has also been reported (Navarro et al., 2021). Other chemicals used against mushroom fly in general are: benomyl, parathion, malathion, beta-cypermethrin, diflubenzuron, and pyriproxyfen (Nair et al., 2023). Analysis of 49 fresh and dried mushroom samples reaching markets in the Czech Republic from several countries found 21 residues of different agro−pesticides (Schusterova et al., 2023). It is, however, unclear whether such chemicals had been directly used on the mushroom crops or were bio−accumulated by the mushrooms from their growing substrates. It is strongly cautioned, however, that use of these or any other alternative synthetic chemical pesticides in mushroom production should be discouraged, particularly in mushroom production and marketing systems not well regulated such as those of Zimbabwe. It however has remained unclear which strategies are in use by Zimbabwean button mushroom growers.

The short life cycles for most button mushroom pests and prevalence of several alternative hosts such as wild mushroom species and rotting organic debris makes it difficult to control mushroom pests (Navarro et al., 2021). However, in Zimbabwe, the first step in identifying and appreciating the pest range and biology is still in its infancy. The most frequently and most damaging pests have not been determined and may vary by geographical region, thereby necessitating this survey. Elsewhere outside Zimbabwe, several fly pests within the three taxonomic families have been found and specific control measures developed for the examples in **Table 1**.

Table 1. Most frequently and most damaging mushroom pests and control measures employed

Pest	**Alternative hosts**	**Damage caused**	**Nonchemical control methods**	**References**
Sciarid fly [Sciaridae:*Lycoriella* sp., *Bradysia* sp.] (dark−winged fungus gnats)	Wild mushrooms, plant roots, algae, rust and smut fungi, decaying plant debris, lichens, ferns	Eat [!]**MM** mycelium and compost, larvae tunnel stipes, discolouration of caps, transmit fungal, viral and bacterial contaminants	***Bb**; [†]**PM+Ma; light traps,** sticky or pheromone or yellow traps, physical barriers, temperature control between 16 and 18°C, parasitoid wasps, repellent plants like mint or basil	Andreadis et al. (2021); Tavoosi Ajvad et al. (2019); Nair et al. (2023); Rijal et al. (2021); Anderson et al. (2021)
Phorid fly [Phoridae: *Megaselia* sp.] (humpbacked/scuttle fly)	Wild mushrooms, dead arthropods, decaying flesh, rust and smuts	Feed on mushroom mycelium, transmit *Verticillium* contaminant, bacteria and viruses	***Bb**; eclosion, juvenile hormone analogues, attractant volatile laced traps, **EPNs**; **Bt**; **PM**; plant extracts, parasitoid wasp, physical barriers	Andreadis et al. (2021);Navarro et al. (2021); Jaiswal & Kumar (2020)
Cecid fly [Cecidomyiidae: *Mycophila* sp. *Heteropeza* sp.] (gall midge)	Wild mushrooms, plant aerial and subterranean parts, rusts, smuts, ferns, mosses, bacteria, algae,	Feed on mycelium; gall on sporophores; sporophore deformation and discolouration; size reduction; vector mites, nematodes. disease	Parasitoids, physical barriers, traps, horticultural oil	Jaiswal & Kumar (2020); Rijal et al. (2021)

[!]Mushroom mycelium (**MM**);*eg BotaniGard® with *Beauveria bassiana* (***Bb***);[†]*Metarhizium anisopliae* (Hypocreales: Clavicipitaceae) Metchnikoff (Sorokin) plus **P**redatory **M**ites *Gaeolaelaps aculeifer* (Canestrini) (Mesostigmata: Laelapidae) syn. *Hypoaspis aculeifer* Beaulieu (**PM+Ma**); entomopathogenic nematodes (**EPNs**); *Bacillus thuringiensis* (**Bt**);

The general characteristic anatomical features and conditions conducive for development of mushroom fly pest infestations on button mushrooms vary in production areas with many factors including the nature of the production system and prevalence of alternative hosts in the production area.

In white button production areas where there is a short mushroom growing tradition or little local research knowledge such as Zimbabwe, yield loss is largely attributed to mushroom fly. Through this button mushroom grower survey, the objectives set were to determine: 1) the type of white button mushroom Dipteran pests encountered and the perceived damage they cause, 2) the comparative frequencies of pest incidence for each location and for each cropping stage up to the second flush, 3) mathematical model for incidence of each Dipteran pest for four production stages, *viz*. spawn running, pinning, capping and second flush as predicted by farmer location and

farmer experience, 4) the difference in percent yield losses across three recognized seasons of production and among the locations studied, 5) the presumed sources of mushroom fly infestations and 6) the pest management methods in use. Hence the role such pests play in white button mushroom production in Zimbabwe can be better understood from findings of this research.

Materials and methods

Study site

The farmer survey was conducted across four major population and button mushroom production centers of Zimbabwe: Harare, Gweru, Masvingo and Bulawayo as an exploratory survey. The snowballing technique, where the spawn supplier identified the population of grower respondents (spawn purchasers/customers) was used (Moxley et al., 2022; Mutema et al., 2019). This snowballing technique was the most effective approach owing to the latency of button mushroom growers in Zimbabwe linked to the unregulated nature of this sector.

Survey research design, instrument and sample size

A descriptive survey was conducted among white button mushroom farmers of Zimbabwe to determine the pest inventory observed on their crops, the nature of damage they caused and control strategies they employed. Semi structured questionnaires were conducted from a population of 480 growers of white button mushroom distributed unevenly throughout the country and with noted categories of button mushroom growing experience of less than two years, two to five years or more than five years. All questionnaires were administered through the android assisted Kobo Collect application on the WhatsApp platform to cover a sample of 62 respondents selected in a location population proportionate stratified sampling manner. This sample size covered 15% of the total number of button mushroom growers in Zimbabwe with 100% questionnaire return rate.

Data collection

From each respondent, data were gathered on: grower location; button mushroom growing experience in years; Dipteran pests encountered by grower by season and production phase of the crop; suspected or proved sources of infestation; suspected or proved alternative pest hosts; ranking of pest severity by growing season; symptoms of crop damage; percent yield loss where applicable by season, and methods used to manage the Dipteran pests and estimated effectiveness

of such methods. Responses from the survey were collated in tabular data capture form in MS Excel as questionnaires were returned. The data were coded, cleaned, validated and required computations made before analysis. The survey captured data in in the following main categories: Location, experience, symptoms of damage by mushroom fly, mushroom fly pests encountered, suspected sources of infestation, severity of damage by season (0 to 10% or > 10% yield loss) and methods used to manage/control infestations.

Data analyses

All analyses were conducted in SPSS 20.0 (IBM, 2011). Data from surveys was computed and bar-graphed in order to visualize frequency trends for the major pests using MS Excel. For all statistical analyses data from the four major button mushroom production centers, *viz*. Harare, Gweru, Masvingo and Bulawayo were converted into response frequencies by data category and visualized using bar charts generated in MS Excel. Binary logistic models for incidence of each of sciarid, phorid and cecid flies as predicted by farmer location and farmer experience were developed for each of four cropping phases *viz*. spawn running, pinning, capping and flush 2 to test the regression model:

$$\log(p/[1-p]) = \boldsymbol{\beta 0} + \boldsymbol{\beta 1}\text{Farmer Experience} + \boldsymbol{\beta 2}\text{Location}$$

Where p = probability of pest incidence, $\boldsymbol{\beta 0}$ is the intercept, $\boldsymbol{\beta 1}$ and $\boldsymbol{\beta 2}$ are coefficients

To compare yield loss rankings (low= 0 to 10%; high= > 10%) among three production seasons (September to February, March to May and June to August), a Kruskal Wallis test was used. We also used the Kruskal Wallis test to compare yield loss differences across the four study locations. For statistical analyses conducted, tests of data normality (Shapiro-Wilk) and homogeneity of variance (Bartlett's test) were conducted and descriptive tests done in SPSS.

Results

This study determined Dipteran pest prevalence in Zimbabwe's four major button mushroom production areas, that is, Harare, Gweru, Masvingo and Bulawayo municipal districts. Symptoms of damage, mushroom fly pests involved, crop stages affected, sources of infestation and management measures taken were also determined. Predictive models for pest prevalence as a function of location and farmer experience were then tested to help further explain the data.

Dipteran pests observed and production stages infested

All respondents (100%) were found to experience incidence of three mushroom fly pests, namely, sciarid, phorid and cecid fly to varying degrees at some point in their enterprises annually. The exact species of each group were not characterized as this was beyond the scope of the current study. Stem tunneling was the most frequently reported symptom of damage and most farmers appreciated other additional symptoms of damage (**Figure 1**).

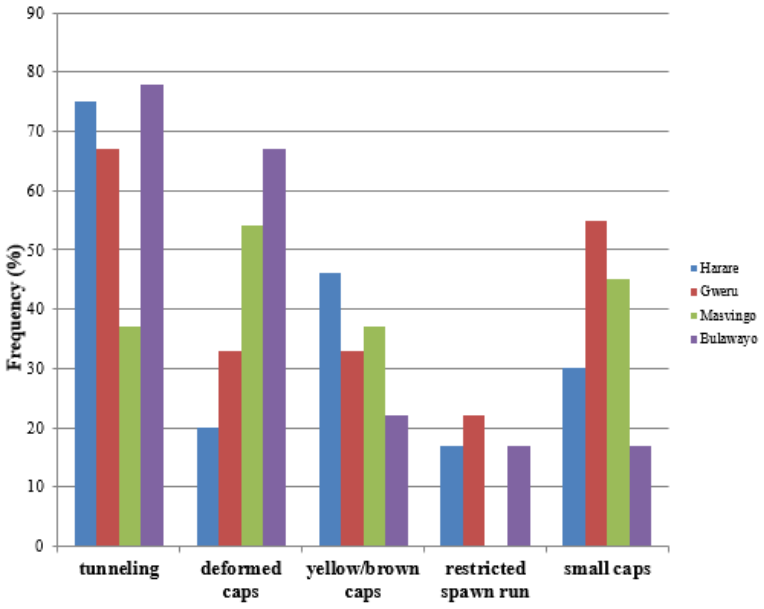

Figure 1. Reported symptoms of damage by mushroom fly pests

The three groups of mushroom pests were found in the four districts as shown in Table 2. Of particular note are the sciarid and phorid flies reported to infest all production stages while cecids were only observed at the two initial stages.

Table 2. Range of pests encountered in button mushroom and stages of production where observed

Pest	Order	Production phase
Sciarid fly	Diptera	All phases
Phorid fly	Diptera	All phases
Cecid fly	Diptera	Spawn running and pinning

Incidence of mushroom fly infestation for the various production stages/phases

The affirmative response frequencies for mushroom fly incidence across the four sites were found to vary throughout the cropping cycle from spawn running to the second flush (**Figure 2**). Peak infestation was found at pinning phase of the first crop while the lowest infestation frequency was at spawn running phase. For all production locations mushroom fly incidence was similar between the capping phases 1 and 2. Across all locations the sciarid fly (=fungus gnat) was affirmatively mentioned most frequently of the three mushroom flies while the cecid fly appeared least mentioned. Hence, both the sciarid and phorid fly pests appeared to be serious pests while cecids were relatively less important.

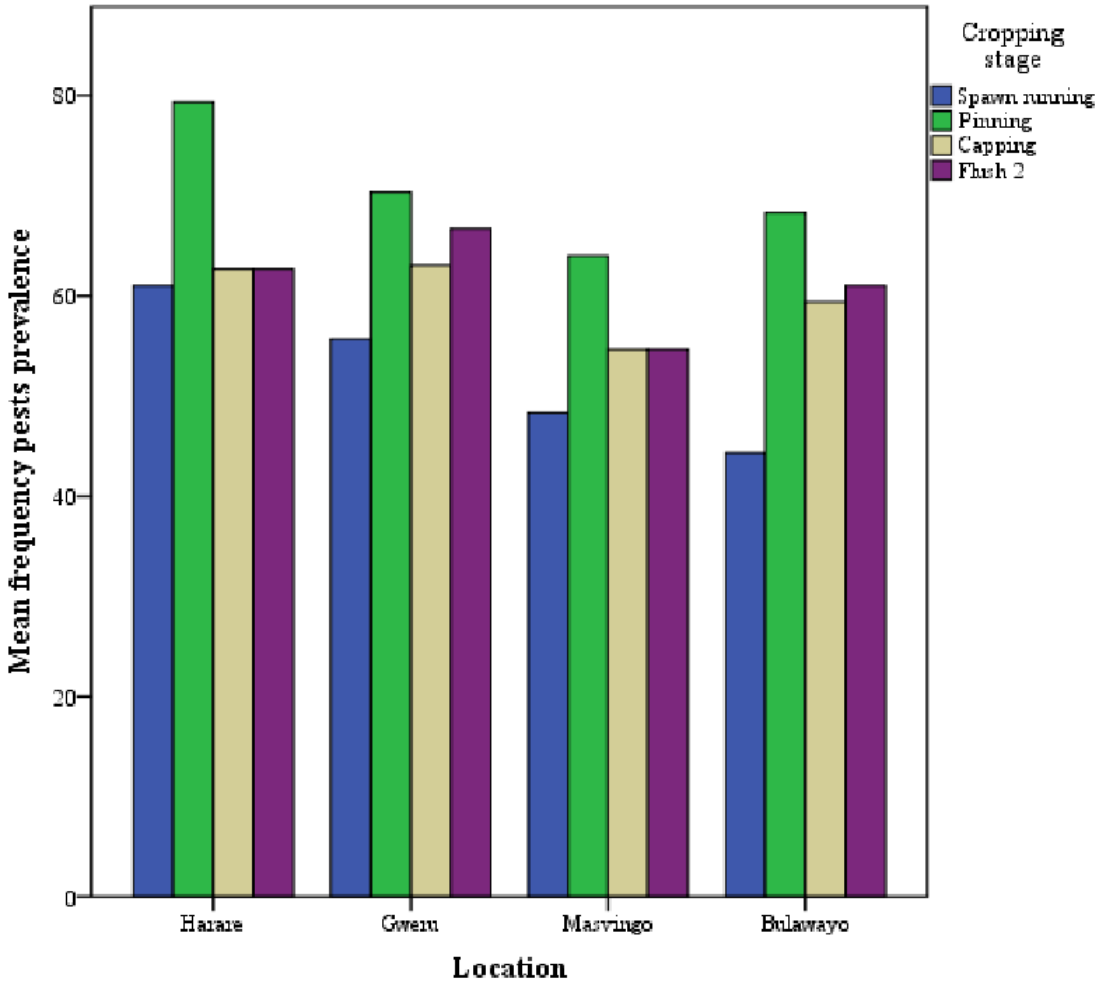

Figure 2. Individual fly incidence frequency across the four production centers

Frequency trends of incidence for the three mushroom flies across the production phases

Sciarid fly affirmative mention frequency was highest at the first capping phase and lowest at the spawn running phase. In contrast, phorid fly mention frequency was highest in the second flush. Cecids appeared to be prevalent only during spawn running and pinning and vanished thereafter (**Figure 3** and **Figure 4**).

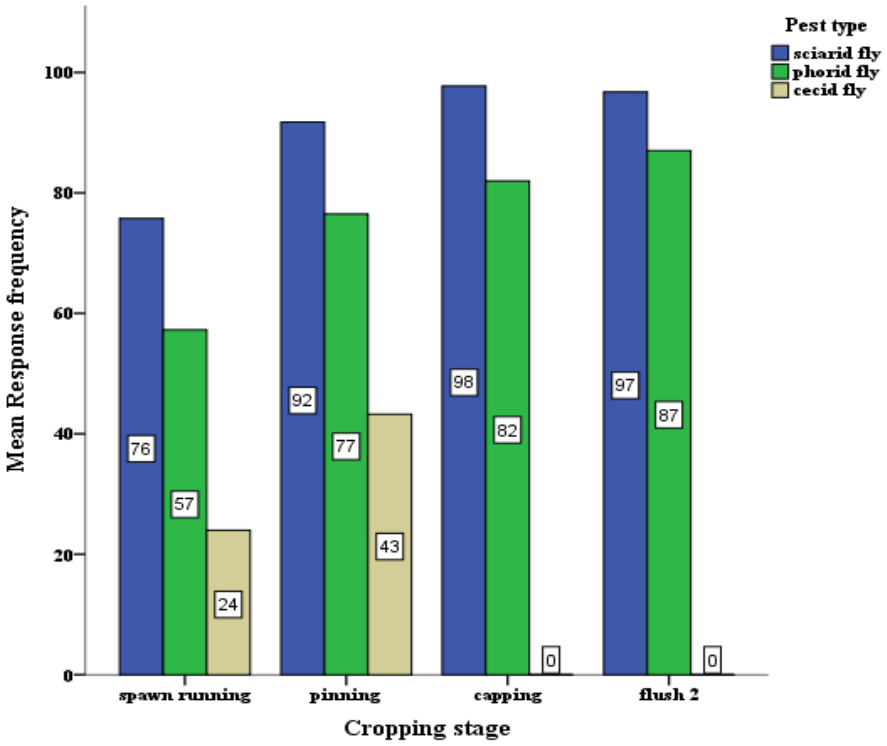

Figure 3. Mushroom fly incidence frequencies for the four stages of cropping

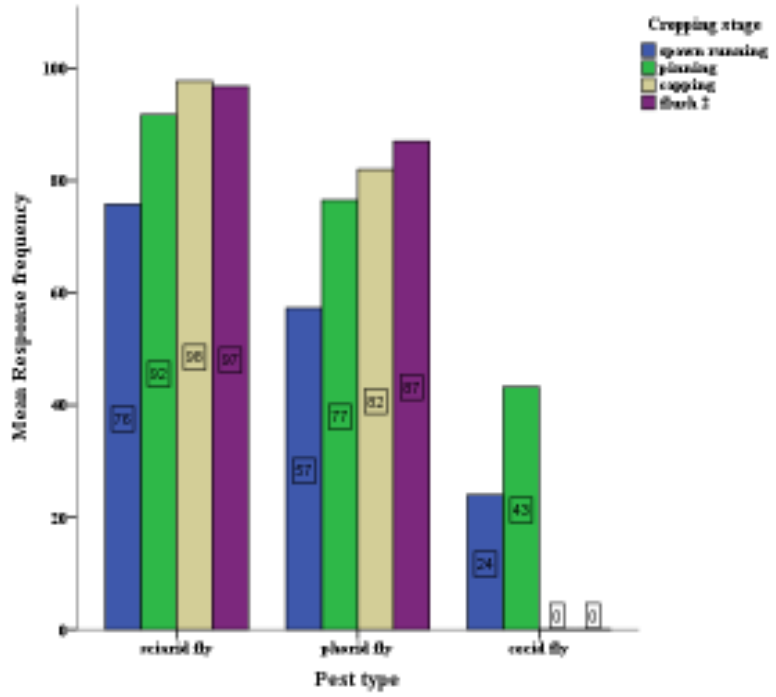

Figure 4. Frequency of pest incidence across the four production stages

Predictive models for pest incidence

Farmer location and farmer experience were regressed on incidence frequency for each mushroom fly pest type and for the mushroom production phases: spawn running, pinning, capping (first flush) and second flush. We ran binary logistic regression in SPSS 20.0 to test our data on the model:

$$\log(p/[1-p]) = \boldsymbol{\beta 0} + \boldsymbol{\beta 1}\text{FarmerExperience} + \boldsymbol{\beta 2}\text{Location}$$

Since cecid fly incidence was not observed and hence not reported neither at capping nor flush 2 across all farmer locations, these analyses were not run.

Regression of farmer experience and location on probability of pest incidence at spawn running

Although the constant was significant ($p< 0.05$) neither of the predictors (farmer experience and farmer location) were significant ($p> 0.05$). For the incidence of sciarid, phorid and cecid fly incidence both the Cox & Snell and Nagelkerke R square were less than 25% (**Table 3**), indicating that each of the model accounted for less than 25% of the total variance, hence farmer experience

and location do not explain incidence of these pests. This model was therefore not significant for any of the three pests.

Table 3. Binary logistic regression for pest incidence at spawn running phase as predicted by location and farmer experience

	Sciarid fly	Phorid fly	Cecid fly
Hosmer–Lemenshow value	P=0.902	P=0.946	P=0. 581
–2 Log Likelihood value	66.945	77.975	65.366
Cox & Snell R Square	0.060	0.106	0.140
Nagelkerke R square	0.089	0.142	0.200
N	62	62	62
Constant	P<0.001	P=0.311	P=0.001

Regression of farmer experience and location on probability of pest incidence at pinning

We found a significant ($p< 0.001$) constant but neither farmer experience nor location was significant ($p> 0.05$) with a not so low Nagelkerke R-square value of 22.1% for sciarid fly (**Table 4**). Overall, the R-squared value was also below 25% for any of the three pests for the pinning stage and hence, not significant.

Table 4. Binary logistic regression for pest incidence at pinning phase as predicted by location and farmer experience

	Sciarid fly	Phorid fly	Cecid fly
Hosmer–Lemenshow value	P=0.782	P=0.720	P=0. 957
–2 Log Likelihood value	32.626	56. 646	81.140
Cox & Snell R Square	0.104	0.107	0.059
Nagelkerke R square	0.221	0.167	0.079
N	62	62	62
Constant	P<0.001	P<0.001	P=0.311

Regression of farmer experience and location on probability of pest incidence at capping stage

The constant was significant ($p< 0.001$) for both sciarid and phorid fly incidence though with low Nagelkerke R-square value for both pests (**Table 5**). Our model was also not significant for both pests for the capping stage.

Table 5. Binary logistic regression for pest incidence at capping phase as predicted by location and farmer experience

	Sciarid fly	Phorid fly	Cecid fly
Hosmer–Lemenshow value	P=0.771	P=0.134	−
–2 Log Likelihood value	16. 946	45.230	−
Cox & Snell R Square	0.012	0.039	−
Nagelkerke R square	0.047	0.072	−
N	62	62	62
Constant	P<0.001	P<0.001	−

Regression of farmer experience and location on probability of pest incidence at flush 2 stage

The constant was significant ($p< 0.001$) for both sciarid and phorid fly incidence but with low Nagelkerke R-square for both pests (**Table 6**). Our model was also not significant for both pests for the flush 2 stage.

Table 6. Binary logistic regression results for pest incidence at flush 2 as predicted by location and farmer experience

	Sciarid fly	Phorid fly	Cecid fly
Hosmer–Lemenshow value	P=0.771	P=0.134	−
–2 Log Likelihood value	16.946	45.230	−
Cox & Snell R Square	0.012	0.039	−
Nagelkerke R square	0.047	0.072	−
N	62	62	62
Constant	P<0.001	P<0.001	−

Nature of damage and yield loss versus production season

Farmers were aware of the symptoms of fly damage *viz*. tunneling of sporophores, deformed caps, yellowing/browning caps, restricted spawn run and small size sporophores. They appreciated that any form of damage directly led to yield loss and that off−quality produce was not marketable. Using the Spearman Correlation test, we found a significant ($p< 0.001$) moderate negative correlation ($r = –0.290$; n = 186) between yield loss magnitude and production season (from summer–winter–spring). We used the Kruskal−Wallis test in SPSS 20.0 to test the difference in the reported button mushroom yield losses among the three production seasons (for all production locations). More yield loss was experienced in summer than winter and more in winter than spring (**Table 7**). There was no significant ($p< 0.05$) difference in reported yield loss from mushroom fly among the study locations.

Table 7. Kruskal–Wallis mean rankings of button mushroom yield loss in three production seasons

Statistic	Value
Season	Mean rank (yield loss)
September to February	108.00
March to May	97. 50
June to August	75.00
Chi–square value	16.221
df	2
p	< 0.001

Presumed sources of mushroom fly infestations

Four sources of mushroom fly infestations were succinctly mentioned as compost, spawn, nearby fruit trees and the unhygienic, overly humid environment while a sizeable number of respondents appeared not to know the sources (**Figure 5**).

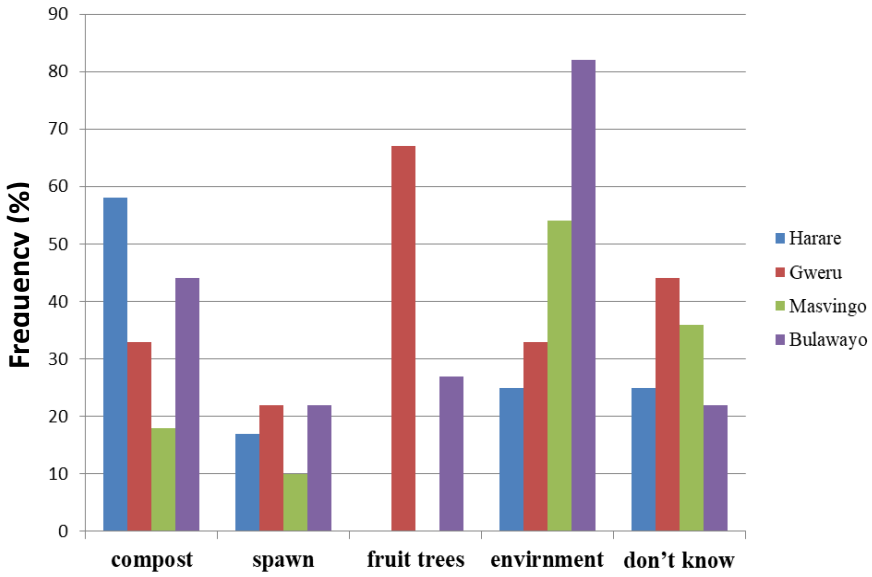

Figure 5. Respondent frequencies for mention of the presumed sources of infestation

Management methods for mushroom fly

Across the surveyed locations, button mushroom farmers reported use of thorough compost sterilization, plugging of all entry points for mushroom fly into the mushroom house. They also

remove fly sources such as vegetation, waste food dumps. Diazinon pesticide sprays were administered inside the mushroom house to control fly infestations.

Discussion

This study showed that mushroom fly (both sciarid and phorid groups) were the most important pest of button mushroom in the major production locations of Zimbabwe. This finding is similar to studies elsewhere in India (Kakraliya, 2022); in Korea (Lee et al., 2016); the United Kingdom and the US (Navarro et al., 2021). Like reports by Navarro et al. (2021); Navarro et al. (2020) and Babytskiy et al. (2019), we also found higher incidence for sciarid than phorid fly incidence (**Figures 2**−**4**). Chidziya et al. (2013) reported the sciarid *Lycoriella mali* as the most damaging in Zimbabwe, which is consistent with our findings. Throughout this survey, farmers appeared to be aware of the identities of three distinct groups of mushroom fly, *viz*. sciarids, phorids and cecids. However, a few farmers could not assign the observed fly pests to their taxonomic species but were able to describe their structure and behavior. This indicates a critical knowledge gap for which correct prescription of effective fly management methods could be resolved. Our findings demonstrated that mushroom fly; in particular, sciarid and phorid groups were location and season ubiquitous on button mushroom farms in this study. However, yield losses peaked in summer contrary to reports by Navarro et al (2021; 2024) where phorid fly infestations, in particular, peaked in spring and autumn in temperate climates. The high value placed on button mushroom quality makes it imperative for farmers to swiftly trace the damage to fly infestations experienced. Hence farmers promptly seek expert advice from mushroom consultants and entomologists to identify the pests and recommend control measures. We also observed that farmers frequently share knowledge through the WhatsApp platform groups such as the one we used in collecting data for this study. With the advent of the Internet global information and artificial intelligence tools, farmers are also able to search for solutions using their smart phones for the bare basics such as the difference between the three groups of mushroom fly. Since the main incentive for venturing into button mushroom production is profit making prospects, most farmers do not necessarily have formal training in entomology, nor do they employ an entomologist owing to the small scale of production which constrains hiring of such specialists.

The ubiquity of mushroom fly we found is consistent with prevailing conditions of cool to warm temperatures, high humidity and dark conditions maintained inside button mushroom houses

irrespective of seasonality and geographical location (Navarro et al., 2020). Typically, for spawn running internal temperatures are maintained between 19 and 24°C and humidity ca. 85% under pitch dark conditions coinciding with the optimum conditions favoring successful completion of all stages of mushroom fly life cycle. Under such conditions, therefore, it is very likely that the damaging fly larvae observed during spawn running arise from early infestation of the compost when eggs are laid at or just after spawning rather than before spawning infestation. A study by Kakraliya (2022) and Rijal et al. (2021) found similar infestation patterns in India where fly maggots was highest towards end of spawn running, also implying highest adult incidence at pinning. Hence, the early spawn running phase appears the strongest stimulus for sciarid and phorid fly oviposition compared to subsequent stages. Within seven days, eggs hatch into larvae which start feeding on the still sparse mushroom mycelium thereby slowing spawn running. After completing the life cycle, a new and larger wave of infestation begins if uncontrolled. In particular, sciarid fly is known to complete its life cycle in 25 days at 21°C (Chidziya et al., 2013) which represents the first wave of adults found in the mushroom house. It is therefore critical that early exclusion of the fly be effected to arrest early infestations, particularly in the warm season when adults can freely mate to allow for good pinning and the subsequent capping.

The higher frequencies of sciarid and phorid fly incidence in Harare and Gweru than the other two locations (**Figure 2**) is explained by higher humidity experienced in these areas, indicating that there is a higher likelihood of reserve fly populations in humid areas, with abundant wild mushrooms and decaying litter being the most likely alternative hosts in the summer. In drier areas of Masvingo and Bulawayo the longer drier winters tend to suppress reserve populations thereby allowing a lower pest incidence in the following summer crop. On the other hand, cecids appear to be a minor challenge throughout the four areas. This is attributed to cecids preference for fresh plant material rather than fungal mycelium. Hence the rare encounter with cecids makes them insignificant as button mushroom pests within the studied areas, being just a transient pest where their primary plant hosts are unavailable.

As expected, the populations of sciarid and phorid fly larvae and adults increase after spawning and peak off at capping (Navarro et al., 2021). This phenomenon is demonstrated by the trends in their incidence (**Figure 3**) indicating that farmers generally establish their button mushroom crop with relatively uninfested compost. Whether initial infestations of the compost arise from the

compost itself or the environment, pest numbers increase on the growing mycelium as their primary food and the subsequent fruit body primordia at end of spawn running. Hence the large number of emerged adult flies at the first capping stage. It is at this stage that farmers apply and intensify chemical control measures which tend to suppress resurgence of pest populations possibly leaving the residual pupa population unharmed. Furthermore, the leveling off in the infestation at capping, more clearly shown in **Figure 4** is because sporophores are less favorable as forage than fresh compost and fungal mycelium. Although our survey focused on pest incidence frequency rather than actual pest population numbers, higher population numbers of sciarid than phorid were explained on the higher trophic and reproductive fitness of the former than the latter. Whereas sciarids can oviposit on unspawned compost phorids do not. Adult sciarids start oviposition within six hours after eclosion whereas phorids oviposit three days after eclosion (Jaiswal and Kumar. 2020). This difference in oviposition fitness may be extrapolated, albeit with caution, to explain the higher frequency of sciarid than phorid incidence and population dynamics in all cases.

Farmer location and experience proved poor predictors of mushroom fly incidence in general, only being able to explain less than 25% of the variation. However, the significant ($p< 0.001$) constant we found in all cases indicates that indeed, there are other factors than farmer location or experience which could be explored. A nonlinear more robust model accounting for factors other than those we considered may be required for practical application on mushroom farms. We however, did not collect pertinent data on parameters such as composting methods used, fly species or exact growing conditions which might be better predictors for fly pest incidence. Data on the pest management practices used by different farmers to resolve the challenge of pest incidence were also not collected. In Zimbabwe there is currently little data on mushroom fly species identity and diversity or distribution in relation to mushroom production.

Farmers clearly identified some of the visible damage directly arising from mushroom fly. They appreciated the quality loss as this also directly impacted on marketability of their produce, giving them incentive to manage mushroom fly infestations. Stem tunneling and cap browning we found as caused by fly larvae was also reported elsewhere in India by Ruchika et al. (2024) as a major quality loss for button mushrooms. However, they were unable to relate the subterranean effects of the fly larvae damage on mycelium and the compost. None of the respondents mentioned

observation of pupae, which usually are visible on the surface of the substrate starting in the second and third week after spawning, an indicator which could guide timing of chemical control. The difference in yield losses (**Table 7**) attributed to mushroom fly among the seasons is directly linked with the differences in infestation rates experienced in the seasons. The summer months are characterized by highest mushroom fly activity when outdoor temperatures are highest and thus most suitable for mating of flies just outside the mushroom houses (Navarro et al., 2021; Limbule et al., 2021).

Temperature, relative humidity and, hence, litter decomposition in the surrounding galleries and woodlands are also suitable for breeding large populations of fly constituting sources of infestation. On the contrary, as outdoor temperatures and humidity fall, external sources of infestation also diminish leading to less yield losses into the cold dry winter. Generally, farmers appeared to trust their spawning material as free from pest infestation (**Figure 5**). The major sources of pest infestations were believed to be the compost when not properly pasteurized and the environment such as rotting litter and refuse dumps. Less likely sources were the general environment, that is, fly pests were perceived as endemic, with fruit trees being suspected to harbor reserve pest populations. All these suspicions seem plausible as mushroom flies are known to be generalists, capable of feeding on a wide range of decomposing materials. Hence, continued removal of refuse dumps, removal of suspected breeding and overwintering habitats such as fruit trees, food waste containers, and proper sterilization of composts continue to remain viable chosen methods. However, for such methods, proper planning and sequencing is required while more environment-friendly methods need to be developed.

Conclusion and future perspectives

This study found that sciarid, phorid and cecid mushroom fly species were the prevalent pests of button mushroom across Harare, Bulawayo, Gweru, Mutare and Masvingo production areas. These pests cause yield and quality losses throughout the production seasons, particularly in the summer months. They were reported to feed on the compost, tunnel mushroom stems and causing mushroom browning leading to unmarketable produce. No association was found between study location or farmer experience and prevalence on the mushroom farms. The major sources of infestation reported were the immediate environment and poorly pastuerised compost. Hence respondents using effective compost sterilization techniques and maintaining hygienic

environments as the most viable pest management approaches. Although the sciarid fly was reported as the most important fly pest the damage caused by individual pest genus was not determinable as the infestation cycles of the three pest groups tend to overlap across crop production phases and flushes. Hence robust mushroom fly management methods are essential in attempting to reduce this threat, particularly during wet warmer months of the year. With little mushroom pest research published so far focusing on button mushroom pests, more research needs to be done towards accurately characterizing the mushroom fly pest complex in Zimbabwe and develop safe, affordable, effective and sustainable methods to manage them. Hence this contribution challenges research institutions to channel resources towards developing local methods of managing mushroom fly in Zimbabwe. While these findings provide significant insights into the prevalence of mushroom fly pests in the areas of study, it is essential to interpret them with caution due to the exploratory nature of this study, which may limit the generalizability of the results.

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Evaluation of Synchronization Protocols and Semen Quality Characteristics on Reproductive Efficiency and Fertility Outcomes in Zimbabwean Dairy Cattle Production.

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Abstract

This review addresses the technical challenges affecting the success rate of artificial insemination (AI) in dairy cattle, with a specific focus on heat synchronization protocols and semen quality for artificial insemination. Both heat synchronization and semen quality play significant roles in determining artificial insemination success rates. Furthermore, the influence of body condition score on reproductive performance and AI outcomes has been reviewed, particularly in dairy cattle in Zimbabwe. In Zimbabwe, artificial insemination success rates are notably low, particularly on communal farms, despite over 80% of the country's cattle population being located in the smallholder sector. A systematic literature review was conducted from January 2022 to January 2024 utilizing Google Scholar and PubMed to assess how heat synchronization protocols, semen quality, and body condition scores affect artificial insemination success, mainly in dairy cattle in Zimbabwe. The review also considered the impact of body condition scores on offspring sex determination. A total of 62 full articles were included, consisting of 45 research papers and 17 narrative reviews. In Zimbabwe, the demand for artificial insemination services has significantly risen over the past four years across both communal and commercial farms. However, many farmers are unaware of the factors influencing artificial insemination success. Various elements contribute to the low artificial insemination success rates in the country which are poor heat detection and timing, inseminator skill,animal healh and nutrition and semen handling technics. In conclusion, systematically identifying the factors that affect AI success in cattle can aid AI technicians and farmers in better understanding the animal requirements and technical procedures involved, fostering cooperation to enhance AI outcomes.

Keywords: Artificial Insemination, Heat synchronization, semen quality, Reproductive performance, Zimbabwean dairy cattle industry.

Introduction

Reproductive inefficiencies remain a major barrier to Zimbabwe's dairy industry, which is essential to the country's livestock business. AI has a key role in increasing fertility rates when combined with carefully considered heat synchronization and semen selection(Zuidema et al., 2021). With an emphasis on Zimbabwe dairy industry, this review critically investigates these elements. Dairy farming's sustainability and profitability depend heavily on reproductive efficiency, especially in Zimbabwe, where milk production is essential to both economic growth and food security.Cow's body condition score (BCS),along with heat synchronisation and semen quality , are some of the important factors affecting the success of reproduction(Roche *et al.,* 2007). Dairy farmers in Zimbabwe continue to struggle with low conception rates, inadequate estrus detection, and less than ideal fertility results despite the growing use of AI in the country (Rashidi et al. 2023).

The quality of the semen used is one of the most important factors that determines AI success.Sexed semen used in Zimbabwe is imported from semen producers around the world since the semen centres in Zimbabwe have no equipment for semen sexing although they are a number of players currently producing conventional dairy semen the likes of Chinhoyi University of Technology, Matopos Research Institute and Mazowe bull centre.There is no article which has evaluated the quality of semen from these suppliers to see which producer in Zimbabwe is supplying the best semen.Sperm motility, viability, morphology, and concentration are among the characteristics commonly used to evaluate semen quality, and they have a direct impact on the success of fertilization (Hallap et al., 2006). Dairy producers may now predict the sex of their progeny through the development of sexed semen technology, mainly to boost the proportion of female calves available for milk production (Seidel et al, 2014).

Semen Quality and its influence on reproductive success

However, due to the sorting procedure, which may affect sperm concentration and longevity, studies indicate that sexed semen typically has poor motility and post-thaw viability compared to conventional semen (Bisinotto et al., 2014). Advanced methods like Computer-Assisted Semen Analysis (CASA) can be used for objective evaluation because there is little research in Zimbabwe comparing the quality of conventional and sexed semen from various dairy breeds. Cattle semen production benefits greatly from computer-aided semen analysis (CASA),

especially in artificial insemination (AI) programs where high reliability and accuracy are crucial. One of the primary advantages of CASA is its capacity to produce consistent and objective results by reducing human error and variability, which are common in manual semen examination.

In large-scale cow breeding operations, where consistency and standardization are essential to maintaining quality control, this objectivity is especially crucial (Amann and Waberski, 2014). In AI centers that handle semen from numerous bulls, CASA systems are essential for efficiency as they enable quick evaluation of thousands of sperm cells in a matter of seconds (Zuidema, Kerns, and Sutovsky, 2021). Furthermore, CASA offers a thorough evaluation of sperm motility and kinetics, providing a full profile that aids in more accurate fertility prediction than conventional techniques. This includes metrics that are essential markers of sperm function and fertilizing capacity, such as amplitude of lateral head displacement (ALH), curvilinear velocity (VCL), straight-line velocity (VSL), and total and progressive motility (Tesfay et al., 2020).

Sperm morphology can be assessed using CASA systems, which can detect defects in the head, midpiece, or tail that could reduce fertility. Before semen doses are sent out for insemination, this automated method guarantees that they fulfill international criteria while also increasing diagnostic accuracy. CASA is a crucial tool for routine semen quality monitoring as well as research since it offers digital records, high-throughput analysis, data archiving, and longitudinal tracking of bull fertility. Overall, by improving the precision, speed, and repeatability of semen analysis, CASA technology helps create more effective and successful cow reproductive programs (Ayad, 2018).

Estrus Synchronisation and its Influence on Fertility

The synchronization of dairy cows' estrus is another element that influences reproductive efficiency(Bisinotto et al., 2014). Better estrus detection and fixed-time AI are made possible by heat synchronization techniques (Pursley et al., 1995). Ovsynch, which uses prostaglandin (PGF2α) and gonadotropin-releasing hormone (GnRH), and CIDR-based protocols, which comprise controlled internal drug-releasing devices containing progesterone, are the two most widely utilized synchronization procedures in cows(Dahiri *et al.,* 2022). The efficiency of synchronization protocols varies by breed, environmental conditions, and management techniques, even though they have enhanced reproductive performance in numerous dairy sectors globally (Bisinotto et al., 2014). To determine the best approach for raising conception

rates in dairy breeds in Zimbabwe, it is necessary to evaluate the efficacy of various synchronization techniques in the local environment.

Body Condition Score and its influence on reproductive performance

A visible indicator of body fat stores, BCS has a big impact on reproductive outcomes like conception rates and pregnancy maintenance (Berry et al., 2007). While cows with an abnormally high BCS (3–5) are more likely to suffer from metabolic diseases that impair fertility, cows with a low BCS (1–2.5) frequently have delayed estrus, inconsistent ovulation, and increased embryo loss(Hendrikse et al., 2020). A possible correlation between BCS and offspring sex ratio has been proposed by several researchers, who postulate that hormonal factors during conception increase the likelihood that cows in superior physical condition will give birth to female calves (Cameron et al., 2017).

However, further research is needed to ascertain how dietary management might be adjusted to affect offspring sex ratio and reproductive performance, as this relationship has not been well researched in Zimbabwean dairy herds. Given the importance of these factors, the purpose of this review is to compare the conception rates of AI between two heat synchronization protocols in dairy breeds, evaluate the impact of cow BCS on the sex of offspring after AI, and use of CASA to analyze the quality of sexed and conventional dairy bull semen from a commercial semen supplier in Zimbabwe. This study offers a thorough grasp of how these reproductive management techniques might be modified to enhance fertility results in Zimbabwean dairy cattle by combining the available research and identifying knowledge gaps.

Dairy Production in Zimbabwe

Cattle farming is a vital part of the agricultural economy and rural livelihoods in developing nations like Zimbabwe, where the effectiveness of artificial insemination (AI) is crucial to raising the genetic quality and production of livestock (Kumar Patel *et al.,* 2017). Zimbabwe's dairy industry has experienced significant growth in recent years, driven by strategic investments, improved farming practices, and collaborative efforts between the government and the private sector. In 2023, the country achieved a notable 9% increase in milk production, reaching 90.31 million litres, up from 83.06 million litres in 2022 . This upward trajectory continued into 2024, with raw milk production soaring 14.9% to a record 114.7 million litres, surpassing the previous peak of 100 million litres achieved in 2005. The national dairy herd expanded by 13.4% from 53,250 in 2022 to 60,398 in 2023, and the number of milking cows

increased by 122% from 17,968 to 39,811 over the same period(Dairy Industry Targets Fourfold Milk Production...,)

Despite these advancements, Zimbabwe's per capita milk consumption remains below the World Health Organization's recommended 45 litres for low- to middle-income countries. In response, the dairy industry has set an ambitious target to quadruple milk production to 480 million litres annually by 2030, aiming to meet rising domestic demand and reduce reliance on imports. Key strategies to achieve this goal include expanding the population of lactating cows to 100,000 by 2030, enhancing milk yields per cow from 3,000 to 5,000 litres annually, and increasing per capita milk consumption to 30 litres(Zimbabwe’s Raw Milk Production Soars 14.9%, Reaches Record 114.7 Million Litres in 2024 - ZiMetro News).

The dairy sector's growth has been supported by various government initiatives, such as the Presidential Silage Inputs Scheme and the Livestock Recovery and Growth Plan, which aim to reduce feed costs and improve overall productivity. Additionally, public-private partnerships have played a crucial role in revitalizing the industry, with investments in processing plants, cold storage, and distribution systems enhancing milk handling and reducing post-harvest losses . However, challenges such as power and water shortages, high feed costs, limited access to financing, and competition from smuggled dairy products continue to pose obstacles to the sector's growth(Zimbabwe’s Raw Milk Production Soars 14.9%, Reaches Record 114.7 Million Litres in 2024 - ZiMetro News).

The bulk of Zimbabwe's cattle herd found in communal agricultural systems, which is where AI success rates are low despite the potential advantages (Rashidi et al., 2023). Reproductive failure has a direct impact on production and financial results, making it a major concern for the livestock industry (Inchaisri *et al.,* 2010). Enhancing reproductive efficiency is critical to increasing yields in dairy and beef cattle, and this requires a deeper comprehension of the variables affecting AI effectiveness.

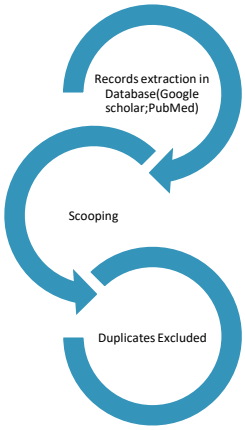
Therefore, this systematic review aims to compile the body of research on these crucial elements and offer a thorough examination of how they affect AI success in Zimbabwe. By doing this, the project will provide farmers, policymakers, and AI Technicians with insightful information that will help them decide on reproductive control strategies. In the end, raising AI success rates will help boost rural livelihoods, improve food security, and increase cattle productivity, all of which are in line with Zimbabwe's larger objectives for sustainable agricultural development.

Materials and Methods

Procedure

A systematic review of the literature was carried out by Kitchenham & Charters' (2007) recommendations. The years 2000–2023 were included in the search. Google Scholar and PubMed were used to retrieve articles that were selected for their thorough coverage of peer-reviewed literature and ease of use. Grey literature, including newspaper stories, conference proceedings, and unpublished reports about heat synchronization procedures and semen quality in dairy cattle, was not included in the search; it was limited to published journal papers that were accessible online. The trustworthiness and usefulness of grey literature are questioned because it is frequently not subjected to thorough peer review (Paez, 2017).

Figure 1 below provides a comprehensive search strategy, including the identification and selection procedure for the publications considered in this study.



Results and Discussion

Identification and selection of articles for inclusion

As shown in Figure 2, a total of 943 full-text articles were assessed for research relevance. Figure 2 also shows the breakdown of the articles that were found using particular search phrases. The search terms Heat Synchronization Protocols, Semen Quality," "Reproductive Efficiency, Body condition score" and "Fertility Outcomes in Zimbabwean Dairy Cattle" were used to extract articles.

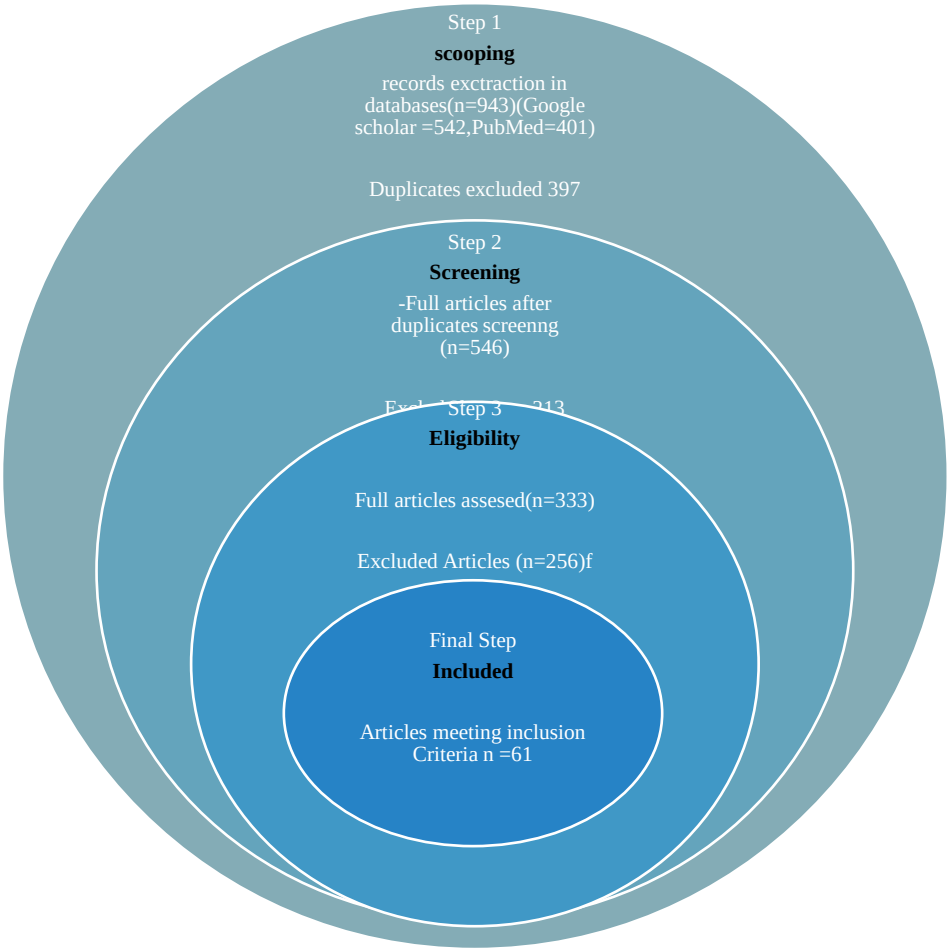


Figure 2: Summary of identification and selection of articles for the study

Sixty-two (62) full-text journal articles satisfied the requirements for inclusion. Of them, seventeen were narrative reviews, and forty-five were research studies. Artificial Insemination (AI) is one reproductive technology that can improve fertility and reproductive efficiency in Zimbabwean dairy cattle, especially when combined with heat synchronization protocols to increase semen usage and conception rates.

1 Semen Quality in Artificial Insemination Success

Since semen quality has a direct impact on fertilization rates, embryo development, and overall reproductive efficiency, it is a crucial factor in determining the success of artificial insemination (AI) programs in cattle (Baruselli *et al.*, 2017). The fertilizing potential of semen doses utilized in AI is determined by important semen quality indicators, such as sperm motility, viability, morphology, and concentration (Aman et al., 2014). Improved conception rates are linked to high sperm motility because these sperm have a higher chance of effectively fertilizing the oocyte and navigating the female reproductive system(Demetrio *et al.*, 2007). The percentage of

living sperm in a sample, or sperm viability, is equally important because damaged or dead sperm cannot successfully initiate fertilization. For frozen-thawed semen used in artificial insemination (AI), studies have indicated that post-thaw sperm viability above 40% is required for optimal conception rates (DeJarnette *et al.,* 1992). Significant improvements in semen quality have been made in Zimbabwe's cattle breeding business in recent years due to increased investments in artificial insemination (AI), better management practices, and enhanced quality control measures. Standardizing the production and distribution of semen has been made possible by the development of the Zimbabwe National Cattle breeding centres, which are now equipped with advanced semen analysis equipment including Computer-Aided Semen Analysis (CASA). This guarantees that farmers can only access high-quality semen. The adoption of modern reproduction technologies and the thorough training of AI staff have significantly aided these efforts.

Additionally, structural abnormalities in the sperm head, midpiece, or tail might hinder motility and the capacity to penetrate the oocyte's zona pellucida, making sperm morphology a crucial factor in fertility outcomes (Barth and Oko, 1991; Brito *et al.,* 2003). Research has shown that AI success rates are considerably reduced for semen samples containing above 20% defective spermatozoa (Gillan et al., 2005; Walsh et al., 2011).Additionally ,due to sperm competition or impaired capacitation, over dilution or high sperm concentration might result in decreased fertility (DeJarnette *et al.,* 2011). By increasing post-thaw sperm viability and longevity, improvements in semen processing and storage methods have greatly increased AI success rates (Bailey et al., 2000). Long-term sperm preservation is possible with cryopreservation, a popular method for storing semen, but it also causes oxidative stress and osmotic damage, which lowers sperm motility and viability (Anger et al., 2003). It has been demonstrated that adding cryoprotectants such as glycerol and antioxidants to semen extenders reduces cryo-damage and enhances the quality of post-thaw sperm. Furthermore, sperm survivability during storage and transit has been further improved by the invention of better semen extenders, such as formulations based on egg yolk and milk (Holt , 2000).

2 Recent Developments in Sperm Quality Assesments

Technological advancement in cattle breeding programmes worldwide have significantly enhanced reproductive efficiency(Vishwanath, 2003)**.**By offering accurate and objective measurements of sperm motility, viability, and morphology, contemporary semen evaluation

methods like flow cytometry and Computer-Assisted Sperm Analysis (CASA) have completely changed the evaluation of semen quality(Amann and Waberski, 2014). Researchers and AI Technicians have improved semen selection for AI by using CASA technology to identify minute variations in sperm dynamics that could affect reproductive outcomes (Kastelic, 2014). Furthermore, the selection of bulls with superior reproductive performance is now possible because of proteomic and genomic studies that have revealed important biomarkers linked to high-fertility semen (Gillan et al., 2005).

However, there are still difficulties in guaranteeing consistent semen quality for AI, especially in commercial semen production and distribution, even with improvements in semen processing and evaluation (Baruselli et al., 2017).

3 Environmental factors affecting semen quality

Strict quality control procedures are required to maximize fertility results due to the variation in semen quality among bulls, even within the same breed (Pérez-Cerezales *et al.,* 2018). Furthermore, environmental factors like heat stress and malnutrition can have a detrimental effect on the quality of semen, underscoring the necessity of managing breeding bulls properly to preserve peak reproductive performance. Lower AI success rates in warmer climates can result from heat stress, which has been shown to decrease sperm motility and increase sperm abnormalities dramatically (Hansen, 2009). Therefore, negative consequences can be minimized and AI success can be improved by putting measures like controlled housing, nutritional supplementation, and optimal semen storage protocols into practice (Brito *et al.,* 2003; Kastelic, 2014).

In summary, sperm motility, viability, morphology, and concentration are important factors that determine reproductive outcomes, and semen quality is a vital component impacting the success of AI in cattle. A more accurate selection of superior semen for breeding operations is now possible due to large improvements in AI success rates brought about by advancements in semen processing, cryopreservation, and evaluation technology. To optimize reproductive efficiency, however, issues such as environmental factors and bull variability call for more research and improvement of semen management techniques. AI systems can increase conception rates and promote genetic development and productivity worldwide in the beef and

dairy cattle sector by ensuring the use of high-quality semen through rigorous evaluation and ideal storage conditions (Baruselli *et al.*, 2017).

4 Comparative Quality of Sexed and Conventional Semen

In cattle reproductive management, the relative quality of sexed and conventional semen has been the focus of much research, especially in artificial insemination (AI) programs that seek to improve genetic selection and reproductive efficiency and more importantly in the dairy industry. Because of its greater post-thaw survivability and higher conception rates, conventional semen—which contains roughly equal amounts of X- and Y-bearing sperm—has been employed extensively in artificial insemination for decades (Garner and Seidel, 2008; Seidel, 2014). By allowing producers to predict the sex of their offspring, sexed semen technology—which separates sperm bearing X and Y chromosomes—has transformed the dairy and beef industries and improved herd replacement strategies and financial returns. Notwithstanding its benefits, sexed semen has drawbacks, including lower sperm quality, lower conception rates, and higher processing expenses, which calls for more research to determine how effective it is in comparison to traditional semen. The reduced sperm quality of sexed semen is one of the main stressors, mostly because of the flow cytometric sorting method that separates sperm according to DNA content (Seidel, 2014). The sorting process exposes spermatozoa to high-pressure flow, laser stimulation, and electrical charging, all of which can cause physical and biochemical stress and lower sperm motility, membrane integrity, DNA damage and overall survival.Reduced embryo development rates and early pregnancy losses may result from sperm sorting's association with higher DNA fragmentation (Pérez-Cerezales *et al.,* 2018). Nevertheless, recent advancements in sorting methods , like cutting down on pressing time and maximizing laser intensity , have reduced DNA damage and may enhance the fertility results of AI algorithms that use sexed semen(Gillan, Evans and Maxwell, 2005). Additionally, depending on the breed and processing circumstances, sexed semen can have post-thaw motility decreases of up to 20–30% when compared to conventional semen (Hallap et al., 2006). Further contributing to lower fertility outcomes is the fact that the sorting process requires dilution of semen, which results in fewer sperm per AI dose (usually 2 to 4 million sperm per straw in sexed semen compared to 10 to 20 million in conventional semen(Seidel, 2014). To illustrate the reproductive disadvantage of sperm sorting, Seidel and Schenk (2008) reported that conception rates in Holstein cows utilizing sexed semen varied from 60 to 70 percent of those attained with conventional semen. Sperm damage during sorting, decreased sperm counts per

AI dose, and changes in capacitation and acrosomal integrity—all of which hinder sperm's capacity to properly access the oocyte are the reasons for the decreased fertility of sexed semen (Seidel, 2014).

In the dairy business, where female progeny are preferred for milk production, sexed semen is nevertheless a useful tool for genetic improvement despite the semen quality challenges. Dairy farmers can maximize herd replacement rates, reduce the need for culling, and increase genetic gain by producing heifer calves with an accuracy of over 90% (Garner and Seidel, 2008). Furthermore, sexed semen's fertility performance has increased over time due to advancements in sperm sorting technology, cryopreservation methods, and artificial intelligence strategies, making it more competitive with conventional semen for instance, the creation of "SexedULTRA" semen processing that has resulted in higher post-thaw motility and conception rates that are on par with conventional semen (Vishwanath and Shannon, 2000).

To maximize the success of sexed semen, aspects such as cow fertility status, estrus synchronization methods, and AI timing should be optimized in addition to technological advancements (Bisinotto et al 2014). Despite that poor reproductive health might further lower conception rates, research indicates that sexed semen works best in heifers and cows with excellent body condition scores(Pryce et al., 2001). Additionally, deep uterine insemination techniques and fixed-time AI (FTAI) procedures have been suggested as ways to increase the fertility of sexed semen, guaranteeing that fewer sperm per dosage nevertheless achieve sufficient fertilization success (DeJarnette *et al.,* 2011). When used strategically, sexed semen can improve genetic progress and reproductive efficiency in cow breeding, even though it poses problems on sperm quality, fertility, and cost (Amann and Waberski, 2014). Because of its greater conception rates and better post-thaw survivability, conventional semen is still the gold standard for AI and is the recommended option for commercial breeding operations aiming to maximize reproductive results (Larson *et al.,* 2006). The performance difference between sexed and conventional semen is, however, closing as sorting technology advances and AI management techniques are improved, making sexed semen a more viable reproductive tool in contemporary cattle breeding (Garner and Seidel, 2008). To further increase the effectiveness and success rates of sexed semen, future studies should concentrate on improving cryopreservation techniques, discovering biomarkers of high-fertility sperm, and improving sperm sorting protocols (Pérez-Cerezales *et al.,* 2018). Although sexed semen allows for sex

selection, which is advantageous for herd expansion, its viability may be weakened in comparison to conventional semen.

5 Heat Synchronization Protocols and Conception Rates

In dairy and beef production systems, cattle heat synchronization techniques are essential for increasing reproductive efficiency, raising artificial insemination (AI) success rates, and maximizing calving intervals. Controlling and regulating the estrous cycle in a herd of cows or heifers to accomplish timed artificial insemination (TAI) without the use of heat detection is the main objective of estrus synchronization (Gebremichael, 2015) The use of exogenous hormones, including prostaglandins, gonadotropin-releasing hormone (GnRH), progesterone, and estrogen, to control follicular growth and ovulation timing has led to the creation of several synchronization procedures (Lucy, 2001) Breed, physiological state, and environmental factors all affect how effective these protocols are, therefore selecting the right synchronization plan is crucial to maximizing fertility results (Perry et al., 2007). The prostaglandin-based procedure, which uses prostaglandin F2-alpha (PGF2α) to produce luteolysis and synchronize estrus in cyclic cows, is one of the oldest and most popular synchronization techniques (Ayantoye *et al.*, 2025)The conventional method is giving one or two doses of PGF2α at intervals of 11–14 days, with AI carried out either at a predetermined time after treatment or based on observed estrus (Bisinotto et al., 2014; Tadesse et al., 2015). Cows that do not cycle or are in the early stages of diestrus do not respond well to PGF2α because it is only effective in animals with a functional corpus luteum (CL) (Santos *et al.*, 2004).

GnRH-based synchronization methods, like Ovsynch, have been developed to address the shortcomings of estrus detection and offer a more regulated method of ovulation timing(Dahiri *et al.*, 2022). Ovsynch protocol entails sequentially administering GnRH to promote ovulation and start a fresh follicular wave, then PGF2α to induce luteolysis, and a second GnRH injection to trigger final follicular maturation and ovulation. This method increases the reproductive efficiency of both dairy and beef cattle by doing away with the requirement for estrus identification and permitting TAI at a specified time(Pursley et al., 1995). By guaranteeing adequate follicular condition before synchronization, modified variants of the Ovsynch protocol, such as Pre-Synch Ovsynch and Double Ovsynch, have been developed to increase conception rates. Presynchronization increases the chance of ovulation in response to the initial GnRH injection, which raises the probability of conception in dairy cows (Wiltbank et al., 2014).The progesterone-based protocol is another popular synchronization technique that uses

progesterone-releasing intravaginal devices (PRID) or controlled internal drug release (CIDR) devices to maintain high progesterone levels and synchronize estrous in both cyclic and anestrous cows.The standard procedure is to place a CIDR for 7–10 days, administer PGF2α to cause luteolysis, remove the device, and then utilize either fixed-time AI or estrus detection (Bó and Baruselli, 2014). Research has demonstrated that CIDR-based procedures increase conception rates more than PGF2α alone, particularly in heifers and postpartum anestrous cows with body condition ratings below optimum(Bisinotto et al., 2014).

Protocols like the Co-Synch + CIDR and the G6G protocol, which further optimize estrus synchronization to increase fertility, were developed as a result of the interaction of progesterone, GnRH, and PGF2α (Wiltbank et al., 2014). To ensure accurate ovulation control, the Co-Synch + CIDR procedure includes giving GnRH at CIDR insertion, PGF2α at CIDR removal, and a second GnRH injection at TAI(Larson *et al.*, 2006). Because it can increase pregnancy rates while requiring less work, this approach has been widely used in beef cattle AI programs (Bó *et al.*, 2019).In high-producing dairy cows, where metabolic issues frequently threaten fertility, emerging synchronization tactics concentrate on optimizing hormone combinations and enhancing reproductive efficiency (Wiltbank et al., 2014). To increase conception rates in repeat breeders, new protocols like Double Ovsynch and Resynch seek to optimize pre-synchronization and resynchronization techniques. Furthermore, studies on estradiol-based synchronization protocols and long-acting GnRH analogs are still being conducted. According to some research, synchronization success in Bos indicus breeds—which differ from Bos taurus cattle in terms of ovarian dynamics may be enhanced by the addition of estradiol cypionate (Colazo et al., 2003)

In conclusion, over the past several decades, heat synchronization techniques for cattle have changed dramatically, giving farmers a variety of choices to maximize AI success rates and reproductive efficiency. While GnRH-based protocols, such as Ovsynch, provide precise ovulation control and ease timed artificial insemination, PGF2α-based procedures are still extensively utilized but need rigorous estrus diagnosis. Anestrous cows respond especially well to progesterone-based treatments that use CIDR devices, increasing fertility in animals with low ovarian activity. Conception rates and synchronization success are further increased by combining several hormonal strategies, as demonstrated by Co-Synch + CIDR and Double Ovsynch. To optimize fertility results and financial efficiency in the cattle sector, more research

are required to improve synchronization methods for various breeds, could be optimized for various breeds, production systems, and environmental variables as reproductive technologies develop.

6 Environmental and Management Factors Affecting Synchronization Success

One commonly used reproductive management strategy for dairy cattle is synchronization of estrus, which aims to increase fertility and reproductive efficiency. In dairy farming operations, where improving output and profitability requires optimizing reproduction rates, this technique is very important. However, several environmental and managerial factors, which might differ depending on the region and farming system, affect the efficacy of estrus synchronization works. Around the world, a complicated interplay between genetics, nutrition, environmental factors, and farm management techniques affects how effective synchronization measures are. It has been demonstrated that environmental factors including temperature, humidity, and photoperiod have an impact on how well synchronization procedures work. By increasing heat stress, which affects ovarian function and estrus expression, high ambient temperatures, particularly during the summer, might have a detrimental effect on reproductive performance (El-Tarabany and El-Tarabany, 2015). Heat stress has been shown to decrease the release of reproductive hormones, which can lead to a decreased rate of pregnancy after synchronization therapies (De Rensis et al., 2015). It has been suggested that cooling devices be included to lessen the impacts of heat stress and that synchronization time be changed to avoid periods of high temperatures in tropical regions where heat stress is common (Hansen and Aréchiga, 1999).For synchronization measures to be successful, dietary control is just as important as environmental factors. Hormonal regulation required for proper estrus synchronization might be disrupted by nutritional deficits, especially in energy and protein. Pre-synchronization feeding techniques can increase estrus expression and pregnancy rates, while cows with low body condition scores (BCS) are less likely to react favorably to synchronization treatments (Kasimanickam *et al.*, 2011; Segura *et al.*, 2013). Effective heat detection, herd health management, and the choice of suitable synchronization methods are all examples of management techniques that have a significant impact on synchronization success. Nutritional and environmental factors, including body condition score (BCS), heat stress, and postpartum interval, also affect how effective heat synchronization techniques are (Berry et al., 2007). Negative energy balance, which affects ovarian function and synchronization response, frequently results in decreased fertility in high-producing dairy cows. According to studies,

cows with a BCS of less than 2.5 on a 5-point scale are less likely to conceive after synchronization than cows with a BCS of 3.0 to 4.0(Wiltbank et al., 2014). The effectiveness of synchronization is also adversely affected by heat stress; studies have shown that conception rates are reduced by 20–30% during hot seasons (El-Tarabany and El-Tarabany, 2015).

According to studies, results can be enhanced by employing techniques that are customized for particular herd conditions, such as the use of scheduled artificial insemination (AI) as opposed to natural heat detection. The herd's overall health affects synchronization success because conditions like mastitis and infections of the reproductive tract can impair fertility and estrus expression (Klopfenstein, 2021).Furthermore, it has been determined that combining synchronization techniques with genetic selection for better reproductive qualities is a viable way to improve fertility results globally (Brito *et al.,* 2021).

In conclusion, a variety of environmental and managerial factors, such as climate, nutritional status, herd health, and the particular protocols used, affect the successful synchronization of estrus in dairy cows. To increase the efficacy of estrus synchronization programs and boost reproductive efficiency in dairy farming globally, these aspects must be addressed with the right solutions. Farmers must take managerial and environmental factors into account and modify their methods appropriately, utilizing scientific research and technological advancements, to attain the best results.

7 Body Condition Score as an Indicator of Reproductive Performance

It is commonly acknowledged that the body condition score (BCS) is a trustworthy predictor of dairy cattle's ability to reproduce. Since BCS is a reflection of dairy cows' energy stores and general health, which have a direct impact on their capacity to conceive, the relationship between BCS and reproductive results has been well investigated. Higher conception rates, normal reproductive cycles, and favorable responses to estrus synchronization treatments are all more likely to occur in cows with an ideal BCS. On the other hand, cows with poor BCS whether too high or too low frequently face reproductive challenges, such as poor embryo quality, delayed estrus, and decreased pregnancy rates (Lucy, 2001). The significance of preserving an optimal BCS range for maximizing reproductive success has been emphasized by numerous studies.According to studies, cows with a BCS of less than 2.5on a 5-point scale are less likelyto conceive after synchronisation than cowswith a BCS of 3.0 to 4.0(Wiltbank et

al., 2014). According to several studies (Makki et al., 2022), cows with a BCS of 3.0 to 3.5 (on a scale of 1 to 5) typically had better reproductive outcomes than those with either excessive or inadequate body condition. Low BCS can cause hormonal imbalances that interfere with estrus cycles and lower the chance of conception, it is frequently observed in underfed cows or those that are experiencing negative energy balance (NEB) after giving birth, cows with overfeeding or sedentary management practices tend to have abnormally high BCS, which is associated with a higher risk of metabolic diseases that impair reproduction .BCS can affect long-term fertility in addition to the immediate postpartum period when it comes to reproductive performance(Morley and Murray, 2014). According to (Makki et al., 2022) cows with low BCS at calving had decreased first-service conception rates and delayed uterine involution when compared to cows with appropriate body condition. Moreover, extended anestrus and poor reproductive results are more likely to occur in cows which undergo major variations in BCS during the lactation cycle, especially those that lose a significant amount of body condition after giving birth (Morley and Murray, 2014).Early identification of cows at risk for reproductive issues through BCS monitoring during the lactation cycle allows for prompt interventions, such as nutrition modifications or alterations to management techniques (Roche *et al.*, 2007).

Beyond just measuring body fat, BCS is used as a tool for controlling reproductive health. It is an essential part of a larger reproductive health plan that also involves efficient synchronization procedures, appropriate heat detection, and routine veterinary monitoring. Farmers and veterinarians can improve herd fertility and overall production by using BCS, an inexpensive and commonly available indication of the nutritional and metabolic health of dairy cows (Vanholder *et al.,* 2005).

8 The Influence of body condition score on Offspring Sex Ratio

Despite that the body condition score (BCS) of cows has long been known to have a significant impact on overall fertility and reproductive performance in dairy cattle, animal scientists are becoming increasingly interested in how it affects the offspring sex ratio. It has been suggested that BCS, which gauges an animal's body fat and general health, affects a number of reproductive outcomes, including calving ease, gestation length, and conception rates(Roche *et al.,* 2007, 2009) . Recent research, however, indicates that a cow's body condition score may also influence the sex of its progeny; however, this relationship is not fully understood and varies between studies and species. Given the potential financial implications of skewing the

sex ratio in favor of one sex, typically females, which are more valued for milk production, research has centered on the effect of maternal BCS on the offspring sex ratio in dairy cows. According to some research, cows with higher body condition score at conception or calving might give birth to more male calves, while cows with lower BCS might give birth to more females (Arango et al., 2002). According to the Trivers-Willard hypothesis, a mother's ability to produce one sex over the other may be influenced by her health and the resources she has available. Male children are more likely to be produced by a mother in good health, whereas female offspring are more likely to be produced by a mother in poor health. This theory was confirmed by a study by (Pike & Petrie (2005), which discovered that peafowl with a greater BCS at conception had a higher chance of reproducing more male offsprings although this have not been confirmed in cattle yet.

Other studies, however, have produced contradictory findings; according to certain studies, there is no meaningful correlation between body condition score and sex ratio(Pryce et al., 2001). Apart from BCS, the offspring sex ratio has also been discovered to be influenced by maternal age, diet, and hormonal conditions. Cows are not the only animals whose progeny sex ratio is impacted by BCS and maternal health. Similar patterns, although with differing degrees of effectiveness in reproducing the Trivers-Willard hypothesis, have been noted in other animals, including horses and monkeys. According to certain studies, mares with better body condition scores are more likely to give birth to male foals in horses, whereas mares with lower body condition scores are more likely to give birth to females (Cameron *et al.,* 1999). Similar to this, research on a variety of wild mammal species has revealed that the mother health affects the sex ratio of offspring, especially in species that exhibit sexually dimorphic features, where it is more expensive to produce a male child (Pike and Petrie, 2005).

However, it is crucial to remember that there is ongoing debate on the relationship between BCS and offspring sex ratio. The results that maternal condition affects offspring sex have not been confirmed by several research, indicating that the factors influencing sex determination may be more complicated than only BCS. In certain instances, it is believed that genetic variables and environmental factors, including stress, temperature, and seasonality, significantly influence the sex of calves(Rezende *et al.,* 2020) and affect the sex ratio of offspring in cows and other animals. Sex ratio results are further influenced by factors that interact with BCS, including maternal age, energy balance, and nutritional condition. In livestock management and breeding operations, more research is required to better understand

the underlying mechanisms and ascertain whether maternal body condition may be employed as a valid predictor of offspring sex.

Conclusions and Recommendations

To enhance the success of artificial insemination (AI) in Zimbabwe's dairy industry, it is crucial to address several key factors that influence fertility rates. Semen quality, synchronization procedures, and body condition score (BCS) management play significant roles in AI outcomes. Semen quality, which can vary due to factors such as management practices, environmental stress, and the genetic quality of the bulls, is critical for improving fertilization rates. Enhancing semen quality through better management of bull diets, semen collection, and cryopreservation methods can help reduce discrepancies and boost AI success.

Synchronization protocols are vital to ensure that cows are inseminated at the optimal time for conception. While traditional methods like prostaglandin-based systems are common, newer approaches using GnRH and progesterone-based protocols show promise in improving synchronization and conception rates. In Zimbabwe, where climatic factors and resource limitations may affect synchronization, adapting these protocols to local conditions is necessary. Additionally, utilizing heat detection technology can improve estrus detection, ensuring that insemination occurs at the right moment.

BCS management is an essential aspect of reproductive success. Cows with an ideal BCS are more likely to have regular estrous cycles and respond well to synchronization procedures. Poor BCS, often due to malnutrition or energy deficiencies, can result in lower conception rates and poor reproductive performance. Conversely, an excessively high BCS can also impair fertility. Proper feeding programs and regular BCS monitoring can significantly improve reproductive outcomes in Zimbabwe, where nutritional challenges are common, especially in smallholder systems.

Future research should focus on evaluating the cost- effectiveness of AI compared to natural breeding, particularly in resource- limited settings, and assess its impact on herd genetics, milk production, and overall farm profitability. Such studies will help develop affordable, multi faceted solutions tailored to a sustainable reproductive technologies driven Zimbabwe' s dairy sector.

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Exploring the potential of sweet sorghum (*Sorghum bicolor* (L.) Moench) grain meal as a supplement for diabetic patients in African diets

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Abstract

In the context of Africa's rich cultural and traditional practices in healthcare, this study explored the potential of sweet sorghum (*Sorghum bicolor* (L.) Moench) grain meal as a supplement for managing diabetes within African diets. Diabetes poses a significant health challenge in Africa, prompting the search for appropriate dietary interventions. Sweet sorghum, a versatile traditional African crop, possesses unique nutritional and phytochemical properties that may offer benefits for diabetes management. Through a thorough literature review of reputable sources, including PubMed, Science Direct, Google Scholar, and NCBI, this study examined sweet sorghum's glycemic index, impact on blood sugar levels, and influence of its high fibre content on blood sugar control and metabolism within the African diet context. Additionally, this study assessed the cultural acceptability and feasibility of incorporating sweet sorghum grain meal into conventional African recipes, considering its culinary adaptability and potential to enhance regional dietary customs. The findings of this study highlight the promising potential of sweet sorghum grain meal as a dietary supplement for managing diabetes within African diets, emphasizing its unique nutritional and phytochemical properties. Despite its promising attributes, challenges such as limited availability, processing, and preparation techniques were identified. By integrating existing evidence and considering the specifics of the African diet, this research elucidates the potential advantages of sweet sorghum grain meal as a dietary supplement in the fight against diabetes in Africa. This finding underscores the importance of evidence-based dietary recommendations and long-term diabetes management strategies tailored to African communities' cultural and nutritional contexts. This study recommends further research, community engagement, and legislative support to promote the adoption of sweet sorghum grain meal as a dietary supplement for managing diabetes in Africa, emphasizing the importance of evidence-based dietary recommendations tailored to African communities' cultural and nutritional contexts.

Key words: sweet sorghum, grain meal, dietary supplement, diabetes

Introduction

The increasing incidence of diabetes mellitus constitutes a serious health risk for Africa, necessitating the adoption of novel and alternative diabetes care strategies. Dietary changes are essential for regulating blood sugar levels and lowering the risk of complications from diabetes (Olawole *et al*., 2018). To meet the special requirements of African communities, it is crucial to investigate locally accessible and culturally suitable food solutions. Sweet sorghum (*Sorghum bicolor* (L.) Moench) grain meal, widely cultivated and consumed across numerous African nations, exhibits potential as a prospective dietary adjunct for individuals with diabetes. (Ziółkiewicz *et al*., 2023; Motsi *et al*., 2022). The grain confers numerous health benefits as shown in **Figure 1.**

Figure 1. Health benefits of sweet sorghum (adapted from Mohamed *et al*., 2022).

The lack of gluten also conforms to the dietary needs of people with celiac disease or gluten sensitivity (Kahlon *et al*., 2021). Understanding the potential advantages and including sweet sorghum grain meal in African diets can support sustainable solutions and effective diabetes management strategies. By taking into account its glycemic response, nutritional makeup, cultural acceptability, and culinary versatility, this investigation intends to explore the potential of sweet sorghum grain meal as a dietary supplement for diabetic patients within the context of African

cuisines. This study seeks to provide useful insights for healthcare professionals, policymakers, and people with diabetes in Africa by emphasizing the need for individualized interventions and comprehensive methods.

Type II Diabetes

Type II diabetes is a chronic condition marked by elevated blood glucose levels (Harvard Health Publishing, 2022). Approximately 90% to 95% of all cases of diabetes are type II, making it the most prevalent type (GBD,2021). Type II diabetes develops when the cells in the body become less responsive to insulin's intended function of bringing blood glucose inside the cells consequently inducing glucose accumulation in the blood (Harvard Health Publishing, 2022). The adverse effects of insulin on the body's major organs make it more difficult for them to use blood glucose. Moreover, the ability of the pancreas to produce insulin becomes severely impaired (Rahman et al., 2021).

Epidemiology of type II diabetes mellitus

Approximately 422 million people worldwide have diabetes, the majority of whom live in low- and middle-income nations (WHO, 2023). Most of these people have type II diabetes since this is the most prevalent type and accounts for approximately 90% to 95% of the total diabetes cases (Centers for Disease Control, 2022). Diabetes is directly responsible for 1.5 million fatalities annually and over the past few decades, both the incidence and prevalence of chronic diabetes have progressively increased (WHO, 2023). China has the greatest risk of diabetes, with approximately 116 million diabetic patients, while India has the second greatest risk 77 million followed by the United States of America, at 31 million (Alam *et al*., 2021). In Africa, there are approximately 24 million adults who have diabetes and by 2045, this number is expected to increase by 129% to 55 million (WHO, 2023). Type II diabetes is projected affect 11% of the world's population (783 million people) by 2045 (Dysted *et al*., 2021). Obesity is a significant contributing factor to type II diabetes, primarily due to the adoption of poor diets and inactivity (Ruze *et al*., 2023).

Management of type II diabetes mellitus

Promoting a lifestyle that includes a good diet, regular exercise, quitting smoking, and maintaining a healthy body weight is the cornerstone of type II diabetes care (Ogurtsova *et al*., 2021). Weight loss should be a top priority for individuals with type II diabetes because most people are prone to obesity. Each person's caloric intake needs to be customized for their unique body mass index and level of frequent activity (Butt, 2022). Through insulin dependent glucose transfer into muscle, moderate exercise helps reduce fat, and aids in reducing blood glucose levels (Alam *et al*., 2021). Daily moderate-intensity exercise of half an hour reduces glycaemia, improves cholesterol levels, lowers blood pressure, and helps people lose weight (by reducing the resting heart rate, increasing systolic volume, and reducing cardiac work) (Butt, 2022). The final stage in managing diabetes is medication (Alam *et al*., 2021) including injections of insulin, metformin tablets, sulfonylureas, and sodium-glucose co-transporter-2 (SGLT-2) inhibitors (Mayo Clinic, 2021). Along with blood sugar-lowering medications, people with diabetes frequently require blood pressure medications and statins to lower their risk of complications, such as foot care to treat ulcers, kidney disease screening and treatment, and eye exams to screen for retinopathy (WHO, 2023). Hypoglycemia, which is more dangerous than hyperglycemia, can occasionally result from improper insulin administration. It is frequently recommended that people with type II diabetes using insulin supplements should carry sugar or chocolate to combat this occurrence (Alam *et al*., 2021).

Dietary control of type II diabetes

The management and prevention of type II diabetes heavily rely on dietary considerations. Dietary recommendations must be customized to match the individual demands of each patient (precision diet) to achieve the overall aims of the treatment (Butt, 2022). Fruits (apples, pears, apricots, grapefruit and berries), vegetables (carrots, broccoli, cabbage, lettuce and tomatoes), whole grains (wheat, oats, barley, maize, rye, millets and brown rice), lean meats, and nonfat or low-fat dairy products should all be included in the meal plan (Centre for Disease Control, 2022). Foods with fewer calories, saturated fat, trans-fats, sugar, and salt should be chosen (Mayo Clinic, 2021). Fewer than 30% of calories should come from fat, with fewer than 10% of those calories coming from saturated fats; at the same time, proteins should make up 10% to 20% of the calories ingested (Butt, 2022). Broccoli, spinach, and green beans are examples of non-starchy vegetables that should be consumed more frequently, while added sugars and refined grains should be avoided

(Mayo Clinic, 2021). Wherever possible, whole foods should be preferred to highly processed foods (Touvier et al., 2023). Monitoring blood sugar levels and eating at regular intervals without skipping meals are also essential (Centers for Disease Control, 2022). Alcohol consumption should be kept to a minimum and water should always be preferred over sugar-sweetened beverages (Mayo Clinic, 2021). Beef, chicken, and fish can be substituted with plant-based protein meals such as beans, lentils, nuts, and soy-based products (Reynolds and Mitri,2019). In this context, the inclusion of sweet sorghum grain meal as a dietary supplement holds promise for enhancing the dietary control of diabetes. With its low glycemic index and potential to provide essential nutrients, sweet sorghum grain meal offers a valuable addition to the precision dieting approach in managing diabetes effectively.

Properties of sorghum

Nutritional characteristics of sweet sorghum grain

The grains are approximately 2 to 4 mm in diameter, and can be orange, tan, red, white, bronze, black and purple depending on variety (Osman *et al*., 2022). Grains are rich in vitamins and micronutrients such as iron, copper, phosphorous, zinc, potassium and magnesium (Osman *et al*., 2021), however, their calcium content is relatively low in comparison to that of finger millet (Abah *et al*., 2020, Ojulong *et al*., 2021). The wide and varied mineral and amino acids content of the grain makes it a good source for fighting micronutrient malnutrition particularly in Africa where the crop is widely consumed (Abah, 2020; Lin *et al*., 2021). Sweet sorghum grains contain approximately 4 - 21.1% protein, of which prolamin and albumin are predominant, and the glutelin content is lower than that of wheat; approximately 55.6 - 76% starch and 1.3 – 3.5% total minerals such as ash and 6.7% fibre (Abah *et al*.., 2020; Khalid *et al* 2022c). Lower glutelin and high iron contents are important they make the crop suitable for consumption by those individuals suffering from celiac disease, and anemia and the high fibre content is suitable for people with diabetes (Ajani *et al*., 2021, Osman *et al*., 2021). The pericarp contains tannins, hydrocyanic acid, and bioactive compounds such as ferrullic acid and gallic acid, which are key ingredients in food and medical industries (Hu *et al*., 2022).

Phytochemical composition of sweet sorghum grain

Phytochemicals are plant-based compounds (secondary metabolites) that help plants fend off herbivory and microbial infections, although they are not essential nutrients for humans or animals. However, they play important roles in antioxidant and anti-inflammatory responses as well as cancer fighting properties (Lee *et al*., 2020; Lee *et al*., 2021; Wang &Wei *et al*., 2022). The phenolic compounds present in sweet sorghum grain include flavonoids such as naringenin, luteolinidin and apigeninidin as well as phenolic compounds such as caffeic acid, ferrullic acid, gallic acid, p-coumaric acid, and 3-deoxyanthocynindins (3-DXA) (Khoddami *et al*., 2021; Hu *et al*., 2022; Pontieri *et al*., 2022). Phenolic compounds protect against cellular damage by scavenging free radicals thus they prevent oxidative stress, and their antioxidant properties also help reduce gastric indigestion (Lin *et al*., 2020; Mohamed *et al*., 2022). Flavonoids, phenolics and phytosterols also display antimicrobial, antiatherogenic, anticancer and antidiabetic properties (Lee *et al*., 2020; Mohamed *et al*., 2022; Pontieri *et al*., 2022). Tocopherols (α- and γ-tocopherols), and carotenoids (beta carotene and lutein), are also antioxidants that are involved in the formation of vitamin E and vitamin A respectively (Wang & Wei, 2022), and they play a significant role in inhibiting the inflammatory response through gene silencing (Mohamed *et al*., 2022; Cruet-Burgos *et al*., 2023). Phytosterols, polycosanols and saponins which regulate cholesterol levels in blood, and thus help prevent cardiac diseases and dyslipidemia, are also phytochemicals found in sweet sorghum grain (Mohamed *et al*., 2022; Pontieri, 2022).

Sweet sorghum grain meal in the control of type II diabetes

Sweet sorghum grain meal has gained attention for its potential in managing type II diabetes. It offers several beneficial components that can help regulate blood sugar levels and manage diabetes. Because of its high fibre content and antioxidant content, digestion is easier and gradually reduces insulin surges in diabetic patients (Singh *et al*., 2022).

Dietary fibre

Sweet sorghum grain meal is rich in dietary fibre, including both soluble and insoluble fibre. Soluble dietary fibres (SDF) (pectin, mucilage, gums, fructans and β-glucan) are fermented in the colon (Soliman, 2019; Motsi *et al*., 2022) and play a crucial role in managing blood glucose levels by slowing the digestion and absorption of carbohydrates. Millets have a low glycaemic load, and

their metabolism is prolonged; thus, they require less insulin for glucose absorption (Ren *et al*., 2022). Fermentable gastrointestinal soluble fibres and soluble dietary fibre supplements improve glycaemic control by increasing the viscosity of chyme, delaying gastric motility and lowering glucose absorption (glycaemic impact) in the small intestine (Tsitsou *et al*., 2023) hence nutrients reach the distal ileum (Karthikeyan *et al*., 2019). Reduced digestibility of soluble dietary fibres and short-chain fatty acids (SCFAs) produced from colonic fermentation may also contribute to glycemic control. SCFAs act on intestinal endocrine cells and/or neurons of the enteric nervous system to alter gastrointestinal motility and secretion (Giuntini *et al*., 2022). If an SDF delays the arrival of sugars in the intestinal lumen, it limits their accessibility to their respective enterocyte receptors (Alexander *et al*., 2019).

Inulin, a non-viscous and prebiotic SDF, delays gastric emptying, reducing glucose absorption and postprandial blood glucose elevation. Propionic acid, a fermentation product, may reduce hepatic gluconeogenesis and affect hepatic glucose metabolism (Wang *et al*., 2019). Studies have shown improvements in insulin sensitivity, delayed glucose entry, and decreased postprandial blood glucose rise due to the viscosity of soluble fibres in the gastrointestinal tract (Abutair *et al*., 2016). Postprandial hyperglycemia and hyperinsulinemia are significantly influenced by gastric emptying and intestinal glucose absorption (Dimitriadis *et al*., 2021). Derivative fibre from cereals may improve body weight and insulin sensitivity, and high-fibre intake has been linked to a reduced risk of type II diabetes (T2DM) (Weickett & Pfeiffer, 2018). A systematic review revealed that dietary fibre significantly reduced glycated hemoglobin A1c, fasting glucose, insulin, and homeostatic model assessment for insulin resistance (HOMA-IR) in patients with T2DM (Mao *et al*., 2021). Soluble fibre serves as a prebiotic, providing nourishment for beneficial gut bacteria. These bacteria can produce short-chain fatty acids, which have been shown to improve insulin sensitivity and glucose metabolism (Meena *et al*., 2022).

Polyphenols and antioxidants

Sweet sorghum grain meal contains various polyphenols and antioxidants, including phenolic acids, flavonoids, and tannins as shown in **Figure 2**. These compounds possess anti-inflammatory and antioxidant properties, which can help reduce oxidative stress and inflammation associated with diabetes (Khalid *et al*., 2022). Additionally, some studies suggest that polyphenols may enhance insulin sensitivity and improve glucose metabolism.

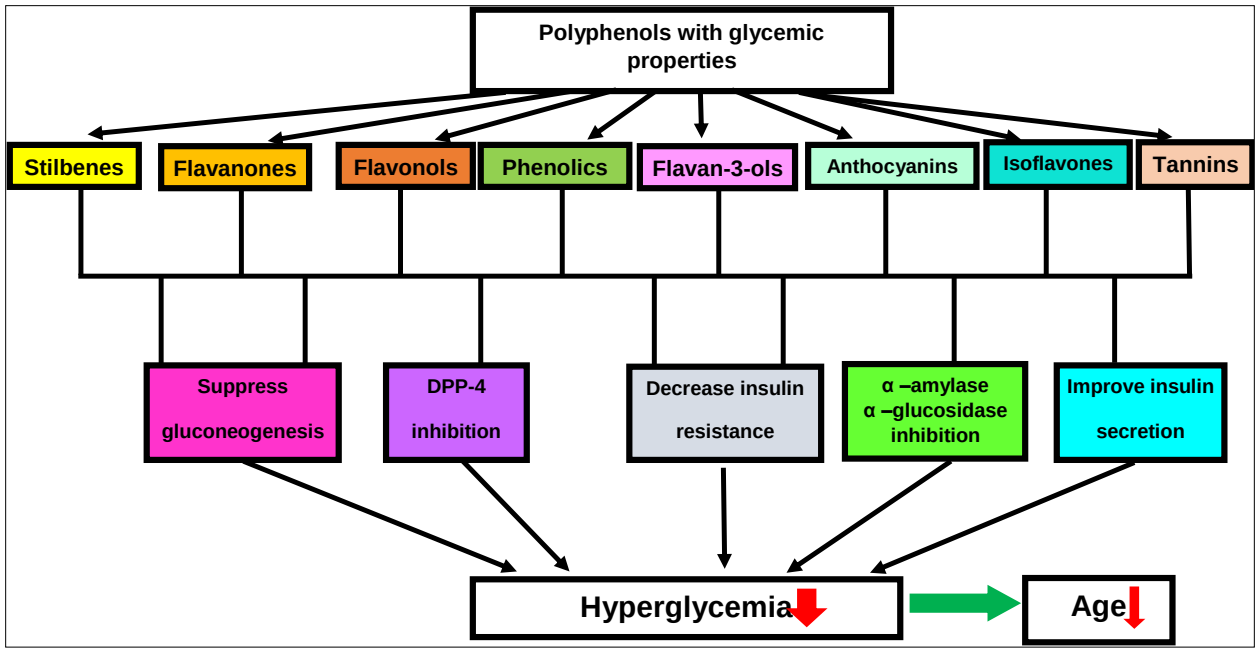

Figure 2. Phytochemical profile of sweet sorghum and its functions in the management of diabetes

Sweet sorghum contains bioactive phenolic compounds such as flavonoids, gallic, ferulic and caffeic acids and tannins that are linked to decreased risk of diabetes (Chen *et al*., 2021). Flavonoid-rich phenolic compounds inhibit α-glycosidase and α-amylase catalysis by binding to amino acid residues in their active sites. These inhibitors have potential applications in therapeutic approaches to manage the effects of type II diabetes (Ofosu *et al*., 2021; Meena *et al*., 2022). α-Glycosidase and α-amylase are responsible for dietary starch digestion, oligosaccharide degradation and glucose absorption in the small intestines, which results in an increase in postprandial glucose (Corkovic *et al*., 2022). By maintaining glucose levels, diabetic patients may experience fewer fluctuations in blood glucose levels, reducing the risk of shock and other complications. Raimundo *et al*. (2020) conducted a meta-analysis of interventional studies and concluded that the consumption of polyphenols may contribute to lower glucose levels in individuals with T2DM or at risk of diabetes and that these compounds may also act in combination with antidiabetic drugs. The antidiabetic properties of phenolics enhance the effect of insulin on skeletal muscle and liver cells by decreasing plasma free fatty acid levels, and hepatic gluconeogenesis, and increasing glucose uptake (Golovinskaia *et al*., 2023).

Studies have shown that millets are effective in glycemic management, lowering fasting, lowering the insulin index and resistance, and lowering glycosylated haemoglobin (Geetha *et al*., 2020;

Singh *et al*., 2020; Sobhona *et al*., 2020). In a study among diabetic patients who consumed control foods (wheat, maize and rice) and those who included sweet sorghum grain in their diet, decreases in glucose and insulin levels of 26% and 55% respectively were observed (Anitha *et al*., 2021; Nagaraju *et al*., 2020; Sobhona *et al*., 2020). High tannin containing sorghum is characterized by a low glycemic index, which is beneficial for people with diabetes due to its prolonged digestibility (Li *et al*., 2018; Khalid *et al*., 2022). Anthocyanins, on the other hand, are known for their antioxidant and anti-inflammatory properties, which may contribute to overall health and potentially have a positive impact on diabetes management (Frankowski *et al*., 2022).

Weight Management

Managing and maintaining of a healthy weight is paramount for individuals with type II diabetes. The low calorific high dietary fibre content of sweet sorghum increases satiety and is indispensable in improving insulin sensitivity and glycemic control in individuals with diabetes (Weickert and Pfeiffer, 2018; Meena *et al*., 2022).

Reduced Insulin Resistance

Type II diabetes is characterized by insulin resistance, an event in which body cells are less responsive to insulin. However, soluble fibre found in sweet sorghum grain has been shown to improve insulin sensitivity, allowing cells to respond effectively to insulin and facilitating the uptake and utilization of glucose and the utilization of glucose (Cutler *et al*., 2019; Moraes *et al*., 2018). A reduction of insulin resistance caused by dietary fibre helps improve overall glycemic control in individuals with type II diabetes (Dimitriadis *et al*, 2021). Insulin resistance manifests as postprandial hyperglycemia and can induce oxidative stress, the formation of advanced glycation end products (AGEs), and lipid peroxidative products, leading to endothelial dysfunction, dyslipidemia, and the expression of inflammatory genes (Giri *et al*., 2018). Postprandial hyperglycemia occurs after a meal high in carbohydrates due to the hydrolysis of starch by digestive enzymes (α-amylase and α-glucosidase) and glucose absorption in the small intestine. Postprandial hyperglycemia can be improved by suppressing α-amylase or α-glucosidase in the digestive tract (Khalid *et al*., 2022). The numerous pharmacologically active components of natural products, such as phenolics, reduce hyperglycemia by reducing insulin resistance and inhibiting α-glucosidase in the small intestine.

Mineral Content

Sweet sorghum grain meal is a good source of essential minerals such as magnesium and potassium. A 192-gram serving of sorghum grain contains 24.96 mg of calcium and 697 mg of potassium (Moraes *et al*., 2018). Magnesium plays a crucial role in glucose metabolism and insulin secretion, and magnesium deficiency has been linked to insulin resistance and impaired glucose control (Moraes *et al*., 2018). Magnesium is required for the activation of enzymes involved in glucose metabolism and the synthesis of insulin. Potassium, on the other hand, helps maintain normal blood pressure and supports heart health, which is particularly important for individuals with type II diabetes who are at a greater risk of cardiovascular complications (Baqar *et al*., 2020; Chatterjee *et al*., 2011; Badr Eslam *et al*., 2020).

Overall, the diverse array of beneficial components present in sweet sorghum grain meal makes it a valuable addition to the diet for individuals with type II diabetes. Its inclusion, alongside other dietary modifications and lifestyle changes, can contribute to better glycemic control, reduced risk of complications, and improved overall health outcomes for individuals managing type II diabetes.

Dietary implementation of sweet sorghum grain meal

Most foods consumed from sweet sorghum grain meal are boiled, baked or processed (Kam *et al*., 2016; Olawole *et al*., 2018). **Table 1** shows possible meal course plan designs that were developed for breakfast, lunch, supper and snacks that incorporate sweet sorghum grain meal/ flour.

Table 1. Applications of Sweet sorghum grain meal/flour in various recipes

Recipe	Preparation steps	Benefits/Uses
Unfermented porridge	Boil water, add sweet sorghum grain meal, simmer and serve	Quick and easy to prepare; versatile base for various toppings
Fermented porridge (sour porridge)	Soak sweet sorghum grain meal overnight in water, heat until thickened, simmer and serve	Enhanced flavor and nutrition due to fermentation; improved digestibility
Bread	Add salt and yeast to sweet sorghum grain flour, add warm water and mix	Offers a nutritious and filling bread

	thoroughly to a make dough, bake and serve	alternative; versatile for sweet or savory toppings
Dumplings (*Amaqebelengwane*/Ndebele)	Mix sweet sorghum grain flour/meal, bicarbonate of soda, salt and water/milk	Traditional African muffins; suitable for various accompaniments or eaten on their own
***Mpholokoqo*/Ndebele**	Mix sweet sorghum grain meal with salt, boil in water	Quick and easy side dish; complements tea or other beverages
Lunch/ Supper	Prepare thick porridge/sadza (Shona)/isitshwala (Ndebele) with sweet sorghum grain meal	Traditional main staple dish; complements various meat or vegetable relishes
Boiled grains as a snack *Muchakachi/ Shona Uhayezi/Ndebele*	Using mortar and pestle, pound the sweet sorghum grains until the outer layer is removed, winnow to remove chaff. Put the grains in hot water and steam until cooked, then add a pinch of salt as seasoning then serve.	
Non-alcoholic beverage *Maheu*/Shona *Amahewu*/Ndebele	Add grain meal to boiling water as if you are preparing porridge then allow to simmer for 5-10 minutes. Let the porridge cool then add cold water and stir to mix. Put the grist in a closed container and leave it for a day or two to ferment. Stir then serve as drink.	Maheu is a nourishing food and drink.
Bread	Put a cup of grain flour in a bowl. Add a pinch of salt, a teaspoon of sugar, a quarter of a teaspoon of yeast and mix the dry ingredients. Add a cup of warm water and mix to form thick dough. Put the dough in a pot, place the pot on hot charcoal and place the hot charcoal on the lid of the pot. Bake until golden brown and serve.	

Pancakes	Put a cup of grain flour in a bowl. Add a pinch of salt, a teaspoon of sugar and a teaspoon of baking powder. Add a cup of milk and mix to a smooth paste of pouring consistency. Then, use a frying pan to prepare the pancakes.

Sweet sorghum grain can also be used to make, using modern technology, instant cereals and a variety of baked confectionaries including buns, cookies, muffins and cup-cakes (Mohamed *et al*., 2022).

Integrating traditional healing practices into modern healthcare systems: strengths and challenges

Traditional healing practices have long been ingrained in African cultures, offering alternative approaches to healthcare. Integrating these practices into modern healthcare systems presents both strengths and challenges, particularly in the context of exploring the potential of sweet sorghum grain meal as a supplement for diabetic patients in African diets. These practices often incorporate holistic views of health, considering not only physical but also mental, emotional, and spiritual well-being (Zhang, 2015). In the management of diabetes, traditional systems may offer culturally sensitive approaches that resonate with patients' beliefs and lifestyles, enhancing treatment adherence and outcomes.

Moreover, traditional medicine practices often utilize locally available resources, such as sweet sorghum grain, which can be beneficial for promoting health and managing diseases like diabetes (Frankowski *et al*., 2022). In the case of sweet sorghum grain meal, which has shown potential in regulating blood sugar levels and improving insulin sensitivity, thus integrating it into traditional medicine practices can leverage indigenous knowledge systems to address health challenges effectively (Levy, 2024; Badasar *et al*., 2024). Furthermore, traditional medicine plays crucial roles in community healthcare delivery, especially in rural and underserved areas where access to modern healthcare facilities may be limited. Traditional medicine can complement the efforts of modern healthcare systems in reaching marginalized populations (Zhang, 2015).

However, integrating traditional medicine practices into modern healthcare systems also poses significant challenges. One major challenge is the lack of standardization and regulation, which

may lead to variability in treatment quality, outcome and safety (Dew & Liyanagunawardena, 2023). Balancing the integration of traditional healing with modern medical standards poses regulatory challenges related to licensing, accountability, and ethical considerations (WHO, 2023). In the case of sweet sorghum grain meal supplementation for diabetes management, ensuring consistent and evidence-based practices is essential to safeguard patient health and optimize treatment outcomes. Additionally, there may be cultural and ideological differences between traditional and modern healthcare systems, leading to tensions or conflicts in their integration (Mutombo *et al*., 2023). Modern healthcare systems, often rooted in biomedical models, may overlook or dismiss traditional medicine practices, undermining their potential contributions to patient care. Bridging these gaps requires open communication, mutual respect, and collaboration between practitioners of both systems.

Moreover, traditional healing practices may face stigma within modern healthcare settings, hindering their acceptance and integration (Mutombo *et al*., 2023). Addressing these perceptions necessitates raising awareness about the value of traditional knowledge and practices, backed by scientific evidence where available, to foster greater acceptance and collaboration between traditional and modern healthcare practitioners.

Implications of incorporating sweet sorghum grain into the African diet for diabetic patients

The adoption and incorporation of sweet sorghum grain meal into African diets can have several implications. There is a fundamental need to boost sweet sorghum production in both the commercial and smallholder sectors to meet domestic needs and curb imports. This can lead to increased income for farmers and contribute to economic growth (Cifuentes *et al*., 2014). Sweet sorghum grain meal can be used as a healthier alternative to refined grains, such as white rice or wheat flour. Refined grains have undergone extensive processing, resulting in a loss of dietary fibre and nutrients. By replacing refined grains with sweet sorghum grain meal, individuals with type II diabetes can improve their overall diet quality, increase fibre intake, and better manage their blood sugar levels (Anitha *et al*., 2021).

Sweet sorghum is a nutritious whole grain that contains essential nutrients such as vitamins (B vitamins), minerals (iron, magnesium and potassium), and dietary fibre (Osman *et al*., 2021; Abah *et al*., 2021; Khalid *et al*., 2022c). By incorporating sweet sorghum into their diets, Africans can

access a rich source of nutrients that contribute to overall health and well-being. The consumption of sweet sorghum grain can help increase mineral intake and improve overall health, including glucose control and insulin sensitivity (Pereira & Hawkes, 2022; Baqar *et al*., 2020; Morae *et al*., 2018). Sweet sorghum grain contains phytochemicals with glucose-lowering or hypoglycemic properties, improving insulin sensitivity and antidiabetic effects in animal models (Khodami *et al*., 2021; Mohamed *et al*., 2022). Incorporating sweet sorghum grain meal into diabetic diets may help regulate blood sugar levels and improve glucose control. A low glycemic index prevents rapid spikes in blood sugar and promotes better glycemic control (Anitha *et al*., 2021).

Sweet sorghum is a resilient crop that can grow well in arid and semi-arid regions, making it suitable for parts of Africa facing food insecurity and climate challenges. Integrating sweet sorghum cultivation can help diversify food sources and reduce dependency on a limited range of crops (Pereira & Hawkes, 2022). Many African countries heavily rely on a few staple foods such as maize, rice, and wheat. The introduction of sweet sorghum as a new staple food diversifies the diet and helps ensure that a wider range of nutrients are available. Sweet sorghum is a multi-use crop that can be utilized for food, fuel, fibre, and fodder. The incorporation of sweet sorghum into the African diet can help address socioeconomic challenges for smallholder farmers and improve food security and poverty alleviation in sub-Saharan Africa (Malobane *et al*., 2018).

Sweet sorghum requires less water and fertilizer inputs than certain other cereals, making it a more sustainable crop choice. Promoting the cultivation of sweet sorghum can foster sustainable agricultural practices, especially in regions with limited water resources. Sweet sorghum is a drought-tolerant crop that can grow on marginal land (Nasidi *et al*., 2019). Incorporating sweet sorghum into the African diet can help promote food security and sustainability by reducing the dependence on other crops that require more water and resources. In many African countries, sorghum has a long history as a traditional staple food (Maphosa & Dube, 2022; Khodami *et al*., 2021)). By adopting sweet sorghum grain meal, communities can preserve their cultural heritage and culinary traditions. The incorporation of sweet sorghum grain meal into the diet supports the utilization of a locally available and sustainable crop, making it accessible to a larger population.

Conclusion and future perspectives

The findings from this study reveal that incorporating sweet sorghum grain meal as a diabetic supplement in African diets can be beneficial. The soluble fibre in sweet sorghum plays a crucial role in slowing down glucose absorption, leading to reduced post-meal blood sugar spikes and improved insulin response. Furthermore, its gluten-free nature makes it a viable option for individuals with gluten sensitivities. The nutritional benefits of sweet sorghum, including essential vitamins, minerals, and dietary fibre, address concerns related to nutrient deficiencies commonly observed in diabetic diets. Additionally, promoting the cultivation and consumption of sweet sorghum can contribute to food security and sustainable agriculture in Africa due to its adaptability to semi-arid regions. Further research is crucial to establish the efficacy and safety of sweet sorghum grain meal as a diabetic supplement in African diets. Clinical trials with larger sample sizes are needed, along with clear guidelines for its inclusion in diabetes management. Awareness campaigns, value chain development, and educational initiatives targeting both individuals with diabetes and healthcare professionals will promote its acceptance and integration into local diets. Government policies supporting sweet sorghum cultivation and research funding are necessary, recognizing its role as a supplement alongside traditional diabetes treatments and lifestyle interventions.

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Emerging trends on epidemiology of infectious coryza disease in Mashonaland West Province of Zimbabwe

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Abstract

Infectious coryza disease is an upper respiratory disease of avian species, commonly affecting chickens. It is caused by *Avibacterium paragallinarum*, a gram-negative bacterium. Infectious coryza poses a threat to the economy due to increased culling rates of infected chickens and a decrease in egg production of up to 40%. This study aimed to determine the spatial and temporal distribution of Infectious Coryza disease in Mashonaland West Province of Zimbabwe across seven districts from 2018- 2021, with a focus on disease prevalence and risk assessment. A retrospective method was used using a database obtained from the Central Veterinary Laboratory, which indicated infectious coryza disease cases in Mashonaland West Province of Zimbabwe. Data was examined using correlation analysis to determine the relationships between the total number of cases and deaths, and chi-square test to evaluate infectious coryza prevalence across districts .Prevalence of infectious coryza among districts was significant ($p<0.05$)for the period of 2018 -2021.Low disease incidence was reported in 2018 across all the seven districts ;2019 had a peak increase of infectious coryza disease prevalence across all the districts with Zvimba district having cases above 2500.A weak correlation between total cases and deaths (co - efficient 0.115), not statistically significant ($p> 0.05$), indicating other factors influencing the mortality rates. These findings highlight the need to improve management practices and vaccination programs in poultry production across Mashonaland West Province of Zimbabwe.

Keywords: Avibacterium *paragallinarum*, Infectious coryza, prevalence, Zimbabwe

Introduction

Infectious coryza (IC) is a respiratory disease that is common in chickens, mostly layers. The disease is caused by the bacterium *Avibacterium paragallinarum* previously called *Haemophilus paragallinarum.* The incubation period of the bacterium is 1-3 days(Nouri et al. 2021) . *Avibacterium paragallinarum* is widely distributed worldwide in areas with intensive poultry production (Babazadeh and Abd El-Ghany 2023), (Roy, 2009).Infectious coryza is characterized by nasal discharge, sneezing and facial swelling, swollen wattles, loss of condition, decreased egg production, and difficulty in breathing. Infectious coryza symptoms are more severe when it occurs with other infections (Mei et al. 2023). The disease occurs worldwide, and it has a negative impact on the economic side of the poultry industry due to increased culling rates(Mei et al. 2023). This study aims to determine the disease prevalence of infectious coryza in Mashonaland Province of Zimbabwe.

The first cause of infectious coryza was discovered in 1930 and the causative agent was isolated in 1931 ((Deshmukh 2015), (Mei et al. 2023).Chickens of all age groups are prone to the disease, but susceptibility increases with age, mostly after 4 weeks (Dereja and Hailemichael 2017) .Infectious coryza has been reported to affect broiler chickens in United States and layers in Pakistan .Serovar A and C were reported in Japan, Australia ,Indonesia and Malaysia(Roy 2009).Serovar A was reported in Korea in the 1980s (Han et al. 2016) .A study in South Africa reported the emergence of C-3 serovar of Kume ,the incidence of Kume C-3 serovar has increased from 30% to over 70% in the early 1990s(Blackall 1999).Infectious coryza is transmitted mainly through direct contact of birds, via contaminated drinking water or feed, airborne droplets through dust or respiratory droplets and carrier birds. The disease is reported to affect other avian species other than chickens (Nouri et al. 2021).

Infectious coryza poses a significant threat to the poultry industry, affecting turkeys, indigenous chickens and layer chickens (Marit, 2024). Infectious coryza has been reported to be the second important bacterial disease associated with mortalities in India after *Salmonellosis*. A study in Morocco highlighted that infectious outbreaks were associated with a drop in egg production ranging from 14 % to 54 % and mortality rates of 0,7 % (Blackall 1999) . Stress from respiratory distress reduces feed intake and feed conversion, thereby affecting the overall growth rate (Marit 2024). Infectious coryza occurs mainly on farms rearing birds of different ages, it is influenced

by environmental factors such as overcrowding and virulence of the bacteria (Author et al. 2007).A study on village chickens in Thailand reported that infectious coryza is the most cause of death in chickens younger than 2 months and those older than 6 months (Blackall 1999).

Infectious coryza is most common during the brooding and laying phases of chickens, especially when stressed (Getaw Deresse 2022). Poor ventilation in poultry houses can cause infectious coryza (Veronica et al. 2022). Infectious coryza can be prevented by practicing good management practices, having a comprehensive biosecurity plan and vaccinating all birds. *Avibacterium paragallinarum* falls into nine serovars, making it a challenge to control the disease through inactivated vaccines due to limited cross protection among serovars(Roy 2009). In Zimbabwe, infectious coryza quickly spreads in communal areas where free-range birds move between households (homesteads) and fewer vaccinations are done in communal farms due to dosages of commercial vaccines per vial (1000 doses).

Materials and Method

Study site

The study focused on Mashonaland West Province of Zimbabwe which is situated in the northern region of Zimbabwe. It is in agro-ecological region 11 b. Mashonaland West Province has 6 administrative districts, namely Kariba, Sanyati, Zvimba, Chegutu, Makonde, Mhondoro - Ngezi and Hurungwe. Kariba falls under agro ecological region 5, which is located in the Zambezi valley where there is low farming activity. Hurungwe district falls under natural region 2b and is located in the northern part where game reserves is the main activity. Sanyati district is under natural farming region 2b and 3 of Zimbabwe where, crop production is the main farming activity done. Chegutu district is under agro- ecological region 3 where semi-intensive farming is carried out. Makonde district is under natural region 2a,3 and 4. Most areas are under agro ecological region 2a under intensive livestock farming. Mhondoro district falls under agro-ecological region 3 with semi–intensive farming activities.

Data collection

Data on IC cases reported from January 2018- December 2021 were extracted from the national disease surveillance database at Central Veterinary Laboratories for analysis. The database highlighted tentative diagnosis, final diagnosis, source of infection (vector, feed and water, or contact), total cases, deaths, age, and type of intervention (treatment), vaccination numbers, and month collected. Assistant veterinary officers compiled the database from the districts within the province. Data was collected based on clinical signs and owner's claim report and final diagnosis basis. Data on the outbreaks was compiled from communal farmers, commercial farmers, A1 and A2 farmers.

Statistical analysis

Data was examined using correlation analysis to determine the relationship between the total number of cases, one–way ANOVA ($p= 0.05$) to determine distribution and deaths, and chi-square tests to evaluate infectious coryza prevalence across districts. All the analysis were done using Python version 3.11.10 and R studio version 4.3.3.

Results

Coryza patterns across districts showed minimal variation among the districts ($F=0.454$). There was no statistically significant variation in infectious coryza prevalence between districts ($p > 0.05$).

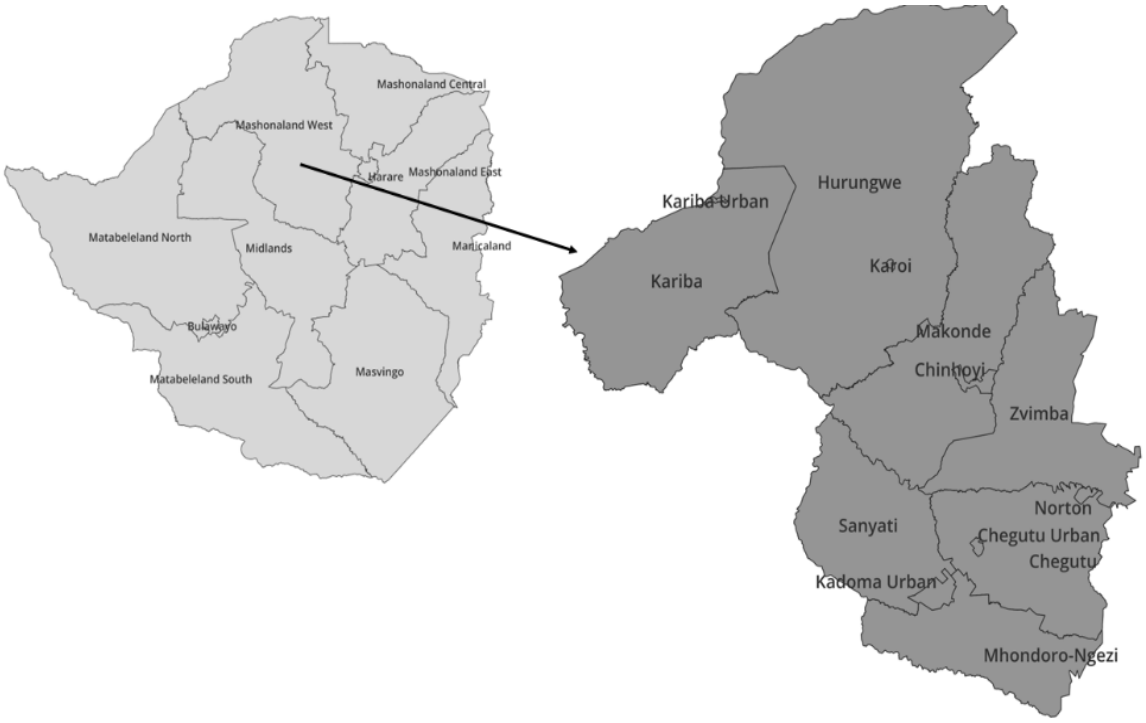

Figure 1: Map showing the districts in Mashonaland West Province

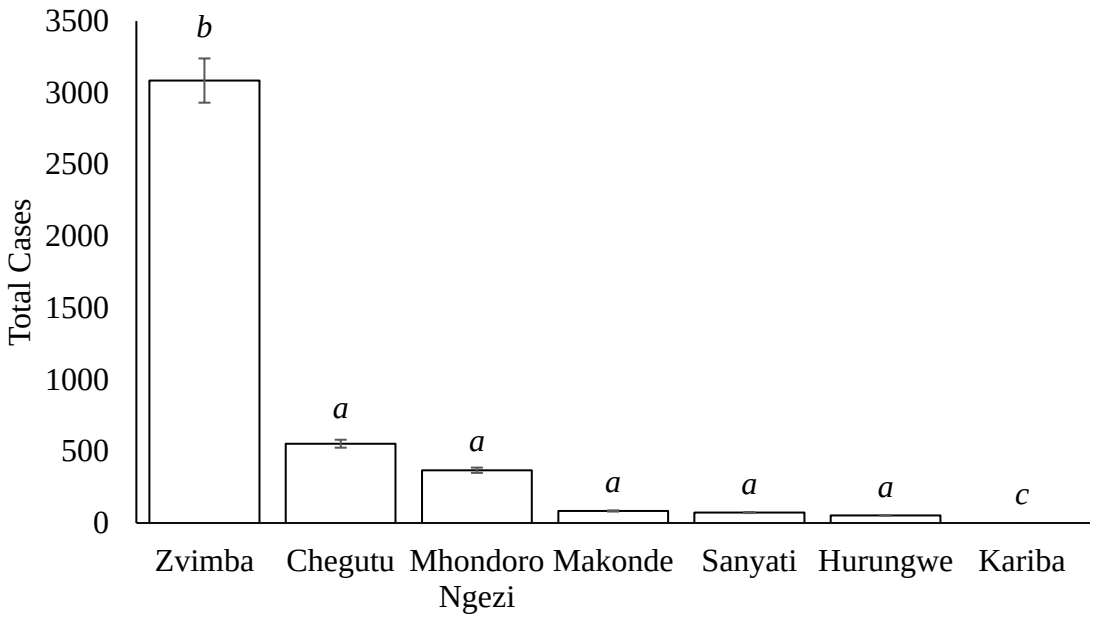

Figure 2. Total number of cases by district from 2018 – 2021 for infectious coryza in Mashonaland West Province

There is no significant difference in the total number of cases in Chegutu, Mhondoro-Ngezi, Makonde, and Hurungwe districts.

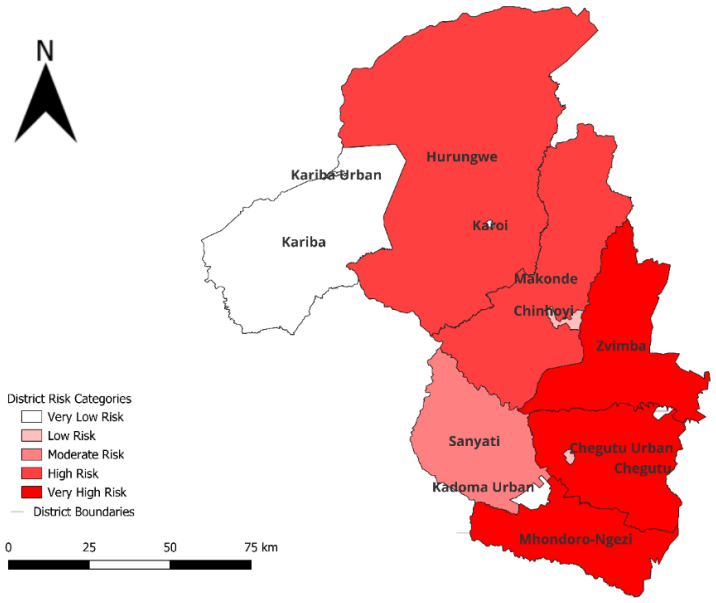

*Figure 3***.** Hotspot identification and risk assessment of the districts within Mashonaland West Province.

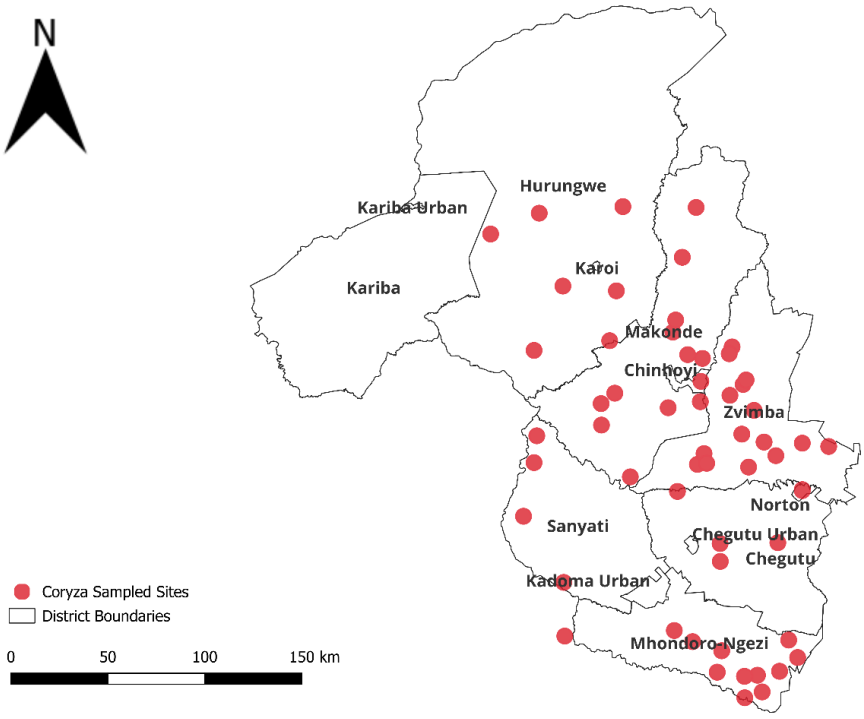

Figure 4. The distribution of Infectious Coryza in the various districts in Mashonaland West Province, Zimbabwe.

There was a substantial divergence in the prevalence of coryza across the districts in the province (figure 4), as indicated by the chi-square test analysis ($X^2 = 9978.002$, $p < 0.05$). This was seen in the study of the prevalence of infectious coryza throughout the districts. There was significant difference in prevalence between districts (p=0).

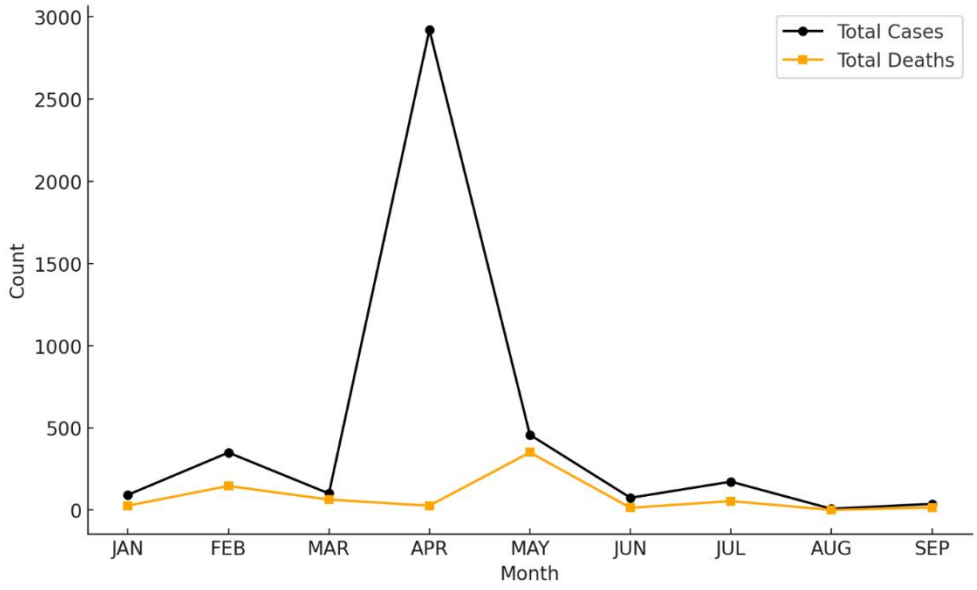

Figure 5. Spatial and temporal trends of infectious coryza disease by month from 2018 to 2021

The incidence of cases and fatalities for the period 2018 - 2021, was examined and indicated April has a notable increase in cases, totaling 2,920, but fatalities remained minimal, as shown in figure 5. February and May had a substantial number of cases and mortality figures, with 350 total cases and 147 deaths in February and 458 total cases and 351 deaths in May for the period of 2018-2021. From June to September, there was a decrease, with September recording the least number of total cases, with a mean of -12 from 2018 to 2021.

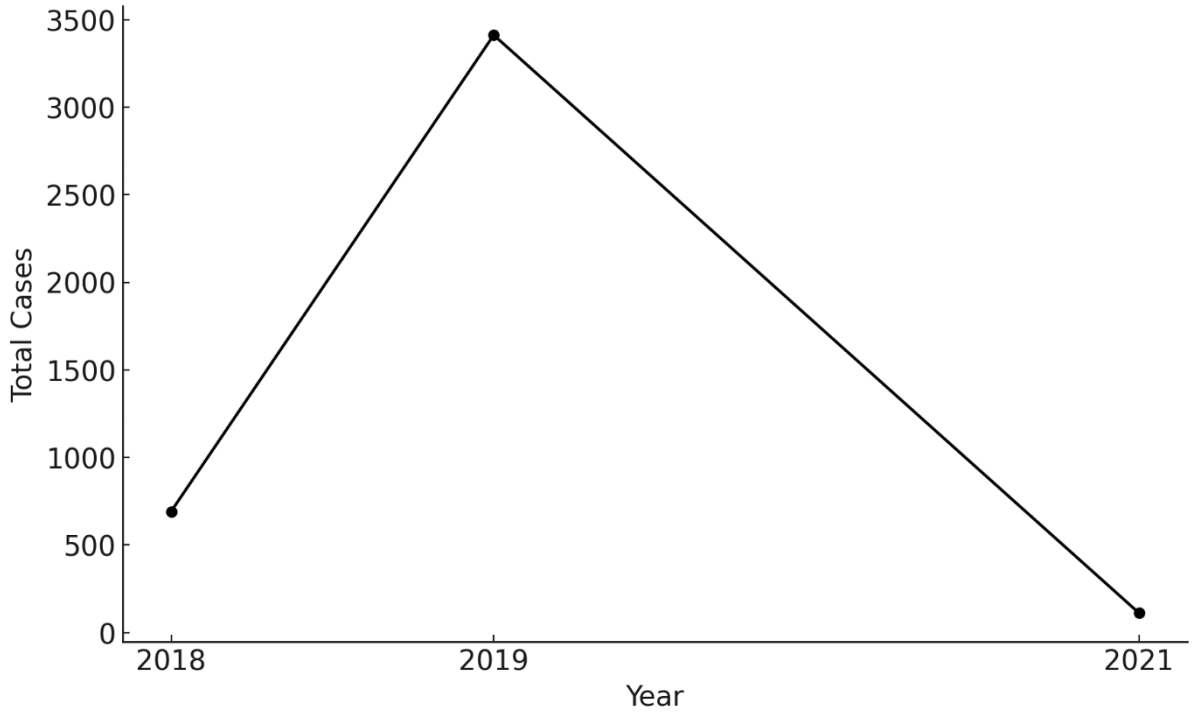

Figure 6. Temporal disease trends of infectious coryza total cases from 2018 to 2021

There was a considerable increase in the number of cases of infectious coryza in the Mashonaland West Province in 2019, with 3,412 cases, which indicates a serious epidemic (figure 6). However, in 2020, data on disease cases was missing due to the COVID-19 pandemic and lockdowns, which resulted in underreporting of cases to the relevant authorities. The number of cases in 2021 was much lower, this might be attributed to effective intervention efforts, decreased transmission, or underreporting.

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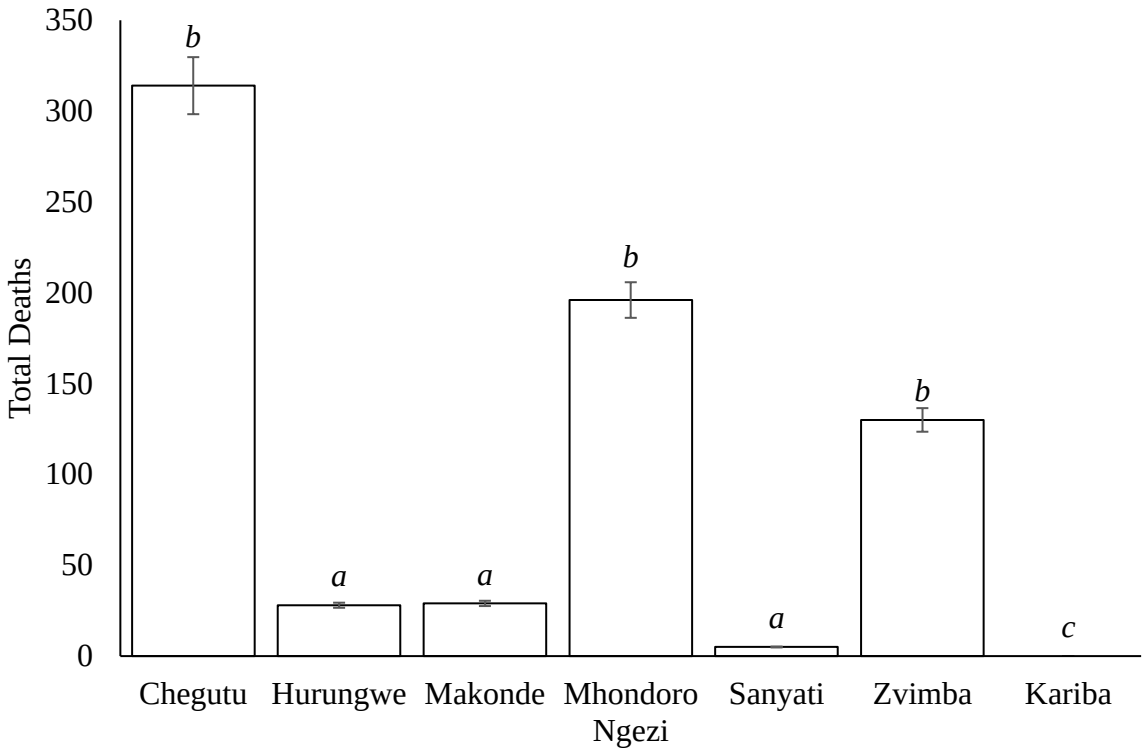

Figure 7. Total number of deaths by district from 2018 - 2021 for infectious coryza in Mashonaland West Province

Hurungwe, Makonde and Sanyati districts have no significant difference in number of deaths. Chegutu, Mhondoro – Ngezi and Zvimba are statistically significant with a higher number of deaths. Chegutu recorded the highest number of deaths, with 314 deaths in comparison to other districts. Mhondoro-Ngezi recorded the second highest incidence and mortality with 368 total cases and 196 fatalities. Other districts, including Makonde, Sanyati and Hurungwe, reported fewer cases and deaths.

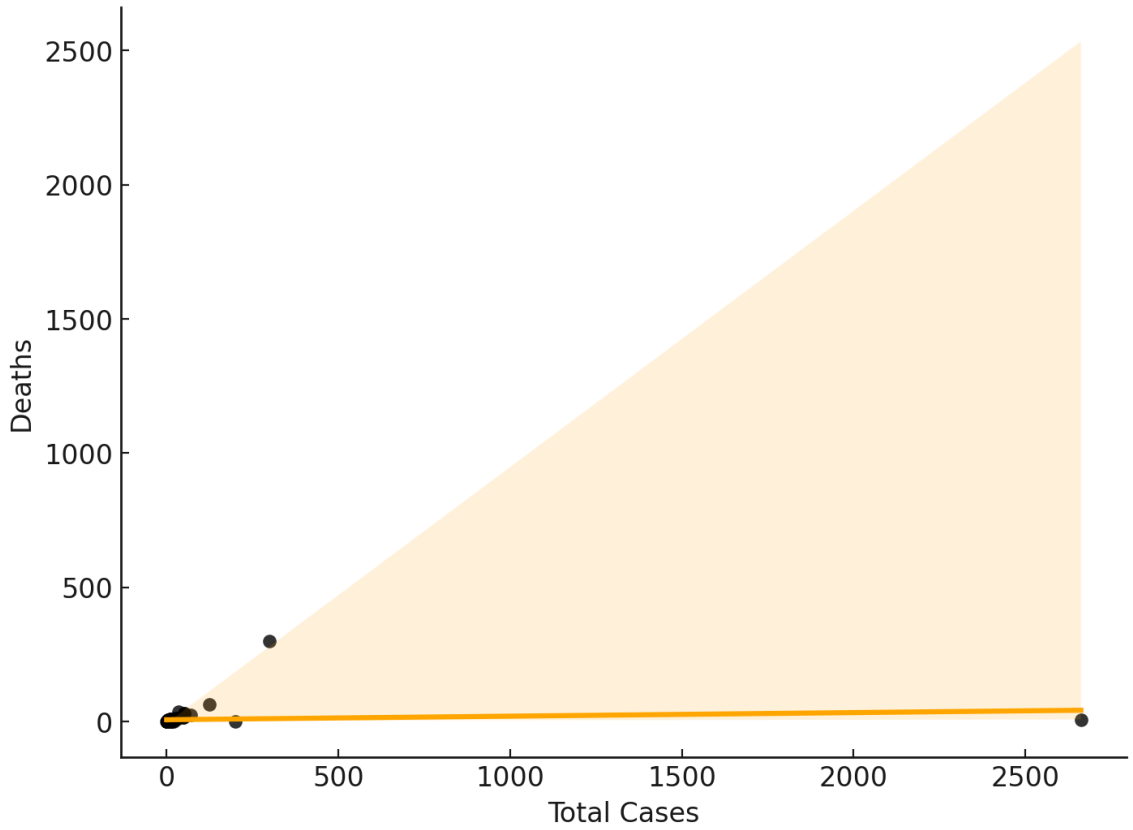

Figure 8. Correlation between total cases and deaths from infectious coryza disease from 2018-2021

There is a weak positive correlation (p=0.115) between total cases and deaths. However, the relationship is not statistically significant (p-value > 0.05). Infectious coryza has high morbidity rates but low mortality rates (Figure 8).

Discussion

The study focused on infectious coryza disease prevalence and factors influencing distribution in Mashonaland West Province of Zimbabwe. Chegutu has a high disease incidence among other districts in the Mashonaland West Province. This might be due to the scale of poultry production carried out in the district, most farmers are urban farmers and rely on backyard farming practices (Zimunya and Dube 2021). Vaccinations and proper biosecurity programs are difficult to implement due to the limited space of land used for poultry production. Kariba district has no or low infectious coryza cases due to the absence of intensive poultry farming. As shown in figure 3, Kariba district has low risk of infectious coryza incidence. This might be due to environmental conditions in Kariba, it is characterized by high temperatures during most times of the year, hindering the proliferation of *Avibacterium paragallinarum*. The main farming activities are fish farming and crocodile farming.

The least number of infectious coryza cases was recorded in 2021 as illustrated in figure 6, this might be attributed to effective intervention efforts, decreased transmission, underreporting of the cases or implementation of the vaccination program across the province. This points to the possibility of a connection between the reporting of diseases and their spread. Vaccination as an intervention method has proved to be effective on individual farms (Edgardo Soriamo-Vargas 2024) Vaccinations on farms are carried out between 10 and 20 weeks of age, and layers are protected by administering 2 injections.

Infectious coryza cases are commonly reported from intensive poultry production farms in developing countries due to poor management and the presence of other infections (Babazadeh and Abd El-Ghany 2023). In most developing countries occurrence of the disease is high due to the rearing of all age groups at the same place in free-range farming (Author et al. 2007) .Reports from a study conducted in Egypt from 2013 to 2015 indicated the presence of *Avibacterium paragallinarum*. A molecular characterization method was used on field isolates, revealing four isolates of serovar A, three of serovar C, and two of serovar B. (El-Naenaeey, Abd El-Aziz, and Asaad 2021).Difference in prevalence and distribution worldwide might be due to differences in climate conditions. The tropical climate is favorable for the proliferation of microorganisms (Dereja and Hailemichael 2017).

IC has been reported to be the second most significant bacterial disease associated with mortalities in Pakistan (Muhammand Hamza, 2024).Infectious coryza cases are commonly reported from intensive poultry production farms in developing countries due to poor management and the presence of other infections (Babazadeh and Abd El-Ghany 2023).

The seasonal patterns as indicated in figure 5 show that, the peak season for epidemics is late summer and low prevalence in winter months, June having 160 cases and July having 130 cases .*Avibacterium paragallinarum* pathogenicity is influenced by humid and warmer environment, which favors bacterial survival and transmission (Deshmukh 2015) The highest incidence of disease was in April with 2 920 cases as shown in figure 5, in Zimbabwe during this month, the temperatures are high and humid environments are common, *Avibacterium paragallinarum* proliferation is robust in these conditions. These findings differ from those of Dereja and Hailemichael (2017) who reported high disease incidence in January to April in Ethiopia, these are the windy months of the year so bacterial transmission is more rapid.

Observations from the correlation analysis state that there is a weak correlation between total number of cases and deaths $p > 0.05$ ($p = 0.283$). This suggests that other factors beyond the number of cases may influence the number of deaths observed. Flocks in Argentina, both broilers and layers have been reported to have *Salmonella spp* and infectious bronchitis virus. The disease is more common in adult birds because of the weak immune system in older birds. This makes the spread of microbes much easier. A study conducted in Jimma (Ethiopia) highlighted that younger chickens are more resistant compared to adult birds. this is in agreement with the work conducted in Thailand, where prevalence was high in chickens above six months (Dereja and Hailemichael, 2017).

Double-dose vaccination done with a 3-week time interval has been reported to offer long-term immune protection of 30-40 weeks after vaccination. Inactivated vaccines are the most common type of vaccines being used worldwide (El-Naenaeey et al. 2021)

Conclusion

This study highlights the emerging trends on epidemiological patterns of infectious coryza disease in Mashonaland West Province of Zimbabwe. It is difficult to control infectious coryza disease due to the presence of different serovars of *Avibacterium paragallinarum* around the world. Key risk factors, includes poor biosecurity measures, poor vaccination programs and interaction between commercial and backyard poultry systems, contributes to the persistence and spread of the disease .The increasing disease incidence worldwide highlights the need to improve biosecurity measures and vaccination programs in poultry production farms.Re-emergence of infectious coryza highlights the need for better disease surveillance and improved diagnostic services , use of laboratory diagnostic facilities enhances early detection of the bacterium and enhances controlled movement of birds .

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The effect of consuming a local Ready- to - Use Supplementary Food on human blood sugar concentration

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Abstract

Blood sugar may spike after meals and then stabilises as the sugars are converted to energy or fat. Bioactive phytochemicals, fibres, minerals, and proteins can stabilise blood glucose concentration. The objective of this study was to determine the effect of consuming a local Ready -to -Use Supplementary Food and a reference meal on postprandial blood glucose concentration, insulin concentration, and urine glucose concentration on 32 participants by using the Quantum Resonance Magnetic Analyser machine. The post meal blood glucose concentration was measured after one hour and two hours for group one that ate RUSF only, group two that consumed the reference meal plus the local RUSF, and group three that ate reference meal only. Satiety was rated using a 7-point rating scale. Data was analysed by Sigma Plot Version 12**.** There was no significant spike ($p > 0.05$) in glucose concentration in all participants after two hours but there was a statistically significant rise ($p<0.05$) in blood glucose levels one hour after meal treatments. The mean postprandial blood glucose concentrations were 5.50 ± 1.34 mmol/L for group one, 5.51 ± 1.34 mmol/L for group three, and 5.42 ± 1.78 mmol/L for group two respectively. Satiety was rated between two and four at base line testing and between five and seven after meal treatments. Mean Insulin and urine sugar levels changes were insignificant ($p > 0.05$). The local Ready -to -Use Supplementary Food had low glycemic index due to bio-active compounds, proteins, and fibres which regulated the release of glucose into the blood stream and maintained the steady blood glucose concentration in participants. From this study, it was concluded that incorporation of the local Ready -to -Use Supplementary Food in routine diets could reduce spiking of postprandial blood glucose, insulin, and urine glucose levels, and maintain satiety for long hours in humans.

Key words: blood sugar, postprandial glucose level, Ready-to-Use Supplementary Food, satiety, glycemic index

Introduction

Forms of malnutrition include undernutrition (wasting, stunting, underweight), insufficient minerals or vitamins, overweight, obesity, and the resulting diet associated non communicable diseases. In 2024, 150.2 million children under 5 years of age were too short for their age (stunting), 42.8 million were too thin for their height (wasting) and 35.5 million were too heavy for their height (overweight). In 2024, 23.2 % of all children under five years were stunted and 5.5 % were obese (WHO,2024). Obesity and overweight are conditions when a people are too heavy for their height. Excessive accumulation of fat can impair health. Obesity and overweight result from consumption of too much energy and expending too little energy. Globally, consumers are eating more energy-dense foods (high in fats and sugars) and drinks and engaging in inadequate physical activity. Body mass index (BMI) is the index of weight-for-height frequently used to classify obesity and overweight. It is a person's weight in kilograms divided by the square of his or her height in meters (kg/m^2). Obesity is referred to a BMI of 30 or more while overweight is defined as a BMI of 25 or more in adults. Known strong links between poor metabolic health, including obesity and diabetes highlighted the significance of enhancing improved nutrition for good health globally. Tackling poor diets and all forms of malnutrition, the underlying inequities, policies, and systems that drive them are important to ensure that the populations are resilient to such shocks in the future (Global Nutrition Report, 2021).

Lower -income countries persistently have lowest consumption of key health-promoting foods like fruits and vegetables and have highest levels of underweight, whereas, higher income countries have the highest consumption of foods with high health and environmental impacts, including red meat, processed meat and dairy products, and have the highest levels of obesity and overweight (Global Nutrition Report,2021).

The glycemic index (GI) of a food indicates the speed at which the carbohydrates in a particular food is converted to sugar in the body. The GI is a point scale used to check how blood sugar and insulin spike after consuming the same amount of carbohydrates from different foods. Foods that are slowly digested gradually releases sugar into the blood stream which maintains stable blood glucose. Such foods have low GI and are healthier, for example, nuts have a low GI of 14. Glucose plays a pivotal role in energy consumption. Carbohydrates, lipids, and proteins finally break down into glucose.

Glucose serves as the primary metabolic fuel for mammals and the universal fuel for the fetus. Glucose is the main precursor for the synthesis of various carbohydrates like glycogen, ribose and deoxyribose, galactose, glycolipids, glycoproteins, and proteoglycans. Glucose is the final substrate that enters the tissue cells and changes to adenosine triphosphate (ATP) at cellular level (Miller *et al.,* 2021).

Fasting blood glucose measures the quantity of sugar in the blood eight to 12 hours of fasting after eating a meal while postprandial means after a meal, usually two hours and may be tested on general people without diabetes. This test is done to see how your body responds to sugar and starch after you eat a meal. As you digest the food in your stomach, blood glucose, or blood sugar, levels rise sharply. In response, your pancreas releases insulin to help move these sugars from the blood into the cells of muscles and other tissues to be used for fuel. Postprandial test checks how the body responds to sugar and starch after consumption of a meal. When food is digested in the stomach blood glucose or blood sugar concentration increases sharply. The pancreas releases insulin to remove excess sugars into cells of the muscles and other tissues for utilisation as fuel. Within 2 hours after consuming a meal, insulin and glucose levels should return to normal. If blood glucose remains high the person might be diabetic (Miller *et al.,* 2021).

The mean fasting blood glucose concentration (no meal for the last eight-12 hours) is 80 mg/dl. On average, postprandial blood glucose may increase up to 120 or 140 ml/dl. The body's feedback mechanisms can return the glucose concentration to normal within 2 hours. During starvation, the liver supplies glucose to the body through gluconeogenesis, a process that synthesizes glucose from lactate and amino acids (Miller *et al*., 2021). The liver serves as the buffer for blood glucose concentration. After a meal, the blood glucose concentration rises and raises insulin secretion from the pancreas simultaneously. Insulin causes glucose to be deposited in the liver as glycogen and when blood glucose concentration decreases, the liver releases glucose back into the blood stream which stabilises the fluctuations of the blood glucose concentration (Miller *et al*., 2021). This signifies that during severe liver disease, it's extremely difficult to maintain stable blood glucose concentration. Insulin and glucagon worked together to maintain stable glucose concentration in participants. High blood glucose induces insulin secretion to lower blood glucose levels as glucose is moved from extracellular to intracellular. Conversely, a fall in blood glucose levels stimulates glucagon secretion to raise blood glucose levels.

Clinically, impaired and inadequate insulin secretion leads to diabetes mellitus (Miller *et al*., 2021). Prolonged hypoglycemia for hours and days leads to the secretion of growth hormone and cortisol that maintains blood glucose concentration by increasing fat utilisation and decreasing the rate of glucose utilisation by cells (Chen *et al*., 2021).

The normal fasting blood glucose concentration ranges between 70.00 mg/dL and 100.00 mg/Dl (3.90 millimoles per liter (mmol/L) and 5.60 mmol/L). Normal fasting blood glucose concentration ranging from 100 to 125.00 mg/Dl (5.60 to 6.90 mmol/L) is considered prediabetes and changes in life style and monitoring glycemia are recommended. If fasting glucose is 126.00 mg/dL (7.00 mmol/L) or more on two separate tests then the person has diabetes. Low fasting glucose concentration (hypoglycemia), below 70.00 mg/dL (3.90 mmol/L) may cause dizziness, sweating, palpitations, or blurred vision. Higher fasting blood glucose concentration (hyperglycemia) shows high risk of diabetes (WHO,2022). Fasting glucose level can be stabilised in a narrow physiological range of 3.50 to 5.50 mmol/L if the individual is not diabetic or during use of effective glucose -lowering medication in diabetics. Blood glucose may flicker to either side of the normal blood glucose concentration after meals but it is rapidly and spontaneously reverted to normal range (Kaufman,2000). In this study, the flicking of glucose to either side of the normal blood glucose was observed due to presence of minimal blood glucose of 2.24 mmol/L and maximum blood glucose content of 7.79 mmol/L in some of the participants after consuming the local RUSF.

Ready -to -Use Supplementary Foods are nutrient dense therapeutic foods consisting of carbohydrates, lipids, high fibre, proteins, and bioactive phytochemicals which help to reduce non-communicable diseases. RUSF is consumed together with normal routine meals for treatment of moderate acute malnutrition (MAM). To our knowledge, very few studies previously attempted to determine the effect of local Ready -to -Use Supplementary Food on blood glucose level, insulin response, and urine glucose concentration on individuals with or without diabetes. This study intended to determine the effect of eating the local RUSF on the blood sugar levels of various healthy people.

Materials and methods

Study design and participants.

Completely randomised block design was used. There were 3 treatments where one group ate the local RUSF only, the other group ate the reference meal only, while the third group ate the local RUSF plus the reference meal. The study included 32 healthy members of staff and students at Chinhoyi University of Technology in Zimbabwe. Face-to -face interviews were used to collect information from participants by trained interviewers using standard pre-tested questionnaires. The 24 - hour recall was used to gather information about foods which were consumed prior to this study. The reported foods were summarised into food group variables (see **Table 2**). The mean age, mean Body Mass Index (BMI; Kg/m^2), fasting blood glucose concentration, average waist circumference, and average height of participants were obtained. All participants fulfilled the inclusion criteria which was no history of diabetes mellitus, no allergies to RUSF and the reference diet, no recent major medical or surgical events, and no uptake of medication. The research was conducted in line with the 1964 Helsinki Declaration and its 2013 amendments and it was approved by the Chinhoyi University of Technology Ethics Committee. Informed consent was obtained from all study participants before starting the research.

All participants were recommended to eat a regular evening meal followed by 10 to 12 hours of overnight fasting. All participants were advised to avoid drinking alcohol and refrain from excessive physical activity. During the testing day, all participants were tested for blood glucose concentration, insulin concentration, and the urine glucose concentration using the Quantum Resonance Magnetic Analyser machine after 8 hours of fasting and at one hour and two hours after meal treatments. The results were recorded. The participants were split into three groups then one group consumed the reference meal plus the local RUSF, the second group ate the reference meal only, and the third group consumed the local RUSF only. All participants were given 500 ml of clean portable water to drink. At one hour and two hours after meal treatments, all participants were retested for blood glucose concentration, insulin concentration, and the urine glucose concentration using the Quantum Resonance Magnetic Analyser machine and the results were recorded. The results were compared with known standards to determine the effect of eating RUSF on different people's blood glucose concentration, insulin levels, and urine glucose levels.

Intervention meals

RUSF composition

The RUSF was composed of baobab fruit powder, extruded soy meal and sorghum powders, icing sugar, sunflower oil, and peanut butter. The proximate composition of the local RUSF was provided by the analytical results from the accredited Government Analyst Laboratory (GAL).

Table 1. Analytical results of the local RUSF.

Analytical parameter	Result(s)
Carbohydrates (g/100 g)	44.70
Proteins (g/100 g)	15.50
Fat (g/100 g)	31.17
Energy (kcal/Kg)	514.92
Fatty acids	Oleic acid, palmitoleic acid, linoleic acid
Phytochemicals	Phenolic acids, tannins, flavonoids, saponins, anthraquinones, alkaloids
Fibre (g/100 g)	2.20

The reference meal for participants

Care was taken to ensure that equal portions and corresponding carbohydrates were ingested by all participants. The meal consisted of one fried egg, 200.00 g Cashel Valley baked beans, 3.00 slices of white Lobels wheat bread with 10.00 g Buttercup margarine, and 300.00 ml of tea with Dendairy full cream cow milk.

Groups of foods consumed by participants prior to fasting

The 24- hour recall form was used to find the foods which were consumed by the participants prior to this study. The participants consumed foods which comprised grains, roots and tubers, legumes and nuts, dairy products (cheese, milk, and yoghurt), flesh foods (fish, meat, poultry, liver, kidney), eggs, vitamin rich fruits and vegetables, and other fruits and vegetables as summarised in the table 2.

Table 2. Groups of foods consumed by participants before the fasting blood glucose test

Food groups	Dietary Components	Consumers' proportion (%)
1	Grains, roots and tubers	100.00
2	Legumes and Nuts	14.40
3	Dairy Products (milk, yogurt, cheese)	48.20
4	Flesh foods (meat, fish, poultry, and liver/organ meats)	15.70
5	Eggs	3.90
6	Vitamin A rich fruits and Vegetables	11.3
7	Other fruits and Vegetables	6.50
8	Breastmilk consumption	0.00

Foods consumed by participants were recorded by the researchers and categorised into standard food groups. The number of participants were categorised according to the group of foods they ate prior to this study.

Experimental procedures

Anthropometric measurement

Body weight, height, and waist circumference were measured and the ages were recorded. Weight was measured by a scale to the nearest 0.01 kg with the participant wearing light clothes and without shoes. The waist circumference was measured by a tape measure to the nearest 0.00 m and height was measured by a vertical measuring board to the nearest 0.00 m. The weights and heights were used to calculate the BMIs of the participants.

Pre- and postprandial blood glucose concentration

Convenience sampling was used to choose staff members and students at Chinhoyi University of Technology (CUT) who verbally accepted to take part in this study. Pre- and postprandial blood glucose concentration, insulin concentration, and urine glucose concentration were measured in triplicate by Quantum Resonance Magnetic Analyser machine. On the experimental day, participants who had verbally accepted to take part in this study arrived at 0800 hours and sat relaxed on laboratory stools until 0830 hours.

The fasting glucose concentration, insulin concentration, and urine glucose concentration were sequentially measured in triplicate by Quantum Resonance Magnetic Analyser machine. Participants held the Quantum Resonance Magnetic Analyser machine's probe firmly while the machine scanned the whole body and displayed the measured parameters' reports. After the initial scan, the participants were randomly split into three groups. Group one ate reference meal only in 16 minutes. Group two consumed the reference meal plus 100.00 g of RUSF in 24 minutes. Group three consumed RUSF only in 13 minutes. All participants were freed to do their normal routine activities and then returned for the second and third measurements of post- meal blood glucose concentration, blood insulin, and urine glucose levels after one hour and two hours respectively. After these sessions, all participants were given a token of appreciation for making the study successful. The confidential results were compared with known standards to determine the effect of eating RUSF on different people's blood glucose concentration, insulin concentration, and urine glucose levels.

Satiety

Soon after recording each body scan for blood glucose concentration, the participants rated their subjective satiety feeling using a 7- point category rating scale where one was hungry and seven was not hungry. The results were used to determine how the local RUSF fulfilled satiety of the participants and how long it suppressed the hunger feeling.

Data analysis

Data was analysed using Sigma Plot Version 12. Data was analysed for normal distribution of values. Data was reported as mean values with standard deviations. Descriptive statistics was used to summarise and analyse characteristics of the participants and the outcomes of each experiment.

Results

Participants' characteristics

There were more females than males.

Table 3. Characteristics of Research participants by Gender

Gender	Frequency	Proportion (%)
Female	19	59.37
Male	13	40.63
Total	**32**	**100.00**

The Mean age for participants was 27.54 ±4.23 years and their range were 18.00 to 63.00 years. Mean Body Mass Index (BMI; Kg/m^2) was 23.79 ±5.371 and the range were 17.10 to 38.40 Kg/m^2. Fasting blood glucose concentration was 5.09 ±1.03 mmol/L and the range was 4.90 to 6.10 mmol/L. Average waist circumference was 67.79 cm and the range were 42.31 to 104.72 cm. The average height was 1.695 ±4.263 m and the range were 1.52 to1.85 m.

Table 4. Pre- meal treatment characteristics of panelists

Description of panelists' characteristics

Characteristics	Mean at baseline	Minimum	Maximum
BMI status (Kg/m^2)	23.79 ±5.37	17.10	38.41
Weight (kg)	68.89 4±4.84	42.10	113.16
Height (m)	1.695 ±4.26	1.52	1.85
Fasting blood glucose (mmol/L)	5.092 ±1.72	2.24	7.79
Urine sugar (mmol/L)	2.536 ±0.15	2.30	2.91
Fasting insulin (µU/mL)	3.100 ±0.17	2.83	3.56

Tabulated values were expressed as mean ± standard deviation (SD) for measurements.

The sampled participants were 12.50 % underweight, 56.25 % healthy weight, 12.50 % overweight, and 18.75 % obese. After the overnight fasting period, 9 participants were below 3.90 mmol/L indicating that they were hypoglycemic.

The normal blood glucose concentration of 5.60 mmol/L to 6.90 mmol/L range had 15 participants which showed that some of the participants were able to stabilise their normal blood glucose concentration. Hyperglycemic participants with blood glucose above 7.00 mmol/L were 8 who either had relative or absolute lack of insulin activity or had excessive glucagon activity.

Blood glucose concentration after meal treatments

After consuming the reference meal and the local RUSF there were four participants below the normal blood glucose concentration, 22 in the normal blood glucose range, and six in the diabetic blood glucose range. Consumption of the reference meal and the treatment with the local RUSF had several different effects on the post blood glucose concentration. Overally, the mean blood glucose concentration rose by 0.37 mmol/ L for all participants. The mean blood glucose concentration for participants who ate RUSF only increased insignificantly ($p > 0.05$) by 0.41 mmol/L while the mean blood glucose concentration for participants who ate the reference meal rose insignificantly ($p > 0.05$) by 0.41 mmol/L only. The increase in mean blood glucose concentration for participants who ate the reference meal plus the local RUSF was 0.33 mmol/L. Minimum blood glucose level was 2.25 mmol/L and maximum blood glucose level was 7.81 mmol/L for the two-hour experimental period. The mean fasting blood glucose concentration was 5.02 ±1.72 mmol/L and the range was 2.24 to 7.79 mmol/L for all participants.

Consumption of various meals increased the blood glucose concentration within one hour of treatment which showed that both the reference meal and the local RUSF had adequate nutrients which were converted to glucose that raised the blood glucose levels insignificantly ($p > 0.05$) for participants. Considering the full two-hour experiment, there were no significant ($p > 0.05$) group mean differences on average postprandial blood glucose concentration as the levels normalised. The blood glucose concentrations for all participants were summarised in figure1 below.

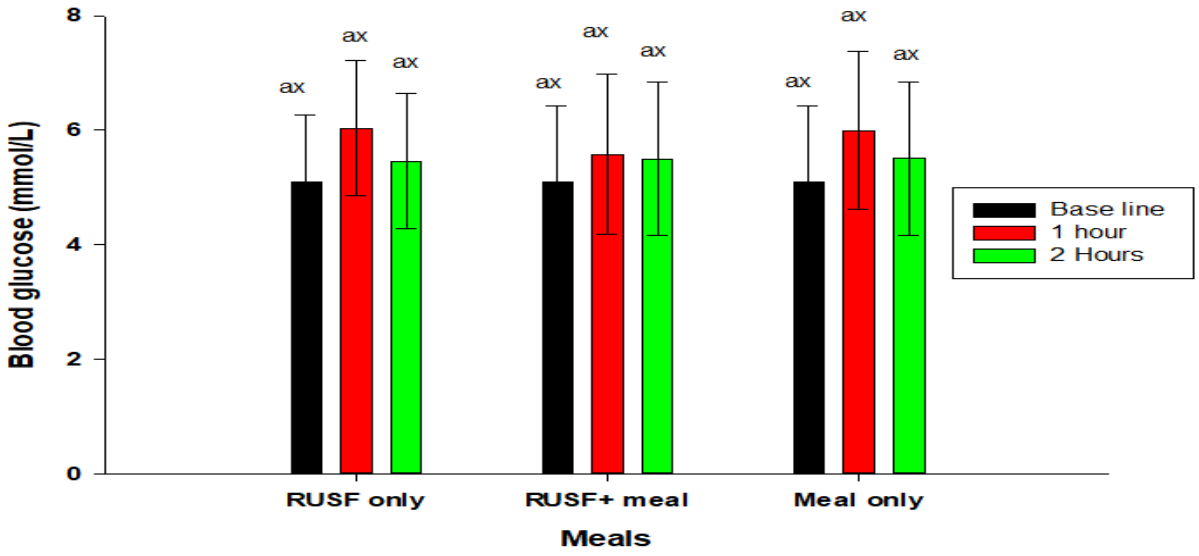

Figure 1: Mean blood glucose concentration of participants

The highest spike in blood glucose concentration occurred for participants who consumed the reference meal only followed by those that ate the local RUSF only and lastly those who consumed reference meal plus the local RUSF. The mean blood glucose concentrations spiked at approximately one hour and decreased back to normal at two hours. This study showed that increasing the amount of food consumed contributed to higher blood glucose concentration. Obese and overweight participants in the local RUSF only group naturally had higher blood glucose concentration and they also had a wider range for blood glucose levels but, however, all changes were statically not significant ($p > 0.05$) as they were below 15 mmol/L.

Insulin concentration after meal treatments

The minimum insulin level was 2.83 µU/mL and the maximum insulin concentration was 3.57 µU/mL while the mean insulin concentration was 3.10 ± 0.17 µU/mL.

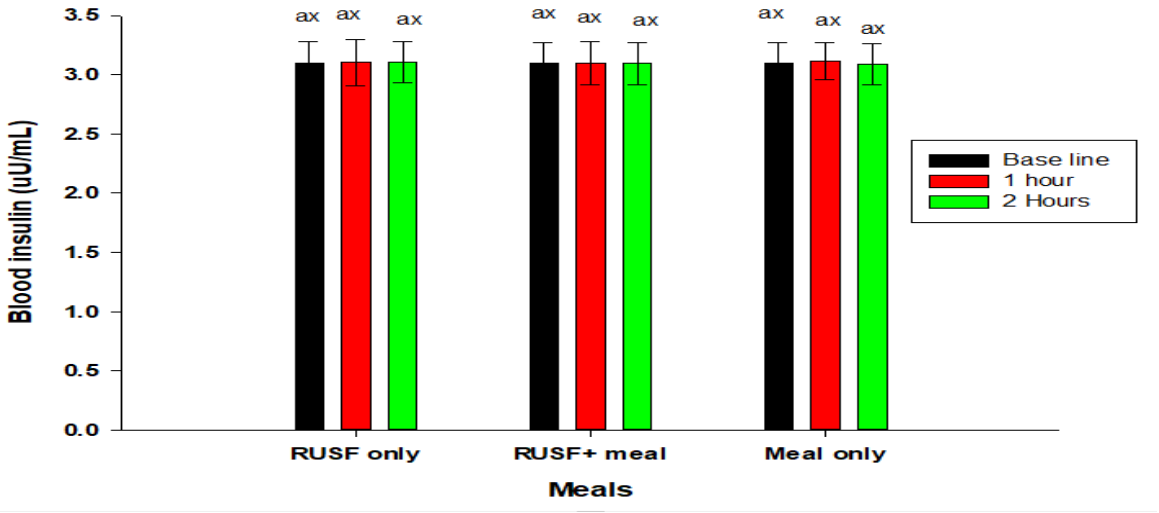

Figure 2: Mean insulin concentration in participants

The mean insulin concentration for all participants rose insignificantly ($p > 0.05$) by 0,01 µU/mL two hours after meal treatments. A decrease of -0.01 µU/mL was observed for participants who consumed RUSF only while a reduction of -0.01 µU/mL was observed for participants who ate the reference meal only. There was no change in the concentration of insulin for participants who ate the reference meal plus the local RUSF. There was a steady state of insulin concentration in the participants two hours after the meal treatments.

Urine sugar concentration after meal treatments

Excess sugar in the body was excreted in urine as urine sugar. Some participants were below the normal urine sugar range while others were in the normal urine sugar range. Maximum urine sugar level was 2.91 mmol/L and minimum urine sugar level was 2.30 mmol/L.

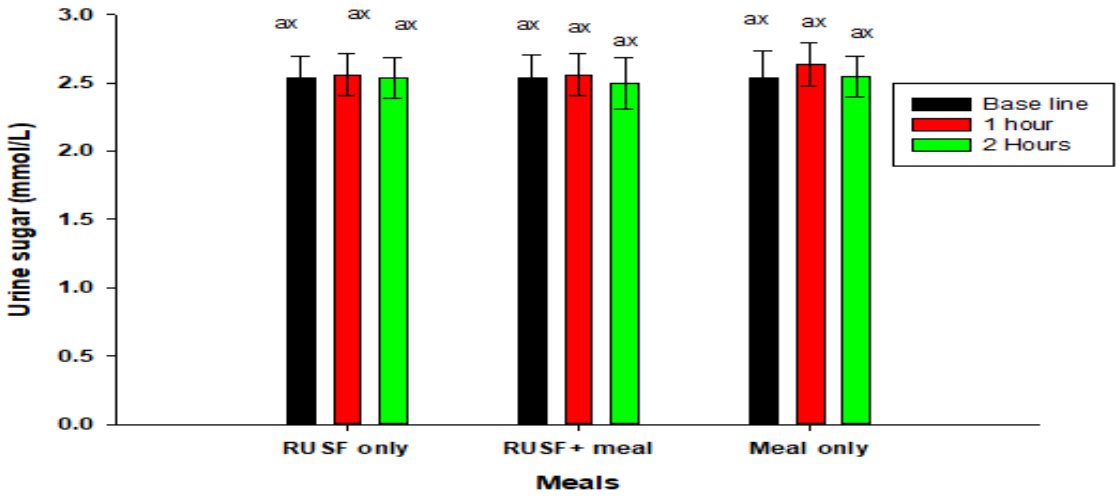

Figure 3: Mean urine sugar concentration of participants

The mean urine sugar concentration rose by 0.04 mmol/L for all participants after two hours of meal treatments. Urine sugar concentration decreased insignificantly ($p > 0.05$) by-0.04 mmol/L for participants who ate RUSF only and rose insignificantly ($p > 0.05$) by 0.01 mmol/ for participants who consumed the reference meal only. Urine sugar concentration for participants who ate reference meal plus the local RUSF was raised insignificantly ($p > 0.05$) by 0.05 mmol/L. The amount and nutritional quality of food consumed was associated with the increase in amount of urine sugar level. More food was linked to higher urine sugar concentrations. Obese and overweight participants had the highest urine sugar levels.

Satiety

Satiety was rated between two and four at base line testing since all participants were hungry after completing eight to 12 hours of fasting. Satiety was rated between five and seven, 2 hours after meal treatments by all participants. The subjectively rated satiety values after meal treatments were insignificantly different ($p>0.05$). The group that had obese and overweight participants initially had the lowest satiety but after the intake of the treatment meals they maintained stable satiety throughout the observation period. Stable satiety was highest for consumers of the local RUSF plus the reference meal probably because they ate more food than other test groups which contributed more starches which were converted to sugars that increased the blood sugars.

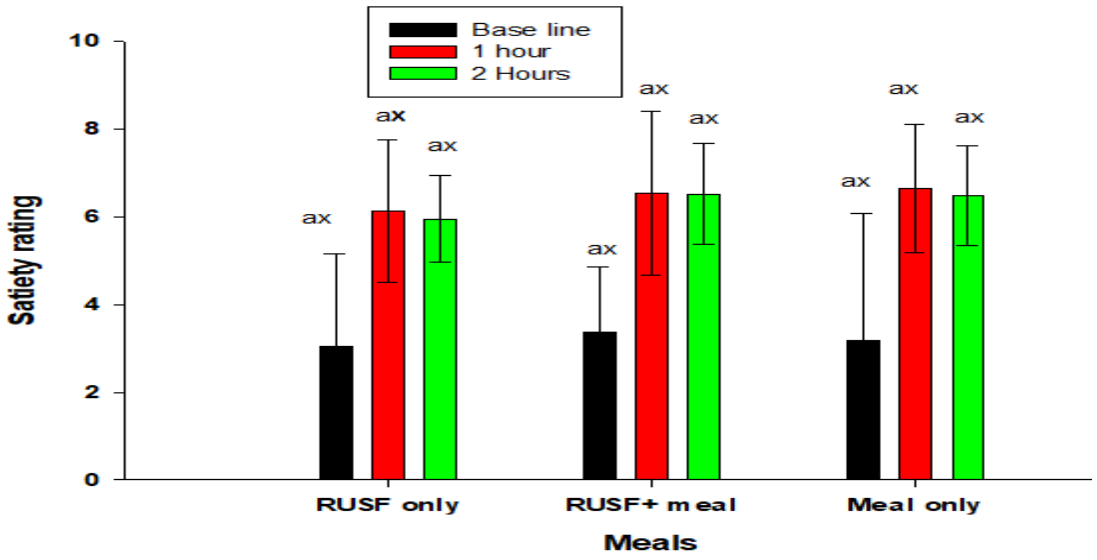

Figure 4: Mean satiety of participants over two hours

Discussions

The three different meal treatments produced comparable blood glucose, insulin, and urine sugar responses resulting in a few outliers. After the overnight fasting period, nine participants were below 3.90 mmol/L indicating that they were hypoglycemic. The normal blood glucose concentration of 5.60 mmol/L to 6.90 mmol/L range had 15 participants which showed that some of the participants were able to stabilise their blood glucose concentration. The overall mean fasting blood glucose concentration was 5.09 ±1.72 mmol/L. Hyperglycemic participants with blood glucose concentration above 7.00 mmol/L were six who either had relative or absolute lack of insulin activity or had excessive glucagon activity (American Diabetes Association, 2022). Considering the full two-hour experiment, there were no significant group differences ($p > 0.05$) on postprandial blood glucose concentration, insulin levels, and urine sugar levels in all participants. Consumption of the reference meal only had the highest spike in mean blood glucose (8.11 %), followed by consumption of RUSF only (7.99 %), and lastly consumption of the local RUSF plus the reference meal with a 6.44 % rise. Number of participants in the three blood glucose categories (hypoglycemic, normal, and hyperglycemic levels) did not change two hours after meal treatments. This showed that the three treatments meals had low glycemic index, therefore, they did not cause any significant spike in blood glucose levels in most participants. Since there were no significant ($p > 0.05$) spikes in the blood glucose levels and as a result it was unnecessary to

release lots of insulin to regulate the blood sugar levels. This was proved by the decrease in mean insulin levels two hours after consuming the local RUSF only (-0.42 %) and -0.16 % after eating the reference meal only while there was no change after eating the local RUSF plus the reference meal (0.00 %).

The mean urine sugar concentration decreased after consuming the local RUSF only (-1.54 %). A negative urine sugar test result means that no significant amount of glucose was detected in the urine sample. This typically indicates that blood glucose levels have remained within a normal range, and that the kidneys are effectively reabsorbing glucose, preventing it from spilling into the urine. The consumption of reference meal only and the reference meal plus the local RUSF had 0.39 % and 1.85 % increases respectively. It was observed that the mean urine sugar concentration increased with the corresponding increase in the quantity and nutritional quality of the food that was consumed.

Blood sugar refers to glucose in blood that includes disaccharides and polysaccharides converted to glucose in the body. The blood glucose concentration of a healthy human being stays in a stable and balanced state and if the steady state is disrupted then diabetes appears (American Diabetes Association, 2019). In this study, consumption of the local RUSF maintained stable blood glucose concentration in most of the participants since they remained in their blood glucose ranges as before the meal treatments. Physiological increase >7.32 mmol/ L is observed one to two hours after meals after injection of glucose or adrenalin preparation during emotional stress. Blood sugar concentration <2.16 mmol/L shows blood sugar reduction during sports, when hungry, during exposure to long term malnutrition or acute liver injury (Luyckx and Lefebvre, 1974). Consumption of the local RUSF did not disrupt the steady state of blood glucose in most participants as the local RUSF's low GI and GL released sugar into the blood stream slowly and consistently.

Fasting glucose level is 70.00 to 100.00 mg/dL (3.90 to 5.60 mmol/L). Most times, the blood glucose level is approximately 125.00mg/dL (6.90 mmol/L) or less (American Diabetes Association, 2019) and there were more participants in this category. Blood glucose concentration ranging from 100.00 to 125.00mg/dL (5.60 to 6.90 mmol/L) showed impaired fasting glucose, a prediabetes condition that indicates high risk of developing type 2- diabetes. Blood glucose concentration of 126.00 mg/dL (7.00 mmol/L) or higher shows that the person has diabetes

(American Diabetes Association, 2019). This was observed on participants with larger waist circumferences, obesity, or overweight who had higher blood glucose spikes after meal treatments.

Glucose is the building block of carbohydrates. Carbohydrates are quickly converted into glucose in the body and this can raise blood glucose level. Meals consisting of carbohydrates (Skytte *et al*., 2021) and nutritional factors like bioactive phytochemicals, more fibre, lipids, proteins, and minerals may influence glycemic response after meal consumptions. The local RUSF analysis results showed that it consisted of nutritional and bioactive factors that assisted in the regulation of the blood glucose level, the insulin concentration, and the urine sugar levels in participants. These nutritional and bioactive factors were contributed by the nutrient dense local ingredients such as baobab fruit pulp, extruded soy and sorghum powder, soybean oil, and peanut butter that were used to manufacture the local RUSF. Beneficial glycemic response could be linked to the bioactive compounds in baobab fruit extract (Coe, 2013; Evang *et al*., 2021; Shahat,2004) that was proved to be rich in polyphenols such as epicatechin and procyanidins (Shahat,2004). These bioactive compounds have the potential antihyperglycemic effect through promotion of insulin secretion by increasing the level of 1 Glucagon-Like Protein 1 (GLP 1) that lowers blood sugar.

Baobab has high fibre content (Magaia *et al*., 2013) which may reduce blood glucose levels by inhibiting glucose absorption (Gill *et al*., 2021). The influence of dietary fibre on glucose metabolism was attributed to soluble rather than insoluble fibre. Soluble fibre physiologically modulated the postprandial glycemic response by delaying gastric emptying, modifying gastrointestinal myoelectrical activity, delaying small bowel transit, reducing glucose diffusion through the unstirred water layer, and reduced access to alpha- amylase to its substrates due to increased viscosity of gut contents. Fiber, especially soluble fiber, forms a gel-like substance in the digestive tract that slows down the movement of food from the stomach into the small intestine. This slowed digestion means that carbohydrates are broken down and absorbed into the bloodstream at a slower rate. Furthermore, both soluble and insoluble fibres consumption improved glycemic control by increasing insulin sensitivity (Ylonen, 2003) which homeostatically regulated blood sugar levels. The gradual release of glucose into the bloodstream helps to prevent the sharp increases in blood sugar levels that can occur after eating foods high in refined carbohydrates. High-fiber foods tend to be more filling, which can help with weight management and reduce the likelihood of overeating or choosing high-sugar snacks.

High-fiber foods generally have a lower glycemic index (GI), meaning they cause a slower and lower rise in blood sugar compared to low-fiber foods.

The type and amount of carbohydrates can modify the postprandial blood glucose concentrations (Wheeler and Pi-Sunyer, 2008). Consumption of insoluble and soluble fibre from baobab in the local RUSF could have resulted in formation of health- promoting compounds during fermentation in the large bowel while insoluble fibres increase and softens the stool bulk thereby shortening the transit time through the intestinal tract (Anderson *et al*., 2009) which reduces absorption of sugars. Soluble fiber dissolves in water and forms a gel, while insoluble fiber adds bulk to the stool and can help regulate bowel movements. Fibre may bind to bile acids and decreases reabsorption of bile acids and cholesterol from the intestines.

The local RUSF had high protein content from soy extrudate. Proteins increase satiety and attenuate glucose excursions by delaying gastric emptying, slowing glucose absorption and or stimulating insulin secretion prior to the main glucose load in the meal (Watson *et al*. 2019, Ma *et al*., 2009). Other proteins were supplied by peanut butter to the local RUSF. Study participants who ate high levels of plant protein reduced their risk of type 2 diabetes by nine percent as peanuts improved both fasting glucose levels and two-hour postprandial glucose concentrations (glucose levels tested two hours after a meal (Lesley *et al*., 2018) as proteins reduced glucose absorption. These studies support that those proteins in the local RUSF delayed absorption of sugars and reduced sugar spikes in participants.

Oil containing pre-loads increase satiety and attenuate glucose excursions by delaying gastric emptying, slowing glucose absorption and or stimulating insulin secretion prior to the main glucose load in the meal (Gentilcore *et al*., 2006). This was supported by some studies which suggested that fat may modify the rate of glucose absorption by delaying gastric emptying (Gentilcore *et al*., 2006). With fat at 37 % in the local RUSF, it could have been enough to delay glucose absorption and maintained the glucose levels in participants.

Substantial evidence showed that nuts are linked to lower risk of coronary vein diseases and type 2 diabetes (Afshin *et al.,* 2014). These findings were supported by trials which showed that nuts reduced the risk of coronary vein diseases risk factors (Guasch-Ferre *et al*., 2018; Liu *et al*., 2020, Del Gobbo *et al*., 2015) and improved markers of glycemic control (Viguiliouk *et al*., 2014, Tindall *et al*., 2014). Peanuts and peanut butter have been shown to help to reduce the spike in blood sugar

when paired with high carbohydrate or high - glycemic load. Peanuts and peanut butter are both low glycemic index and low glycemic load foods. They both contain healthy oils, proteins, and fibre that positively stabilises blood sugar regulation (American Association of Clinical Endocrinologists, 2001). Presence of peanut butter in the local RUSF meant that the above-mentioned nutrients could be linked to the stabilisation of blood glucose in participants. This was supported by Reis and colleagues who showed that when peanuts and peanut butter were eaten in the morning, they positively assisted in controlling blood sugar throughout the day for women at high risk for type 2 diabetes (Reis, 2013). The study showed that blood sugar levels were prevented from spiking even after taking high - carbohydrate lunch without peanuts or peanut butter due to high protein and healthy fat content consumed in the morning. These findings supported previous studies that indicated that regular consumption of peanuts and peanut butter does not promote weight gain and reduced type 2 diabetes risk (Malik *et al.,* 2016). Peanuts improved both fasting blood glucose concentration and postprandial blood glucose levels tested 2 hours after consuming a meal (Lesley *et al*., 2018). The consumption of the local RUSF which contained peanut butter could be associated with the steady blood glucose levels of participants.

Magnesium content in the local RUSF could be linked to blood glucose regulation in participants. Peanuts and peanut butter contain 12.00 % of the daily recommended value of magnesium which regulates the release and absorption of insulin in the body. Consumption of peanuts for three weeks contributed towards higher magnesium intake and improved blood magnesium to more than recommended concentrations (American Association of Clinical Endocrinologists, 2001, The Peanut Institute, 2022). Magnesium in the local RUSF could have regulated the insulin levels in participants which in turn steadily regulated the blood glucose concentration for the participants.

Satiety

In this study, a standardised and pretested questionnaire was used to determine the subjective feelings of satiety after consuming treatment meals. It was observed that consumption of a local RUSF reduced the spiking of blood glucose levels. Increasing the quantity of food eaten by consuming the local RUSF plus the reference meal increased the postprandial glucose concentration and satiety. The local RUSF had high concentration of fibre and polyunsaturated fatty acids from peanut butter and high protein from the soy bean meal. Protein, fat, and fibre are important foods for maintaining satiety (The peanut institute, 2022).

Consumption of reference meal only had the highest blood glucose spike and lowest concentration of blood glucose concentration in some participants. This was probably caused by lower proteins, fats, and fibres in the reference meal such that it was difficult to maintain a steady supply of glucose throughout the two hours of experimentation. Nuts have high satiety value. Human trials showed that nut consumption moderates' appetite in the post - meal period (Tan *et al*., 2014). Peanuts were proven to suppress hunger and the desire to eat and increases fullness ratings after consuming them. The presence of peanut butter in the RUSF probably helped to suppress hunger and improved satiety in participants.

These current study results strongly supported the observation that consumption of the local RUSF provide adequate nutrients to counteract large blood glucose fluctuations during 2 hours after meal consumption. This study supported the general hypothesis that inclusion of bioactive phytochemicals, healthy fats and oils, fibre, proteins, and minerals such as magnesium improved the blood glucose control during the day but not forgetting that other foods consumed besides the local RUSF might contribute in explaining our findings. This study demonstrated the nutritional benefits of consuming the local RUSF in addition to normal routine meals to attenuate high postprandial excursions of blood glucose concentrations in human bodies. Consumption of the local RUSF was beneficial to people with poor glucose tolerance since it helps to maintain a steady- state of blood glucose, insulin, and urine sugar levels in participants. Regular consumption of the local RUSF could be beneficial in weight reduction and prevention of obesity and the type 2 diabetes since it assists in regulation of blood glucose after meals. High satiety over long periods of time plus attenuated glucose levels resulted in lower calorific content in people thereby reducing the risks of coronary vein diseases and diabetes. High energy local RUSF reduced the hungry feeling and suppressed the desire of continuous food consumption which prevented spiking of blood glucose. The addition of the local RUSF to routine meals resulted in low GI and GL which is highly associated with maintenance of a steady state of blood glucose levels thereby counteracted overweight and insulin resistance (Mattes, 2010). Our study showed that consumption of the local RUSF by people within targeted fasting blood glucose range met their postprandial glucose levels within 2 hours on the same day.

Recommendations

People should focus on consumption of the local RUSF which has a low glycemic index and low glycemic load to keep blood sugar levels in check and reduce the risk of obesity and type 2 diabetes.

Limitation

The design of this study is not appropriate to evaluate the different effects of each particular ingredient, and this represents a limitation of this study. There was potential bias through the use of self-reported food consumption data for the correlation analysis.

Conclusions

The intake of a local RUSF with bioactive phytochemicals from baobab powder, fats, fibres, proteins, and magnesium plus routine meals was a good strategy to promote increased satiety and reduce postprandial hyperglycemia. Increasing the amount reference meal and its nutritional composition in addition to the local RUSF directly increased the spike of blood glucose concentrations and provided satiety to participants over the two - hour experimentation period. Inclusion of 100 g of the local RUSF to normal meals helped to regulate blood glucose levels, insulin secretions, and urine sugar concentrations in participants. Therefore, the present results encouraged the use of the local RUSF as a diet component that proved that the use of natural and local nutrient dense foods could provide adequate nutrients that can reduce moderate acute malnutrition and food associated diabetes through controlling postprandial blood glucose levels.

Conflict of Interest: None

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