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BOOKLET

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Research Paper

Body length as predictor for improving body weight of White Leghorn chicken breed

Tyasi TL, Mookamedi KO, Mokoena K and Molabe KM.

Online J. Anim. Feed Res., 14(4): 218-224, 2024; pii: S222877012400026-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.26

Abstract
The association between live body weight and morphometric traits plays a major role in the daily management and improvement of poultry. The objective of the current study was to determine the association between morphometric features and live body weight, as well as to investigate the direct and indirect effects of morphometric traits on White Leghorn laying hens' live body weight. Live body weight (BW) and morphometric traits including shank circumference (SC), body length (BL), wing length (WL), shank length (SL), toe to back length (TBL), beak length (BKL), beak to comb length (BCL), height (CH) and chest girth (CG) were collected from one hundred (n = 100) White Leghorn laying hens aged 40 weeks. The correlation findings showed that BW was positively correlated to SL, WL, SC, BL, and CH ($p < 0.05$). The Path analysis results reported that BL (0.45) had the highest direct effect on BW while WL (0.14) had the highest indirect effect on BW via BL. Correlation results propose that improvement of BL, SL, SC, CG and CH might increase the BW of White Leghorn hens. Path analysis results on the other hand, imply that BL and SC may be used as selection basis during breeding to improve BW in chickens. This study suggests that BW of White Leghorn is correlated with some morphometric traits that might be used during breeding. The findings also suggest that body length directly influence the live body weight of White Leghorn chicken breed.
Keywords: Correlation matrix, Morphometric traits, Regression, Shank circumference, Wing length.

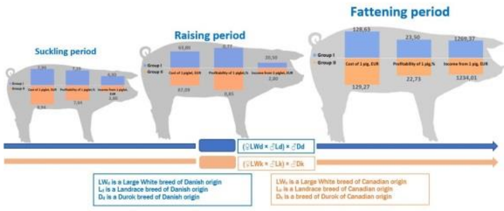
[Full text-PDF]

Research Paper

The efficiency of pigs from different genetic origins under industrial conditions in Ukraine

Voloshynov V, Povod M, Mykhalko O, Verbelchuk T, Verbelchuk S, Koberniuk V, Lavryniuk O, and Shcherbatiuk N.

Online J. Anim. Feed Res., 14(4): 225-233, 2024; pii: S222877012400027-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.27



Abstract
The study investigated the dependence of the fattening qualities of pigs and the economic efficiency of their breeding on their genetic origin. Two groups of 28 sows of Danish and Canadian origin inseminated with semen from Durok boars served as research material. A control group consisted of F1 sows of the Landrace and Large White Danish breeds inseminated with semen from Danish Durok boars. The group II, on the other hand, consisted of F1 sows of similar breeds from Canadian selection inseminated with semen from Canadian Durok boars. The studies focused on the efficiency of the sows' reproductive function, the growth intensity of the hybrid piglets and the efficiency and profitability of their rearing and fattening. Methods of analogue pairs and statistical data analysis were used. It was found that piglets of Canadian origin had a 7.5% higher average head weight during the weaning period, which contributed to a 7.5% higher market value and at the same time to a 6.7% higher income from rearing a piglet during this period and to a 3% higher profitability of its rearing compared to analogues of Danish origin. It was shown that animals of Danish origin had a 9.6% higher gross growth of the piglet litter during the fattening period, which gave them a 7.6% higher weight at the end of the fattening period and contributed to a 7% higher cost price for this period, a 7.6% higher market value and a 10.1% higher feedlot income and a 0.77% better feedlot profitability compared to Canadian-bred counterparts. We recommend the use of sows of Danish origin if the farm intends to sell weaned piglets, in

the industrial farms. If the farm intends to sell full-grown or (fattened) slaughter pigs, it is advisable to use pigs of Canadian origin.
Keywords: Breeding, Farm costs, Income, Market value, Piglet growth.

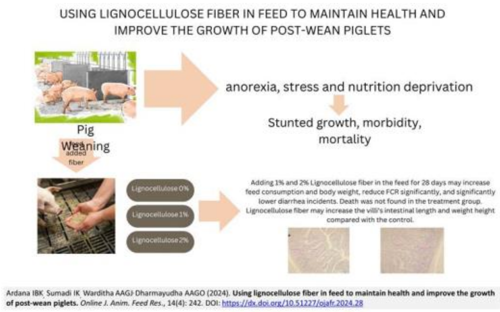
[Full text-PDF]

Research Paper

Using lignocellulose fiber in feed to maintain health and improve the growth of post-wean piglets

Ardana IBK, Sumadi IK, Warditha AAGJ, Dharmayudha AAGO.
Online J. Anim. Feed Res., 14(4): 234-242, 2024; pii: S222877012400028-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.28

Abstract
This study aims to determine how adding fiber lignocellulose in feed affects performance, intestinal health, morbidity, and mortality in post-wean piglets. The animal model used was 54 piglets divided into three groups of treatments: the control group was given starter commercial feed, group T1 was given starter pig feed with added 1% lignocellulose fiber, and the T2 group was assigned starter feed with the additional 2% lignocellulose fiber. Treatment is given for 4 weeks starting at 41-68 days old. Health observations were also carried out during the research. Piglet performance is determined based on feed intake, body weight and feed conversion ratio (FCR). Examination of the health of the gastrointestinal tract by measuring the length and weight of the intestine, microscopic length of the villi and depth of the crypts, as well as the number of *Escherichia coli* in the piglet's small intestine. The research showed that adding 1% and 2% lignocellulose fiber in the feed for 28 days may increase feed intake and body weight and reduce FCR significantly. Adding lignocellulose fiber may significantly lower diarrhea incidents, and death was not found in the treatment group. Lignocellulose fiber may increase villi's intestinal length and weight height compared with control. It can be concluded that supplementing lignocellulose fiber through feed may increase the piglet's health growth and efficiency.



Keywords: Body weight, Gut health, Lignocellulose fiber, Performance, Post-wean piglet.

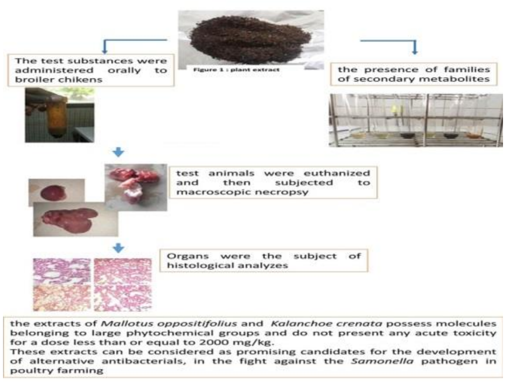
[Full text-PDF]

Research Paper

Prospects for the use of medicinal plants extracts (*Mallotus oppositifolius* and *Kalanchoe crenata*) as antimicrobials against salmonellosis in poultry

Rivière AK, Alassane T, Carole BA, and Germain KT.
Online J. Anim. Feed Res., 14(4): 243-251, 2024; pii: S222877012400029-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.29

Abstract
This study is a contribution to the search for alternatives to combat antibiotic resistance in *Salmonella* strains in poultry farming. The objective of this work is to highlight the main phytochemical compounds of 2 Ivorian medicinal plants (*Mallotus oppositifolius* and *Kalanchoe crenata*) and to evaluate their acute oral toxicity with a view to their use in the poultry sector, to fight against certain avian pathologies, including Salmonellosis. The phytochemical compounds of the different extracts of the plants used in this study were highlighted by colouring and precipitation methods. Acute oral toxicity was adapted to broilers according to the guideline OECD 425, 2008. This experimental study, which is the very first adapted to broiler chickens, was carried out with the agreement of the National Ethics Committee for Life and Health Sciences. The phytochemical screening carried out showed that each of these three antibacterial extracts possesses at least the major phytochemical groups sought. At the end of the acute oral toxicity study, no mortality was observed and the biochemical analysis of the subjects' blood showed creatinine values ≤ 10 mg/L.; aspartate aminotransferase (ASAT) ≤ 275 IU/L; alanine aminotransferase (ALT) ≤ 50 IU/L, urea=0.01g/L, CRP≤6 mg/L; and blood sugar was between 2 and 5 g/L in subjects from different batches. Ultimately, the aqueous and ethanolic extracts of *Mallotus oppositifolius* and the ethanolic extract of *Kalanchoe crenata* can be used as an antibacterial in broiler farming.



Keywords: Antimicrobial supplements, Medicinal plants, Phytochemicals, Poultry, Salmonella.

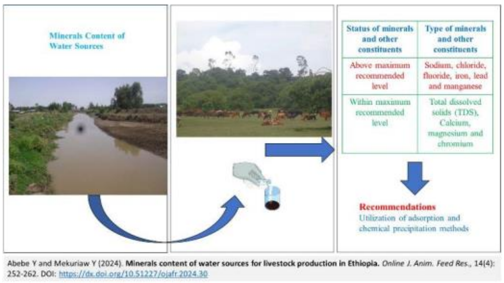
[Full text-PDF]

Review

Minerals content of water sources for livestock production in Ethiopia

Abebe Y and Mekuriaw Y.

Online J. Anim. Feed Res., 14(4): 252-262, 2024; pii: S222877012400030-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.30



Abstract
Minerals are essential nutrients for sustainable livestock production and productivity. Water is a source of minerals to livestock production beside of feed minerals. Presence of some minerals in water at higher levels will be toxic to animals and will affect animal health and productivity. So, it is essential to know the mineral content of water sources for livestock consumption in the country. This paper is based on a review of literature that were conducted on the mineral content and quality of water sources mainly for human consumption and other purposes in Ethiopia. Based on the literature values of the mineral content of the water sources and recommended values of minerals in livestock drinking water, the water sources were assessed for their suitability for livestock production. The review showed that the presence of variation in the mineral content of the water sources in Ethiopia. In addition, there is variation in the mineral content of the water sources between the dry and the wet season. The total dissolved solids (TDS), Calcium, magnesium, chromium and zinc content of the water sources in Ethiopia is within acceptable levels for livestock consumption. But the sodium, chloride, copper, fluoride, iron, lead and manganese content of some of the water sources (river, well and lake) in the country is beyond the maximum recommended level. This demands implementation of mitigation mechanisms to reduce the mineral contents of water sources; otherwise, it will result in deleterious effects on the health and productivity of animals. Generally, there is lack of adequate research on the mineral content of water sources for livestock production in the country. So, there is a need to conduct more research on the water sources being consumed by livestock in the country in the future.
Keywords: Ethiopia, Livestock production, Minerals, Season, Toxic elements, Water sources.

[Full text-PDF]

Research Paper

Principal breeding factors influencing milk yield and reproduction of Red Chittagong cattle

Tabassum M, Prank R, Paul SK, Akter N, Islam S, Islam S and Hossain E.

Online J. Anim. Feed Res., 14(4): 263-273, 2024; pii: S222877012400031-14
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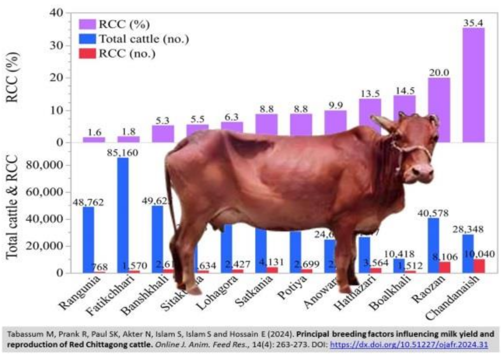

Abstract
The study aimed to investigate the principal breeding factors influencing milk yield and reproduction in the Red Chittagong cattle (RCC). Retrospective records of a total of 20 dairy cows from the 1st to the 2nd parities were collected from the record sheet from January 2020 to June 2022. Results indicated that birth weight of the RCC was 7.5% higher (P=0.023) in parity 2 when compared with parity 1. Accordingly, total milk yield per lactation was 10.2% higher (P=0.004) in parity 2 in comparison with parity 1. Age at first service was 34.7% higher (P=0.001) in parity 2 compared with parity 1. Accordingly, age at first conception was 38.3% higher (P=0.001) in parity 2 compared with parity 1. The dry period was 22.8% higher (P=0.001) in parity 1 compared with parity 2. Age at first service was 18.3% higher (P=0.014) in natural service (NS) compared with artificial insemination (AI). Age at first conception was 16.5% higher (P=0.023) in NS compared with AI. Post-partum period was 11.9% higher (P=0.008) in AI compared with NS. Days open was 8.9% higher (P=0.018) in AI compared with NS. Calving interval was 2.9% higher (P=0.006) in AI compared with NS. An increased probability of infertility was associated with NS compared with AI. Birth weight of the calf and dry period of the dam were negatively correlated while live weight and post-partum period of the dam were positively correlated milk yield at the expense of reproductive health. A decreased probability of milk fever, mastitis, metritis and infertility was associated with increased milk yield. Principal component analysis revealed that days open, calving interval and service per conception were the principal eigenvectors determining performance of RCC. Overall, RCC performed better in the 2nd parity compared with the 1st parity.
Keywords: Birth weight, Lactation, Milk yield, Parity, Red Chittagong cattle.

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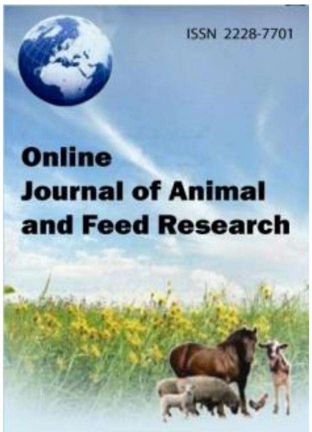

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BODY LENGTH AS PREDICTOR FOR IMPROVING BODY WEIGHT OF WHITE LEGHORN CHICKEN BREED

Thobela L. TYASI, Kgashane O. MOOKAMEDI, Kwena MOKOENA and Kagisho M. MOLABE

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Supporting Information

RESEARCH ARTICLE
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ABSTRACT: The association between live body weight and morphometric traits plays a major role in the daily management and improvement of poultry. The objective of the current study was to determine the association between morphometric features and live body weight, as well as to investigate the direct and indirect effects of morphometric traits on White Leghorn laying hens' live body weight. Live body weight (BW) and morphometric traits including shank circumference (SC), body length (BL), wing length (WL), shank length (SL), toe to back length (TBL), beak length (BKL), beak to comb length (BCL), height (CH) and chest girth (CG) were collected from one hundred White Leghorn laying hens aged 40 weeks. The correlation findings showed that BW was positively correlated to SL, WL, SC, BL, and CH ($p < 0.05$). The Path analysis results reported that BL (0.45) had the highest direct effect on BW while WL (0.14) had the highest indirect effect on BW via BL. Correlation results proposed that improvement of BL, SL, SC, CG and CH might increase the BW of White Leghorn hens. Path analysis results, on the other hand, imply that BL and SC may be used as selection basis during breeding to improve BW in chickens. This study suggests that BW of White Leghorn is correlated with some morphometric traits that might be used during breeding. The findings also suggest that body length directly influences the live body weight of White Leghorn chicken breed.

Keywords: Correlation matrix, Morphometric traits, Regression, Shank circumference, Wing length.

INTRODUCTION

White Leghorn chicken is an egg layering breed, known for its production of large white eggs of good quality (Dalal et al., 2020). As stated by Enab and El-Tahawy (2021), White Leghorn chicken is characterised by a small to medium body sized with a slender build and white feathers and Liao et al. (2016) added that White Leghorn have a high disease resistance, good performance, can survive under harsh environmental, nutritional conditions. Dalal et al. (2020) highlighted that body weight in White Leghorn chickens is the important parameter which determines the size and quality of eggs produced. According to Sadick et al. (2020), morphometric traits and body weight are important aspects for pricing an animal and breeding purposes.

However, one of the main challenges that farmers experience is the lack of access to weighing scales, which are the accurate way to determine body weight (Vincent et al., 2015). This disadvantages them from practicing proper management in their flock. Abdel-Lattif (2019) added that morphometric traits provide essential information that can improve the performance of the chickens and carcass value. Body weight of chickens can be predicted using morphometric traits in the absence of weighing scales (Sadick et al., 2020). On the report of Bila et al. (2021) knowing body weight of livestock assist in management practices such as correct dosage, feeding, setting prices when selling and to select animals as parents of the next generation mostly at rural areas. Path analysis is a statistical technique that is frequently applied to many livestock species to ascertain the influence of morphometric traits on live body weight, both directly and indirectly (Norris et al., 2015; Tyasi et al., 2020).

There are many researches that have been done on the prediction of body weight from morphometric traits of chickens (Ogunshola et al., 2017; Sabo et al., 2020; Negash, 2021). However, based on the authors' knowledge (based on searching in databases) there is no literature that has been conducted on prediction of body weight from morphometric traits of White Leghorn laying hens using path analysis. The goals of the current study were 1) to identify the correlation within morphometric traits and body weight, 2) to examine the direct and indirect effects of morphometric traits on body weight of White Leghorn chickens. The current study will help White Leghorn chicken farmers in the selection of morphometric traits during breeding for body weight improvement.

MATERIALS AND METHODS

Study area

The research investigation took place at the University of Limpopo Experimental Farm in the province of Limpopo. During summer, the room temperatures in the study area ranged from 20 °C to 36 °C, and during winter, the room temperature ranged from 5 °C to 25 °C. The location of the experimental farm was 27.55 S latitude and 24.77 E

Citation: Tyasi TL, Mookamedi KO, Mokoena K and Molabe KM (2024). Body length as predictor for improving body weight of White Leghorn chicken breed. *Online J. Anim. Feed Res.*, 14(4): 218-224. DOI: https://dx.doi.org/10.51227/ojafr.2024.26

longitude. It has a dry season from April to October and a rainy season from November to March. It receives less than 446.8 mm of mean annual rainfall (Hlokoe and Tyasi, 2022).

Experimental animal and management

The study used a total of 100 White leghorn laying chickens. White leghorn chicken is known as a breed that has high egg production (Dalal et al., 2020). The management practices for this study adopted the ones that were currently used at the experimental farm, where the chickens were kept in a battery system, feed was provided in the morning and evening, the water system was automated, and the light was provided 24 hours per day. The housing of the chickens was cleaned frequently, and faeces were removed every day.

Study design

The study used a cross-sectional design, where morphometric traits and body weight of all White leghorn chickens at the experimental farm were measured at a single point in time, and the variables were considered without influencing them.

Data collection

Body weight and morphometric characteristics were measured using the Dalal et al. (2020) method. Body weight was measured using Electronic Digital weighing scale known as MICRO SS AEO-1012 calibrated in kilograms. Nine morphometric traits were obtained using a tailor measuring tape on each bird, this includes: SC: shank circumference; WL: wing length; BKL: beak length; CG: chest girth; SL: shank length; BCL: beak to comb length; CH: height; BW: body weight; TBL: toe to back length; BL: body length. All traits were collected by one person to eliminate individual variation.

Statistical analyses

The data collected was analysed using Statistical Package for Social Sciences (IBM SPSS, 2022) version number 29.0. Pearson's correlation was employed to discover the relationship among morphometric traits and body weight. Stepwise regression was applied to come up with a predictive model from morphometric traits. The most optimal fitting model was identified using the mean square error (MSE) and coefficient of determination (R^2).

The following is a regression model used in the study: $Y = a + b1X1 + \ldots + bnXn$ (1); Where: Y = Dependent variable (body weight), a = Intercept, b1-bn = regression coefficients of the independent variables; (morphometric traits), X1-Xn = Independent variables (morphometric traits). The stepwise regression process was followed in adding independent variables to the regression model one at a time.

The stepwise regression analysis was performed to calculate the standardized partial regression coefficient, which was then employed as the path coefficient (beta weight). This number represented the morphometric features' direct impact on body weight. The path analysis method was done in accordance with Tyasi et al. (2020)'s instructions. Briefly, path analysis was computed as follows: $\mathrm{Pyxi} = \frac{\mathrm{biSxi}}{\mathrm{Sy}} \quad (2)$; Where, Pyxi = path coefficient from Xi to Y (i =BL, WL, SL, SC, CG, BKL, BCL, CH, TBL), bi = partial regression coefficient, Sxi = standard deviation of Xi and Sy = standard deviation of Y.

In multiple regression analysis, the significance of the path coefficient was evaluated using the t-statistic. Indirect effects of morphometric traits on body weight through direct effect were computed as follows: IEyxi = rxixjPyxj, Where, IEyxi = direct effect of biometric traits via direct effect on body weight, rxiyj = correlation coefficient between ith and jth morphometric traits trait and Pyxj = path coefficient that indicates the direct effect of jth morphometric trait on body weight.

Ethical consideration

The University of Limpopo Animal Research and Ethics Committee, in South Africa approved the study (AREC/42/2023:UG).

RESULTS

Descriptive statistics of measured traits

The descriptive statistics recorded from morphometric traits and body weight of White Leghorn chickens is presented in Table 1. The outcomes revealed that BW had the mean value of 2.09 kg. The results further indicated that the coefficient of variation (CV%) ranges from 0.01% to 2.21%.

Correlation matrix

The Pearson's correlation between morphometric characteristics and body weight is displayed in Table 2. The correlation matrix results revealed a significant correlation ($p < 0.05$) between BW with BL, SL, WL, CH, SC and CG respectively. However, BW indicated no association with BKL, BCL and TBL ($p > 0.05$).

Table 1 - Descriptive statistics of measured traits

Traits	Mean ± SE	CV (%)	Minimum	Maximum
BW (kg)	2.09 ± 0.03	0.01	1.20	2.57
BL (cm)	24.78 ± 0.22	0.89	20.00	29.00
WL (cm)	20.07 ± 0.17	0.85	16.00	23.00
SL (cm)	8.72 ± 0.09	1.03	7.00	10.00
SC (cm)	4.81 ± 0.05	1.04	4.00	6.00
CG (cm)	37.46 ± 0.27	0.72	31.00	43.00
BKL (cm)	3.17 ± 0.07	2.21	2.00	5.00
BCL (cm)	6.44 ± 0.13	2.02	4.00	10.00
CH (cm)	42.64 ± 0.35	0.82	36.00	50.00
TBL (cm)	26.52 ± 0.22	0.83	13.00	31.00

SE: standard error; SC: shank circumference; BW: body weight; SL: shank length; CG: chest girth; CV: coefficient of variation; BKL: beak length; BCL: beak to comb length; BL: body length; CH: chicken height; WL: wing length; TBL: toe to back length

Table 2 - Pearson's correlation between body weight and morphometric traits

Traits	BW	BL	WL	SL	SC	CG	BKL	BCL	CH	TBL
BW										
BL	0.49*									
WL	0.27*	0.30*								
SL	0.38*	0.17*	0.40*							
SC	0.20*	-0.01^{ns}	0.02^{ns}	-0.16^{ns}						
CG	0.18*	0.06^{ns}	-0.00^{ns}	-0.02^{ns}	0.10^{ns}					
BKL	0.05 ^{ns}	-0.02^{ns}	0.06^{ns}	0.02^{ns}	-0.05^{ns}	-0.19^{ns}				
BCL	0.12^{ns}	-0.04^{ns}	0.15*	0.22*	0.12^{ns}	-0.01^{ns}	0.21*			
CH	0.21*	-0.09^{ns}	0.16^{ns}	0.26*	0.15*	0.05^{ns}	0.04^{ns}	0.04^{ns}		
TBL	0.14 ^{ns}	-0.02^{ns}	0.25 *	0.19 ^{ns}	0.15*	0.00 ^{ns}	0.08 ^{ns}	0.19*	0.28*	

**: correlation is significant at p<0.01; ^{ns}: not significant correlation; *: correlation is significant at p<0.05; SC: shank circumference; BW: body weight; SL: shank length; CG: chest girth; CV: coefficient of variation; BKL: beak length; BCL: beak to comb length; BL: body length; CH: chicken height; WL: wing length; TBL: toe to back length.

Construction of preliminary regression equations

Primary models for prediction of White Leghorn chicken's body weight from morphometric traits were calculated using Stepwise linear regression model and the findings are shown in Table 3. The outcome showed that all the developed models were highly significant for prediction of BW ($p < 0.01$). The findings revealed that the model consisting of BL, SL, WL, CH and SC contributes 40% variation on BW.

Direct and indirect effects of morphometric traits on body weight

Direct and indirect effects of morphometric traits on live body weight of White Leghorn chickens was employed using Path analysis as shown in Table 4. Path analysis results showed that BL (0.45), SL (0.31), SC (0.22), CG (0.15) and CH (0.13) were statistically significant ($p < 0.05$) as straight effects on body weight of White Leghorn chickens. WL showed a highest indirect effect on body weight of White Leghorn chickens via BL.

Table 3 - Stepwise regression model for BW from morphometric traits

Traits	Equation	MSE	R^2	Sig
BL	0.584 + 0.061 BL	0.05	0.24	<0.001
SL	- 0.79 + 0.55 BL +0.094 SL	0.05	0.33	<0.001
WL	- 0.114 + 0.054 BL + 0.091 SL + 0.004 WL	0.05	0.33	<0.001
CH	-0.627 + 0.054 BL + 0.076 + 0.000 WL + 0.014 CH	0.05	0.37	<0.001
SC	- 1.707 + 0.057 BL + 0.080 SL - 1,824 WL+ 0.12 CH + 0.109 SC	0.05	0.40	<0.001

MSE: Mean Square Error. R^2: Determination coefficient. BL: Body length. WL: Wing length. SC: Shank circumference. BKL: Beak length. BCL: Back length. BW: Body weight. CH: Chicken height. SL: Shank length. TBL: Tail to back length.

Table 4 - Path coefficient analysis of morphometric traits and body weight of White Leghorn chickens

Morphometric traits	Correlation coefficient with BW	Direct effect	Indirect effect								
			BL	WL	SL	SC	CG	BKL	BCL	CH	TLB
BL	0.49*	0.45*		-0.01	0.05	-0	0	-0	-0	-0.01	-0
WL	0.27*	-0.03ns	0.14		0.12	0	0	0	0	0.02	0.01
SL	0.38*	0.31*	0.08	-0.01		-0.04	-0	0	0	0.03	0
SC	0.20*	0.22*	-0	-0	-0.05		0.02	-0	0	0.02	0
CG	0.18*	0.15*	0.03	0	-0.01	0.02		-0.02	-0	0.01	0
BKL	0.05ns	0.08ns	-0.01	-0	0.01	-0.01	-0.03		0	0	0
BCL	0.12ns	0.02ns	-0.02	-0	0.09	0.03	-0	0.02		0	0
CH	0.21*	0.13*	-0.04	-0	0.08	0.03	0.01	0	0		0.01
TBL	0.14ns	0.02ns	-0.01	-0.01	0.06	0.03	0	0.01	0	0.04	

BL: Body length; WL: Wing length; SC: Shank circumference;CG: Chest girth; BKL: Beak length; BCL: Beak to comb length; BW: Body weight; CH: chicken height; SL: Shank length; TBL: Toe to back length.

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Removal of less significant morphometric traits in the construction on model

Morphometric traits which were not statistically significant were removed from the stepwise linear regression analysis. Path analysis indicated that coefficient of WL, BKL, BCL and TBL were non-significant ($p > 0.05$) on BW. All the morphometric traits that were not significant to BW were removed from the stepwise linear regression model, the coefficient of determination (R2) and mean square error (MSE) changed when characteristics that are not significant to BW were eliminated.

Construction of optimum regression models for prediction of body weight

The Greatest Stepwise linear regression equation for prediction of body weight of White Leghorn chicken is shown in Table 5. After the deletion of non-significant morphometric traits (WL, BLK, BCL and TBL), the remaining morphometric characters (BL, SL, CH, SC and CG) were analysed again using stepwise regression technique to predict body weight. Findings showed that all the included morphometric traits were highly significant for prediction of BW ($p < 0.01$). Model consisting of CG, BL, SL, CH, SC and CG had the highest R2 (0.44) with the lowest MSE (0.04).

The model: BW = -1.471 + 0.056BL + 0.081SL + 0.012H + 0.102SC + 0.013CG was noted to be the optimal model to predict body weight of White Leghorn laying hens. The findings showed that 44% of the body weight variation was explained by the morphometric traits included in the model.

Table 5 - Optimum regression models for prediction of body weight

Traits	Equation	MSE	R^2	Sig
BL	0.584 + 0.061 BL	0.06	0.24	<0.001
SL	- 0.079 + 0.055 BL + 0.094 SL	0.05	0.33	<0.001
CH	- 0.625 + 0.058 BL + 0.077 SL + 0.014 CH	0.05	0.37	<0.001
SC	- 1.070 + 0.057 BL + 0.080 SL + 0.12 CH + 0.109 SC	0.04	0.40	<0.001
CG	-1.471 + 0.056 BL + 0.081 SL + 0.012 CH + 0.102 SC + 0.013 CG	0.04	0.44	<0.001

MSE: mean square error. R^2: determination coefficient. BL: body length. WL: wing length. SC: shank circumference. BKL: beak length. BCL: back length. BW: body weight. CH: chicken height. SL: shank length. TBL: tail to back length.

DISCUSSION

The method for examining the direct and indirect relationships between the independent and dependent variables is path analysis (Molabe and TyasI, 2021). The summary outcome of the present study showed that the average live body weight of White Leghorn laying hens was higher than those recorded by Bila et al. (2021) in Ross 308 broiler chickens and in indigenous Nigeria chickens reported by Egena et al. (2014). The difference may be due to chicken breed variations. Live body weight is a vital trait used for management purposes such as dosage of medication, feeding, marketing, and breeding purposes (Bila et al., 2021). The correlation outcomes of the current study reported that body weight was correlated with shank length, wing length, shank circumference, body length, chicken height and chest girth. The findings are in harmony with the finding of Bila et al. (2021) which highlighted that the shank circumference was correlated with body weight in Ross 308 chicken breed. Similarly, Egena et al. (2014) reported that body weight was linked with the length of the body, shank length, wing length in indigenous Nigeria chickens. However, the findings disagree with the study of Tyasi et al. (2016) which identified no association among body measurements and body weight in Chinese Dagu chickens. The variation could be related to various breeds and environments. The current study's association data indicate that that by increasing the SL, WL, SC, BL, CH, and CG will increase BW since Bila et al. (2021) revealed that correlated characteristics are regulated by the same genes. The results from correlation analysis only give the association between variables but not determining straight and indirect effects of morphological characteristics on live body mass. Hence, the path analysis was utilized to examine the straight and indirect influences of morphometric characteristics on live body mass of White Leghorn laying hens. The path analysis findings revealed that body length, shank length, shank circumference, chest girth and height had an immediate influence on body mass, with the highest contribution from body length. The present findings are aligned with the study of indigenous Nigerian chickens which reported that body length had the highest direct contribution to body weight (Egena et al., 2014). Bila et al. (2021) reported similar finding in Ross 308 breed of broiler chickens with body length as traits, which can be utilized to predict body weight. Contrary to the outcome of the study, Liswaniso et al. (2020) highlighted that chest circumference had the indirect effect on body weight of Zambian indigenous free-range chickens. The path analysis findings suggest that BL could be used to improve body weight of White Leghorn laying hens. The findings of the present study might be used during chicken breeding for improving live body weight of White Leghorn chickens.

CONCLUSION

It is concluded that body weight of White Leghorn hens had association some morphometric traits. Body length and shank circumference influenced the live body weight of White Leghorn laying hens as indicated by path analysis technique. However, more studies need to be done on prediction of body weight using linear body measurements using path analysis on chicken breeds.

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DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Authors' contribution

Tyasi TL designed the study, Mookamedi KO, Mokoena K and Molabe KM performed the fieldwork, analyzed the data and drafted the manuscript. Mookamedi KO and Tyasi TL edited the manuscript and approved the final manuscript.

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Competing interests

The authors have not declared any conflict of interests.

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THE EFFICIENCY OF PIGS FROM DIFFERENT GENETIC ORIGINS UNDER INDUSTRIAL CONDITIONS IN UKRAINE

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ABSTRACT: The study investigated the dependence of the fattening qualities of pigs and the economic efficiency of their breeding on their genetic origin. Two groups of 28 sows of Danish and Canadian origin inseminated with semen from Durok boars served as research material. A control group consisted of F_1 sows of the Landrace and Large White Danish breeds inseminated with semen from Danish Durok boars. The group II, on the other hand, consisted of F_1 sows of similar breeds from Canadian selection inseminated with semen from Canadian Durok boars. The studies focused on the efficiency of the sows' reproductive function, the growth intensity of the hybrid piglets and the efficiency and profitability of their rearing and fattening. Methods of analogue pairs and statistical data analysis were used. It was found that piglets of Canadian origin had a 7.5% higher average head weight during the weaning period, which contributed to a 7.5% higher market value and at the same time to a 6.7% higher income from rearing a piglet during this period and to a 3% higher profitability of its rearing compared to analogues of Danish origin. It was shown that animals of Danish origin had a 9.6% higher gross growth of the piglet litter during the fattening period, which gave them a 7.6% higher weight at the end of the fattening period and contributed to a 7% higher cost price for this period, a 7.6% higher market value and a 10.1% higher feedlot income and a 0.77% better feedlot profitability compared to Canadian-bred counterparts. We recommend the use of sows of Danish origin if the farm intends to sell weaned piglets, in the industrial farms. If the farm intends to sell full-grown or (fattened) slaughter pigs, it is advisable to use pigs of Canadian origin.

Keywords: Breeding, Farm costs, Income, Market value, Piglet growth.

Abbreviations: LW_d is a large white breed of Danish origin; L_d is a Landrace breed of Danish origin; LW_k is a Large White breed of Canadian origin; L_k is a Landrace breed of Canadian origin; D_d is a Durok breed of Danish origin; D_k is a breed of Durok of Canadian origin, EUR is official currency of 20 EU countries, kg is kilogram.

INTRODUCTION

Pig farming is an important branch of agriculture, as it can quickly supply a large part of the population with high-quality products (Kim et al., 2024). The production and quality of pork is influenced by many factors, including animal breed characteristics, breeding methods, housing conditions, microclimatic parameters, veterinary measures, feeding technology, biosecurity measures and others (Cornelison et al., 2018; Li, 2020; Smith et al., 2021; Van Mierlo et al., 2021). To achieve efficient production, it is necessary not only to use modern equipment and good animal care in the pig complex, but also to successfully combine the reproductive and productive characteristics of pigs of different genotypes and the characteristics of different animal breeding methods (Knox, 2014; Khramkova, 2019).

The basis of the production process of pork production in all farms with a closed cycle is the reproduction of the pig herd (Maes et al., 2020). Pig breeding farms pay particular attention to the use of breeding methods that enable the most effective utilisation of the biological characteristics of the pig carcass, which subsequently determine the productivity level of the animals (Kanis et al., 2004). It is possible to implement such an approach in the conditions of an industrial pig farm by achieving the effect of heterosis through the use of hybridisation or industrial crossbreeding. According to (Vargovic et al., 2022) hybridisation represents the highest level of industrial crossbreeding, provided that specifically selected parental and maternal forms of animals are used in the breeding process, which are able to stably and with high probability transmit their best productive qualities to their offspring.

The existence of alternative opinions on the effectiveness of using different parental components leads to the existence of different hybridisation systems based on the use of sows of different combinations: Large White × Landrace, Landrace × Large White, Large White × Welsh, Welsh × Large White, Welsh × Landrace, Landrace × Welsh, etc. (Tsereniuk, 2011; Harmatiuk, 2022). It should be noted that today in Ukraine there is no unified opinion on the use of

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terminal (terminal) boars, since the main terminal parental forms that are widely used are Durok, Pietren, Alba, Optimus, Maxter, Maxgrow and others (Pundyk, 2023).

It should be noted that the process of pedigree breeding in pig breeding requires the use of previously created and subsequently genetically developed and improved genotypes of pigs based on the evaluation of their breeding value separately for different breeds and types that differ in high growth intensity (Khakhula and Svynous, 2017). Even today, the breeding process includes the use of the best breed types and lines in industrial pig farms as well as targeted selection for traits such as stress resistance and high resistance of animals to many diseases (Guy et al., 2012). It is worth noting that the experience of using foreign-bred pigs shows that imported breeds have certain problems, because in production conditions an important requirement of animal breeding is violated - separate production use, as well as appropriate conditions of keeping and feeding, which negatively affects the productivity of animals, resource intensity and economic efficiency of the industry (Ibatullin, 2017).

Therefore, the biological characteristics of the pig carcass determine the quantitative and qualitative characteristics of the company's production activity, both from a zootechnical and economic point of view. The rational use of different pig breeds is one of the ways to increase animal productivity and strengthen the profitability of the industry (Matache, 2016; Ibatullin et al., 2019). Danish genetics is the most represented in Ukraine, as its potential is very high. The Danish Landrace is one of the parent breeds in the Danish crossbreeding programme. Due to the fact that this breed is characterized by exceptional fertility, high reproductive and good slaughter characteristics, it is used as a dam line for the production of an F1 hybrid pig, which is known worldwide for its economic indicators in the production of fattening pigs (Bergman et al., 2019; Bublyk, 2023).

The Danish F1 hybrid pig is the result of crossing the Danish Landrace with the Danish Yorkshire, which provides the most ideal production basis for producing commercial pigs in terms of economic yield and production efficiency. All this is ensured by low feed conversion ratio, high weight gain, hyper-multifertility, good maternal traits, persistency and excellent fattening traits of the offspring of these pigs (Traspov et al., 2016). The Danish Durok is a terminal boar in the breeding program of Danish Genetics. Duroc is known for its high gains, low feed conversion, high yields, and good meat quality. This is why the Duroc is the obvious choice for the parent line in the insemination of hybrid gilts for the production of commercial pigs because this cross achieves ideal production results (Cilla et al., 2006; Illing 2018). Pigs of Danish origin are quite competitive in Ukraine and account for about 40% of the breeding stock among all industrial pork producers in our country (Mahfuz et al., 2022).

Recently, however, pigs of other genetic origin have become increasingly popular on the Ukrainian market, among which animals of Canadian genetics, obtained by 100% heterosis and breed complementarity, stand out. Pigs of Canadian origin are focused on productivity, fast growth, fattening efficiency and high final results (Simon, 2023) In the breeding of pigs of Canadian origin, purebred Landrace, Yorkshire and Duroc pigs are used as genetic material, which ensures the homogeneity of the herd through crossbreeding. As a result, purebred Canadian Duroc terminal pigs dominate in independent studies on growth rate, feed conversion and carcass characteristics, resulting in the production of darker pork with greater marbling and higher pH (Khakhula, 2020).

Thanks to the long-term breeding program for Canadian pigs (Kennedyl et al., 2023; Statistics Canada, 2023), pigs of Canadian origin today have a higher feed intake than most other genotypes and better feed conversion, which at the same time enables them to cope with stress factors thanks to a good appetite, which has a positive effect on growth and thus on the profits of pig farms (Grossi et al., 2017).

Therefore, considering the constant competition between the used genotypes of pigs of foreign origin among pork producers in Ukraine and the different approaches to their breeding, which have a significant economic impact on the efficiency of pig farms, further research in this area of the pig industry remains relevant.

The purpose of the work was to establish the economic efficiency of obtaining, rearing and fattening pigs of Danish and Canadian origin in conditions of intensive pork production in the southern region of Ukraine.

MATERIALS AND METHODS

Biological material

The study was conducted at Agro Novoraiske LLC in the Kherson region of Ukraine. The subject of the study was the productive characteristics and fattening indicators of pigs (weight of 1 pig at the end of fattening; absolute growth of one pig at fattening; weight of a nest of pigs at the end of fattening; gross gain of a nest of piglets during the fattening period) derived from crossbred sows of different genetic origin. For the studies in 2023, two groups of sows of Danish and Canadian origin, 28 animals each, were formed according to the experimental design (Table 1) using the method of analogous pairs according to generally accepted methods (Ladyka et al., 2023).

The first group, which was considered the control, included F_1 sows derived from animals of the Danish Landrace and Great White breeds and inseminated with semen from Danish Duroc boars. The second group, defined as the experimental group, included F_1 analogues derived from pigs of similar breeds but Canadian selection to be inseminated with the semen of Canadian Duroc boars.

Table 1 - Scheme of the experiment.

Indicators	Group I	Group II
Number of sows in the group, head	28	28
Fertility of sows	(♀LWd × ♂Ld)	(♀LWк × ♂Lк)
Number of boars, head	3	3
A breed of boars	Dd	Dк
Genotype of piglets	(♀LWd × ♂Ld) × Dd	(♀LWк × ♂Lк) × Dк
Average age at weaning of piglets, days	28	
Method of feeding suckling piglets	Dry starters from the 14th day	
The method of keeping piglets for growing	Floor-pen on a solid lattice floor, in groups of 25 heads	
The method of feeding piglets for growing	Dry full-rational granulated fodder	
Average age of piglets at the beginning of fattening, days	79	
The method of keeping pigs for fattening	Floor-pen on a partially latticed concrete floor, in groups of 25 heads	
Method of feeding pigs	Dry full-ration loose fodder	
The average age of pigs at the end of the experiment, days	175	

Feeding and rearing conditions

The sows were kept in individual pens on a partially slatted floor during the resting and rearing periods. The sows in the experimental groups were inseminated vaginally according to the experimental plan using disposable catheters from the company "MS Schippers" (Netherlands) with freshly diluted boar semen, which were located in the farm's artificial insemination station. After insemination, all test sows were kept in the same individual pens in which the insemination was carried out until the 28th day after insemination of the main sow group. On the 29th day after insemination, all animals in the experimental groups underwent ultrasound diagnostics to determine the presence of fertility. They were then regrouped according to the results obtained and moved to a room for sows with proven fertility, where they were kept until the 112th day after insemination.

All experimental sows were moved to the farrowing room when they had reached 110-112 days of gestation. The sows in this workshop were housed individually, restrained, in 1.8 × 2.5 m pens on a fully slatted floor. To create a local microclimate for the piglets, each pen is equipped with a mat for contact heating of the piglets and an infrared lamp above it. The sows were fed in all physiological periods with fully rationed, balanced feed mixtures according to suitable recipes that corresponded to the recommendations of the feed suppliers and the condition of the animals. Feeding of the piglets was started from the 14th day of life with a pre-starter mixed feed distributed in the automatic feeder attached to the rear of the farrowing pen.

Upon completion of the suckling period, two groups of piglets, each consisting of 250 heads from the sows of the I and II groups, were formed using the group-analog method according to the methodology of (Ladyka et al., 2023). For this purpose, all healthy and well-developed piglets from each experimental group were sorted by sex and weighed separately, gilts and boars. Then, the average weight of the animals in each group was determined. Each experimental piglet was individually weighed, tagged with a numbered ear tag of the corresponding color (green for the group I and red for the group II), and marked on its back with a marker indicating its weight in grams. Piglets with weights closest to the group's average weight were selected for the both groups. After forming the groups of 250 heads each and determining the average actual weight for the group, the average weight was corrected by replacing pigs of different weights but the same sex within each group until the actual group weight matched the calculated group weight. In this composition, except for animals that were withdrawn, the groups of pigs remained throughout the entire growing period and were subsequently housed in pens of 25 heads during the fattening period. Piglets of both groups were weighed individually when they were transferred from the breeder to the rearing shop, where they were kept in identical pens of 25 heads each, on a fully latticed floor at the rate of 0.35 m^2 of the pen area per head.

Ventilation in the room was negative pressure due to exhaust wall fans located on one side of the room and inflow aerodynamic valves located on the other side of the room, from the side of the gallery. The piglets were fed with full-rational balanced pelleted feed.

All technological, veterinary and preventive measures for piglets of both groups were carried out according to the same protocol. Feed consumption by piglets was recorded daily by weighing it when it was loaded into the hoppers of self-feeders, and the number, weight, and reasons for dropping animals from the experiment were taken into account. At the end of rearing, the piglets of the experimental groups were weighed individually during the transfer from rearing to fattening and, based on the results of this weighing, two groups of pigs of different genetic origin were formed according to the research scheme, by the analogue group method according to the methodology (Ladyka et al., 2023). In the fattening house, the animals of both experimental groups were kept in identical pens with 25 animals each on a partially barred concrete floor at a ratio of 0.75 m^2 of pen area per animal.

The rooms were ventilated via roof fans and supply air valves located on both sides of the rooms. Manure was removed in all stalls by a periodically operating vacuum gravity system. The pigs were fed with fully rational, balanced bulk feed in a multi-phase mode. The conditions of feeding, watering, maintenance, care and prevention of the animals in the experiment took place in accordance with the European legislation on the protection of animals and their comfort (Council Directive, 2010).

Statistical analysis

The trial investigated the dependence of the reproductive performance of sows of Danish and Canadian origin, the growth intensity from weaning to slaughter of their hybrid offspring, the efficiency and profitability of rearing and fattening a nest of their piglets. The experimental data were processed by the method of variation statistics using computer equipment and the software packages MS Excel 2016 and Statistisa V.5.5 (Kramarenko et al., 2019).

RESULTS AND DISCUSSION

Based on the results of studies on the dependence of the reproductive and fattening qualities of pigs on their genetic origin, an assessment of the efficiency of rearing and fattening a litter of piglets from sows of Danish and Canadian origin was carried out. Since the sows of both experimental groups were selected according to the method of analogy groups, the costs of keeping them until the beginning of farrowing were the same. However, due to the different fertility of the sows, the cost of a piglet at birth was not the same (Table 2).

Table 2 - The efficiency of raising suckling piglets of different genetic origin

Indicators	Group I	Group II
The average cost of keeping one sow during farrowing, EUR	119,78	119.78
Multifertility, pigs	15.1±0.31**	13.4±0.24
Cost of one piglet at birth, EUR	7.93	8.94
The cost of keeping a sow during the suckling period, EUR	30.19	30.19
The cost of a nest of piglets at weaning, EUR	149.97	149.97
Number of piglets at weaning, pigs	13.3±0.29**	12.1±0.21
Cost of one piglet at weaning, EUR	11.28	12.39
Average weight of one piglet at weaning, kg	6.7±0.19	7.2±0.14*
Cost of 1 kg of live weight of piglets at weaning, EUR	1.68	1.72
Cost of 1 kg of live weight gain of piglets before weaning, EUR	2.08	2.14
Weight of the nest of piglets at weaning, kg	89.1±2.34	87.1±2.11
Market value without VAT of 1 kg of piglets at weaning, EUR	6.81	6.81
Market value of one piglet at weaning, EUR	45.62	49.03
Market value of a nest of piglets at weaning, EUR	606.73	593.11
Income from rearing the first piglet, EUR	34.35	36.63
Profitability of raising one piglet,%	7.25	7.04
Income from obtaining and growing a nest of piglets, EUR	456.76	443.14
Profitability of growing a nest of piglets, EUR	7.25	7.04

*: P <0.05; **: P <0.01.

The cost of a piglet at birth for sows of Danish origin, which had 1.7 piglets' higher fertility, was therefore 1.00 EUR lower than for sows of Canadian origin. Since the cost of keeping a sow during lactation was the same for both groups, the cost of a nest of piglets at weaning was also the same for both groups at the end of lactation. However, taking into account the fact that the number of piglets at weaning was 1.2 higher in the nests of the sows in the group I, the cost of a piglet at the end of lactation was 1.11 EUR lower than in the group II. The piglets in the group II grew more intensively during the post-weaning period and ended up with a 0.5 kg higher live weight, but due to the higher cost per piglet, the cost per 1 kg of growth was 0.052 EUR higher for the animals in the group II, and the cost per 1 kg of live weight of the piglets weaned at this time was 0.038 EUR higher than for the animals in the group I. With the same market price per 1 kg live weight of weaned piglets, the costs for a piglet nest differed due to the different weights in the I and II groups.

Due to the 2.0 kg higher live weight of the piglet nest when weaned from animals of Danish origin, the cost of the piglet nest was 13.61 EUR higher than for the animals of Canadian origin. At the same time, the market value of a piglet was 3.40 EUR higher than that of an animal from Canada due to the higher live weight at weaning.

The income from raising one piglet in the weaning period was 2.28 EUR higher in the group II, while the income from raising a nest of piglets before weaning was already 13.61 EUR higher in animals of the group I, which caused a 9.08% improvement in profitability of raising one piglet and their nest as a whole.

The animals in the group II had a 7.5% higher average weight of a piglet after weaning, which contributed to a 7.5% higher market value at weaning, a 6.7% higher income from rearing a piglet during this period and a 3.0% higher profitability of rearing compared to the animals in the group I. At the same time, they had 12.7% higher costs for a piglet at birth, 9.9% higher costs for a piglet at weaning, 2.3% higher costs for 1 kg live weight of piglets at weaning, 2.5% higher costs for 1 kg live weight of piglets before weaning, but a 2.2% lower market value of a piglet litter in this period, a 3.0% lower income from obtaining and rearing a piglet litter and a 3% worse profitability of this process.

The different orientation of the efficiency of rearing a piglet nest and a piglet was also evident in the rearing of animals of Danish and Canadian origin (Table 3). There were 250 piglets in group I and 250 in group II. Since there were 1.07 fewer piglets at the beginning of rearing in the nests of piglets of the group II, but during the period of rearing due to higher growth intensity, they had a greater absolute gain of 1.68 kg, which caused a higher weight of each animal of this group by 2.18 kg at the end of this period. At the same time, due to the smaller number of piglets in the nest in this group, they had 2.47 kg less gross growth of the piglet nest at the end of rearing, and 3.71 kg of its weight at that time. This resulted in a 0.058 EUR lower cost of 1 kg of live weight at the end of rearing in this group, a 0.080 EUR lower cost of 1 kg of weight gain for this period, a 3.30 EUR higher cost of rearing one piglet, and a 6.65 EUR its market value, 3.35 EUR more income from raising one pig, and 3.41% better profitability of its raising.

Table 3 - The efficiency of raising piglets of different genetic origins

Indicators	Group I	Group II
The number of piglets in the nest at the end of rearing, pigs	12.93	11.86
Absolute growth of piglets during the rearing period, kg	21.0±0.53	22.6±0.42**
Weight of 1 head of piglets at the end of growing, kg	27.7±0.57	29.8±0.44**
Weight of the nest of piglets at the end of rearing, kg	8.51	8.43
Gross growth of the nest of piglets at the end of rearing, kg	6.45	6.39
The cost of a nest of piglets at the beginning of rearing, EUR	149.97	149.97
The cost of a nest of piglets at the end of rearing, EUR	824.82	795.73
The cost of one pig at the end of growing, EUR	63.80	67.09
Cost of 1 kg of live weight at the end of growing, EUR	2.31	2.25
Cost of 1 kg of weight gain at the end of growing, EUR	3.04	2.96
The cost of 1 kg of live weight of a pig without VAT, EUR	3.05	3.05
The cost of one pig at the end of growing, EUR	84.30	90.95
Income from growing one piglet, EUR	20.50	23.86
Profitability of raising one piglet, %	0.77	0.85
The cost of a nest of piglets at the end of rearing, EUR	1089.80	1078.70
Income from growing a nest of piglets, EUR	264.98	282.97
Profitability of growing a nest of piglets,%	0.77	0.85

**: P <0.01.

At the same time, in the calculation of the nest of piglets in this group, the cost price of the nest of piglets at the end of rearing was recorded to be 29.08 EUR lower, its market value by 11.29 EUR at that time, but the income from its rearing was higher by 17.78 EUR and better by 3.41% profitability of this process.

Thus, during rearing, a 2.6% lower cost of 1 kg of weight gain, a 2.5% lower cost of 1 kg of live weight for this period, and a 5.2% higher cost of rearing one piglet was recorded in hybrid piglets of Canadian origin at the end of rearing and by 7.9% of its market value at the end of the period, 16.3% higher income from rearing one pig, and 3.41% better profitability of its rearing. Whereas Canadian-bred piglets had a 3.5% lower end-of-rearing nest cost, a 1.0% lower market value at that time, but a 6.7% higher rearing income and a 3.41 % profitability of growing.

A slightly different situation was observed when pigs of both genetic lines were fattened. There were 250 piglets in group I and 250 in group II. At the time of fattening, pigs of Danish origin had 0.95 more heads in the nest than pigs from Canadian breeding. At the same time, in contrast to the growth period, the growth intensity of the animals of Canadian origin proved to be lower during fattening compared to the animals of Danish origin, so that they had 1.95 kg less absolute weight gain and at the end of fattening their mass was almost balanced. At the same time, the gross growth of the piglet nest during the fattening period was 111.57 kg higher in the animals of the control group, which resulted in a 115% higher gross growth of the piglet nest during the fattening period, which resulted in a 114.99 EUR higher cost price, a 153.70 EUR higher market value at that time, a 38.70 EUR higher fattening income and a 0.77% higher profitability of fattening compared to the animals of Canadian origin.

When calculating these indicators per animal, it was found that the pigs in the experimental group had a 0.64 EUR higher price per animal and a 0.006 EUR higher price per 1 kg of live weight at the end of fattening, while at the same time the market value at the end of fattening was 0.19 EUR lower, the fattening income was 0.84 EUR lower and the profitability was 0.77% lower (Table 4).

Table 4 - Efficiency of fattening piglets of different genetic origin

Indicators	Group I	Group II
The number of piglets in the nest after fattening, pigs	12.71	11.76
Weight of 1 head at the end of fattening, kg	119.1±1.76	119.0±1.39
Absolute growth of one head at fattening, kg	90.8±1.72	88.9±1.32
Weight of the nest of pigs at the end of fattening, kg	36.06	33.32
Gross growth of a litter of piglets during the fattening period, kg	27.55	24.13
Cost of 1 kg of live weight of pigs after fattening, EUR	1.08	1.09
The cost of a nest of pigs at the end of fattening, EUR	1635.16	1520.17
Cost of 1 head upon completion of fattening, EUR	128.63	129.27
The price without VAT of 1 kg of live weight of fattening pigs, EUR	1.33	1.33
Cost of one head without VAT at the end of fattening, EUR	158.85	158.66
Price without VAT of a nest of pigs at the end of fattening, EUR	2019.37	1865.67
Income from fattening a nest of piglets, EUR	384.20	345.50
Income from fattening one pig, EUR	1269,37	1234,01
Profitability of fattening one pig, %	23,50	22,73
Profitability of fattening a nest of piglets, %	23,50	22,73

Animals of Danish origin showed a 9.6 % higher gross growth of the piglet litter during the fattening period, which gave them a 7.6 % higher weight at the end of fattening and led to a 7.0 % higher cost price at that time, a 7.6 % higher market value and contributed to a 10.1 % higher feedlot income and a 0.77 % better feedlot profitability compared to Canadian-bred peers.

At the same time, the cost price for 1 head at the end of fattening was 0.5 % higher for Canadian-bred animals, the cost price for 1 kg live weight at that time was 0.6 % higher, the market value for 1 head at the end of fattening was 0.1 % lower, the income from their fattening was 2.8 % lower and the profitability of fattening was 0.77 % lower.

In our work, we confirmed the effectiveness of using breed-line hybridization with specialized genotypes of foreign selection in modern industrial production conditions (Harmatiuk, 2022; Khramkova, 2019; Mahfuz et al., 2022; Matache, 2016; Tsereniuk, 2011). Additionally, our conclusions regarding the higher prolificacy of Danish sows were consistent with reports (Bergman et al., 2019; Vargovic et al., 2022; Bublyk, 2023) on the high prolificacy of Danish sows. According to their data, the average number of piglets weaned from Danish-origin sows was 13.5-14.0 piglets per litter, while in our studies, this figure was 13.3 heads, which is significantly higher than that of Canadian-origin animals and aligns with the conclusions of Traspov et al. (2016) about the European origin of these pigs. Our findings also confirm the reports (Illing, 2018; Matache, 2016; Vasylevych, 2021) on the high efficiency of breeding Danish pigs in Ukraine and Europe, as the profitability of piglet production in our experiment was 9.1% higher using Danish-origin pigs compared to Canadian ones, contradicting Simon (2023) who claims significant competition from Canadian-origin pigs in the Ukrainian pork market. Simultaneously, our research supports the view (Kennedyl et al., 1996; Cilla et al., 2006; Smith et al., 2021) on the high genetic potential of Canadian-origin pigs, as in our studies, pigs imported from Canada had a 7.6% higher weight at the end of the growing period, resulting in better fattening profitability compared to their Danish counterparts, which is confirmed by Grossi et al. (2017) but contradicts Bublyk (2023), who asserts higher production efficiency with Danish-origin pigs. Overall, the comparison of pork production efficiency using pigs of different genetic origins should be continued with a larger population.

CONCLUSION

It was found that piglets of Canadian origin had a higher average weight during the weaning phase by 7.5%, higher market value by 7.5%, higher revenue per piglet raised by 6.7%, and higher profitability of raising by 3.0% compared to Danish-origin piglets. However, they had higher costs per piglet at birth and weaning by 12.7%, the cost per kilogram of live weight at weaning by 9.9%, lower market value of the piglet nest by 2.2%, and lower income by 3.0% and profitability of obtaining and raising the nest by 3.0% compared to Danish-origin counterparts.

During the growing period, hybrid piglets of Canadian origin had a lower cost per kilogram of live weight by 2.6%, higher growing costs per piglet by 5.2%, higher market value by 7.9%, higher revenue per piglet raised by 16.3%, and better growing profitability by 3.41%. It was shown that Danish-origin animals had a higher gross gain of the piglet nest during the fattening period by 9.6%, higher weight at the end of fattening by 7.6%, higher cost per kilogram of live weight by 7.0%, higher market value by 7.6%, higher revenue from fattening by 10.1%, and better fattening profitability by 0.77% compared to Canadian-origin counterparts. At the same time, there was practically no difference in the cost per head and per kilogram of live weight, and the market value per head at the end of fattening. However, Canadian-origin animals showed lower income from fattening per head by 2.8% and lower fattening profitability by 0.77%.

On the basis of the conducted research, it can be proposed to use pigs of Danish origin in the conditions of industrial pig complexes of Ukraine instead of analogues that come from Canada, which will increase the efficiency of pork production.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethical considerations:

All operations and manipulation with pigs during the study were humane and did not cause animal suffering. Any treatment of pigs was respectively with the provisions of European legislation in the field of humane treatment of animals (Council Directive 86/609/EEC, 1986). The methodology of the experiment was agreed and checked by Bioethical Commissions of Sumy National Agrarian University, Sumy region, Ukraine (ethical approval number VT-24-0322-03).

Authors' contribution

O. Mykhalko contributed on data analysis and the write up of the manuscript and M. Povod conducted research; T. Verbelchuk assisted in data collecting; S. Verbelchuk reviewed the work critically. V. Voloshynov collected data and interpreted the results; V. Koberniuk compiled the manuscript. O. Lavryniuk and N. Shcherbatiuk contributed to the preparation and correction of the text. All authors read and approved the final paper for publication.

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Competing interests

The authors have not declared any conflict of interests.

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USING LIGNOCELLULOSE FIBER IN FEED TO MAINTAIN HEALTH AND IMPROVE THE GROWTH OF POST-WEAN PIGLETS

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ABSTRACT: This study aims to determine how adding fiber lignocellulose in feed affects performance, intestinal health, morbidity, and mortality in post-wean piglets. The animal model used was 54 piglets divided into three groups of treatments: the control group was given starter commercial feed, group T1 was given starter pig feed with added 1% lignocellulose fiber, and the T2 group was assigned starter feed with the additional 2% lignocellulose fiber. Treatment is given for 4 weeks starting at 41-68 days old. Health observations were also carried out during the research. Piglet performance is determined based on feed intake, body weight and feed conversion ratio (FCR). Examination of the health of the gastrointestinal tract by measuring the length and weight of the intestine, microscopic length of the villi and depth of the crypts, as well as the number of *Escherichia coli* in the piglet's small intestine. The research showed that adding 1% and 2% lignocellulose fiber in the feed for 28 days may increase feed intake and body weight and reduce FCR significantly. Adding lignocellulose fiber may significantly lower diarrhea incidents, and death was not found in the treatment group. Lignocellulose fiber may increase villi's intestinal length and weight height compared with control. It can be concluded that supplementing lignocellulose fiber through feed may increase the piglet's health growth and efficiency.

Keywords: Body weight, Gut health, Lignocellulose fiber, Performance, Post-wean piglet.

INTRODUCTION

Early weaning of piglets is often accompanied by stunted growth and severe diarrhea (Campbell et al., 2013). In the first three days, as many as 25% of post-wean piglets reported experiencing anorexia, stress and nutrition deprivation so that the condition becomes weak and vulnerable to various disease infectious (Pensaert and Martelli, 2016; Eriksen et al., 2021). It is known that the main etiology of this event is multi-factorial, such as anorexia and malnutrition in piglets' gastrointestinal disorders include changes in the small intestine's structure and enzyme activity (Pickard, 2003; Kobek-Kjeldager, et al., 2022). Recent data show a transient increase in intestinal wall mucosal permeability, disturbance of the electrolyte-secretory-absorptive balance and local changes in inflammatory cytokine patterns after weaning (De Groot et al., 2021; Tang et al., 2022; Michiels et al., 2023). Here, new insights into the interactions between feed components, commensal microbiota and the physiology and immunology of the host gastrointestinal tract need to be gained, and several new dietary strategies have been studied that focus on improving gut health (Danneskiold-Samsøe et al., 2019). Prebiotics and probiotics are obvious nutritional choices, as are other bioactive substances of plant origin (Lalle`s et al. 2007). Using carboxymethylcellulose fiber mixed into piglet feed after weaning can protect the gastrointestinal tract from colibacillosis infection (McDonald et al. 2001; Lalle's et al. 2006). Adding this fiber is thought to stimulate the growth of gastrointestinal villi in piglets (Van Nevel et al., 2003). The use of fiber in feed for piglets after weaning is vital to maintain digestive tract health, intestinal motility, and animal welfare (Bosse, 2020). Fiber content in feed must be included to maintain the physiological function of the livestock's intestines. Nutritionists have long been aware of the importance of fiber in pig feed, but there are not many positive studies on the use of fiber. One of the fibers that is easy to obtain is lignocellulose, whose main components are cellulose, hemicellulose, and lignin. For this reason, this research aims to determine the effect of adding lignocellulosic fiber in post-weaning piglets' feed on feed consumption, body weight, feed efficiency and gastrointestinal health by looking at the length and weight of the intestine, the height of the villi and the depth of the crypts of the jejunum and ilium as well as the presence of gastrointestinal *E. coli*. It is also hoped that we can find out the optimal dose for using lignocellulose fiber for weaning piglets (Bosse, 2020).

This research aimed to determine how adding fiber lignocellulose in feed affects performance, intestinal health, morbidity, and mortality in post-wean piglets.

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MATERIALS AND METHODS

Experiment design

A total of 54 post-weaning landrace piglets, in healthy condition, with an average weight of 15 kg, were divided into three groups, namely T0 as a control which was given starter pig feed. Treatment group T1 was given starter feed plus 1% lignocellulose fiber, and T2 was given starter feed with supplementation of 2% lignocellulose fiber. Treatment was given for 28 days, starting from piglets aged 41-64 days. The lignocellulose fiber provided combines Cellulose, Hemicellulose and Lignin in balanced proportions. The nutritional content of the starter pig feed used contains a maximum water content 13%, protein 21-23%, fat minimal 5%, fiber maximal 5%, ash content maximal 7%, calcium minimal 0.9%, phosphorus min 0.6%, and Metabolizable Energy (ME) 2900-3000 Kcal/kg.

After the treatment period ended, all piglets were given 551 starter feed until 68 days of age (the end of the starter phase). The amount of drinking water given is as needed. The piglets' initial body weight data was measured the day before they were given treatment, while the piglets' body weight data after treatment was measured at the end of the study, namely 68 days of age. Weight gain is calculated as final body weight minus initial body weight. The amount of feed used is done by weighing the feed given daily and the remaining feed given. The amount consumed is the amount given minus the remaining feed per day. The total feed spent during the study was obtained by adding daily feed. The Feed Conversion Ratio (FCR) calculation divided the total feed consumed during the study by body weight gain.

Morbidity data was observed for clinical symptoms such as diarrhea and mortality from the time the treatment was given until the end of the study. Data Isolation and identification of bacteria was carried out by taking fecal samples with a rectal swab, which were then placed in transport media to be taken to the laboratory after one week of treatment. Data on the weight and length of the intestine and the length of the small intestine's villi were obtained at the end of the study. Pigs that have received treatment are slaughtered, their intestines are taken, the feces are removed, and the length (in cm) and the weight of the intestine (in grams) are measured. Histological preparations were made and examined under a microscope to measure the length of the villi and crypts of the jejunum and ilium (Yin, 2001). Data on the amount of feed consumption, body weight gain and FCR were analyzed using the Variety Test. If there was a real effect, the analysis was continued with the Duncan Multiple Range Test. Meanwhile, morbidity, mortality, small intestine wall thickness, villi length and E. coli isolation were analyzed descriptively.

RESULTS AND DISCUSSION

Pig performance

Pig performance was measured with count amount of feed consumption, increase of body weight and Feeds Conversion Ratio (FCR). The performance of piglets during the study can be seen in Table 1. According to Table 1, the control group (lignocellulose 0%) consumed significantly less feed, totaling 47.56 kg, from 41 to 68 days of age compared to the groups given lignocellulose 1% (49.25 kg) and lignocellulose 2% (50.96 kg). However, there was no significant difference in feed consumption between the lignocellulose 1% and 2% groups. Lignocellulose, a type of crude fiber that does not dissolve in water, can increase the amount of feed consumed by piglets. This fiber affects intestinal function by expanding and speeding up intestinal peristalsis, which reduces constipation and endotoxin impact on gut health. Adding vegetable fiber to piglet feed can also promote gastrointestinal development in terms of size and functionality (Van Hees et al., 2019; Ndou et al., 2019; Vastolo et al., 2022).

Table 1 - Influence of lignocellulose Fiber Addition in feed for piglets aged 41-64 days to performance.

Treatment	Feed intake (Kg)	Body weight gain (Kg)	FCR
Lignocellulose 0% (N=18)	47.57^{a}	15.93^{a}	3.00^{a}
Lignocellulose 1% (N=18)	49.25^{ab}	18.22^{b}	2.75^{b}
Lignocellulose 2% (N=18)	50.96^{bc}	20.10^{c}	2.56^{c}

Same letters on the same column: no significant difference (p > 0.05). The lignocellulose used is Arbocel Rc-fine Arbocell contains 65% fiber consisting of hemicellulose, cellulose and lignin. Last weighing done at 68 days old.

According to this research, an increase in feed intake leads to increased body weight in piglets. The study found that piglets fed with 1% lignocellulose gained an average weight of 18.22 Kg, while those fed with 2% lignocellulose gained 20.10 Kg between 41–64 days. These values were significantly higher than the control group which gained 15.93 Kg. Additionally, the group given 2% lignocellulose showed a greater increase in weight than the group given 1%. Insoluble fiber in feed such as barley husk has been found to enhance intestinal morphology, improve villi length, and activate enzymatic mucosa, unlike soluble fiber (such as pectin) found in feed. The number of effects of insoluble fiber lignocellulose (Arbocel RC-Fine) are increased growth hormone (GH), Insulin-Like Growth Factor-1 (IGF-1), Insulin-Like Growth Factor Binding Protein-3 (IGFBP-3), which can decrease pro-inflammatory cytokines, IL-6 gene expression but not TNF-α and IL-1β (Superchi et al., 2017).

This study demonstrated that the group of piglets fed with 2% lignocellulose had a significantly lower FCR of 2.56 compared to the group fed with 1% lignocellulose with an FCR of 2.75. Additionally, the group fed with 1% lignocellulose had a significantly lower FCR than the control group with an FCR of 3.0. These findings suggest that piglets that consume more food tend to produce more meat.

Morbidity and mortality

Results of piglet observation after giving lignocellulose in feed to incident mortality and morbidity can observe in Table 2. According to Table 2, the control group had a morbidity rate of 83.3%, while the group given 1% lignocellulose had a morbidity rate of 55.6%. The group given 2% lignocellulose had a morbidity rate of 50%, with diarrhea being a common symptom. These findings suggest that adding lignocellulose to animal feed may not be effective in preventing diarrhea, which is in agreement with Silva-Guillen et al. (2022). The exact cause of diarrhea, whether it is due to a bacterial infection or other factors, remains unknown, and further research is needed. In this study, all subjects tested positive for bacteria in their feces, such as *E. coli*, Staphylococcus sp, and Bacillus sp. However, additional studies are required to determine if these bacteria are responsible for causing sickness.

Table 2 - Influence of lignocellulose in feed for piglets aged 41-68 days to morbidity and mortality.

Dosage	Morbidity (n, %)	Mortality (%)	Remarks
0% Lignocellulose (n=18)	15 (83.3)	0	diarrhea
1% Lignocellulose (n=18)	10 (55.6)	0	diarrhea
2% Lignocellulose (n=18)	9 (50.0)	0	diarrhea

Isolation and Identification of Bacteria from the intestines of pigs after being given lignocellulose

Bacteria in piglet intestines were isolated and identified before and after lignocellulose treatment using fecal samples (Table 3). Table 3 displays the presence of bacteria like *E. coli, Bacillus sp,* and *Staphylococcus sp* in all subjects' feces. Lignocellulose in feed may be ineffective in killing the bacteria in the digestive tract.

Table 3 - Types Bacteria present in feces before and after being given lignocellulose in feed.

No	0% Lignocellulose		1% Lignocellulose		2% Lignocellulose	
1	Before	After	Before	After	Before	After
2	*Bacillus sp*	*Bacillus Sp*	*E.Coli*	*E.coli*	*E.coli*	*E.coli*
3	*E.coli*	*E.coli*	*E.coli*	*Ecoli*	*E.coli*	*E.coli*
4	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
5	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*Staphylococcus sp*	*Staphylococcus sp*
6	*Ecoli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
7	*E.coli*	*E.coli*	*Staphylococcus sp*	*Staphylococcus sp*	*E.coli*	*E.coli*
8	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
9	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
10	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
11	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
12	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
13	*Ecoli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
14	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
15	*Ecoli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
16	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
17	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*E.coli*
18	*E.coli*	*E.coli*	*E.coli*	*E.coli*	*Bacillus sp*	*Bacillus sp*

Length and weight of subjects' small intestines

According to Table 4, subjects who were given 1% or 2% lignocellulose from ages 41-64 days had significantly heavier intestinal weights (0.9 kg and 1.2 kg, respectively) than the control group (0.6 kg) (P<0.05). However, there was no significant difference in intestinal weight between pigs given 1% and those given 2% lignocellulose (P>0.05). When the dose of lignocellulose was increased to 2% of the actual length of the intestine, there was a significant increase in length (17.30 meters) compared to the control (P<0.05). However, there was no significant difference in length compared to pigs given 1% lignocellulose. Therefore, it seems that increasing the dose of lignocellulose to 2% did not significantly increase intestinal weight compared to the 1% dose. Given lignocellulose, intestinal length and weight increase, resulting in increased absorption of feed, which has a positive impact on body weight increase.

Table 4 - Influence of lignocellulose in feed addition on the length and weight of pig intestines.

Treatment	Small Intestine length (m)	Small Intestine weight (kg)
Lignocellulose 0%	13.42[a]	0.6[a]
Lignocellulose 1%	15.36[ab]	0.9[ab]
Lignocellulose 2%	17.30[b]	1.2[b]

* the same letters in the same column showed no significant difference (p > 0.05)

Histology of villi height, jejunum crypt and Ilium from subject intestine

Based on the histological analysis of the jejunum and ileum of pigs aged 68 days, there was an increase in the height of villi when they were fed with lignocellulose from 41 to 64 days of age. However, the height of the crypts in both areas appeared to be irregular. This information is available in Table 5.

The histology of the villi in the jejunum and ileum of pig intestines were examined in Table 5. Pigs that were not fed lignocellulose had shorter villi (as seen in Figures 1 and 2), but when given 1% lignocellulose, their villi and ilium increased in height (Figures 3, 4 and Figure 5). Increasing the dose of lignocellulose to 2% further increased the height of the villi and ilium (Figures 6 and 7). This indicates that the small intestine's area for nutrient absorption is wider, allowing for optimal absorption of nutrients. The jejunum is located between the duodenum and ileum, and it is responsible for absorbing almost 90% of the nutrition from digested food (Wijtten et al., 2011; Roura et al., 2022). It represents two-fifths of the whole small intestine's length, while the duodenum is responsible for digestion chemistry (Roura et al., 2022).

Nutrient absorption primarily occurs in the small intestine, specifically in the jejunum. The epithelial cells, villi, and microvilli that make up the surface of the small intestine enhance its absorption capabilities (Mosenthin, 1998). The jejunum is specifically responsible for the absorption of nutrients, such as peptides, amino acids, vitamins, and glucose, which are transported throughout the body through active and passive transportation. Temporary fructose is transported passively. The ileum, the third part of the small intestine, extends from the jejunum to the ileocecal valve and is almost three-fifths the length of the entire small intestine. By adding lignocellulose to pig feed, the length of the villi and ileum can increase, creating a wider absorption area for nutrients and promoting pig growth, which is in agreement with findings of Silva-Guillen et al. (2022) in pigs and Bogusławska-Tryk et al. (2020) in chickens.

Table 5 - Influence of lignocellulose in feed addition height pig intestine villi and crypts (100x magnification).

Lignocellulose level (%)	Villi height (µm)		Crypt height (µm)	
	Jejunum	Ileum	Jejunum	Ileum
Lignocellulose 0%	323.70[a]	326.84[a]	435.18[a]	404.07[a]
Lignocellulose 1%	418.60[b]	485.02[b]	295.50[ab]	374.89[ab]
Lignocellulose 2%	478.85[c]	508.98[c]	435.18[c]	384.46[bc]

* The same letters in the same column showed no significant difference (p > 0.05)

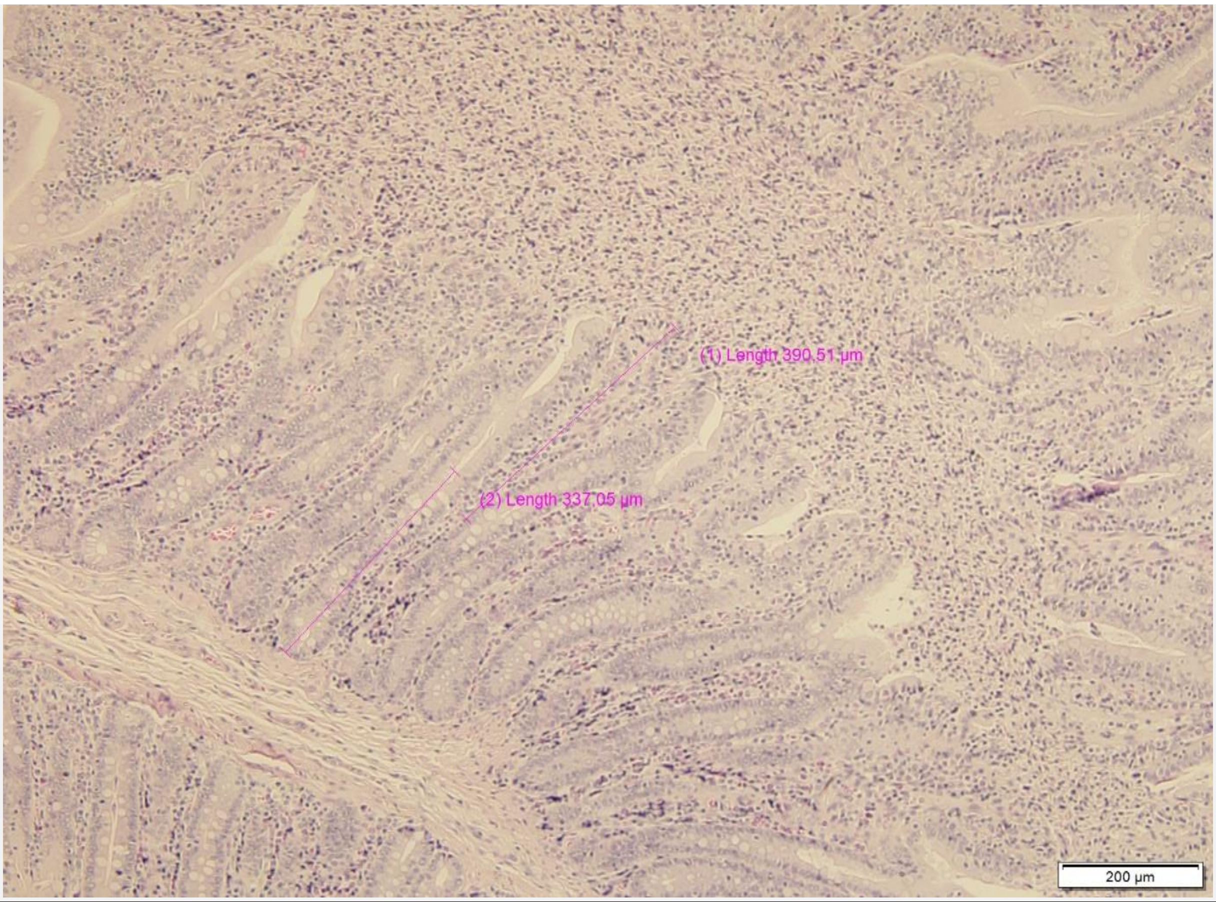

Figure 1 - Overview of Jejunum Villi length without lignocellulose in feed/control group (100x)

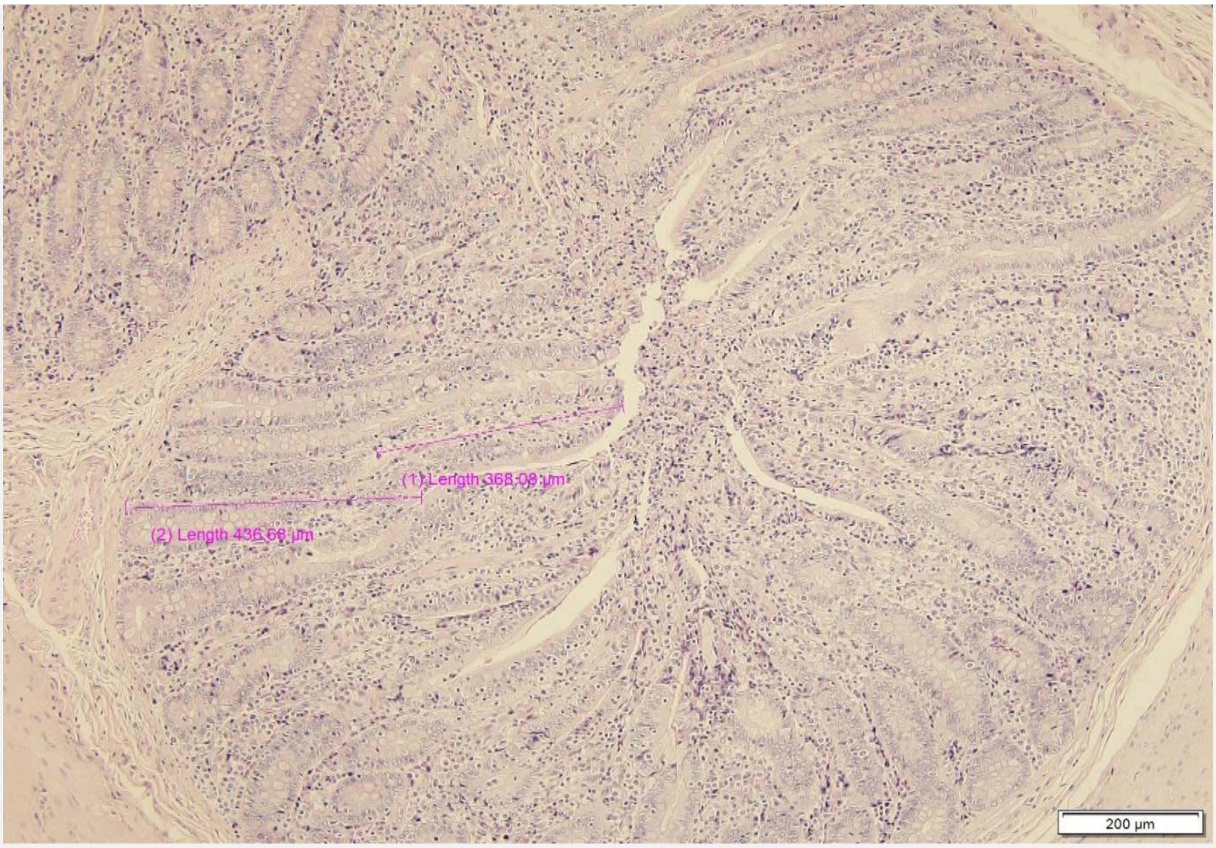

Figure 2 - Overview of Ileum Villi length without lignocellulose in feed/control group (100x)

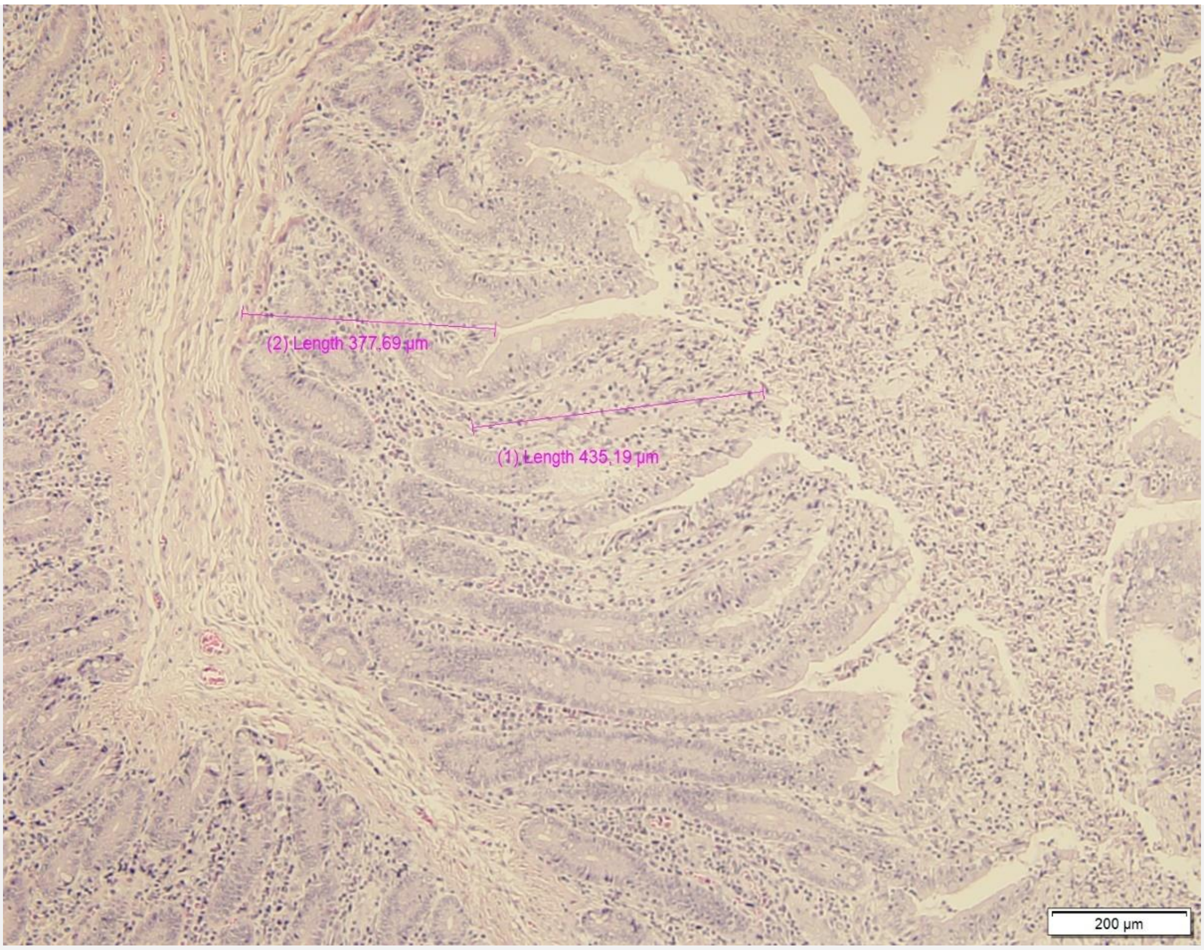

Figure 3 - Overview of Jejunum Villi length with 1% Lignocellulose in feed (100x)

Figure 4 - Overview of Ileum Villi length with 1% lignocellulose in feed (100x)

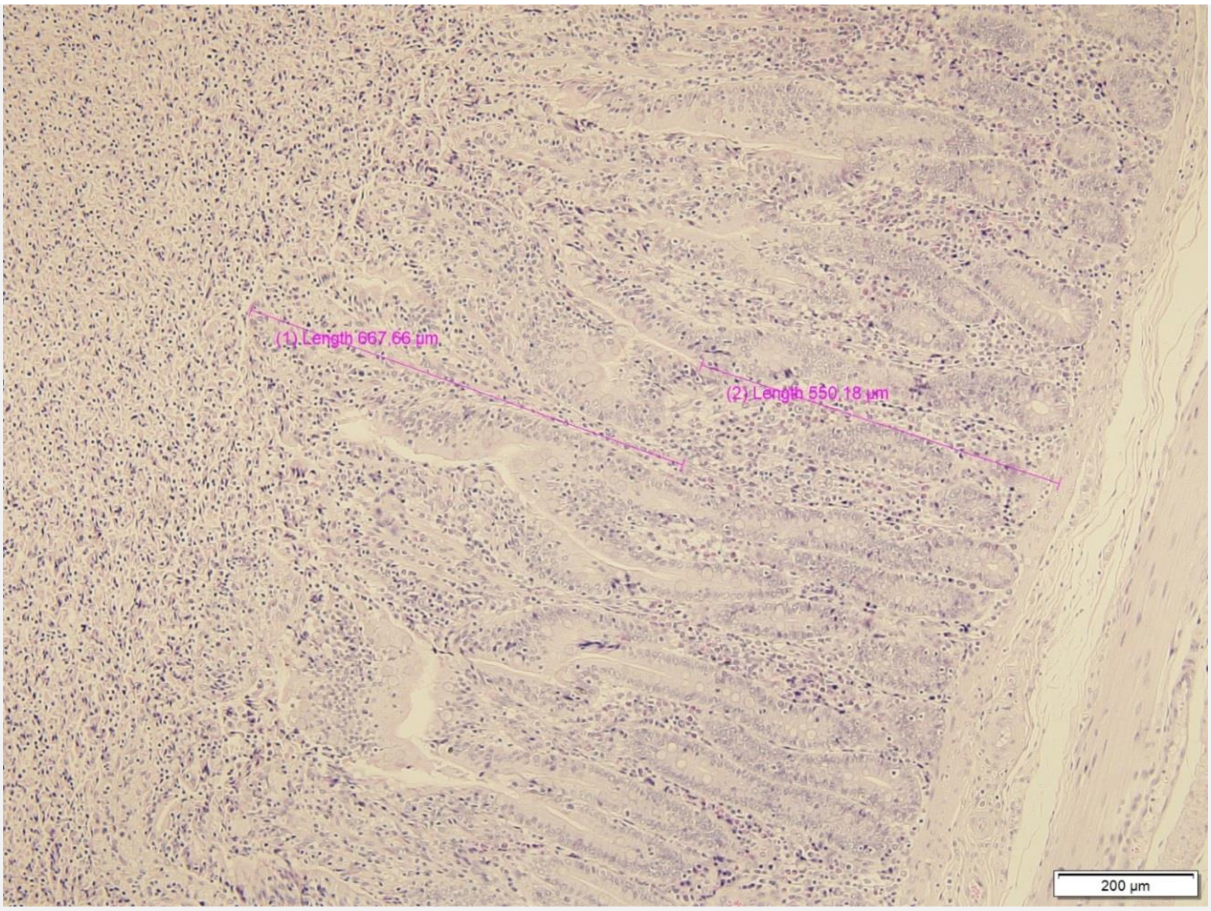

Figure 5 - Overview of Jejunum Villi length with 2% lignocellulose in feed (100x)

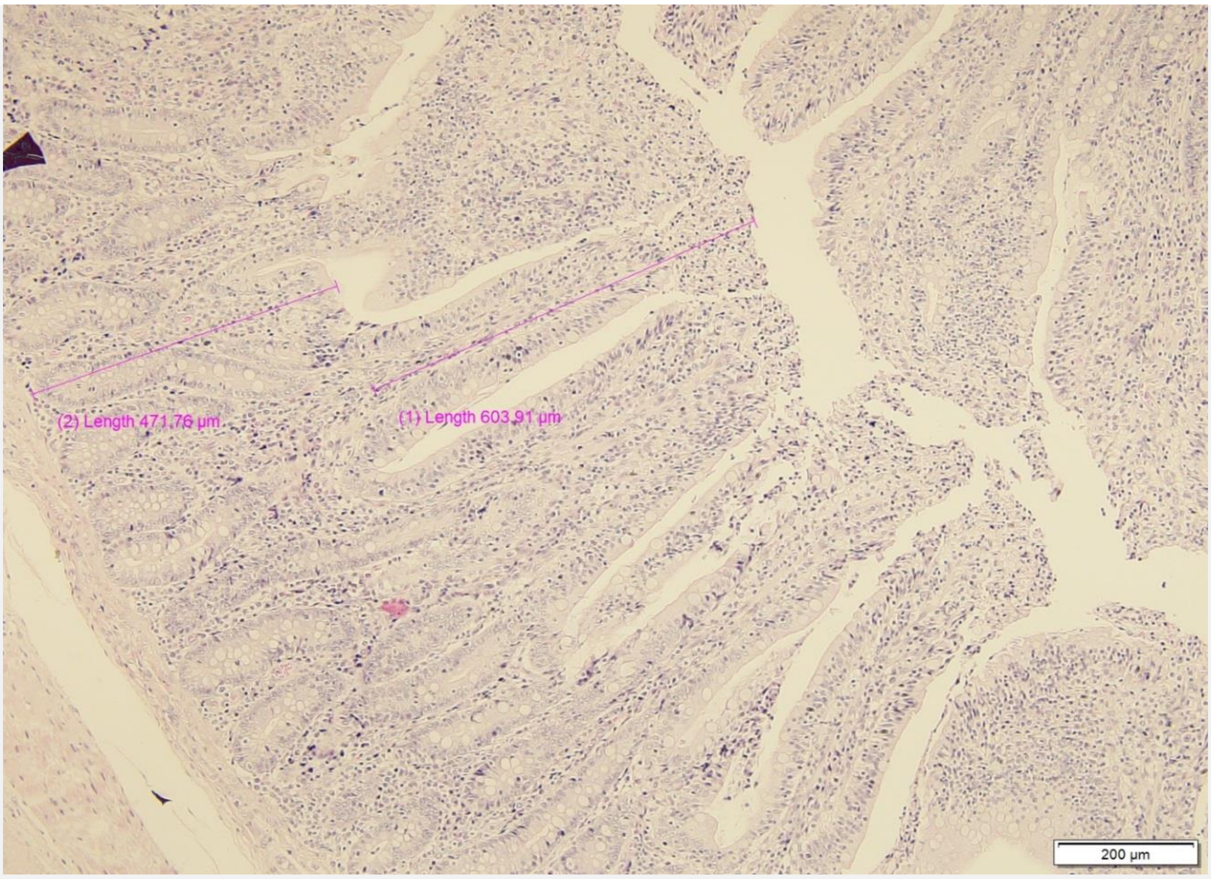

Figure 6 - Overview of Ileum Villi length with 2% lignocellulose in feed (100x)

CONCLUSION

According to the findings, adding 1% or 2% lignocellulose to feed for pigs aged between 41 and 64 days can result in a significant increase in body weight and feed consumption and a drastic reduction in FCR. Lignocellulose can also help prevent mortality in pigs, however, it cannot prevent morbidity or diarrhea incidents completely, nor can it kill all the bacteria in their intestines. Nevertheless, diarrhea and bacteria in the intestines do not affect the small intestine's anatomy and histology. In fact, adding lignocellulose to their diet can significantly increase the weight and length of the intestine and the length of villi and crypts in the small intestine.

DECLERATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethical consideration

This research has been approved by the Animal Commission Ethics Faculty Udayana University Veterinary Medicine with certificate agreement Number B/40/UN14.2.9/PT.01.04/2023.

Author contribution

All authors contributed equally to the study.

Competing interests

The authors declare no competing interests in this research and publication.

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PROSPECTS FOR THE USE OF MEDICINAL PLANTS EXTRACTS (*Mallotus oppositifolius* AND *Kalanchoe crenata*) AS ANTIMICROBIALS AGAINST SALMONELLOSIS IN POULTRY

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Supporting Information

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ABSTRACT: This study is a contribution to the search for alternatives to combat antibiotic resistance in *Salmonella* strains in poultry farming. The objective of this work is to highlight the main phytochemical compounds of 2 Ivorian medicinal plants (*Mallotus oppositifolius* and *Kalanchoe crenata*) and to evaluate their acute oral toxicity with a view to their use in the poultry sector, to fight against certain avian pathologies, including Salmonellosis. The phytochemical compounds of the extracts of the plants used in this study were highlighted by colouring and precipitation methods. Acute oral toxicity was adapted to broilers according to the guideline OECD 425, 2008. The phytochemical screening carried out showed that aqueous extract of *Mallotus oppositifolius* possesses polyphenols and catechical tannins. The ethanolic extract also has anthraquinones, saponosides, sterols, and terpenes. The ethanolic extract of *Kalanchoe crenata* only owns polyphenols and catechical tannins. At the end of the acute oral toxicity study, no mortality was observed in all batches of experimentation and the biochemical analysis of the subject's blood showed creatinine values ≤ 10 mg/L.; aspartate aminotransferase (ASAT) ≤ 275 IU/L; alanine aminotransferase (ALT) ≤ 50 IU/L, urea=0.01g/L, CRP≤6 mg/L; and blood sugar was between 2 and 5 g/L in subjects from different batches. Ultimately, the aqueous and ethanolic extracts of *Mallotus oppositifolius* and the ethanolic extract of *Kalanchoe crenata* can be used as an antibacterial in broiler farming.

Keywords: Antimicrobial supplements, Medicinal plants, Phytochemicals, Poultry, Salmonella.

INTRODUCTION

Infectious diseases represent a significant concern in livestock farming (especially in poultry) because of their frequency of appearance, the economic losses caused and the risk to the health of consumers (Traoré et al., 2012; Chota et al, 2021). The agents responsible for these infections are diverse and varied. They include fungi, viruses, protozoa and bacteria. Among the pathogenic bacteria, those multi-resistant to antibiotics such as bacteria of the *Salmonella* genus are encountered in most poultry farms (Cardinale et al., 2004). Thus, the consumption of poultry, including chicken, could constitute an essential vector in the transmission of multi-resistant *Salmonella* strains to humans (Carole et al, 2022; Yamba, 2023). Indeed, in Côte d'Ivoire, numerous scientific studies have reported the presence of these multi-resistant strains in poultry as well as in chickens (Karou et al., 2013; Bonny et al., 2014) than in native and commercial quails (Bonny et al., 2019). Faced with the problem posed by the spread of microorganisms resistant to antibiotics in general and more particularly by *Salmonella*, it is essential to consider the use of alternative routes to the use of antibiotic molecules, frequently used in the Ivorian poultry sector. Among them, the use of medicinal plants containing bioactive molecules used in the composition of certain pharmaceutical drugs constitutes a promising avenue (Zirintunda et al, 2024).

Indeed, in Africa, for treatment, nearly 80% of patients resort to traditional practitioners (WHO, 2002), holders of an impressive quantity of plant-based recipes with proven active ingredients on certain microorganisms. This study aims to highlight the main antimicrobial compounds of 2 Ivorian medicinal plants and to evaluate their toxicity with a view to their use in the poultry sector, to fight against certain avian pathologies, including Salmonellosis.

MATERIAL AND METHODS

Plant materials

The plants used in this study (Figure 1) were collected from traditional therapists, on the markets selling medicinal plants in the commune of Bingerville (Abidjan, Ivory Coast) (Figure 2). These plants were selected on the basis of their antibacterial activities expressed against *Salmonella* strains of avian origin in the work of Carole et al. (2021). Once

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collected, the leaves of *Kalanchoe crenata* and *Mallotus oppositifolius* plants, known for their antibacterial properties, were dried away from the sun at 21°C for 96 hours and reduced to powder to obtain aqueous and ethanolic extracts.

Production of aqueous and ethanolic extracts of the different plants used

The aqueous and ethanolic extracts of the different plants were obtained according to the protocol described by Bene et al (2015) One hundred grams of powder were macerated in 1 L of distilled water (or in a 70% ethanolic solution) in a blender. The homogenate obtained was filtered successively once through a sieve, then through a cloth and twice through hydrophilic cotton. The filtrate obtained was dried in an oven at 50°C for 48 hours, to obtain the aqueous extract (EA) or the hydroethanolic extract (EE70) (Figure 3). The different extracts obtained are stored at 4°C.

Phytochemical screening of aqueous and ethanolic extracts of plant extracts

This study carried out according to the work of Bagre et al. (2007), allowed the demonstration of the presence of families of secondary metabolites, namely alkaloids, polyphenols, tannins, flavonoids, saponin, polyterpenes or sterols and anthraquinones.

✓ Polyphenols: One drop of 2% alcohol solution of ferric chloride was added to 2 mL of extracts.

✓ Flavonoids: The extracts are taken up in 5 mL of hydrochloric alcohol (mixture of 10 mL of 96° ethanol, 10 mL of distilled water and 10 mL of concentrated hydrochloric acid). Subsequently, two to three magnesium shavings were added.

✓ Sterols and polyterpenes: Liebermann's reagent was used for this demonstration. A mass of 0.1 g of dry extract was dissolved hot in 1 mL of acetic anhydride and collected in a test tube. Then, 0.5 mL of concentrated sulfuric acid (H2SO4) was added to it.

✓ Alkaloids: A mass of 1 g of dry extract was dissolved in 6 mL of ethanol at 60°. A volume of 2 mL of the alcoholic solution thus obtained was distributed into a test tube. 2 drops of DRAGENDORFF reagent (aqueous solution of potassium iodobismuth) are added to the tube.

✓ Catechic tannins: A volume of 1 mL of hydrochloric alcohol (equivolume mixture of alcohol, distilled water and hydrochloric acid) was added to 5 mL of dissolved extract. The mixture was brought to a boil for 15 min.

✓ Detection of saponins: A mass of 0.1 g of dry extract was dissolved in 10 mL of distilled water. The resulting solution was stirred vigorously for 45 seconds. After stirring, the solution was allowed to stand for 15 minutes.

✓ Detection of anthraquinones: To 3 mL of extract, an equivalent volume of 10% aqueous potassium hydroxide (KOH) is added.

Study of the acute oral toxicity of different extracts on broiler chickens

This experimental study, which is the very first adapted to broiler chickens, was carried out with the agreement of the National Ethics Committee for Life and Health Sciences (CNESVS) of the Pasteur Institute of Côte d'Ivoire (N/ Ref: 037-23/MSHPCMU/CNECVS–km). Acute oral toxicity was evaluated in broilers according to the guideline 425 of the OECD (2008), for testing chemical substances. It consisted of testing plant extracts at a dose of 2000 mg/kg.

The test was carried out on 9 broiler chickens and their behaviour was observed as well as the number of deaths over a period of 3 days. After 18 hours of fasting, the chickens were distributed as follows: a control group consisting of 3 chickens receiving distilled water, at a rate of 3 mL per subject; a batch having received an aqueous extract (AE) consisting of 3 chickens, at a rate of 2000 mg/kg of live weight per subject, a batch having received an ethanolic extract (EE) consisting of 3 chickens, at a rate of 2000 mg/kg live weight per subject. The test substances were administered orally by gavage using a 5 cc syringe, without the needle, in a volume of three millilitres (3 mL). A behavioural observation was carried out 3 hours after administration of the substances. Then, hydration and nutrition were carried out daily for 3 days. During this period, signs of toxicity including motility, tremors, mobility as well as mortalities were noted.

The individual weight of each animal was determined shortly before administration of the test substance and then on the 2nd day after administration of the test substance. Weight change over the three days was also recorded. After the experiment, blood samples collected from the subjects of each experimental group were processed to obtain serum for the determination of biochemical parameters such as transaminases (ALT, AST), urea and creatinine. The dosage was carried out using the Cobas c311 automaton (Hitachi, Japan). Afterwards, all test animals were euthanized and then subjected to macroscopic necropsy. Organs such as the kidneys, liver, heart and lungs were the subject of histological analyses to observe potential cellular damage (Figure 4).

Statistical analysais

At the end of the different tests, all data residuals were analyses by using Microsoft Excel (spreadsheet) and XLSTAT software and significance was considered at P<0,05 for analysis of variance. Normality test was applied on all data residuals. Subsequent test used by Tukey's for comparing mean values of the variables (for more than two means). The results obtained were expressed as mean ± standard deviation.

RESULTS

Phytochemical compounds with potential antibacterial activities are alkaloids, anthraquinones, flavonoids, polyphenols, saponosides, sterols, catechin tannins and terpenes. Phytochemical screening of active plant extracts for these compounds showed the presence of at least one compound. Polyphenols and catechic tannins are the compounds most found in aqueous extracts of *Mallotus oppositifolius* and aqueous extracts of *Kalanchoe crenata*. The ethanolic extract of *Mallotus oppositifolius* is the one which contains the most molecules among the extracts analyzed, these are terpenes, sterols, catechic tannins, saponosides, anthraquinones and polyphenols (Table 1).

The study of the acute oral toxicity of the extracts by oral route on broiler chickens revealed no deaths, as well as no clinical signs of toxicity after the administration of the extracts, at a dose of 2000 mg/kg of weight body (pc). All animals survived after 48 hours of observation, which implies that the LD50 is greater than 2000 mg/kg bw. Thus, according to the Globally Harmonized System of Classification and Labelling of chemicals (GHS, 2003), the aqueous and ethanolic extracts of the leaves of *Mallotus oppositifolius* and *Kalanchoe crenata* are non-toxic orally in broilers.

At necropsy, the organs of the test animals showed coloring, appearance, and conditions identical to those observed with control animals. Analysis of histological sections of the organs (heart, kidney, liver and lung) of the test animals revealed no abnormalities related to the proposed treatment (Figure 5).

Table 2 show the variations in serum creatinine in chickens having received different extracts at a concentration of 2000 mg/Kg of body weight and in the control batch during the test period is less than 10 mg/L. The creatinine level observed with the subjects of the ME group is higher than those observed with the other groups. The rate observed with the control batch is the lowest of the different experimental groups. The variations in transaminases (ASAT and ALT) in chickens having received different extracts at a concentration of 2000 mg/Kg body weight and the control batch during the test period vary from 201.2±8.34 IU/L at257.2±8.76 IU/L for aspartate aminotransferase (ASAT) and 7±4.10 IU/L at 9.3±2.82 IU/L for alanine aminotransferase (ALT). In short, the administration of the different active extracts to the test chickens had no effect on their blood biochemical parameters.

Table 1 - Phytochemical screening of plant extracts.

Phytochemical compound	*Mallotus oppositifolius*		*Kalanchoe crenata*
	Aqueous extract	Ethanolic extract	Ethanolic extract
Alkaloids	-	-	-
Anthraquinones	-	+	-
Flavonoids	-	-	-
Polyphenols	+	+	+
Saponosides	-	+	-
Sterols	-	+	-
Catechical tannins	+	+	+
Terpenes	-	+	-

+: presence; - : absence

Table 2 - Biochemical parameters of the different test groups having received 2000 mg/Kg/Pc of extract

Batches	Creatinine (mg/L)	ASAT (IU/L)	ALAT (IU/L)	Urea (g/L)	CRP (mg/L)	Blood sugar (g/L)
Control	0.035±0.03 [d]	201.2±8.34 [a]	7.6±7.7 [b]	0.01±0	0.24±0.02 [c]	2.25±0.04 [b]
MA	0.045±0.02 [d]	215.5±8.06 [a]	7.85±0.7 [b]	0.01±0	0.215±0.14 [c]	2.01±0.08 [b]
ME	0.08±0.02 [d]	257.2±8.76 [a]	9.3±2.82 [b]	0.01±0	0.155±0.14 [c]	2.15±0 [b]
KE	0.05±0.042 [d]	205.75±7.99 [a]	7±4.10 [b]	0.01±0	0.09±0.11 [c]	2,225±0.205 [b]
Reference values	≤ 10	≤ 275	≤ 50	0.01	≤ 6	Between 2 & 5

[a, b, c and d] : Means with different superscripts in the same row were significantly different at $P<0.05$. MA: batch exposed to the ethanolic extract of *Mallotus oppositifolius*; ME: batch exposed to ethanolic extract of *Mallotus oppositifolius*; KE: batch exposed to the ethanolic extract of *Kalanchoe crenata*: control: batch exposed to no extract.

DISCUSSION

The valorization of natural antimicrobials has been the subject of numerous investigations. In this study, plant extracts were shown to possess antibacterial activity against strains of *Salmonella* multi-resistant (Carole et al., 2021).

Thus, phytochemical screening revealed the presence in plants of the main families of chemical compounds likely to confer antimicrobial properties to a plant. These include terpenes, polyphenols, sterols and anthraquinones. Obviously, terpenoids are known to have antifungal properties (Merghache et al., 2012). The works of Tené et al. (2009) showed that butelin and 12-oxohardwickic acid, isolated from *Croton macrostachyus* both belonging to this family, had antifungal and antimicrobial activities. Finally, numerous studies have shown that phenols and phenolic derivatives have antimicrobial activities (Tabopda et al., 2008). Phytochemical screening also allows us to observe variations in the chemical composition of different extracts. The data obtained in this study suggest that it would be possible to produce drugs with antibacterial activities, from the aqueous and ethanolic extracts of *Mallotus oppositifolius* and the ethanolic extract of *Kalanchoe crenata*, for livestock such as chickens.

The administration of so-called toxic substances causes undesirable physiological and biochemical disorders, affecting the structural and functional integrity of tissues. The results of the histological analyses obtained in this work show the maintenance of the tissue integrity of the architecture of the organs analysed, with a remarkable absence of central hemorrhagic necrosis on the histological sections produced. In addition, the subjects who received the different extracts appear to have normal organs with intact cellular architecture, less vacuole formation and an absence of necrosis in the tissues, which reveals their harmless action on the tissues.

On the other hand, the results of biochemical analysis of sera do not indicate any abnormal changes in biochemical parameters such as creatinine, urea, transaminases (alanine aminotransferase and aspartate aminotransferase) and total bilirubin. Transaminases or aminotransferases are tissue enzymes catalysing the transport of alpha-amino radicals from alanine and aspartic acid to alpha-ketoglutaric acid. Transaminases are present in the liver, but also in muscle and ASTs in the kidney, pancreas, and other tissues. They are synthesized in the cytoplasm of the cells of these organs and released into the circulation when these cells are damaged (Peirs, 2005). These enzymes increase in cases of myopathy, rhabdomyolysis or myocardial infarction and AST, particularly in cases of haemolysis. Serum urea and creatinine are considered the main markers of nephrotoxicity.

Figure 1 - Plants of *Kalanchoe crenata* (a, b), *Mallotus oppositifolius* (c, d), Plant stems (a, c); plant leaves (b, d).

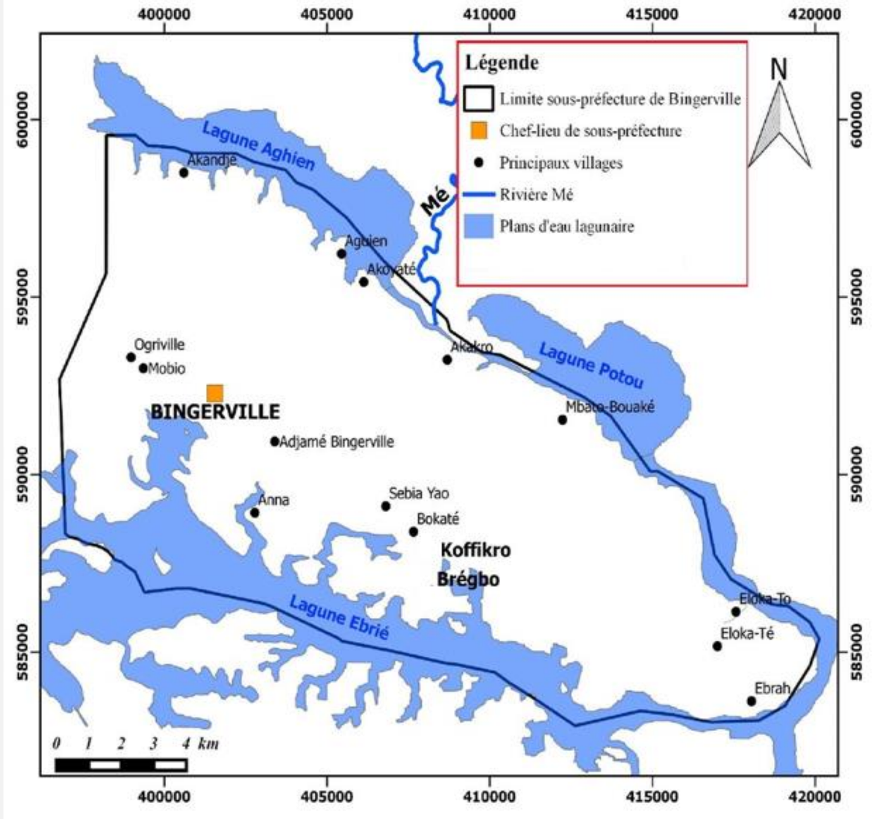
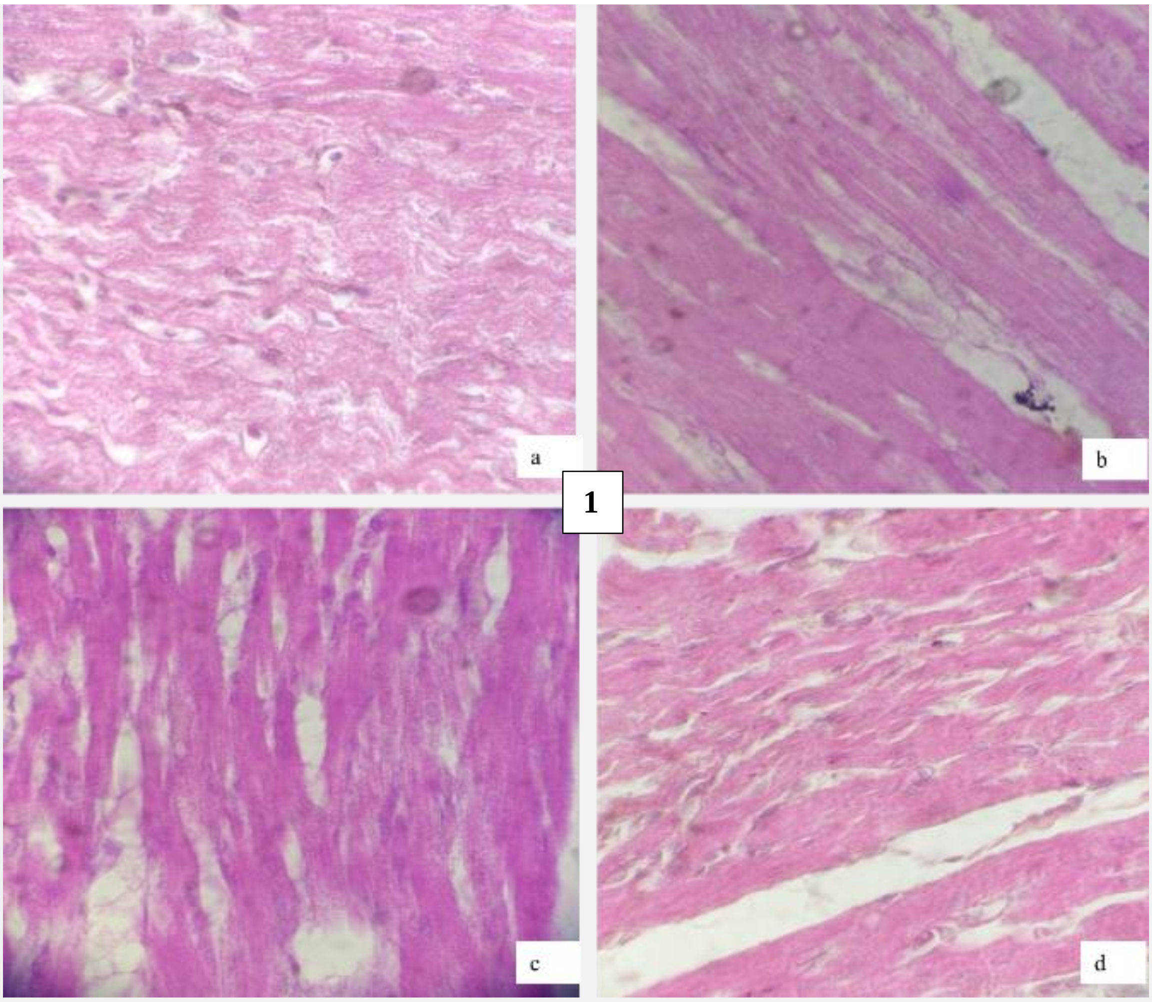
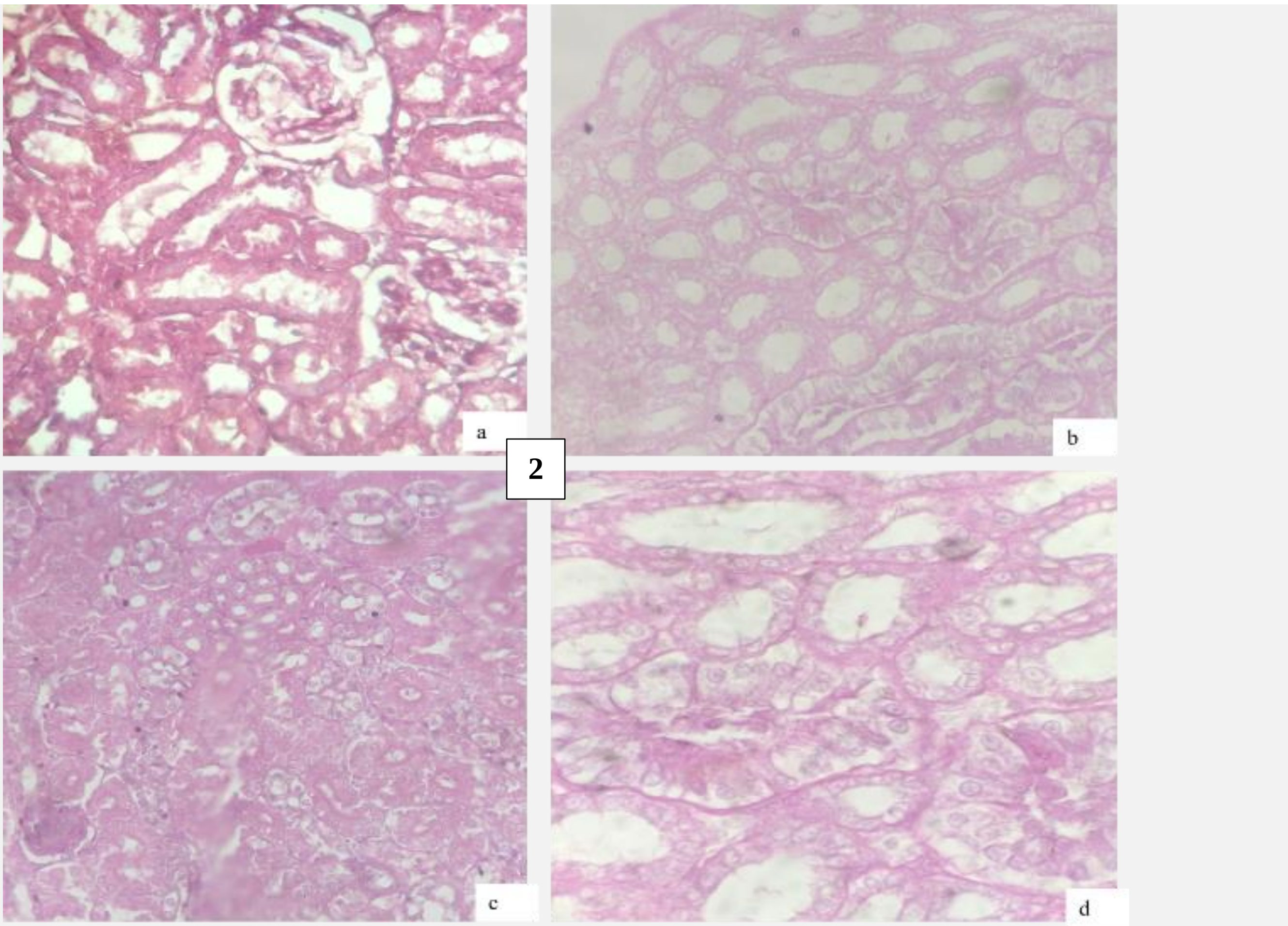


Figure 2 - Geographical location of Bingerville. *Source: Kanohin et al. (2017).

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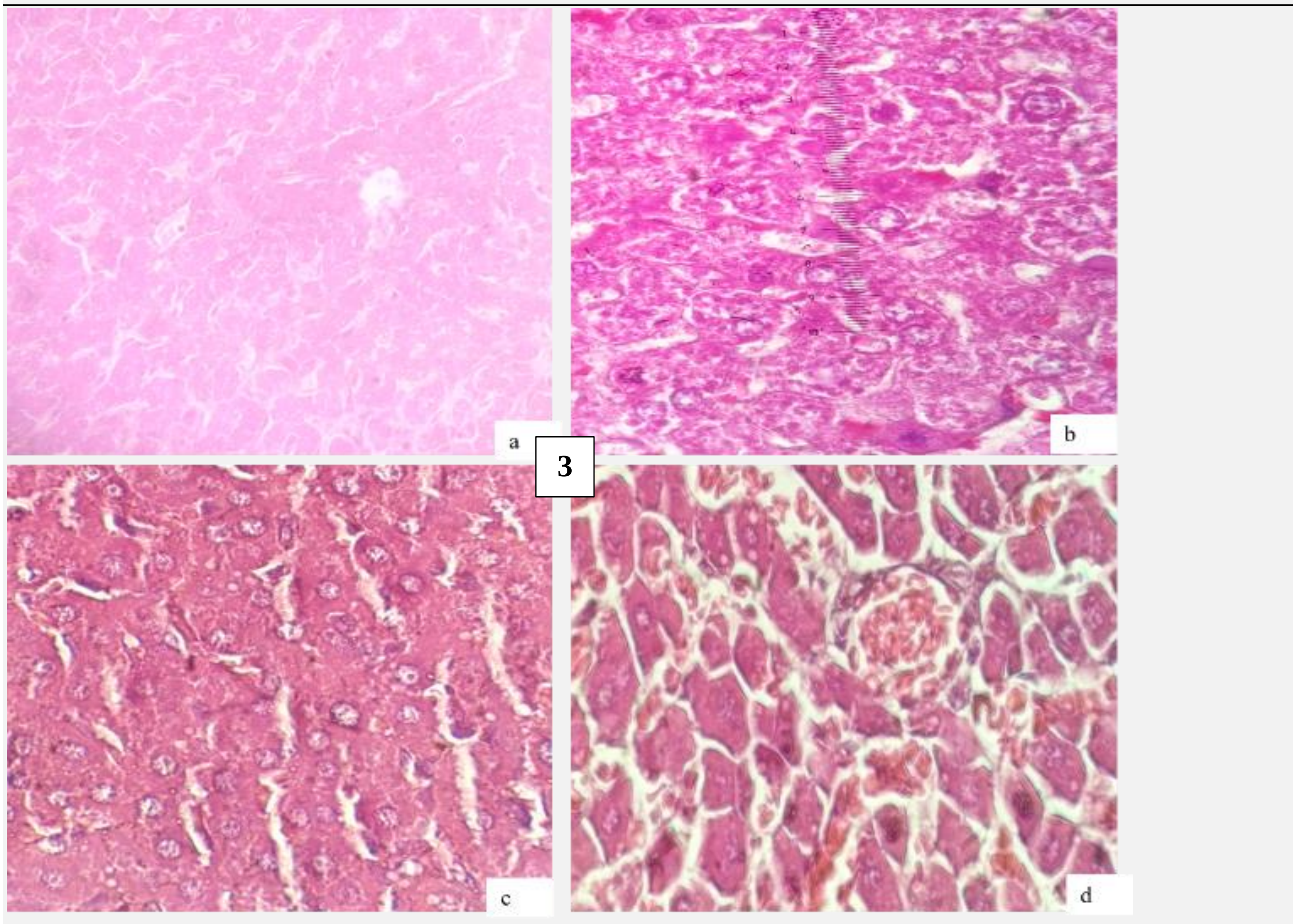
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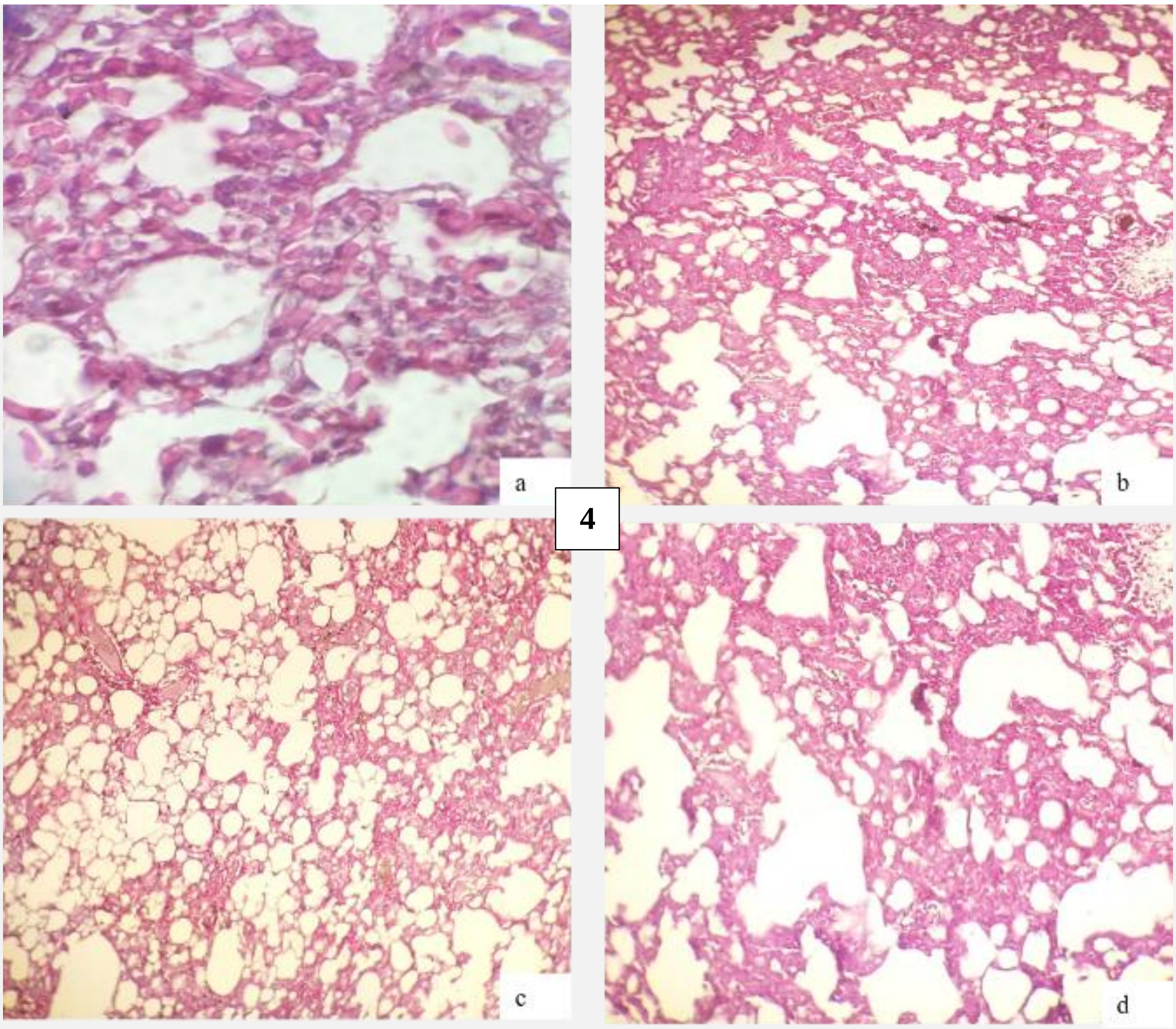

Figure 4 - Histological sections of the organs of the test chickens (Gx400). **a:** batch control witness ; **b:** batch exposed to the ethanolic extract of *Mallotus oppositifolius*; **c**: batch exposed to the aqueous extract *of Mallotus oppositifolius*; **d**: batch exposed ethanolic extract of *Kalanchoe crenata.* **1**: heart organ; **2**: kidney organ; **3**: liver organ; **4**: lung organ

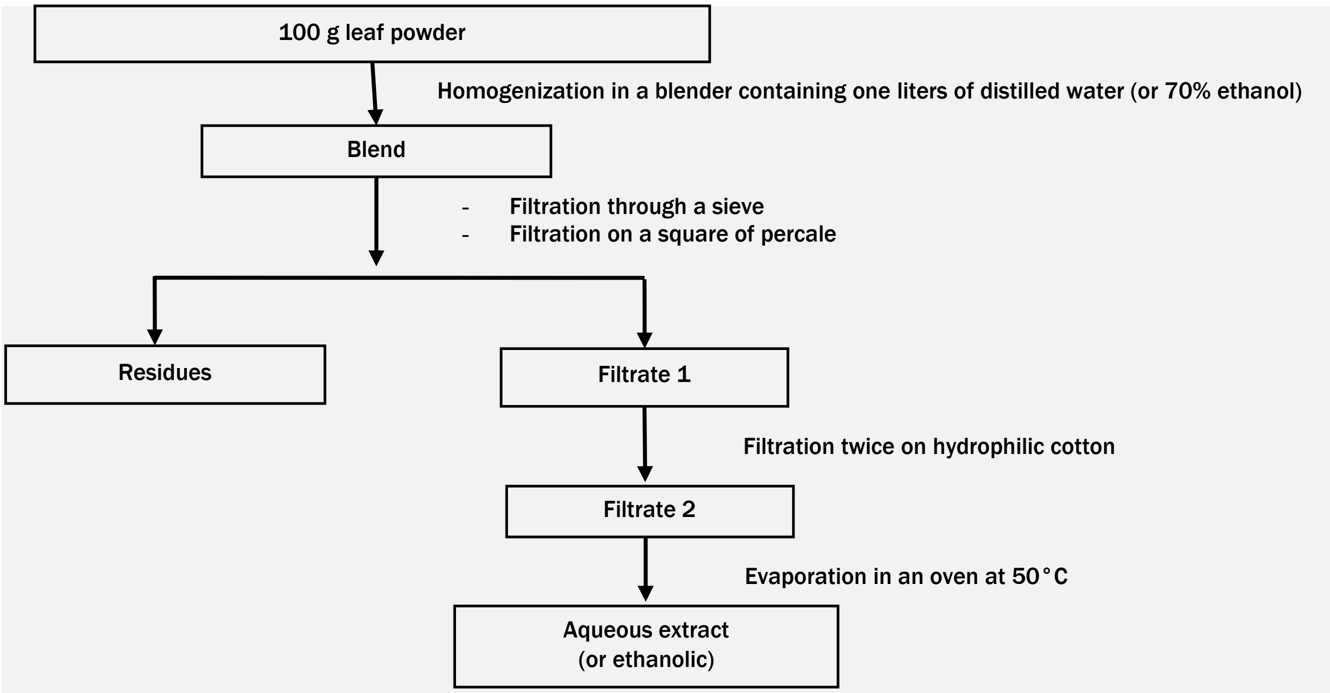

Figure 3 - Protocol for obtaining aqueous and ethanolic extracts from the plants in the study

CONCLUSION

This study shows that the aqueous and ethanolic extracts of *Mallotus oppositifolius* and the ethanolic extract of *Kalanchoe crenata*, having antibacterial properties on different serotypes of multi-resistant avian *Salmonella* strains, possess molecules belonging to large phytochemical groups such as polyphenols, catechin tannins, anthraquinones, saponosides and sterols. In addition, these extracts do not present any acute toxicity for a dose less than or equal to 2000 mg/kg. No signs of behavioral, tissue or biochemical toxicity were observed. These extracts can be considered as promising candidates for the development of alternative antibacterials, in the fight against the *Samonella* pathogen in poultry farming.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author contribution

ASSANDI Kouamé Rivière spearheaded the design and execution of the experiments, conducted results analysis, and contributed to the writing. TOURE Alassane spearheaded the execution histological analyses. BONNY Aya Carole was involved in the design, writing, results analysis, and refining the manuscript's structure. KAROU Tago Germain played a key role in establishing execution sites and coordinating with participating author.

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Ethical approval

This experimental study was carried out with the agreement of the National Ethics Committee for Life and Health Sciences (CNESVS) of the Pasteur Institute of Côte d'Ivoire (N/ Ref: 037-23/ MSHPCMU / CNECVS – km).

Consent to participate

All authors agree to the execution of this experimentation.

Consent for publication

All authors agree to the publication of this manuscript.

Competing interests

The authors declare that they have no competing interests.

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MINERALS CONTENT OF WATER SOURCES FOR LIVESTOCK PRODUCTION IN ETHIOPIA

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ABSTRACT: Minerals are essential nutrients for sustainable livestock production and productivity. Water is a source of minerals to livestock production beside feed minerals. Presence of some minerals in water at higher levels will be toxic to animals and will affect animal health and productivity. So, it is essential to know the mineral content of water sources for livestock consumption in the country. This paper is based on a review of literature that was conducted on the mineral content and quality of water sources mainly for human consumption and other purposes in Ethiopia. Based on the literature values of the mineral content of the water sources and recommended values of minerals in livestock drinking water, the water sources were assessed for their suitability for livestock production. The review showed the presence of variation in the mineral content of the water sources in Ethiopia. In addition, there is variation in the mineral content of the water sources between the dry and the wet season. The total dissolved solids (TDS), Calcium, magnesium, chromium and zinc content of the water sources in Ethiopia is within acceptable levels for livestock consumption. But the sodium, chloride, copper, fluoride, iron, lead and manganese content of some of the water sources (river, well and lake) in the country is beyond the maximum recommended level. This demands implementation of mitigation mechanisms to reduce the mineral contents of water sources; otherwise, it will result in deleterious effects on the health and productivity of animals. Generally, there is a lack of adequate research on the mineral content of water sources for livestock production in the country. So, there is a need to conduct more research on the water sources being consumed by livestock in the country in the future.

Keywords: Ethiopia, Livestock production, Minerals, Season, Toxic elements, Water sources.

INTRODUCTION

Minerals are one of the essential nutrients for livestock production. Minerals are inorganic substances that are required for the maintenance of certain physicochemical processes that are essential to life (Soetan et al., 2010; McDonald et al., 2011). The major elements are required in higher amounts while the trace elements are required in smaller amounts by the animal body. There are certain trace elements in the animal body and plants with no known functions yet (McDonald et al., 2011). Minerals are important for health, reproduction and productivity of livestock. At optimum levels minerals enhance the health, reproduction and productivity of animals. If some minerals are supplied in excess amounts to livestock, they will adversely affect the health, reproduction and productivity of animals. Similarly, if animals are deficient in essential minerals (below the minimum threshold level); their feed intake, growth and development will be affected (Wu, 2018). Feeds and forages are the main sources of minerals for livestock production in the world (Suttle, 2010; Arthington and Ranches, 2021).

Water is not a major source of minerals for livestock production (Suttle, 2010). The minerals contained in water have a valuable contribution to animal nutrition (Chesworth, 1992; Saha and Pathak, 2021). Generally, water usually contains several minerals in it. According to Pagot (1993), water may contain ions of calcium, magnesium, sodium, chlorine and iron in it. These minerals are essential minerals for livestock production (Pagot, 1993). The mineral content of water sources varies depending on the source of water (Petersen et al., 2015).

The quality of drinking water for livestock affects the health and productivity of animals (Umar et al., 2014; Giri et al., 2020). Water can be contaminated by bacteria and algae. Contaminated water will affect the health of animals' especially young ruminant animals (Chesworth, 1992). Drinking water can be one source of livestock contamination with viruses, bacteria and parasites (Pagot, 1993). It is known that drinking water supplies several minerals for livestock.

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Some minerals (trace elements) are needed in smaller amounts by livestock. If these minerals and substances are supplied in excess to livestock the health as well as the productivity of the animals will be affected. For example, water containing above 2 g per litre sodium carbonate causes diarrhoea in cattle (Pagot, 1993). Drinking water that contains 4 g per litre sodium sulphate causes the same effect on livestock as water that contains high levels of sodium carbonate. It is reported that consumption of saline drinking water affects the health and productivity of livestock. According to Dryden (2008), livestock consuming high salinity drinking water near their limit of tolerance show reduced growth (or decline in body weight), occasional diarrhoea and general weakness. To alleviate the adverse effects of the high mineral content of water on livestock production knowledge on the mineral content of the available water sources is crucial. Currently, there is no adequate research on the mineral content of water sources for livestock consumption in Ethiopia. There are several studies in Ethiopia on the mineral content and quality of water sources for human consumption and other purposes. So, the objective of this paper is to review the available literature on the mineral content of different water sources and to assess their suitability for livestock production in Ethiopia.

Recommended levels of minerals in drinking water for livestock

Minerals are required by livestock for their normal metabolism. Minerals in livestock nutrition are divided into three groups based on their requirement by animals (Dryden, 2008). Major minerals are required in large quantity and the requirement of animals per day is expressed in g/kg or per cent. Trace minerals are required by animals in small quantities and the requirement of animals is expressed in mg/day or microgram per day. Minerals that are required in the diet less than 50 microgram per kg are known as ultra-trace minerals (Dryden, 2008). Sodium, K, Ca, Mg, P, S and Cl are major minerals. Generally, minerals are essential for livestock nutrition. However, if some minerals (trace minerals) are supplied to animals in higher amounts they will be toxic, affect production and health of animals. The recommended daily requirement of minerals in water for livestock production is given in Table 1.

The recommended maximum level of minerals and other constituents in water for livestock production is given in Table 2. If livestock drinking water contains minerals and other constituents beyond the maximum recommended level it will have adverse effects on their health and productivity.

Higher levels of minerals in water have variable effects in different livestock species (NRC, 1974) (Table 3). Short-term consumption of high level of minerals in water have less effects than log-term consumption. Different livestock species may react differently to high levels of minerals in water. In addition, the effect may vary between young and mature animals. In some cases, intake of high levels of minerals may not show measurable effects on growth, production and reproduction. But they may cause sub-cellular damage and increase the susceptibility of the animals to diseases and parasitic infection. In other cases, some minerals may not be toxic to livestock but they may accumulate in meat, milk and egg and may be harmful to humans that consume these animal products (NRC, 1974).

Mineral content of water sources in Ethiopia

Several studies have been conducted in Ethiopia to assess the quality and mineral content of different water sources. The studies that were conducted on water quality and mineral content of the different water sources in Ethiopia are given in table 4. Generally, the water sources in Ethiopia contain calcium, chloride, chromium, cobalt, fluoride, iron, lead, magnesium, nickel, potassium and sodium (Table 5).

Total dissolved solids (TDS) content

Saline water is water that contains dissolved soil minerals, trace minerals and other substances (Dryden, 2008). Almost all the water sources in Ethiopia contain less than the maximum recommended level of total dissolved solids (TDS) (Tables 2 and 5). The TDS content of different water sources in Ethiopia ranges from 32.5 to 3017.10 mg/l TDS (Table 5). The TDS level in Ethiopian water sources is lower than the NRC (1989) maximum recommended level as cited by Dryden (2008) for livestock production (Tables 2 and 5). But this level is higher than CCME (1987) recommendations as cited by Dryden (2008) (Tables 2 and 5). Generally, almost all the water sources in Ethiopia have less than the maximum recommended level of TDS in them based on NRC (1989) as cited by Dryden (2008) and ANZECC (2000) recommendations (Tables 2 and 5).

The total dissolved solids (TDS) level in water has variable effects on livestock species. High levels of TDS in water causes livestock poisoning or animals stop drinking this water and leads to loss of production (Drechsel et al., 2023). Tolerance of livestock species to saline water is given in table 6. Tolerance of animals to saline water depends on physiological state of the animal, type of feed eaten and the ability of the animal to concentrate its urine (Dryden, 2008). Generally, young animals are less tolerant than mature animals to saline water.

Table 1 - Recommended daily requirement of mineral elements in drinking water for different livestock species

Animal species	Water intake (liters)	Requirement daily (g)											
		Calcium	Cobalt	Copper	Iodine	Iron	Magnesium	Manganese	Phosphorus	Potassium	Selenium	Sulfur	Zinc
Beef cattle (450 kg)													
Nursing cow	60	28	0.74	79	1.7	0.99	14	49	22	90	0.74	10	0.15
Finishing steer	60	21	0.71	75	1.6	0.94	9	47	21	70	0.71	9	0.14
Dairy cattle (450 kg)													
Lactating cow	90	76	1.4	160	5.1	2.0	14	100	58	99	2.0	20	0.86
Growing heifer	60	15	0.7	80	1.6	1.0	9	50	16	70	1.0	10	0.43
Maintenance cow	60	12	0.5	51	1.6	0.64	9	32	12	45	0.6	6	0.27
Sheep													
Lactating ewe (64 kg)	6	7	0.18	13	1.0	-	1.5	-	5	-	0.1	3	0.25
Fattening lamb (45 kg)	4	3	0.13	9	0.8	-	1.1	-	3	-	0.1	2	0.18
Swine													
Growing (30 kg)	6	10	-	15	-	0.20	1.0	50	9	8	0.25	-	0.13
Fattening (60 – 100 kg)	8	17	-	20	-	0.26	1.0	66	14	9	0.33	-	0.17
Lactating sows (200 – 250 kg)	14	33	-	33	-	0.44	2.2	110	22	14	0.55	-	0.28
Horses (450 kg)													
Medium work	40	14	0.39	78	0.5	0.39	13	-	14	30	-	10	-
Lactating	50	30	0.40	78	-	0.39	15	-	24	35	-	10	-
Poultry													
Chicken (8 wk old)	0.2	1.0	-	14	0.035	0.008	0.05	6	0.7	-	0.01	-	0.005
Laying hen (60% production	0.2	3.4	-	-	0.037	-	-	-	0.8	-	-	-	-
Turkey (8 wk old)	0.2	1.2	-	9	-	0.006	0.05	6	0.8	-	0.02	-	0.007

*Source: NRC (1974)

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Table 2 - Recommended maximum levels of minerals and other constituents in drinking water for animals

Constituent / mineral	Unit	Recommendations			
		ANZECC (2000)	NRC (1974)	CCME (1987)	NRC (1989)
TDS	mg/l	3000 - 13000		3000	6500
pH	-	6.5 – 8.5**			
Nitrate N	mg/l	30.0	99.5	22.5	100.0
Calcium	mg/l	1000		1000	
Chromium	mg/l	1.0	1.0	1.0	1.0
Cobalt	mg/l	1.0	1.0	1.0	1.0
Copper	mg/l	0.5	0.5	0.5 – 5.0	0.5
Fluoride	mg/l	2.0	2.0	2.0	2.0
Lead	mg/l	0.1	0.1	0.1	0.1
Manganese	mg/l	0.01*			
Magnesium	mg/l	600.0			
Nickel	mg/l	1.0	1.0	1.0	1.0
Chloride	mg/l	1.0*			
Iron	mg/l	0.05*			
Phosphate	mg/l	-			
Potassium	mg/l	-			
Sodium	mg/l	50*			
Sulphate	mg/l			1000	
Zinc	mg/l	20.0	25.0	25.0	25.0

#Source: Dryden (2008); * Çapar et al. (2020); **NRC (2005), recommended range.

Table 3 - Effect of high levels of some mineral elements in drinking water in different livestock species

Mineral element	Level in drinking water	Livestock species	Effect on health and production
Copper	625 mg/L	Turkeys	Decreased feed and water intake; fatal
Fluoride	100 mg/L	Calves	Decreased feed intake, growth and Ca absorption, bone decalcified
	11.8 mg/L	Cattle	Mottled teeth
	20 mg/L	sheep	Decreased health; severe teeth mottling
Lead	100 mg/L	Calf	Died after 4 mo of drinking $Pb(NO3)_2$
Manganese	500 mg/L	Cattle	Reduced liver Fe but no toxicity
Iron	17 mg/L	Cattle	In pasture irrigation water; scouring; decreased milk production and body weight
Sulphate	100 mg/L	Cattle	Lost weight; decreased water intake by 35%; feed intake by 30%; and creatinine excretion by 12%
Zinc	2320 mg/L	Hens	Decreased water consumption; egg production stopped after 3 days; body weight decreased

*Source: NRC (1974)

Table 4 - Water quality studies considered in this review paper and type of water sources studied by the authors in Ethiopia

Type of water source	Statistics used in this study	Reference
Tap water	Mean	Amogne et al. (2015)
Well water	Mean	Rango et al. (2012)
Well water	Mean	Berhanu et al. (2021)
Well and spring water	Mean	Abegaz et al. (2021)
Tap water	Mean	Meride and Ayenew (2016)
Spring water	Mean	Reda (2015)
Well water	Mean	Gebresilasie et al. (2021)
Well water	Maximum	Beyene et al. (2019)
Well and spring water	Mean	Lewoyehu (2021)
Well and tap water	Mean	Garoma et al. (2018)
Well water	Mean	Alemu et al. (2017)
River, stream and well water	Mean	Berhe (2020)
River water	Mean	Eliku and Leta (2018)
Lake water	Mean	Dinka (2017)
Tap, well and spring water	Mean	Yasin et al. (2015)
Well and spring water	Mean	Shigut et al. (2017)
Spring, tap and well water	Median	Alemu et al. (2015)
River and Lake water	Mean	Shishaye and Asfaw (2020)
Lake water	Mean	Worako (2015)
Lake water	Mean/ Maximum	Goshu et al. (2017)

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Table 5 - Mean, minimum and maximum mineral and other constituents' content of the water sources reviewed in this review paper

Mineral	N	Mean	Minimum	Maximum
Total dissolved solids (TDS)	30	478.46	32.5	3017.10
pH	35	7.41	6.22	9.56
Calcium	24	50.06	2.52	142.0
Chloride	22	95.52	0.01	929.50
Chromium	4	0.39	0.03	0.75
Cobalt	1	1.09	-	-
Copper	13	0.51	0.01	1.20
Fluoride	19	2.85	0	15.08
Iron	23	0.72	0.03	2.77
Lead	8	0.25	0	0.81
Magnesium	23	15.61	1.35	70.43
Manganese	10	0.33	0.02	0.92
Nickel	3	0.41	0.05	1.08
Nitrate	27	11.36	1.05	45.73
Phosphate	27	0.79	0	9.10
Potassium	17	24.55	0.43	163.0
Sodium	21	271.0	6.36	2584.50
Sulphate	25	98.71	0.33	988.50
Zinc	9	0.59	0.08	1.55

N = Number of studies

Table 6 - Tolerance of livestock species to total dissolved solids (TDS) in drinking water (mg/L)

Livestock species	A: No adverse effects on animals expected	B: Animals may initially exhibit reluctance to drink or there may be some scouring, but stock should adapt without loss of production	C: Loss of production and decline in animal condition and health would be expected. Livestock may tolerate these levels for short periods if introduced gradually
Beef cattle (mature, on dry pasture)	0 – 4000	4000 – 5000	5000 – 10000
Beef cattle (feedlots)	0 – 4000	-	> 4000
Dairy cattle (mature, dry)	0 – 2400	2400 – 4000	4000 – 7000
Dairy cattle (milking)	-	-	3500
Sheep (mature, on dry pasture)	0 – 4000	4000 – 10000	10 000 – 13000[a]
Sheep (mature, dry, feedlots)	0 – 4000	-	> 7000[b]
Sheep (mature, dry confinement feeding)	0 – 4000	-	> 7000[c]
Sheep (weaners, lactating and pregnant on pasture)	0 – 4000	-	6600
Sheep (lambs, intensive feeding)	0 – 4000	-	> 4000
Horses	0 – 4000	4000 – 6000	6000 – 7000
Poultry	0 – 2 000	2000 – 3000	3000 – 4000
Pigs	0 – 4000	4000 – 6000	6000 – 8000

[a] Sheep on lush green feed may tolerate up to 13 000 mg/L TDS without loss of condition or production; [b] Intensive feeding for growth; [c] Confinement feeding for maintenance. *Source: Drechsel et al. (2023).

Macro mineral content of water sources

Calcium content

Calcium is one of the essential minerals for livestock production. It is required in larger amounts and it is crucial for bone and teeth development (McDonald et al., 2011). About 99% of the calcium in the animal body is found in the skeleton and teeth (McDonald et al., 2011). Water is one of the sources of calcium for livestock. Most of the water sources in Ethiopia contain calcium and the calcium content of the water sources in Ethiopia is less than the maximum recommended level of calcium for livestock (Table 2 and 5). Based on several studies in Ethiopia the calcium content of the water sources in Ethiopia ranges from 2.52 to 142.0 mg/l (Table 5). Calcium content of water determines its hardness or softness together with other minerals. Based on calcium content of water sources, the Ethiopian water sources are suitable for livestock production.

Chloride content

Chloride is an essential mineral for livestock production. Almost all of the water sources in Ethiopia contain chloride in them. Chlorine occurs in the gastric secretion and it is required for hydrochloric acid production in the stomach (McDonald et al., 2011). The chloride content of the water sources in Ethiopia ranges from 0.01 to 929.50 mg/l (Table 5). Most of the water sources in Ethiopia contain higher levels of chloride beyond the maximum recommended level (Table 2 and 5). According to Reda (2015), the spring water sources in Arbaminch area in Ethiopia contain higher levels of chloride (260 mg/l and above). This value is higher than the maximum permissible level of chloride for livestock drinking water (Table 2).

Magnesium content

Magnesium is essential for livestock production. Magnesium is important for enzymes in carbohydrate and lipid metabolism (McDonald et al., 2011). The magnesium content of water sources in Ethiopia ranges from 1.35 to 70.43 mg/l (Table 5). The maximum recommended level of magnesium in drinking water for livestock production is 600.0 mg/l (Table 2). All of the water sources tested in the country contain less magnesium than the maximum recommended level of magnesium in drinking water that is used for livestock production.

Potassium content

Potassium is essential for livestock production. It is important in acid-base balance, nerve and muscle excitation (McDonald et al., 2011). The potassium content of water sources in Ethiopia ranges from 0.43 to 163.0 mg/l (Table 5). Hora natural mineral water contains the highest level of potassium (163 mg/l) in it (Alemu et al., 2017). According to Berhanu et al. (2021), Arba Minch University main campus water wells contain high levels of potassium and nitrate in them. Higher levels of potassium (26.9 and 31.8 ppm) in livestock drinking water are also reported in the central highlands of Ethiopia (Mesfin et al., 2015). According to Wu (2018), excessive potassium intake in animals results in reduced feed intake and impaired growth, fatigue and muscle weakness, hypomagnesemia and even death.

Sodium content

Sodium is an essential mineral for livestock production. It is important in acid-base balance in the animal body (McDonald et al., 2011). The sodium content of the water sources in Ethiopia ranges from 6.36 to 2584.50 mg/l (Table 5). Some of the water sources have high levels of sodium beyond the maximum recommended level for livestock production (Table 2 and 5). The sodium content of Lake Basaka in 2015 as reported by Dinka (2017) is the highest (2587 mg/l) in Ethiopia.

Micro mineral and other constituents of water sources

Chromium content

In Ethiopia, Chromium is reported in four water sources (Amogne et al., 2015; Alemu et al. 2017; Eliku and Leta, 2018). Chromium supplements increase dry matter intake and milk yield in dairy cows (McDonald et al., 2011). According to Wu (2018), chromium regulates the metabolism of glucose and lipids in animals. In addition, it is involved in the synthesis of fatty acids and cholesterol in the liver. The chromium content of water sources in Ethiopia ranges from 0.03 and 0.75 mg/l (Table 5). Based on Dryden (2008), the chromium content of the water sources in Ethiopia is less than the maximum recommended level of chromium for livestock production. So, the water sources are safe for livestock production.

Cobalt content

Cobalt is required by micro-organism in the rumen of ruminant animals to synthesize Vitamin B12 (McDonald et al., 2011). From the literature reviewed one source of water was analysed for cobalt content in Ethiopia. The cobalt content of Hora natural mineral water is 1.09 mg/l (Alemu et al., 2017). This value is greater than the recommended maximum level of cobalt in drinking water used for livestock production (Table 5). The recommended maximum level of cobalt in livestock drinking water is 1.0 mg/l (Table 2). Higher levels of cobalt in livestock drinking water sources may have an effect on the health and productivity of animals. According to Wu (2018), excess cobalt in animals results in reduced feed intake, growth restriction, dermatitis, cardiomyopathy and goiter.

Copper

Copper is one of the essential minerals for livestock production. Copper is essential for the activity of several enzymes (Amine oxidase, Ascorbate oxidase, Tyrosine oxidase) (Wu, 2018). In addition, it is also required for the normal red blood cell formation (Pond et al., 2005). According to Pond et al. (2005), sheep and calves are more susceptible to copper toxicity than other species. On average, the copper content of Ethiopian water sources is 0.51 mg/l (Table 5). The copper content of the water sources (spring, river, well and lake) in the country ranges from 0.01 to 1.20 mg/l. The copper content of some of the water sources in Ethiopia is beyond the maximum recommended level for livestock production (Table 2 and 5). Especially cattle and sheep in rural areas of the country will be exposed to this toxicity in the country.

Fluorine content

Higher levels of fluorine are toxic for ruminant animals (McDonald et al., 2011). The fluoride content of the water sources in Ethiopia ranges from 0.0 to 15.08 mg/l (Table 5). Some of the water sources in the country contain higher levels of fluoride beyond the maximum recommended level in drinking water for livestock (Table 2 and 5). The groundwater sources in Jimma Zone have higher levels of fluoride in them and defluorination of the water is recommended to use the water for drinking purposes (Beyene et al., 2019). According to Dryden (2008), the recommended maximum level of fluoride in drinking water for livestock is 2.0 mg/l (Table 2). Higher levels of fluoride in drinking water of humans affects the dental as well as the skeletal system. According to Rango et al. (2012), the water sources in the main Ethiopian Rift valley area in Ethiopia have higher levels of fluoride and there are signs of dental fluorosis on humans living in that area. According to the same source, based on preliminary data, milk intake reduces the adverse effects of high levels of fluoride intake (i.e. dental fluorosis). Based on this study milk intake reduces the severity of dental fluorosis in the study area. According to Wu (2018), chronic exposure to high levels of fluoride in the diet leads to dental fluorosis and osteoporosis in bones in dairy cows.

Iron content

Iron is important for haemoglobin formation and enzymes function in the electron transport chain (McDonald et al., 2011). Most of the water sources in Ethiopia contain iron. The iron content of the Ethiopian water sources ranges from 0.03 to 2.77 mg/l (Table 5). Some of the water sources in the country have higher levels of iron in them (Table 2 and 5). According to Eliku and Leta (2018), Awash River water contains higher levels of iron (2.2 mg/l) in it. This value is beyond the maximum recommended level of iron for livestock production (Table 2). To reduce the iron and heavy metals content of Awash River water establishment of a buffer zone is recommended in order to control entry of soil and agricultural nutrients into Awash River in Ethiopia. According to Gebreselassie et al. (2021), hand-dug well water samples in Kafta Humera District contain higher levels of iron. The iron content of the water sources in this area is beyond the maximum recommended level for use for livestock consumption (Table 2). To reduce the iron content of the hand-dug well waters for human consumption the adoption of water treatment technologies is recommended by the authors in this area. According to Berhe et al. (2020), the water sources in Kombolcha area also have higher levels of iron (0.54 mg/l) beyond the maximum recommended level for livestock production (Table 2). Higher levels of iron (0.33 to 89.95 ppm) in livestock drinking water is also reported in the central highlands of Ethiopia (Mesfin et al., 2015).

Lead content

Higher lead content of water affects the health of humans and animals. According to Wu (2018), excess lead intake inactivates several enzymes that are involved in energy metabolism, protein synthesis, DNA synthesis and repair, immunity and it enhances the production of reactive oxygen species. The lead content of the water sources in Ethiopia ranges from 0 to 0.81 mg/l (Table 5). The recommended maximum level of lead in drinking water for animals is 0.1 mg/l (Table 2). Hora natural mineral water and Awash River water contain higher levels of lead above the maximum recommended level in drinking water for livestock. According to Azimi et al. (2017), there are several methods to reduce heavy metals from water and wastewater sources. These include membrane filtration, ion-exchange, adsorption, chemical precipitation, nanotechnology treatments, electrochemical and advanced oxidation processes. Utilization of the best method based on cost and effectiveness on removal of heavy metals is recommended (Chowdhury et al., 2016).

Manganese

The water sources (spring, river, well and lake) in the country contain manganese in different levels (Table 5). The mean manganese content of the water sources in Ethiopian is 0.33 mg/l (Table 5). The manganese content of the water sources in the country ranges from 0.02 to 0.92 mg/l. Manganese is essential in the animal body and it is activator of many enzymes (McDonald et al., 2011). The manganese content of the water sources is higher than the value reported by Çapar et al. (2020), so safety measures have to be taken by the livestock producers to avert the toxicity. Higher levels of manganese (0.83 to 20.76 ppm) are also reported in livestock drinking water in the central highlands of Ethiopia (Mesfin et al., 2015). According to McDonald et al. (2011), growing pigs are less tolerant to manganese toxicity.

Nickel Content

Three studies report the nickel content of water sources in Ethiopia. The nickel content of the water sources in Ethiopia ranges from 0.05 to 1.08 mg/l (Table 5). The nickel content of Hora natural mineral water and Awash River water is 1.1 and 0.05 mg/l, respectively. Hora natural mineral water contains higher levels of nickel (1.1 mg/l) in it which is higher than the maximum recommended level of nickel in drinking water that is used for livestock production (Table 2). According to Azimi et al. (2017), there are several methods to reduce heavy metals from water and wastewater sources (membrane filtration, ion-exchange, adsorption, chemical precipitation, nanotechnology treatments, electrochemical and advanced oxidation processes). To reduce the high nickel content of the water sources, utilization of the best method based on cost and effectiveness on removal is recommended (Chowdhury et al., 2016). According to Alemu et al. (2017), Hora natural mineral water is used for human and livestock drinking purposes in the study area. It is believed that Hora natural mineral water is still used as natural medicine to cure people and livestock with various health problems (Alemu et al., 2017).

Zinc

Zinc is essential for livestock production. Zinc is a constituent of several enzymes and it is involved in enzyme activation and immune function (Pond et al., 2005). On average, the water sources in Ethiopia contain 0.59 mg/l zinc. The zinc content of the water sources in the country ranges from 0.08 to 1.55 mg/l (Table 5). The zinc content of the Ethiopian water sources is within the acceptable range that is recommended for livestock production (Tables 2 and 5).

Nitrate

On average, the nitrate content of the water sources in Ethiopia is 11.36 mg/l (Table 5). The nitrate content ranges from 1.05 to 45.73 mg/l. The nitrate content of the water sources in the country is within acceptable range that is recommended for livestock production (Tables 2 and 5). According to Pond et al. (2005), nitrate concentrations in water as high as 1320 mg/l may be tolerated by livestock.

Phosphate

Water sources in Ethiopia contain phosphate. On average, the phosphate content of the water sources in the country is 0.63 mg/l (Table 5). The phosphate content of the water sources ranges from 0 to 4.60 mg/l. Generally, there is no maximum recommended level of phosphate in water that is used for livestock production.

Sulphate

Several water sources in Ethiopia contain sulphate. On average, the sulphate content of the water sources in Ethiopia is 101.07 mg/l (Table 5). The sulphate content ranges from 0.33 to 988.50 mg/l. This value is less than the maximum recommended level for livestock drinking water (Table 2). According to Pond et al. (2005), sulphates are more detrimental to animals than carbonates and chlorides.

Variation in mineral content of water sources in the country

There is variation in mineral and other constituents' content of the water sources in the country. According to Khatri and Tyagi (2015), ground and surface water quality is affected by both natural processes and anthropogenic influences. Natural processes include weathering of rocks, evapotranspiration, depositions due to wind, leaching from soil, run-off due to hydrological factors and biological processes in the aquatic environment. Anthropogenic factors include impacts due to agriculture, use of fertilizers, manures and pesticides, animal husbandry activities, inefficient irrigation practices, deforestation of woods and other activities. The TDS content of lake water is higher than other water sources (Table 7). In addition, the chloride, fluoride, phosphate, potassium, sodium and sulphate content of lake water is higher than other water sources. Other studies also reveal that there is variation in mineral content among the water sources (Fasae and Omolaja, 2014; Petersen et al., 2015).

Table 7 - Mean mineral and other constituents content variation among the water sources in Ethiopia

Variable	N	Tap water	N	River water	N	Spring or stream water	N	Well water	N	Lake water	N	Total mean
TDS	4	259.61	3	444.89	6	413.10	14	418.93	3	1212.42	30	478.46
pH	5	7.51	5	7.30	7	7.11	14	7.19	4	8.73	35	7.41
Calcium	3	29.97	3	75.18	5	70.27	9	55.23	4	9.37	24	50.06
Chloride	4	7.71	3	22.74	4	81.09	8	38.33	3	457.14	22	95.52
Copper	-	-	4	0.75	2	0.64	6	0.40	1	0.02	13	0.51
Fluoride	1	0.98	3	0.58	4	0.87	9	2.55	2	12.49	19	2.85
Iron	1	0.07	5	1.29	4	0.47	10	0.58	3	0.82	23	0.72
Magnesium	3	10.15	3	9.45	5	16.95	8	20.42	4	13.06	23	15.61
Nitrate	4	13.69	3	5.53	6	11.11	13	12.71	3	2.99	29	10.77
Phosphate	4	0.48	3	0.19	6	0.29	11	0.41	3	4.27	27	0.80
Potassium	2	13.07	3	4.67	3	1.80	6	32.01	3	59.92	17	24.55
Sodium	3	21.54	3	51.28	4	42.53	7	170.94	4	1026.48	21	271.0
Sulphate	2	1.17	3	76.77	5	76.89	12	41.01	3	452.82	25	98.71

N = Number of studies

Seasonal variation in mineral and other constituent content of water sources

There is seasonal variation in the mineral and other constituent content of water sources in the country. The TDS content of the water sources is higher in the dry season than in the wet season (Table 8). Generally, the chloride, nitrate, sodium and sulphate content of the water sources is higher in the dry season than in the wet season. On the other hand, the copper, fluoride, magnesium and potassium content of the water sources is higher in the wet season than the dry season (Table 8). According to Petersen et al. (2015), there is seasonal variation in the mineral content of water sources in the Northern Great Plains in USA. According to these authors the sodium and TDS content of stock water was higher during the dry season. A study in Ethiopia shows that the heavy metals content of Awash River water varies between the dry and wet seasons (Eliku and Leta, 2018).

Table 8 - Seasonal variation in mineral content of the water sources in Ethiopia

Variable	N	Mean in dry season	Mean in wet season	N	Total mean
TDS	3	638.15	469.83	6	553.99
pH	4	7.68	7.19	8	7.43
Calcium	3	100.85	97.50	6	99.18
Chloride	3	27.89	9.57	6	18.73
Copper	4	0.56	0.78	8	0.67
Fluoride	3	0.004	0.006	6	0.005
Iron	4	1.10	1.0	8	1.05
Magnesium	3	6.57	9.21	6	7.89
Nitrate	3	13.27	4.96	6	9.11
Phosphate	3	0.006	0.004	6	.005
Potassium	3	0.91	0.97	6	0.94
Sodium	3	52.74	0.97	6	0.94
Sulphate	3	116.51	20.45	6	105.70

N= number of studies

CONCLUSION

The water sources in Ethiopia usually contain calcium, chloride, chromium, cobalt, fluoride, iron, lead, magnesium, nickel, potassium and sodium. There is variation in mineral content and other constituents of the different water sources in Ethiopia. The mineral content of the water sources also varies with season. The calcium, chromium, magnesium, zinc and total dissolved solids (TDS) content of the water sources in Ethiopia is within acceptable levels of these minerals and substances for livestock consumption. Some water sources in Ethiopia contain sodium, chloride, copper, fluoride, iron, lead and manganese beyond the maximum recommended level. This might affect livestock production and productivity unless safety measures are taken. Higher levels of minerals in drinking water may have adverse effects on livestock production. So, to make these water sources to have acceptable levels of these minerals, implementation of mechanisms (i.e. adsorption and chemical precipitation) that reduce the mineral content of these waters is recommended. Generally, as the current knowledge on the mineral content of the different water sources in Ethiopia for livestock consumption is inadequate further research is needed in this area in the country in the future to improve the mineral nutrition, productivity and health of livestock in the country.

DECLARATIONS

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Data availability

The datasets collected from research papers and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contribution

Both authors reviewed the paper and contributed in writing this review paper equally.

Competing interests

The authors declare that they have no competing of interests.

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PRINCIPAL BREEDING FACTORS INFLUENCING MILK YIELD AND REPRODUCTION IN RED CHITTAGONG CATTLE

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Supporting Information

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ABSTRACT: The study aimed to investigate the principal breeding factors influencing milk yield and reproduction in the Red Chittagong cattle (RCC). Retrospective records of a total of 20 dairy cows from the 1st to the 2nd parities were collected from the record sheet from January 2020 to June 2022. Results indicated that birth weight of the RCC was 7.5% higher (P=0.023) in parity 2 when compared with parity 1. Accordingly, total milk yield per lactation was 10.2% higher (P=0.004) in parity 2 in comparison with parity 1. Age at first service was 34.7% higher (P=0.001) in parity 2 compared with parity 1. Accordingly, age at first conception was 38.3% higher (P=0.001) in parity 2 compared with parity 1. The dry period was 22.8% higher (P=0.001) in parity 1 compared with parity 2. Age at first service was 18.3% higher (P=0.014) in natural service (NS) compared with artificial insemination (AI). Age at first conception was 16.5% higher (P=0.023) in NS compared with AI. Post-partum period was 11.9% higher (P=0.008) in AI compared with NS. Days open was 8.9% higher (P=0.018) in AI compared with NS. Calving interval was 2.9% higher (P=0.006) in AI compared with NS. An increased probability of infertility was associated with NS compared with AI. Birth weight of the calf and dry period of the dam were negatively correlated while live weight and post-partum period of the dam were positively correlated milk yield at the expense of reproductive health. A decreased probability of milk fever, mastitis, metritis and infertility was associated with increased milk yield. Principal component analysis revealed that days open, calving interval and service per conception were the principal eigenvectors determining performance of RCC. Overall, RCC performed better in the 2nd parity compared with the 1st parity.

Keywords: Birth weight, Lactation, Milk yield, Parity, Red Chittagong cattle.

INTRODUCTION

The Red Chittagong cattle (RCC) are known as one of the popular zebu type native cattle breeds in Bangladesh (Das et al., 2021). The RCC is a legacy breed which is distributed mostly in the south eastern parts of Bangladesh (Amin et al., 2013). The breed has some typical characteristics like smaller size with red coat color and distinct reddish muzzle, horn, hoof, ears, eyeball, eyebrow, vulva and tail switch (Bhuiyan, 2013). The breed is famous for dual-purpose both in dairy and beef production which plays an important role for poverty alleviation of the smallholder dairy farmers. The breed is popular among the rural communities because of short post-partum heat period, high conception rate with greater milk fat content (Bhuiyan, 2013), great calving rate (Khan et al., 2012) and moderate average daily milk production capacity of 2.0±0.65 kg in farm condition and 1.80±0.87 kg under rural farming systems (Koirala et al., 1970). They achieve early sexual maturity and calve regularly than the other non-descriptive indigenous breeds under farm condition. Further, they are more resistant to the parasites and common diseases prevalent in their own habitats than the other cattle (Chowdhury et al., 2017) exhibiting good survivability almost in all ages (Quaderi et al., 2014). RCC raising is more cost-effective than other local cattle breeds, according to a lifelong economic analysis of several dairy cow breeds done in Chittagong's rural districts (Khan et al., 2012). Given the aforementioned characteristics, the RCC may be considered a suitable cow genotype to help Bangladesh overcome the issues associated with large-scale animal production. Although few studies were conducted to evaluate the performance of RCC under extensive system of management in Bangladesh, consistent data pertinent to parity and breeding type-based performance indices under intensive system are scant. Therefore, the purpose of the present research was to look into the deeper impact of parity and breeding type on the production potentials and reproductive efficiency of the RCC while also examining the variables influencing individual and herd productivity in the context of the current intensive farming systems in Chittagong, Bangladesh.

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MATERIALS AND METHODS

A cross-sectional survey was conducted during January 2020 to April 2022 at the Government dairy and cattle development farm, Hathazari, Chattogram which is located at 22.5083°N 91.8083°E, total 20 milch cows of 2nd parity were selected from the farm for the study purpose. The farm occupies 20 acres of land, total 238 animals, milch cow 34, dry cow 80, heifer 43, male calf 29, female calf 21 and bull 31. The milch cow sheds are arranged in the face in and face out system with east-west direction. The sheds have concrete roof type and unpaved floor with plenty of natural light and ventilation. To collect the data needed to meet the study's goals, a structured questionnaire was created. Both close and open questions were addressed in the survey. The questionnaire comprised information on the kind of farm, breed, genotype, housing system, parity, feeding systems, milking systems, service per conception, age, weight, lactation time, average daily milk supply, age at puberty, age at first calf, postpartum duration, and dry period. The questionnaire was pretested before being finalized for pilot testing.

Data collection

All information was gathered directly from farm records, as well as through visiting the chosen farm in the research region and speaking with the officer and personnel during interviews. Direct interviews with the personnel and officers took place. During interview, the staff's verbal approval was obtained. 20 milch cows were purposefully chosen from a total of 238 cows originally chosen throughout the trial period.

Statistical analysis

Inter-quartile range test and variance inflation factors were used to examine outliers and multi-collinearity in the data set. By using the Shapiro Wilk test, the response variable's normality was determined. The general linear model (GLM) was used to examine the data. The dimensionality and strengths of the co-variates were examined using a heatmap comprising several orthogonal comparisons. Bartlett's test of sphericity and Kaiser-Meyer-Olkin criteria of sampling adequacy were used to determine if the data set was appropriate for principal component analysis. SAS 16.2 was used to fit all regression models, Ward's hierarchical cluster models, and response surface models (SAS Institute Inc.). The Duncan's New Multiple Range Test (DMRT) was employed to compare the means where statistical effects were judged significant (P<0.05). Stata 14.1 SE was used to conduct all statistical analyses (Stata Corp LP, College Station, Texas, USA). To calculate the influence of the predictors on the dependent variables, the following model was used (Adhikary et al., 2020; Barua et al., 2021):

$$Y_{ijkln} = \mu_0 + \alpha_{ij} + \beta_{ik} + \gamma_{il} + \ldots\ldots \omega_{in} + \varepsilon_{ijlkn}$$

Where,

- Y_{ijkln} = The observed effect of the trait 'i' at the 'jth' level of the predictor 'α', the 'kth' level of the predictor 'β', 'lth' level of the predictor 'γ'......and the 'nth' level of the predictor 'ω';
- μ_0 = The intercept of the regression model;
- α_{ij} = The slope of the regression model for the trait 'i' at 'jth' level of the predictor 'α' observed on Y_{ijkln};
- β_{ik} = The slope of the regression model for the trait 'i' at 'kth' level of the predictor 'β' observed on Y_{ijkln};
- γ_{il} = The slope of the regression model for the trait 'i' at 'lth' level of the predictor 'γ' observed on Y_{ijkln};
- ω_{in} = The slope of the regression model for the trait 'i' at 'nth' level of the predictor 'ω' observed on Y_{ijkln};
- ε_{ijkln} = The random sampling error of the trait 'i' at the 'jth' level of the predictor 'α', the 'kth' level of the predictor 'β', 'lth' of the predictor 'γ'......the 'nth' level of the predictor 'ω' which is distributed as $\varepsilon_i \sim NID(0,\sigma^2)$.

RESULTS

Productive performance

Mean birth weight of the RCC calf was 18.0 kg. Mean live weight 286.3 kg, body condition score 3.1, lactation length 260.8 day and milk yield per lactation was 267.5 kg irrespective of breeding type and parity under intensive system of management (Table 1). Distribution of milk yield was symmetric. Birth weight of the calf was negatively correlated with milk yield of the dam (Figure 1). Unlike birth weight, milk yield was positively related with the live weight of the dam. Milk yield gradually increased and reached the peak at 75-150 day which declined latter on (Figure 2). Herd level maximum milk yield (>350 litter/lactation) was recorded at 65-day dry period and 375-day calving interval (Figure 3). Days open, calving interval and service per conception were the principal eigenvectors determining variability of milk yield in RCC (Figures 4-5).

Reproductive performance

Mean age at puberty of the RCC was 18.1 month. Mean age at first service 23.5-month, age at first conception 24.7 months, service per conception 1.1, gestation period 282.1 day, dry period 61.4 day, post-partum period 59.2 day, days open 81.6 day and calving interval was 344.1 day irrespective of breeding type and parity under intensive system of management (Table 1). A decreased dry period and an increased post-partum period was correlated with increased milk yield (Figure 1). There was a strong relationship between age at first service, age at first conception, post-partum period, days open and calving interval (Figure 6). However, increased milk yield had negative effects on reproductive health. An increased probability of milk fever, mastitis, metritis and infertility was associated with decreased milk yield (Figure 7).

Effect of parity

Birth weight of the RCC calf was 7.5% higher (P=0.023) in parity 2 compared with parity1. Accordingly, total milk yield per lactation was 10.2% higher (P=0.004) in parity 2 compared with parity 1 (Table 1). However, parity had no influence (P>0.05) on live weight, body condition score and lactation length of the RCC. Age at first service of the RCC cow was 34.7% higher (P=0.001) in parity 2 compared with parity 1. Accordingly, age at first conception was 38.3% higher (P=0.001) in parity 2 compared with parity 1. In contrast, dry period was 22.8% higher (P=0.001) in parity 1 compared with parity 2. However, parity had no influence (P>0.05) on age at puberty, service per conception, gestation period, post-partum period, days open and calving interval of the RCC.

Effect of breeding type

Breeding type of the RCC had no influence (P>0.05) on birth weight of calf, live weight, body condition score, lactation length and milk yield per lactation (Table 2). Age at first service of the RCC cow was 18.3% higher (P=0.014) in natural service (NS) compared with artificial insemination (AI). Age at first conception was 16.5% higher (P=0.023) in NS compared with AI. Post- partum period was 11.9% higher (P=0.008) in AI compared with NS. Days open was 8.9% higher (P=0.018) in AI compared with NS. Calving interval was 2.9% higher (P=0.006) in AI compared with NS. However, breeding type had no influence (P>0.05) on service per conception, gestation period and dry period of the RCC. Overall, an increased probability of infertility was associated with NS compared with AI (Figure 8).

Table 1 - Effects of parity on performance characteristics of Red Chittagong cattle under intensive system of management (N=20)

Parameter / Parity type[1]	Parity 1			Parity 2			Overall mean	SEM	P-value
	Mean	Min	Max	Mean	Min	Max			
Birth weight of calf (kg)	17.3[b]	15.0	20.0	18.7[a]	16.0	22.0	18.0	0.3	0.023
Live weight (kg)	286.6	275.0	298.0	286.0	281.0	298.0	286.3	0.8	0.724
BCS (1-5 scale)	3.2	3.0	3.5	3.1	3.0	3.5	3.1	0.0	0.121
Lactation length (d)	266.6	209.0	287.0	255.0	180.0	275.0	260.8	3.6	0.113
Milk yield/lactation (l)	253.1[b]	208.5	307.5	281.8[a]	216.0	367.5	267.5	5.1	0.004
Age at puberty (m)	18.1	15.0	20.0	18.1	15.0	20.0	18.1	0.2	1.000
Age at first service (m)	18.6[b]	15.0	28.0	28.5[a]	9.0	31.0	23.5	1.0	<0.01
Age at first conception (m)	18.9[b]	15.0	30.5	30.5[a]	27.5	33.5	24.7	1.0	<0.01
Service per conception (n)	1.1	1.0	2.0	1.1	1.0	2.0	1.1	0.0	0.561
Gestation period (d)	282.1	275.0	290.0	282.1	279.0	290.0	282.1	0.5	0.961
Dry period (d)	69.3[a]	55.0	90.0	53.5[b]	40.0	70.0	61.4	2.0	<0.01
Post-partum period (d)	59.5	45.0	80.0	59.0	45.0	80.0	59.2	1.4	0.852
Days open (d)	82.2	66.0	102.0	81.1	66.0	107.0	81.6	1.6	0.752
Calving interval (d)	344.0	324.0	362.0	344.3	328.0	382.0	344.1	1.9	0.930

[1]Min = Minimum; Max = Maximum; SEM = Standard error of the means

Table 2 - Effects of breeding type on performance characteristics of Red Chittagong cattle under intensive system of management (N=20)

Parameter / Breeding type[1]	Artificial insemination			Natural service			Overall mean	SEM	P-value
	Mean	Min	Max	Mean	Min	Max			
Birth weight of calf (kg)	18.0	15.0	22.0	18.0	15.0	22.0	18.0	0.3	0.955
Live weight (kg)	286.8	275.0	298.0	285.6	281.0	292.0	286.3	0.8	0.458
BCS (1-5 scale)	3.1	3.0	3.5	3.1	3.0	3.5	3.1	0.0	0.214
Lactation length (d)	261.8	209.0	287.0	259.6	180.0	287.0	260.8	3.6	0.772
Milk yield/lactation (l)	265.8	208.5	367.5	269.4	216.0	323.5	267.5	5.1	0.730
Age at puberty (m)	18.0	15.0	20.0	18.1	16.0	20.0	18.1	0.2	0.981
Age at first service (m)	21.4[b]	9.0	30.5	26.2[a]	17.0	31.0	23.5	1.0	0.014
Age at first conception (m)	22.7[b]	15.0	32.0	27.2[a]	17.0	33.5	24.7	1.0	0.023
Service per conception (n)	1.0	1.0	2.0	1.1	1.0	2.0	1.1	0.0	0.446
Gestation period (d)	282.9	279.0	290.0	281.1	275.0	290.0	282.1	0.5	0.064
Dry period (d)	63.4	40.0	82.0	58.9	40.0	90.0	61.4	2.0	0.264
Post-partum period (d)	62.6[a]	45.0	80.0	55.1[b]	45.0	65.0	59.2	1.4	0.008
Days open (d)	85.0[a]	66.0	102.0	77.4[b]	66.0	107.0	81.6	1.6	0.018
Calving interval (d)	348.8[a]	328.0	382.0	338.4[b]	324.0	369.0	344.1	1.9	0.006

[1]Min = Minimum; Max = Maximum; SEM = Standard error of the means

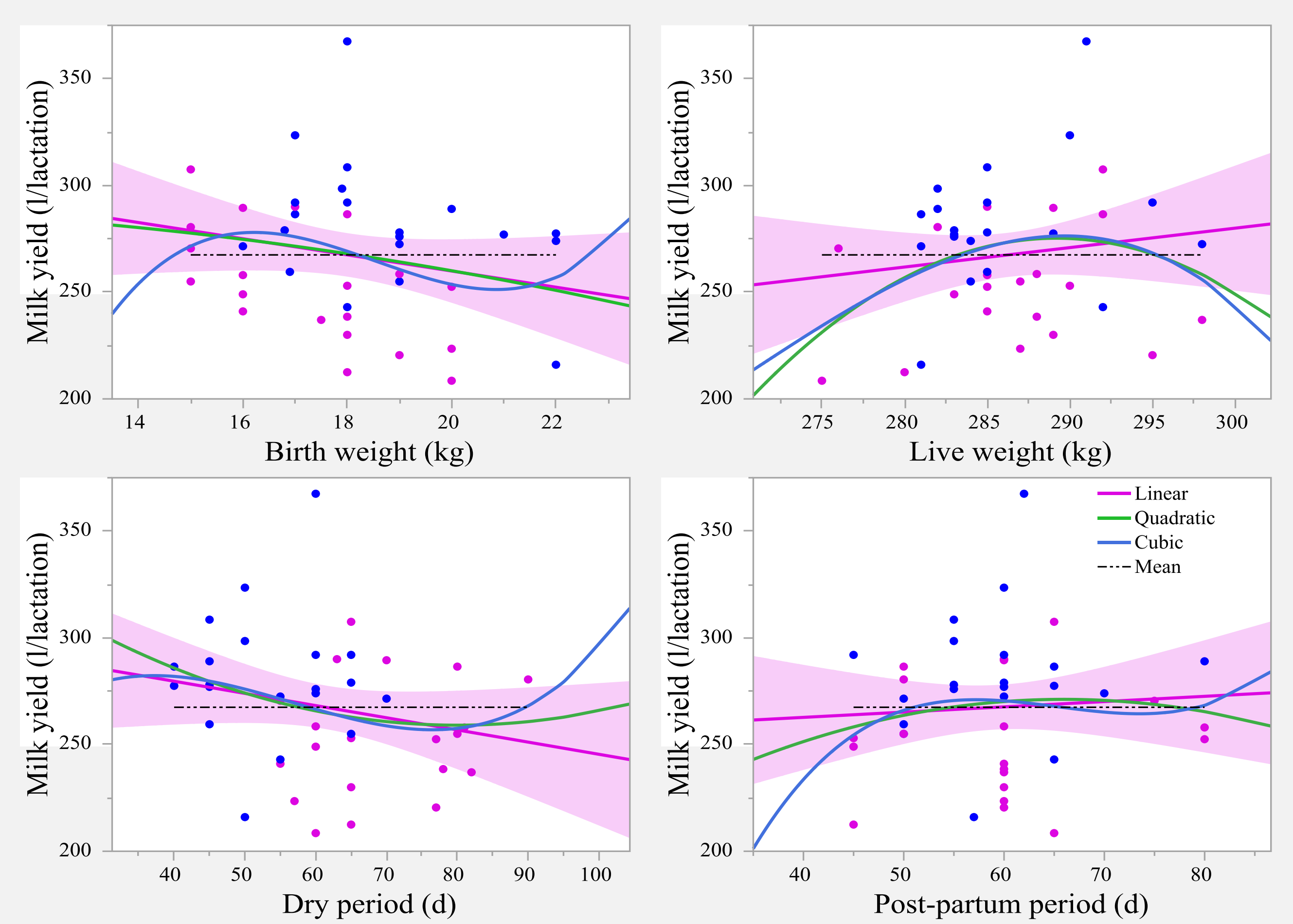

Figure 1 - Effects of birth weight (top left), live weight (top right), dry period (bottom left) and post-partum (bottom right) on milk yield in Red Chittagong cattle (N=20)

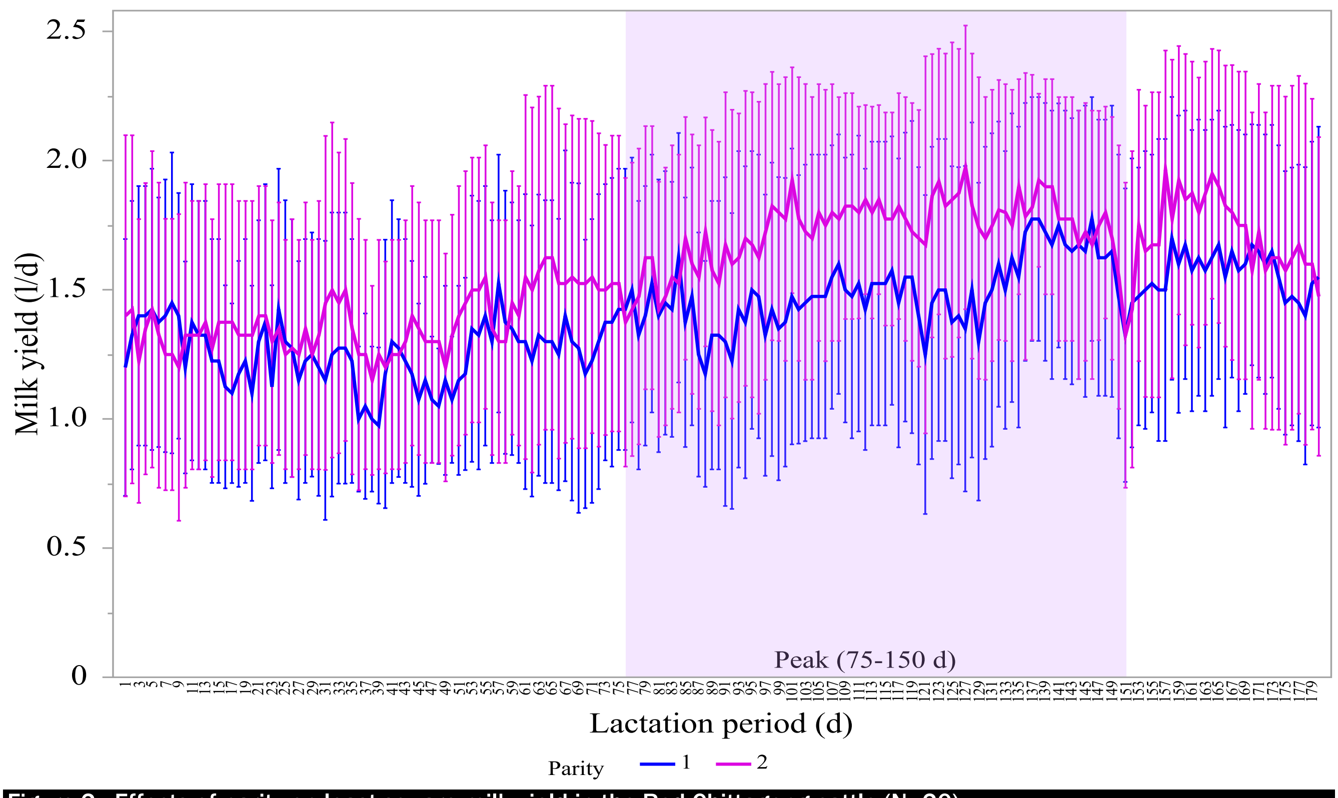

Figure 2 - Effects of parity on least square milk yield in the Red Chittagong cattle (N=20)

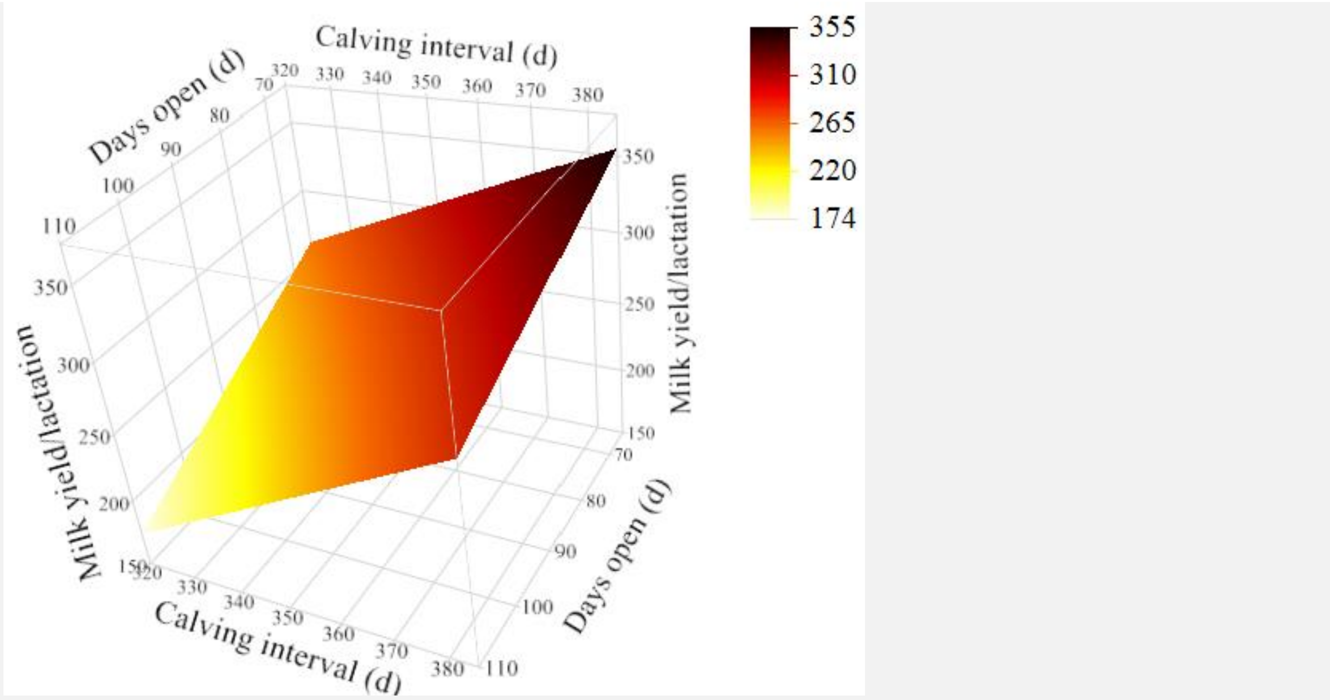

Figure 3 - A response surface model to predict the influence of days open (day) and calving interval on milk yield in Red Chittagong cattle (N=20)

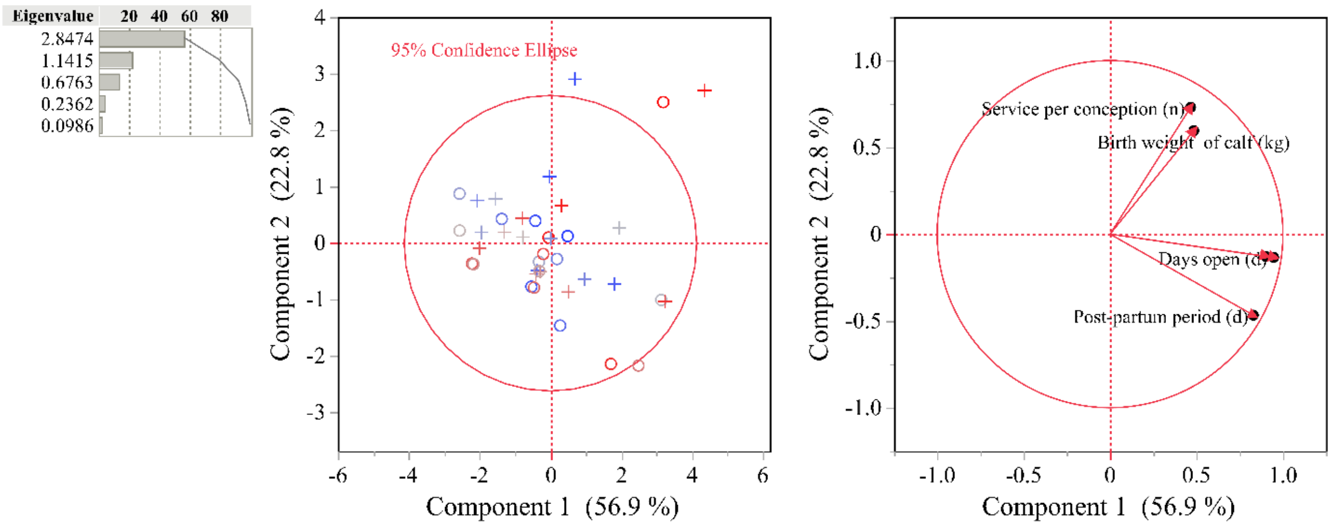

Figure 4 - Extrapolation of the principal component 1 (56.9%; plotted on 'x' axis) and component 2 (22.8%; plotted on 'y' axis) influencing milk yield (litter/lactation) in Red Chittagong cattle (N=20)

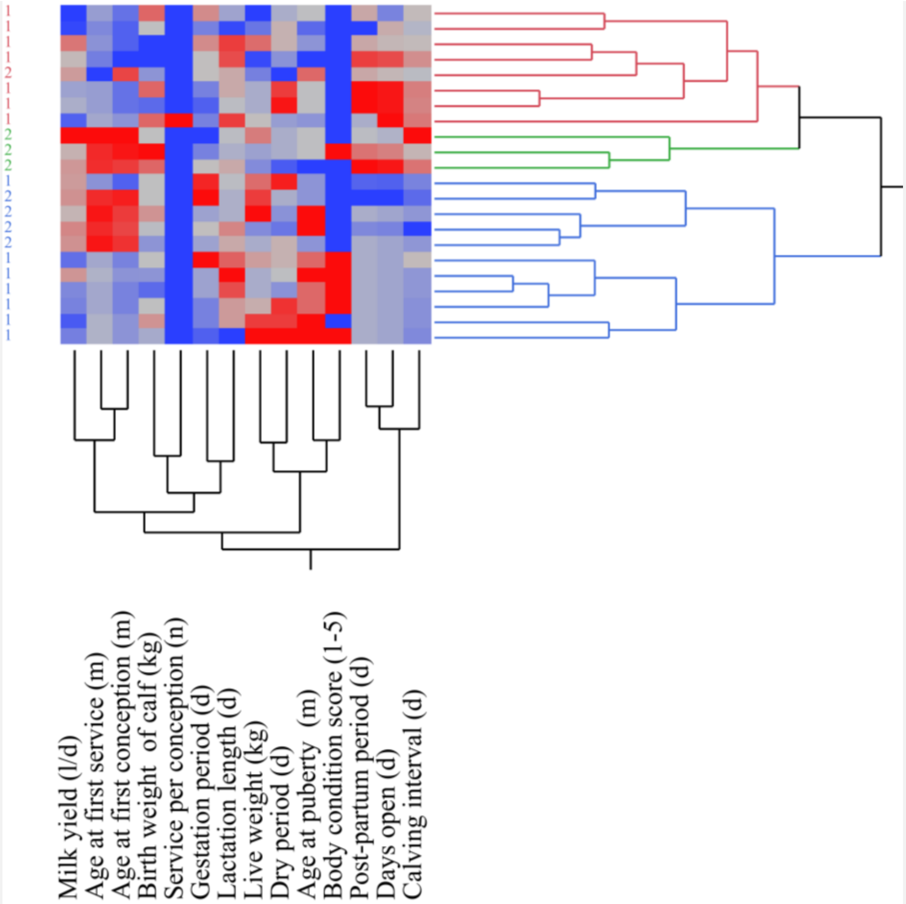

Figure 5 - Hierarchical cluster of the three principal clades (production, breeding and reproduction) of the overall performance parameter of Red Chittagong cattle considering parity as the base level (N=20).

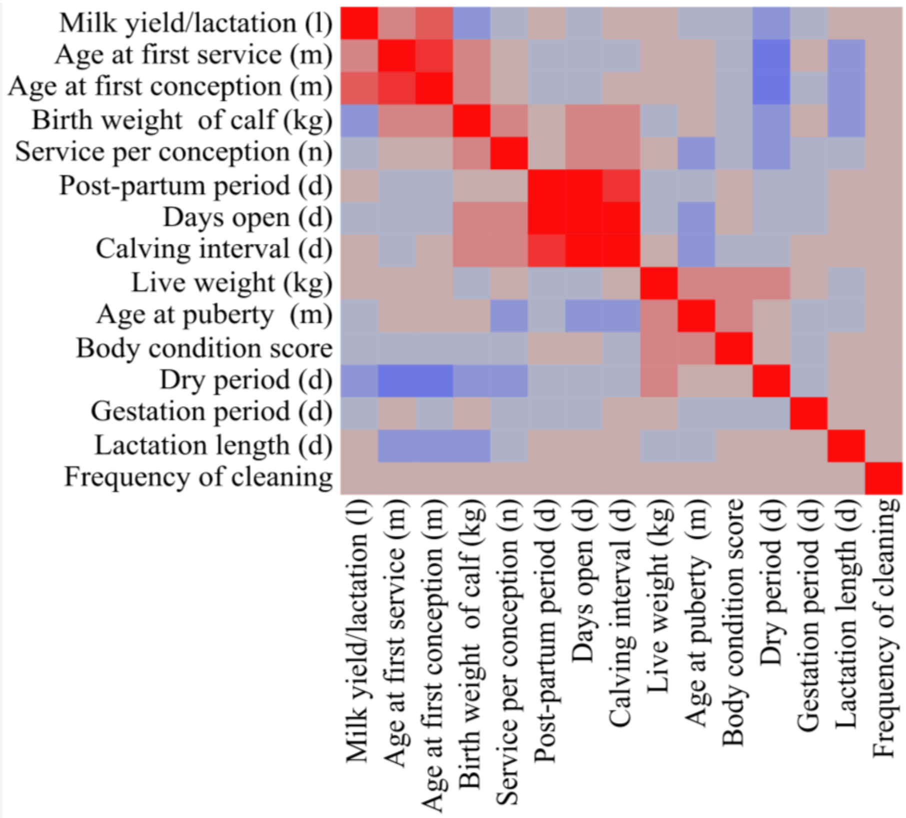

Figure 6 - Heatmap showing orthogonal contrasts of the principal factors influencing milk yield in Red Chittagong cattle (N=20)

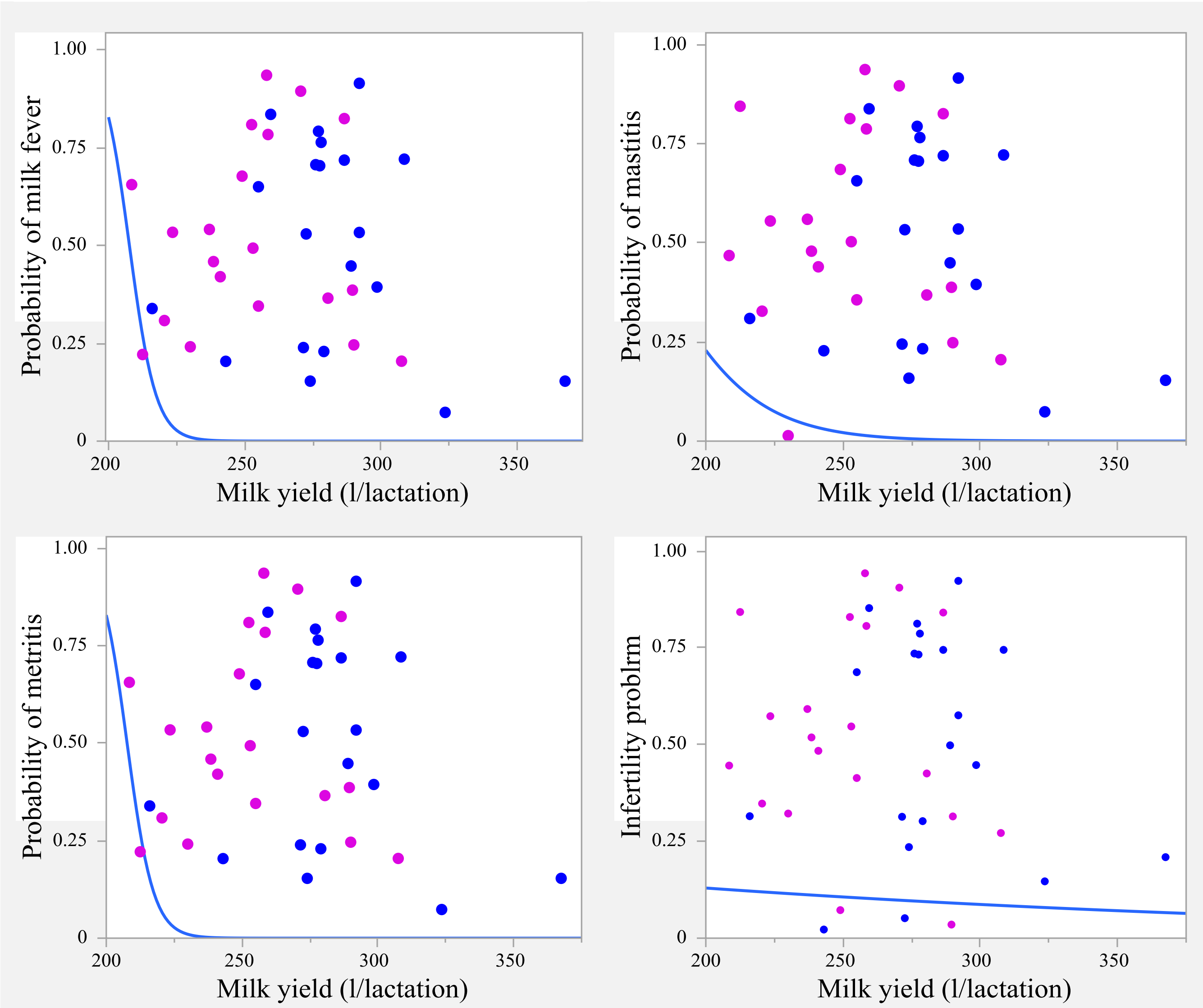

Figure 7 - Bivariate logistic regression showing effects of milk yield on probability of milk fever (top left), mastitis (top right), metritis (bottom left) and infertility (bottom right) in Red Chittagong cattle (N=20)

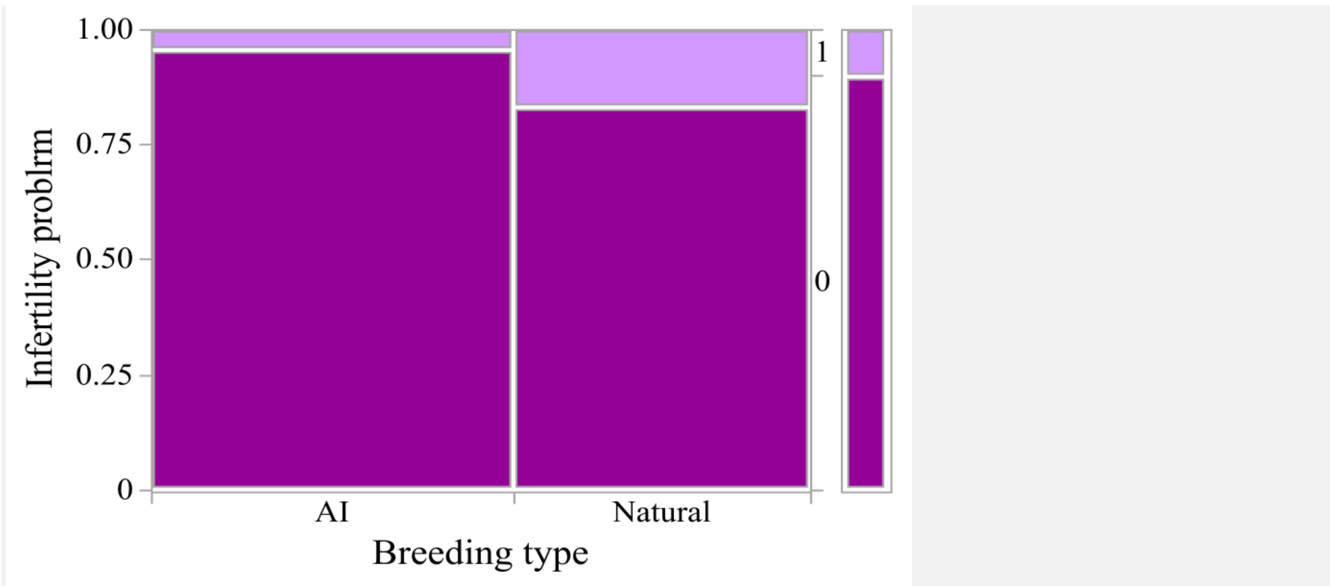

Figure 8 - Mosaic plot showing effects of breeding type on infertility problem in Red Chittagong cattle (N=20)

DISCUSSION

Productive performance

The increased birth weight of the RCC calf was observed in parity 2 compared with parity 1 (Table 1). Similar result was reported in a previous study where cows at parity 4 delivered calves that recorded higher birth weight (39.0 kg) compared with parity 2 (29.2 kg), although, these observed differences were not statistically significant (P>0.05). Calf birth weight usually tends to elevate with increased parity because of less competitive demand for nutrients, reduced mobilization rate and increased live weight of the dam with increased parity number (Hoka et al., 2019; Duncan et al., 2023). Similar to birth weight, the parity affected live weight of the dam in our study. Consistent result was reported in a previous study where increased parity resulted increased live weight because of high nutrient intake (Musa et al., 2012). In a previous study, the BCS was the highest at early lactation and lowest between d 40 and 70 after calving (4.1) which increased gradually at the end of the gestation period (Lassen et al., 2003). In tropical cattle, lactation length gradually increases from 1st to the 2nd parity and milk yield also increases simultaneously (Musa et al., 2012). There was no difference between lactation lengths of the 1st parity from the 2nd parity in our study although milk yield was significantly higher in 2nd parity compared with 1st parity (Table 1). In a previous study (Musa et al., 2012), average daily milk yield increased gradually from the 1st parity at 4.4 kg/day up to 5.8 kg/day in the 3rd parity which reached the peak, persisted for a while and finally decreased for tropical cattle which supports our study.

Reproductive performance

In a previous study, Karim et al. (2019) reported that the age at puberty of the RCC was 37.0±2.2 month which was higher than the present study. It was also reported that the temperate breeds came into maturity at an earlier age than the breeds of the tropical environment (Nath et al., 2016). Novakovic et al. (2011) reported that in case of Holstein-Friesian (HF) cow, the average age at first conception was 491.2±9.4 day or 16.2±0.3 month which was lower than the present study but there was no comparison between the 1st and the 2nd parities. Desselegn et al. (2016) reported that the average age at 1st service was 18.7±3.7 and 18.7±3.5 month for the cross-breed cattle which support the findings of the present study. In another study, cows in parity 2 had significantly higher (P<0.01) conception rate than the cows in parity 1 (72.8% vs. 44.8%) (Yusuf et al., 2017). Das et al. (2022) reported that the gestation length of the RCC was 283.0±3.0 day which was similar to our study but there was no more information regarding the comparison between the 1st and the 2nd parity although in our study there was no significant difference between the two subsequent parities (Table 1).

Habib et al. (2010) reported that the dry period in the 1st and 2nd parity was significantly different (P>0.05) which is consistent with the present study where 1st parity dry period was higher than the 2nd parity. Habib et al. (2010) further reported that post-partum estrous was higher in the 1st parity compared with the 2nd parity which supports our study. Average length of days open did not differ between parity 1 and parity 2 in a previous study (Yusuf et al., 2017) which is closely consistent with our study. The calving interval of the cows in parity 2 and parity 3 were 508.2±121.5 day and 495.5±144.1 day, respectively in a previous study which indicated no significant difference (P=0.39) between the two groups (Yusuf et al., 2017). Closely similar result was reported in the present study (Table 1).

Effect of parity

Milk yield was related to the order of parity of the cows in a series of previous studies (Marumo et al., 2022; Bafandeh et al., 2023). The lowest milk yield was found in the first parity which increased linearly with advancement of lactation until the 4th parity in case of HF cow (Kul, 2021) which support similar trends that we observed in the present study where milk yield was increasing in the 2nd parity compared with the 1st parity. Consistent results were reported elsewhere by Cinar et al. (2015) and Kul et al. (2019) who observed that milk yield was expressively affected by the advancement of parity. The present study further confirmed the findings of Cobanoglu et al. (2019) who identified that milk yield was considerably high (P<0.01) in the 2nd parity compared with the 1st parity. In the same way, Mostert et al., (2001) described that the cows calving in 1st and 2nd lactations had less milk production than those at further mature ages. The variations observed among these studies could be due to different management systems, feeding regime and other environmental factors (Habib et al., 2010) although milk yield was consistently higher in 75-150 day both in 1st and 2nd parities for all the RCC population. Similarly, Habib et al. (2010) noticed significant (P<0.05) difference in the daily milk yield among different parities.

Effect of breeding type

We assumed that the artificial insemination (AI) calf weight will be higher than the natural service (NS) calf which supports the present study. Valergakis et al. (2007) reported that the daughters of proven AI sires were producing 896 kg more milk per cow per year than the daughter of NS bull. In the same way, the HF herds bred primarily by AI had the greatest percentage of cows in milk than the herds bred primarily by the NS bull. More cows conceived earlier in the breeding season by the AI than the natural services in case of HF cow (De Vries, 2005) which supports the present study. The overall pregnancy loss considering the gestation period from day 28 to 56 in the NS group and 32 day for AI was lower (P=0.02) for NS than the AI-bred cows (10.4% vs. 15.2%; P<0.05), respectively. Smith et al. (2004) observed that HF herds bred primarily by AI had significantly fewer days dry period compared with the other groups which does not support the present research. It may be due to breed-to-breed variation. The post-partum period of HF was greater for NS than the AI (NS=84.8% and AI=76.4%, P=0.009). The median time to pregnancy by 223 day postpartum was shorter for NS bred cows (111 day [95% CI=104 to 125) than the AI bred cows (116 day [95% CI=115 to 117]) (Risco et al., 2009) which does not support present study perhaps because of variations due to breed.

CONCLUSION

Milk yield of RCC is positively correlated with live weight and post-partum period. Decreased probability of milk fever, mastitis, metritis and infertility increases milk yield in RCC. Collectively, days open, calving interval and service per conception are the principal determinants of the performance of RCC. Overall, RCC performs better in the 2nd parity compared with the 1st parity.

DECLARATIONS

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Ethics and consent to participate

The entire experimental protocol was followed by the animal welfare law in Bangladesh.

Authors' contributions

M Tabassum performed development of the questionnaire, baseline survey, data collection, literature research, and first draft. Md. R Prank, SK Paul, N Akter, S Islam and S Islam conceptualized the study and developed the questionnaire. Project management, data curation, generalized linear modelling, principal component analysis, hierarchical clustering, response surface modelling, result interpretation, and draft finalization were handled by Md. E Hossain. The final manuscript was reviewed and approved by all the researchers.

Availability of data and materials

The data may be available on request under reasonable ground.

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Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests in this research and publication.

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