# International Journal of Livestock Production

Volume 8 Number 7 July 2017
ISSN 2141-2448

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**International Journal of Livestock Production (IJLP)** (ISSN 2141-2448) is monthly (one volume per year) by Academic Journals.

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International Journal of Livestock Production

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academicJournals

Vol. 8(7), pp. 95-112, July 2017
DOI: 10.5897/IJLP2017.0362
Article Number:: 39B4C8B64993
ISSN 2141-2448

http://www.academicjournals.org/IJLP

**International Journal of Livestock Production**

*Full Length Research Paper*

# Management and phenotypic features of indigenous cattle in Rwanda

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Received 11 January, 2017; Accepted 2 May, 2017

**Breed improvement and conservation are optimally achieved when the available genetic resources are characterised and strategies developed to achieve the goals. This study aimed at investigating the management practices, performance and morphological features of the indigenous cattle ecotypes in Rwanda on 250 cattle farming households. A total of 20 measurements taken on 305 female and 45 male cattle were: body length (BL), height at withers (HW), leg height (LH), heart girth (HG), body weight (BW), tail length (TL), dewlap length (DL), dewlap width (DW), rump width (RW), ear length (EL), muzzle circumference (MC), horn length (HL), distance between horns (HS), hump length (HuL), hump width (HuW), navel depth (ND), udder length (UL), udder depth (UD), teat length (TL), and body condition score (BCS). Morphometric data was analysed by ecotype for each sex and age category since there were non-significant differences in geographical location. Results show that Rwanda has five types of indigenous cattle namely: Inyambo, Inkuku, Inkoromaijo, Inkungu and Bashi. The livestock system mostly used was extensive and household income was mainly from livestock. For Inyambo cattle, the popular ecotype, age at sexual maturity was 27.44±1.04 months for males and 28.76±1.02 months for female cows. Age at first calving was 33.8±0.83 months whereas calving interval was 13.60±0.45 months. Lactation length was found to be 6.84±0.29 months. The mean daily milk was 3.58±0.19 litres and the pre weaning calf survivability was 90±6.5%. Positive and high correlations were observed between BW, HG, HW, HuL, BL and HL. Indigenous cattle population of Rwanda are not homogenous by their morphological features and other productive traits, and therefore conservation will have to target the different ecotypes and this should be done with direct engagement of their keepers.**

**Key words:** Ankole, indigenous cattle, Inyambo, phenotypes, reproductive performance.

## INTRODUCTION

The contribution of livestock to livelihoods of human Communities all over the world has been acclaimed (Hoffmann, 2010; Mwai et al., 2015). Indigenous cattle in particular form the backbone of relevant and sustainable

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livestock production in most rangeland of the world, and in Eastern Africa they have been associated with gods and deities. Fittingly, when compared with their exotic counterparts, they are better adapted to survive and tolerate harsh environments. Based on this peculiarity of indigenous cattle, the ministry of agriculture in Rwanda initiated a program to conserve and ensure equitable utilization of indigenous animal genetic resources. The current global genetic diversity should be maintained being that millions of people directly depend on them for their livelihood (Rege and Gibson, 2003; Mekuriaw and Kebede, 2015; Muchenje et al., 2016). In Rwanda, cattle contribute significantly to livelihoods through provision to farm families with milk, meat, manure and cash income. They also play a significant role in the social and cultural values of the communities that rear them. Cattle produce a total of 703,436 metric tonnes (MT) of milk and 81,000 MT of meat annually in that country (NISR, 2015).

Indigenous cattle in the family of *Bos indicus* derived breeds present enhanced hardiness and disease resistance, low nutritional requirements and higher capability of feed utilization. However, their main products remain meat, milk, hides, and manure. In Rwanda, indigenous cattle are divided into five groups, namely: Inyambo, Inkuku, Bashi, Inkungu and Inkoromoijo. These have unique evolutionary adaptation to harsh climates (Hansen, 2004; Shabtay, 2015; Dossa and Vanvanhossou, 2016) and various endemic diseases (Murray et al., 1984; Mattioli et al., 2000). One of these adaptations is their documented tolerance to trypanosomosis (Roberts and Gray, 1973); a parasitic disease due to infection with *Trypanosoma* sp. whose vector is the tsetse flies. Another is the ability of these cattle to use poor-quality forage and limited quantities of feed. Zebu cattle (*Bos indicus*), are the majority of cattle types in Africa. They are adapted to dry environmental conditions and high temperatures and are known to be more resistant to tick infestation compared to *Bos Taurus* cattle (Mattioli et al., 2000; MRI, 2012). African zebu cattle inhabit western and eastern parts of Africa. Their large body size and high production levels in tsetse-free areas have made them more appealing to producers. The southern Africa region is largely made of cattle that are taurine, Sanga and their crosses (Hanotte et al., 2000).

Although, indigenous cattle genetic diversity remains large, cattle populations or breeds continue to face extinction. Unfortunately, this extinction is not restricted to cattle or livestock, but to other forms of biodiversity to the extent that globally, at least three species are lost per hour to inter alia urbanisation, deforestation and climate change (Byron-Cox, 2016). According to Rege and Tawah (1999) and Mekuriaw and Kebede (2015), 22% of African cattle breeds became extinct in the last century and 32% of the indigenous African cattle breeds are currently in danger of extinction (Guaza and Mamah, 2016). Particularly, the Rwandan indigenous cattle genetic resources are in danger of disappearing more rapidly than predicted, following uncontrolled crossbreeding and breed replacements with exotic breeds, especially of dairy function. This is exacerbated by the general lack of selection-based breed improvement programs while paradoxically; the demand for livestock products is continually increasing. Climate change is putting new pressures on livestock production, while the livestock contribute to the shift, through greenhouse emissions (Houghton and Callander, 1992; Nardone et al., 2010). Moreover, indigenous livestock although adapted to the local environments, are poor milk and meat producers compared to the commercial breeds raised in the extensive system (Renaudeau et al., 2012; Tsegaye et al., 2014; Dossa and Vanvanhossou, 2016).

More than ever, indigenous livestock genetic resources which constitute the largest proportion of livestock in those countries are increasingly being eroded through poorly planned crossbreeding and breed replacements and this ought to be arrested. Characterization of the indigenous cattle in Rwanda has generally been lacking, with just a few isolated studies having been documented hither to this study. One such study reported that there was molecular homogeneity among the different cattle populations in Rwanda (Ndumu et al., 2008) and this could be attributed to similarity in selection criteria identified earlier (Wurzinger et al., 2006). The gain for the country in conducting such studies is widespread public awareness of the resource that must not be lost. Rwandan farmers will gain by promoting good breeding practices for their indigenous animals, which can in the process promote agro-tourism. There is much more potential that can be exploited from these breeds but this can only happen if the animals are not lost. Through this study, we aimed to determine the phenotypic and morphometric characteristics of indigenous cattle breeds in Rwanda and decipher their distribution. Secondly, it was to assess their productive and reproductive performance under the current systems of production and management in order to enable cattle breeders and policy makers to make appropriate decision for their future utilization.

## MATERIALS AND METHODS

### Study area and sampling procedure

The study used a descriptive, purposive and stratified survey design and was carried out in indigenous cattle keeping households of Rwanda from all the four provinces in such a way to capture the different zones of the country (Table 1. The Northern Province is highland, the eastern province is lowland, the southern province is midland while the western province is partly highland and partly lowland. Each province is made up of seven to ten districts. In each province, three districts were randomly selected and from each, three villages were selected from at least two sectors. The indigenous cattle characterized were located in highland (12%), midlands (44%) and lowland (44%). A ANGR-CIM tool was administered to indigenous cattle breeders to gather information on the indigenous cattle they rear.

**Table 1.** Study sub-locations, altitude zones and management systems.

| Factor | Level (n = 250) | Proportion (%) |
|---|---|---|
| Sub-location | Provinces | 100 |
| | Districts | 26.7 |
| | Villages | 4 |
| Altitude zones | Highland | 12 |
| | Midland | 44 |
| | Lowland | 44 |
| Cattle management system | Extensive | 60 |
| | Semi-Intensive | 12 |
| | Intensive | 28 |

**Table 2.** Number of cattle by age category, sex and breed used in the characterisation study.

| Breed | Sex | Calves | Heifers/Bullocks | Adults | Sub-total | Total |
|---|---|---|---|---|---|---|
| Inkungu | Female | 5 | 15 | 15 | 35 | **40** |
| | Male | 5 | 0 | 0 | 5 | |
| Bashi | Female | 5 | 15 | 15 | 35 | **40** |
| | Male | 5 | 0 | 0 | 5 | |
| Inkuku | Female | 10 | 20 | 80 | 110 | **120** |
| | Male | 5 | 5 | 0 | 10 | |
| Inyambo | Female | 10 | 20 | 45 | 75 | **90** |
| | Male | 10 | 0 | 5 | 15 | |
| Inkoromoijo | Female | 5 | 15 | 30 | 50 | **60** |
| | Male | 5 | 5 | 0 | 10 | |
| **Total** | | **65** | **95** | **190** | | **350** |

### Survey instrument, animals and tools

A questionnaire was administered to the 250 households in the Eastern province (n = 80), Northern province (n = 60), Western province (n = 50), and Southern province (n = 60), to generate data on household size and source of income; indigenous cattle breed reared, livestock species reared, division of labour activities in indigenous cattle management; availability, type and nature of grazing land; indigenous cattle herd dynamics at household level, reproductive parameters of cows and bulls. Milk production data was provided by farmers who relied on their memorised records. Cattle of varying age groups, namely: calves, steers, heifers, cows and bulls of known genetic composition and belonging to one of the known indigenous types of Rwanda were then randomly selected from each surveyed household. The number of animals selected from each household depended on the herd size in the household, with a total of 350 animals from different age groups, sexes and breeds (Table 2). Live body weight and 20 body measurements were then taken on the selected animals. The studied animals were mature active breeders. Maturity was ascertained from possession of either three or four pairs of permanent teeth. Additionally, parity was also used for estimating the age of the cows while the number of years the bulls had been in use for breeding was also used for estimating age of bulls. Body morphometric measurements were done with the cattle placed in a confinement crush but while ensuring the animals were free standing as much as possible, to ensure accuracy of measurement.

A descriptor list of phenotypic characteristics to assist with the qualitative description of the animals, a colour chart to describe the coat colour of the animals, and calibrated tapes, a 50-cm spirit level (inclinometer), a pair of 50-cm callipers (outside diameter) and a measuring stick (hippometer) to measure the quantitative physical characteristics such as heart girth (HG) and body length (BL) were also used. The set of measurements taken for the traits considered in this study were as described by Brown et al. (1983), Adeyinka and Mohammed (2006), Kugonza et al. (2011a) and AU-IBAR (2015).

### Data analysis

The filled questionnaires were then coded and entered into the SPSS (ver. 16) computer software. Data analysis was thereafter

**Table 3.** Household membership, cattle herd and small stock flock structure.

| Parameter | Level | Mean (s.e) | Min | Max | Household size (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0 | 1 | 2 | >2 |
| Male children | | 2.48 (0.22) | 1 | 5 | 0.0 | 21.7 | 26.1 | 52.2 |
| Female children | | 2.04 (0.23) | 0 | 4 | 8.7 | 21.7 | 39.1 | 30.4 |
| Male adults | | 1.32 (0.13) | 0 | 3 | 8.0 | 56.0 | 32.0 | 4.0 |
| Female adults | | 1.40 (0.11) | 1 | 3 | 0.0 | 64.0 | 32.0 | 4.0 |
| Local cattle | Inyambo | 15.2 (4.34) | 0 | 75 | | | | |
| | Inkuku | 20.33 (11.4) | 0 | 235 | | | | |
| | Inkoromoijo | 3.09 (1.51) | 0 | 24 | | | | |
| | Bashi | 0.48 (0.14) | 0 | 2 | | | | |
| | Inkungu | 0.32(0.12) | 0 | 1 | | | | |
| | Total | 65.68 (22.05) | 2 | 400 | | | | |
| Crossbred cattle | | 3.29 (3.16) | 0 | 76 | | | | |
| Goats | Inyarwanda | 6.25 (6.25) | 0 | 150 | | | | |
| | Crossbred | 5.04 (4.99) | 0 | 120 | | | | |
| | Total | 56.0 (39.19) | 0 | 800 | | | | |
| Sheep | | 0.0 | 0 | 0 | | | | |
| Local chickens | | 8.0 (5.53) | 0 | 100 | | | | |
| Camels | | 0.32 (0.32) | 0 | 8 | | | | |

performed using Statistical Analysis Systems, Ver. 9.2 (SAS, 2004) least square means and cross tabulation procedures. Reproductive parameters were assessed using general linear models, with breed and location as fixed effects. The general linear model used was:

$y_{ij} = \mu + b_i + e_{ij} \sim N(0, \sigma^2)$

Where y is the observation in breed i. μ is the overall mean, $b_i$ the effect of breed (i = 5), $e_{ij}$ the random effect on the trait, independently and identically distributed with mean = 0 and variance = $\sigma^2$.

A total of 350 indigenous cattle were used for the characterization study across the country. Data was entered into SPSS software data capture system and cleaned of errors. Data analysis was then performed using Statistical Analysis Systems (SAS, version 9.2) software. The statistical model used for analysis was:

$y = \mu + f_i + s_j + a_k + f_i{*}s_j + e_{ijkl}$

Where, y is observation of the trait in farm type *i*, in altitude zone *j*, and for animal age *k*. μ = overall mean, $f_i$ = effect of farm type (*i* = 2), $s_j$ = agro-ecological system (*j* = 3), $a_k$ is the effect of age (*l* = 4), $f_j(s_j)$ is the effect of interaction of farm type and agro-ecological system, $e_{ijkl}$ is the random effect on the trait, independently and identically distributed with mean = 0 and variance = $\sigma^2$.

Mixed models maximum likelihood procedure was also used to analyse the linear body measurements as described by Kugonza et al. (2011a). The 20 measurements taken on each animal are: Body Length (BL), Height at Withers (HW), Leg Height (LH), Heart Girth (HG), Body Weight (BW), Tail Length (TL), Dewlap Length (DL), Dewlap Width (DW), Rump Width (RW), Ear Length (EL), Muzzle Circumference (MC), Horn Length (HL), Distance between horns (HS), Hump Length (HuL), Hump Width (HuW), Navel Depth (ND), Udder Length (UL), Udder Depth (UD), Teat Length (TL), and Body Condition Score (BCS).

Correlation coefficients between HG, HW, HuL, BL, HL, DW, LH, HuW, DL, MC, EL, BCS, HD, UL, RW, TeL, TaL, UD, ND and BW were computed on a within-sex basis to determine linear associations between them. Effort was made to ensure that the physiological status of cows sampled for the linear measurement analysis was similar so that the animals were evaluated as a homogenous group. Linear regression of HW on HG, HW on BL and HG on BW were conducted within each sex category of indigenous cattle.

## RESULTS AND DISCUSSION

### Characteristics of indigenous cattle keepers' households and their herds

The majority of indigenous cattle rearing households were male-headed and only 16% were female-headed. The average number of cattle per household were 15.2±4.34 of Inyambo breed, 20.33±11.4 Inkuku, 3.09±1.51 Inkoromoijo, 0.48±0.14 Bashi and 0.32±0.12 Inkungu (Table 3). Household income was mainly earned from livestock (84%), crop (52%), business (28%) and salary (8%). Other than indigenous cattle, the households were also rearing chickens (12.5%), goats (8.4%), camels (4.2%) but not sheep (0.0%). There were six cattle management activities that the family members were involved in either singly or in various combinations. Sale of cattle was mostly performed by heads of households, followed by animal care particularly grazing, watering, and supplementary feeding from fodder banks

**Table 4.** Major farming activities, household income sources and species of livestock reared.

| Factor | Level | Households (%) |
|---|---|---|
| Major farming activity | Livestock farming | 44.0 |
| | Livestock followed by crops | 24.0 |
| | Crops followed by livestock | 12.0 |
| | Livestock and crops are equal | 20.0 |
| Combinations of income sources | Livestock only | 24.0 |
| | Livestock followed by crops | 16.0 |
| | Crops followed by livestock | 24.0 |
| | Salary | 4.0 |
| | Business | 12.0 |
| | Livestock, crops, salary | 4.0 |
| | Livestock and business | 8.0 |
| | Livestock, crops and business | 8.0 |
| Major Income source* | Livestock | 84.0 |
| | Crops | 52.0 |
| | Salary | 8.0 |
| | Business | 28.0 |
| Species of livestock reared | Cattle | 100.0 |
| | Goats | 8.4 |
| | Chickens | 12.5 |
| | Camels | 4.2 |
| | Sheep | 0.0 |

*The responses on major income sources were non-exclusive.

(Table 4).

In effect, no family member solely implemented any one activity in isolation from other family members. The major farming activities are depicted in Table 4. Though all the farmers kept livestock, only 84% acknowledged livestock as the main source of income. Cattle farmers need to engage in other investments so as to earn enough to sustain their families. It is prudent that the farmers make a choice between purely indigenous cattle crossbreeds, or various levels of upgrades. This will enable them to be able to fit into specific production zones and systems (Mwacharo and Drucker, 2005; Kugonza et al., 2012b). Very few farmers were engaged in only one enterprise at the time of the study, with majority engaging in two or more enterprises. This lack of specialisation may be detrimental to targeting maximum productivity but continues to be a normal feature among smallholders who are more interested in sustainability of livelihoods mainly through diversification of animal and crop enterprises.

## Grazing management and herd dynamics

The average land area for grazing of cattle for most farmers was five hectares or less (Table 5). This is land that is usually ideal for two high grade dairy cows (Mugasi et al., 1999). The major implication of this statistic is that farmers who have little land have to change priorities in terms of breed of choice and or even change the type of genotype they rear, and this change has to be immediate or in the near future. As showed by the type of grazing system, almost all the farmers keep their cattle under confinement, yet many of them still have access to open grasslands. The land use patterns will keep evolving as the land sizes also continuously change.

Majority of the farmers (68%) reported that they purchased the cows they own, and only 28% reported that they inherited and 4% acquired the cows as gifts (Table 5). This differs from findings in Uganda for the Ankole breed (Nabasirye et al., 2012) and for other breeds in Kenya (Rege et al., 2001). Whereas purchase is always associated with commercial-oriented non-traditional pastoralists, it was surprising in this study that inheritance and gifts that are strongly associated with traditional pastoralist communities make such a low contribution in Rwanda. The major shift could be attributed to the heavily commercialised livestock farming in Rwanda such that the socio-cultural practices of freely

**Table 5.** Grazing management and herd dynamics for Inyambo cattle in previous year.

| Factor | Level | HH$^{\phi}$ (%) | Mean (s.e) | Min | Max |
|---|---|---|---|---|---|
| Grazing land area (ha) | <5 | 46.7 | | | |
| | 5–9 | 13.3 | | | |
| | 10–49 | 13.3 | | | |
| | >100 | 26.7 | | | |
| Cropping land area (ha) | <5 | 50.0 | | | |
| | 5–9 | 21.4 | | | |
| | 10–49 | 7.2 | | | |
| | >100 | 21.4 | | | |
| Use of Communal grazing | Yes | 19 | | | |
| | No | 81 | | | |
| Type of grazing land | Open grassland | 73.3 | | | |
| | Tree covered grassland | 20.0 | | | |
| | Bush/Shrub grassland | 6.7 | | | |
| Nature of grazing land | Cleared | 13.3 | | | |
| | Reseeded | 100.0 | | | |
| | Fenced | 6.7 | | | |
| Mode of acquiring cows | Purchased | 68.0 | | | |
| | Inheritance | 28.0 | | | |
| | Gifts | 4.0 | | | |
| Ancestors who reared indigenous cattle | Father | 8.7 | | | |
| | Mother | 8.7 | | | |
| | Grandfather | 21.7 | | | |
| | Grandmother | 17.4 | | | |
| | Great Grandparents | 34.8 | | | |
| | All ancestors | 8.6 | | | |
| Age at owning first indigenous cattle (years) | 10-15 | 62.5 | | | |
| | 16-20 | 25.0 | | | |
| | >20 | 12.5 | | | |
| Entries into herd | Born (male) | | 5.96 (1.73) | 0 | 30 |
| | Born (female) | | 7.76 (2.36) | 0 | 50 |
| | Bought (male) | | 0.32 (0.13) | 0 | 3 |
| | Bought (female) | | 0.52 (0.16) | 0 | 3 |
| | Gifts (male) | | 0.28 (0.13) | 0 | 2 |
| | Gifts (female) | | 0.80 (0.40) | 0 | 10 |
| | Transferred* (male) | | 4.0 (4.0) | 0 | 8 |
| | Transferred (female) | | 8.0 (0.0) | 8 | 8 |
| Exits from the herd | Sold (male) | | 5.92 (2.5) | 0 | 50 |
| | Sold (female) | | 5.68 (2.05) | 0 | 32 |
| | Died (male) | | 1.16 (0.28) | 0 | 6 |
| | Died (female) | | 1.88 (0.4) | 0 | 10 |
| | Stolen (male) | | 0.21 (0.08) | 0 | 1 |
| | Stolen (female) | | - | - | - |
| | Donated (male) | | 1.04 (0.43) | 0 | 10 |
| | Donated (female) | | 1.2 (0.6) | 0 | 15 |

*Transferred from another herd; $^{\phi}$HH means household.

giving away of cattle have been eroded, and indeed, is the way to go for pastoralists to sustainably manage their stocks in the light of growing disease threat and growing economic demands for communities. Most farmers in the study (52%) reported not to carry out selective breeding of their cattle, yet they have some selection criteria for

**Table 6.** Productivity and reproductive parameters of indigenous cattle of Rwanda.

| Traits | Inyambo$^{\Phi}$ | | | Inkuku | Inkungu | Inkoromoijo | Bashi |
|---|---|---|---|---|---|---|---|
| | **Mean (±s.e.)** | **Min** | **Max** | | | | |
| Age at sexual maturity for males (months) | 27.4 (1.04) | 18 | 36 | | | | |
| Age at sexual maturity for females (months) | 28.7 (1.02) | 24 | 40 | | | | |
| Age at first calving (months) | 33.8 (0.83) | 27 | 45 | | | | |
| Calving interval (months) | 13.6 (0.45) | 13 | 18 | | | | |
| Calving % | 70 (2.5) | 30 | 80 | 68 | 59 | 38 | 34 |
| Pre-weaning calf mortality (%) | 5 (2.8) | 0 | 6 | 3 | 5 | 5 | 5 |
| Weaning weight (kg) | 120 (4.0) | 65 | 130 | 100 | 80 | 75 | 70 |
| Calf weaning age (months) | 3.8 (0.15) | 3 | 7 | | | | |
| Milk Yield/day/cow (ltrs) | 3.6 (0.19) | 1 | 5 | | | | |
| Lactation length (months) | 6.8 (0.29) | 3 | 8 | | | | |
| Frequency of milking per day | 1.6 (0.10) | 1 | 2 | | | | |
| Lactation milk yield (kg/year)* | 1440 | | | 1200 | 630 | 390 | 390 |
| Daily milk off take at peak (L) | 8 | | | 5 | 3 | 2 | 2 |

*Projected from daily milk yield and lactation length; For the Inkuku, Inkungu, Inkoromoijo and Bashi cattle, only mean values are given.

preferred traits.

Interestingly, regarding acquisition, over one third of the cattle farmers acquired their first cattle when they were still children, and only 12.5% acquired cattle when 20 years or older (Table 5). All the interviewed respondents had had ancestors who reared local cattle, but what was poignant is that, a greater number reported great grand-parents (34.8%) who reared these cattle, while fewer (19.6%) reported grand-parents and even fewer reported parents (8.7%) having reared indigenous cattle, and there was a drop by half in each generational change.

In general, cattle entered their current owners' herds mostly by birth or transfer (Table 5). Purchase of both cows and bulls, as well as receiving gifts of either cows or bulls are rare events among the farmers of indigenous cattle. This is rather surprising because these cattle still offer cultural roles in the communities where they are reared. Contemporary studies of similar cattle in other great lakes region countries (Ndumu et al., 2008; Kugonza et al., 2012b) show the opposite scenario, though in Kenya, low levels (6.6%) of use of cattle as gifts/dowry were found only for Masaai zebu cattle and absent for other breeds (Mwacharo and Drucker, 2005). On the other hand, exits from the herd are mainly through sale that is higher for male than female cattle. Death of cattle was reported by the farmers though the numbers were quite low, an indication of good health care. The other factor is the better tolerance of the indigenous breed(s) to the common diseases. It was very encouraging to find from the study that cattle thefts are almost absent for male cattle and completely absent for females, a rarity in the great lakes region where cattle rustling and thefts are widespread (Kugonza et al., 2012b). Credit for this should go to the strong law enforcement effort as well as the identification and animal traceability programmes that are widespread in Rwanda. The number of cattle that exit the herd by being donated was higher than the number that is received for the same purpose. The mean exit per year per herd was 17.09 animals while the mean entry per year was 15.64 animals. The implication of this is that the national indigenous herd is shrinking since the direct removals/exits are more than the direct additions/entries. Removal is also indirectly a result of growing of crossbreeding. Therefore only direct conservation efforts may sustain the presence of the breed(s).

## Reproductive and production performance of indigenous cattle in Rwanda

From our study, the age at sexual maturity ranged between 18 and 36 months for male Inyambo cattle while for females, the range was narrower though means for the two sexes were close (Table 6). The mean values were much higher than 23.6 and 22.7 months recently reported for Ugandan Ankole cattle (Kugonza et al., 2011a). Average age at first calving (AFC) was 33.8 months and the range of 27-45 months did not vary from 24-45 (Kugonza et al., 2011a) but varied widely from 42-60 (Payne and Wilson, 1999) and Rege (1999) for Ankole cattle in Uganda. These variations between the contemporary studies could be attributed to variations in improvements in general cattle management practices, particularly disease control and feeding, and shifts in breeding objectives from aesthetic (coat colour patterns and horn shapes) to productive traits (fast growth, body weight, and milk yield). Calving interval, a sparring partner of AFC was similar to 12-18 months recently reported elsewhere (Kugonza et al., 2011a) and better than past studies (Payne and Wilson, 1999). Calving percentages (70%) though much lower than values

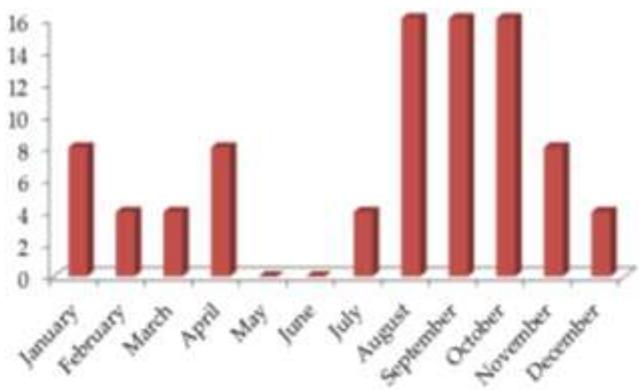


**Figure 1.** Months when most calving occurs.

**Table 7.** Milk composition of Inyambo and Inyambo-Friesian crossbreds in Rwanda.

| Nutrients | Composition (%) | |
|---|---|---|
| | Inyambo | Inyambo-Friesian |
| Protein | 3.56 | 3.23 |
| Lactose | 1.93 | 2.58 |
| Fats | 3.24 | 2.80 |
| Lactic acid | 1.24 | 0.99 |
| Calcium | 55.69 | 49.50 |
| Potassium | 51.95 | 88.45 |
| Magnesium | 3.96 | 3.54 |
| Manganese | 0.22 | 0.05 |
| Sodium | 17.28 | 15.99 |
| Zinc | 0.22 | 0.32 |

reported for dairy breeds in Rwanda, it was higher for Inyambo compared to other indigenous ecotypes (Table 6). Calvings across a calendar year appear to mainly occur in August-October period (Figure 1). This matches squarely with the main rainfall and cropping season. The implication of this is that cows are able to drop their calves when pasture is available and this supports lactation performance.

In general, our study showed that the mean calving rate of indigenous cattle in Rwanda according to the cattle keepers is 55.8%. A conception rate of 79% in Ankole, Boran and unspecified zebu-type cattle in western Uganda was reported (Trail et al., 1971), and was attributed to abundant feed and water alongside diseases controlled. Under traditional farm conditions but with Tswana cattle in Botswana, Rennie et al. (1976) reported average calving rate of 46.4% incomparable with 74.0% for similar animals on a ranch. Under ranch conditions, higher calving rates would result from animals there being better fed and managed than those from the traditional management system. Elsewhere, White Fulani cattle raised on government ranches in Nigeria had percentage of 67%, incomparable with 34-55% for similar animals raised by local herders (Nuru and Dennis, 1976). We observe therefore that Inkoromoijo and Bashi cattle have low calving rate compared to Inyambo and Inkuku. Low calving rate is due to many a small number of “breedable cows” present. It may also be due to age-related factors.

On the other hand, regarding pre-weaning calf mortality, Inyambo cattle did not differ from the other Rwandan indigenous ecotypes (Table 6). There was a clear gulf between the ecotypes regarding weaning weights as well as whole lactation yield. Weaning weight was highest in Inyambo, followed by Inkuku, Inkungu, Inkoromoijo and Bashi. The average lactation length was 204 days slightly lower than 216 months (Kugonza et al., 2011a) and 246 months (Twinamatsiko, 2001). Among the Nguni cattle breed of South Africa that is also Sanga but that has largely been intensively undergoing selection (Bester et al., 2003), much higher lactation lengths (245-270 days) have been recorded (Rege *et al*. 2001). The mean milk off take for Inyambo cows in the current study is quite substantial though with a wide range. At 3.6 kg, the value varies widely from 1.08 kg (De Leeuw and Wilson, 1987), 1.48 kg (Petersen et al., 2003), and 2.2 kg (Kugonza et al., 2012), for the same breed and production conditions. The yield appears to rise with time and could be a result of deliberate or inadvertent selection for milk yield. When projected over an entire lactation, the resultant values supercede those previously estimated at 550 kg in pastoral areas for Ankole cattle (Kugonza et al., 2012), and appear to match the production (300-1100 kg) of a strain of the Small East African zebu in Bukedi, eastern Uganda reported by Payne and Hodges (1997). Inyambo cows produce milk that is higher in protein, butter fat and minerals than crosses with Friesian (Table 7). However, in terms of yields, crossbreds were superior in all parameters.

## Purpose for rearing and record keeping in indigenous cattle in Rwanda

The purpose for rearing cattle in Rwanda is presented in Table 8. Male indigenous cattle are primarily used for income generation (41.7%) when sold and for meat production for the household (37.5%). Female cattle are reared majorly for milk production (45.8%). In all, a total of seven functions are derived from indigenous cattle. From these results, we observe that indigenous cattle continue to be multi-purpose and their valuation has to take this into consideration. Exotic cattle on the other hand predominantly reared for milk (76% of the households). A substantial proportion of households (20%) also derive income from their exotic herd while a very small proportion (4%) use some of their exotic stock for meat, probably the male calves, as has been documented elsewhere (Kugonza et al., 2011a; Nabasirye et al., 2012).

**Table 8.** Purpose of rearing Inyambo cattle among cattle farmers.

| Purpose | Male cattle (%) | Female cattle (%) | Exotic cattle (%) |
|---|---|---|---|
| Meat production | 37.5 | 0.0 | 4.0 |
| Income from sale of animals | 41.7 | 33.4 | 20.0 |
| Savings | 4.2 | 8.3 | 0.0 |
| Aesthetics/Beauty | 8.3 | 4.2 | 0.0 |
| Conservation for future use | 8.3 | 4.2 | 0.0 |
| Milk production | 0.0 | 45.8 | 76.0 |
| Dowry/cultural uses | 0.0 | 4.2 | 0.0 |

**Table 9.** Reason for culling the Inyambo cattle.

| Reason | Bulls | Cows | Young males | Young females | Overall |
|---|---|---|---|---|---|
| Slow growth | 0.0 | 0.0 | **58.3** | **68.0** | **31.6** |
| Poor health | **37.5** | **20.8** | **29.2** | **16.0** | **25.9** |
| Old age | **20.8** | **25.0** | 0.0 | 0.0 | **11.5** |
| Infertility | 4.2 | **25.0** | 0.0 | 0.0 | 7.3 |
| Small sized offspring | 0.0 | 20.2 | 0.0 | 0.0 | 5.1 |
| To avoid inbreeding | **16.7** | 0.0 | 0.0 | 0.0 | 4.2 |
| Bad conformation | 8.3 | 0.0 | 8.3 | 0.0 | 4.2 |
| Unfavourable colour | 0.0 | 0.0 | 0.0 | **16.0** | 4.0 |
| Bad body condition | 8.3 | 0.0 | 4.2 | 0.0 | 3.1 |
| High calf mortality | 0.0 | 8.2 | 0.0 | 0.0 | 2.3 |
| Reduce herd size | 4.2 | 0.0 | 0.0 | 0.0 | 1.1 |

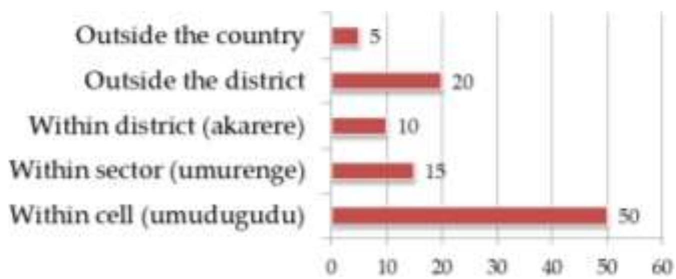


**Figure 2.** Source of breeding bulls.

Inyambo cattle farmers reported that poor health is the main reason for culling indigenous bulls and cows, as indicated by 37.9% of respondents (for bulls); 20.8% of respondents (for cows); 29.2% of respondents (for young males) and 16% of respondents (for young females). Overall, slow growth was the dominant reason for culling (Table 9) but specifically, bulls are culled mostly because of poor health and old age, cows are culled on the basis of old age and infertility, while both young males and females are culled on the basis of slow growth.

Most of the bulls are sourced from within the cell "*umudugudu*" (Figure 2), and three quarters of the respondents' source bulls within the district, only 25% sourced outside the district and of these only 5% source bulls outside the country. These statistics are indicative of a likelihood of inbreeding, since majority of farmers reported that the source of the bull is within the cell, Umudugudu. Literacy levels of the cattle keepers were quite high (Table 10), and this enabled the cattle keepers to keep some records on births and health status.

## Morphological and metric characteristics of indigenous cattle in Rwanda

The average linear body dimensions of male cattle were higher than for females for different age groups and breed ecotypes (Tables 11 and 12). Parameters for the

**Table 10.** Literacy level and cattle record keeping among Inyambo cattle farmers.

| Factor | Level | % of farmers |
|---|---|---|
| Able to read | Yes | 76.0 |
| | No | 24.0 |
| Able to write | Yes | 72.0 |
| | No | 28.0 |
| Keep records | Yes | 50.0 |
| | No | 50.0 |
| Records kept | Birth dates | 70.0 |
| | Health records | 30.0 |
| Method of record keeping | Notebook | 81.8 |
| | Cards/fiche | 18.2 |
| Use of the records | Compute income | 25.0 |
| | Keep track of expenses | 62.5 |
| | To follow up the cow reproduction status | 12.5 |

**Table 11.** Morphometrics of Inyambo, Inkuku and Inkoromoijo cattle.

| Parameter* | Calf | | | | Heifer/Bullocks | | | | Adult | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inkuku | | Inyambo | | Inyambo | | Inkoromoijo | | Inkuku | | Inyambo | |
| | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male |
| Body Length (BL) | 133.0 | 147.8 | 153.4 | 144.7 | 212.0 | - | 182.0 | - | 205.0 | - | 217.9 | 244.0 |
| Height at Withers (HW) | 91.4 | 100.2 | 107.0 | 103.7 | 124.0 | - | 122.0 | - | 130.4 | - | 134.6 | 144.0 |
| Leg Height (LH) | 52.0 | 59.9 | 62.4.0 | 61.3 | 67.5 | - | 69.0 | - | 73.4 | - | 74.5 | 80.0 |
| Heart Girth (HG) | 100.4 | 111.7 | 117.8 | 115.3 | 165.0 | - | 166.0 | - | 167.6 | - | 176.4 | 194.0 |
| Body Weight (BW) | 94.0 | 127.9 | 144.8 | 162.3 | 394.5 | - | 399.0 | - | 399.6 | - | 482.3 | 647.0 |
| Tail Length (TL) | 57.8 | 66.8 | 57.8 | 62.3 | 78.5 | - | 81.0 | - | 88.2 | - | 92.1 | 100.0 |
| Dewlap Length (DL) | 54.0 | 64.1 | 63.8 | 63.0 | 86.0 | - | 66.0 | - | 89.9 | - | 89.4 | 120.0 |
| Dewlap Width (DW) | 8.2 | 11.1 | 17.0 | 15.3 | 17.5 | - | 15.0 | - | 19.0 | - | 18.8 | 32.0 |
| Rump Width (RW) | 23.8 | 26.3 | 26.3 | 29.3 | 42.0 | - | 43.0 | - | 40.9 | - | 45.0 | 56.0 |
| Ear Length (EL) | 12.8 | 14.1 | 13.4 | 12.3 | 11.0 | - | 16.0 | - | 17.6 | - | 17.4 | 17.0 |
| Muzzle Circumference (MC) | 28.4 | 33.1 | 31.0 | 30.3 | 41.0 | - | 44.0 | - | 42.6 | - | 44.8 | 53.0 |
| Horn Length (HL) | 9.0 | 12.5 | 12.4 | 21.5 | 74.8 | - | 39.0 | - | 101.2 | - | 107.7 | 125.0 |
| Distance between horns (HS) | 21.3 | 29.0 | 28.4 | 30.3 | 87.3 | - | 86.0 | - | 80.7 | - | 82.0 | 93.0 |
| Hump Length (HuL) | 12.5 | 15.1 | 14.0 | 15.3 | 24.5 | - | 7.0 | - | 21.1 | - | 22.9 | 40.0 |
| Hump Width (HuW) | 5.3 | 7.8 | 6.5 | 10.3 | 10.3 | - | 4.0 | - | 11.7 | - | 12.7 | 22.5 |
| Navel Depth (ND) | 2.5 | 8.3 | 8.0 | 8.0 | 5.0 | - | 5.0 | - | 6.8 | - | 8.3 | - |
| Udder Length (UL) | - | - | - | - | - | - | 23.0 | - | 24.8 | - | 24.1 | - |
| Udder Depth (UD) | - | - | - | - | - | - | 11.0 | - | 15.7 | - | 13.6 | - |
| Teat Length (TL) | - | - | - | - | - | - | 3.0 | - | 5.3 | - | 4.6 | - |
| Body Condition Score (BCS) | 3.6 | 3.9 | 4.0 | 5.0 | 4.5 | - | 5.0 | - | 3.8 | - | 4.5 | 5.0 |

Inyambo were superior to those of Inkuku and Inkoromoijo at different ages. For bulls, it was difficult to measure them beyond weaning age. Mature body weight of Inyambo cows was 482 kg whereas the bulls had an average weight of 647.0 kg. In appearance, these cattle are elegant, well-bred, and graceful, have a straight

**Table 12.** Body morphometrics of Inkungu and Bashi cattle in Rwanda.

| Parameter* | Calf | | | | Heifer/Bullocks | | | | Adult | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inkungu | | Bashi | | Inkungu | | Bashi | | Inkungu | | Bashi | |
| | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male |
| Body Length (BL) | 133.0 | 147.8 | 153.4 | 144.7 | 212.0 | - | 182.0 | - | 205.0 | - | 217.9 | 244.0 |
| Height at Withers (HW) | 91.4 | 100.2 | 107.0 | 103.7 | 124.0 | - | 122.0 | - | 130.4 | - | 134.6 | 144.0 |
| Leg Height (LH) | 52.0 | 59.9 | 62.4.0 | 61.3 | 67.5 | - | 69.0 | - | 73.4 | - | 74.5 | 80.0 |
| Heart Girth (HG) | 100.4 | 111.7 | 117.8 | 115.3 | 165.0 | - | 166.0 | - | 167.6 | - | 176.4 | 194.0 |
| Body Weight (BW) | 94.0 | 127.9 | 144.8 | 162.3 | 394.5 | - | 399.0 | - | 399.6 | - | 482.3 | 647.0 |
| Tail Length (TL) | 57.8 | 66.8 | 57.8 | 62.3 | 78.5 | - | 81.0 | - | 88.2 | - | 92.1 | 100.0 |
| Dewlap Length (DL) | 54.0 | 64.1 | 63.8 | 63.0 | 86.0 | - | 66.0 | - | 89.9 | - | 89.4 | 120.0 |
| Dewlap Width (DW) | 8.2 | 11.1 | 17.0 | 15.3 | 17.5 | - | 15.0 | - | 19.0 | - | 18.8 | 32.0 |
| Rump Width (RW) | 23.8 | 26.3 | 26.3 | 29.3 | 42.0 | - | 43.0 | - | 40.9 | - | 45.0 | 56.0 |
| Ear Length (EL) | 12.8 | 14.1 | 13.4 | 12.3 | 11.0 | - | 16.0 | - | 17.6 | - | 17.4 | 17.0 |
| Muzzle Circumference (MC) | 28.4 | 33.1 | 31.0 | 30.3 | 41.0 | - | 44.0 | - | 42.6 | - | 44.8 | 53.0 |
| Horn Length (HL) | 9.0 | 12.5 | 12.4 | 21.5 | 74.8 | - | 39.0 | - | 101.2 | - | 107.7 | 125.0 |
| Distance between horns (HS) | 21.3 | 29.0 | 28.4 | 30.3 | 87.3 | - | 86.0 | - | 80.7 | - | 82.0 | 93.0 |
| Hump Length (HuL) | 12.5 | 15.1 | 14.0 | 15.3 | 24.5 | - | 7.0 | - | 21.1 | - | 22.9 | 40.0 |
| Hump Width (HuW) | 5.3 | 7.8 | 6.5 | 10.3 | 10.3 | - | 4.0 | - | 11.7 | - | 12.7 | 22.5 |
| Navel Depth (ND) | 2.5 | 8.3 | 8.0 | 8.0 | 5.0 | - | 5.0 | - | 6.8 | - | 8.3 | - |
| Udder Length (UL) | - | - | - | - | - | - | 23.0 | - | 24.8 | - | 24.1 | - |
| Udder Depth (UD) | - | - | - | - | - | - | 11.0 | - | 15.7 | - | 13.6 | - |
| Teat Length (TL) | - | - | - | - | - | - | 3.0 | - | 5.3 | - | 4.6 | - |
| Body Co Score (BCS) | 3.6 | 3.9 | 4.0 | 5.0 | 4.5 | - | 5.0 | - | 3.8 | - | 4.5 | 5.0 |

**Figure 3.** Inyambo cows characterized by large body frame with long horns.

top/backline and an evenly sloping rump; bulls additionally have cervico-thoracic (neck) humps. The cattle are spotted in colour but single coat coloured animals are dominant. Horns are white, long and symmetrical, with a large base and proportional to horn length (Figures 3 and 4).

The Inkuku is medium in size, and has previously been described as weighing 250–350 kg (cows) and 300–400 kg (bulls) (Felius, 1995), though in or current study, the mean weight was 399 kg (Table 12). Due to their low birth weight, the bulls of this ecotype are useful for breeding to first-calf-heifers of other small breeds. The horns of the adults serve as formidable weapons against any intruders. The Inkuku was previously classified as a short animal that was dominant in high altitude areas (Felius, 1995), with short horns and strong legs to enable

**Figure 4.** An Inyambo bull characterized by dark brown coat colour, a large body frame and long horns.

**Figure 5.** Inkuku cows have a small body framework with medium sized horns.

it to adapt to the environment of high altitude (Figure 5). However, in our study, we found animals of this ecotype in the southern midlands, and the lowlands, the spread having possibly been a result of the displacement and migration in the post-1994 nationwide genocide against the Tutsi in Rwanda.

The Inkoromoijo cattle have a very small body, shorter horns and finer boned (Figure 6) than the Ankole type or Sanga breeds (Felius, 1995). The Inkoromoijo have a smaller body frame size, with cows weighing 200–300 kg and bulls weighing 200–330 kg. In this study, we notably found a mean weight of cows of 399 kg. These cattle are predominant located in Eastern province of Rwanda. The Inkungu have much smaller body, than the other types and are characteristically hornless / polled. They have a small size, with cows weighing 230-300 kg and bulls weighing 230–330 kg (Table 12). Anecdotal reports

**Figure 6.** An Inkoromoijo cow in the foreground.

indicate that calves weigh 25-30 kg at birth. The Bashi cattle (Figures 7and 8) have a smaller body, shorter horns, is finer boned than the other Ankole ecotypes (Felius, 1995). The agricultural-based Bashi tribe brought these cattle with them in the 17th century and settled in their present location (Rege and Tawah, 1999) in western province of Rwanda and in Democratic Republic of Congo. In Rwanda they are located in Rubavu and Rusizi districts. Bashi cows weigh 220–300 kg while bulls weigh 200–330 kg. Newborn calves have been reported to weigh 23–25 kg. Whereas Inkungu (Figure 9) were categorised as a separate breed by the farmers in this study, elsewhere, polled cattle are just a component of a breed, for instance among Ankole cattle in Uganda (Kugonza et al., 2011a), this would probably explain why no studies at breed level have focused on this trait exclusively. Figure 10 shows the various coat colour patterns found among cattle in this study.

Table 13 gives the phenotypic correlation estimates between the various traits for female Inyambo cattle. The correlation coefficients between BW and HW, HuL, BL, HL, DW, and LH were positive and different from zero ($P<0.05$). A high positive correlation (0.98) was also observed between BW and HG; while correlations between BW and HD, and TeL and UD were negative. Generally, BL was negatively correlated to other traits HD, RW, TeL, and UD. Body weight, hearth girth, height at withers, hump length, and dewlap width were all more correlated amongst the group than the rest of the studied traits. Whereas the differences between the morphometric measurements of male and female cattle are attributable to sexual dimorphism (Mwacharo et al., 2006), that results from hormonal differences between the two sexes at respective ages (Kugonza et al., 2011a), variations between the different ecotypes of Ankole cattle may not be easily attributed to a particular phenomenon.

The measurements for Inyambo cattle in this study are comparable for values published for the Ankole cattle generally (Ndumu et al., 2008) and other Sanga breeds (Payne and Hodges, 1997), but lower than values for

**Table 13.** Correlation matrix for body measurements of adult Inyambo cows.

| Correlation | BW | HG | HW | HuL | BL | HL | DW | LH |
|---|---|---|---|---|---|---|---|---|
| HG | **0.98** | | | | | | | |
| HW | **0.68** | **0.71** | | | | | | |
| HuL | **0.64** | **0.64** | **0.58** | | | | | |
| BL | **0.63** | **0.63** | **0.56** | **0.61** | | | | |
| HL | **0.57** | **0.57** | **0.66** | **0.68** | **0.74** | | | |
| DW | **0.39** | **0.42** | **0.39** | **0.42** | **0.42** | **0.63** | | |
| LH | **0.37** | 0.37 | **0.57** | 0.25 | **0.48** | **0.38** | 0.22 | |
| HuW | 0.34 | 0.34 | 0.25 | **0.53** | **0.44** | 0.25 | 0.05 | -0.10 |
| DL | 0.31 | 0.34 | **0.64** | **0.37** | **0.43** | **0.54** | 0.22 | **0.58** |
| MC | 0.30 | 0.25 | 0.32 | **0.50** | 0.29 | 0.35 | 0.24 | 0.31 |
| EL | 0.27 | 0.29 | **0.43** | 0.33 | 0.33 | **0.45** | 0.29 | **0.43** |
| BCS | 0.25 | 0.23 | -0.17 | -0.13 | 0.20 | -0.06 | -0.02 | -0.15 |
| HD | -0.16 | -0.10 | -0.07 | 0.09 | -0.27 | -0.25 | -0.35 | -0.25 |
| UL | 0.15 | 0.20 | 0.14 | **0.41** | 0.24 | 0.23 | 0.24 | 0.14 |
| RW | 0.12 | 0.13 | 0.34 | 0.02 | -0.09 | 0.04 | -0.16 | -0.02 |
| TeL | -0.10 | -0.02 | 0.27 | 0.18 | -0.11 | -0.00 | 0.11 | 0.04 |
| TaL | 0.10 | 0.10 | 0.35 | 0.22 | **0.39** | 0.35 | 0.12 | 0.27 |
| UD | -0.02 | 0.02 | 0.09 | **0.39** | -0.01 | 0.01 | 0.07 | 0.11 |
| ND | 0.01 | 0.01 | 0.31 | 0.10 | 0.22 | 0.11 | -0.01 | **0.45** |

Ankole from other studies (Kugonza et al., 2011a). We consider that Ndumu et al. (2008) study used cattle from Uganda, Rwanda and Tanzania while the Kugonza et al. (2011a) study worked with Ugandan cattle. The implication of this is that Ugandan Ankole cattle have bigger body frames and possible more elite, despite the Inyambo being more strictly selected. It could also have relation with forage availability and biomass production in Ankole cattle rearing rangelands outside Uganda. Limited choice of feed has been reported to negatively impact cattle growth elsewhere (Mashoko et al., 2007). We did find that Inyambo were the superior ecotype followed by Inkuku, Inkungu and Inkoromoijo in descending order. These variations in morphological descriptions are useful for making distinction between animal strains (Gatesy and Arctander, 2000), evaluation of breeding goals (Zechner et al., 2001), and comparing feeding and production systems as postulated above. The height at withers helps in visually appraising beef cattle classes for show business (Alderson, 1999). Whereas width, girth and body weight measurements are related to muscle and fat deposition which are affected by nutritional status of the cattle, skeletal measurements including height at withers and body length are better indicators of inherent size (Kamalzadeh et al. 1998). The high positive correlation (0.98) observed between BW and HG is similar to values of Kugonza et al. (2011a) for the two traits and affirms their reliability for use as proxy measures for accurate estimation of body weight. Qualitative morphological data on Inyambo cattle showed that majority of the cattle have uniform coat colour pattern (Table 14). Interestingly, the preferred coat colours are different forms brown, namely dark brown, brown, light brown and spotted light brown. The colour interest are largely cultural though previous research found it useful in parentage assignment (Kugonza et al., 2012a) and others postulated an association of body coat colour and pricing of Ankole cattle (Kugonza et al., 2011a; 2012b), of which Inyambo are a component. Horn shaping and spacing are also critical traits in enabling cattle to graze in thickets and difficult terrain (Kugonza et al., 2012b).

## Conclusions

Ankole cattle show a high productive potential, though their current performance is relatively low, largely because of the sub-optimal management conditions, and production area constraints. Wide variations in management activities and production levels were also observed in the three livestock production systems. However, this variation in the production levels is indicative of potential for improvement under selection and improved husbandry. A set of six traits are good predictors of body weight. It is good to improve and strengthen the current conservation activities; there could be risk of extinction, leading to loss of this genetic material. It is important to note that for an effective cross breeding, pure parent lines have to be maintained, with a selection program for each of them to improve the genetics and maintain the specific traits of that line. So, in case of Rwanda where crossbreeding is encouraged to

**Table 14.** Qualitative traits in Inyambo cattle.

| Trait | Level | % of sample |
|---|---|---|
| Coat Colour Pattern | Uniform | 80.3 |
| | Pied | 1.5 |
| | Spotted | 18.2 |
| Hair Length | Short | 100 |
| Hair Type | Straight | 100 |
| Face Profile | Straight | 100 |
| Back Profile | Curved | 6.2 |
| | Straight | 93.8 |
| Rump Profile | Sloping | 100 |
| Hump Profile | Cervico-Thoracic | 100 |
| Ear Shape | Straight | 3.1 |
| | Curving | 96.9 |
| Ear Orientation | Straight edged | 100 |
| Horn Presence | Present | 100 |
| Horn Shaping | Natural | 100 |
| Horn spacing | Narrow | 4.8 |
| | Wide | 95.2 |
| Preferred Coat Colour | Dark Brown | 33.33 |
| | Brown | 36.51 |
| | Light Brown | 6.34 |
| | Light Brown spotted | 7.95 |
| | White | 1.59 |
| Horn Shaping | Natural | 100 |
| Horn spacing | Narrow | 4.8 |
| | Wide | 95.2 |
| Preferred Coat Colour | Dark Brown | 33.33 |
| | Brown | 36.51 |
| | Light Brown | 6.34 |
| | Light Brown spotted | 7.95 |
| | White | 1.59 |

**Figure 7.** The Bashi cattle in a woodland area.

increase production through improved genetics, the local breeds lines must be maintained and breeding plans should be designed. In group discussions, all farmers expressed their willingness to participate in and

**Figure 8.** The Bashi cattle on the open range.

**Figure 9.** Inkungu cattle.

contribute materially or financially to any program towards a sustainable use and preservation of the indigenous breed which they perceived as hardy and embedded in their culture. We therefore argue that strategies for its sustainable use and conservation should consist of simultaneously improving general herd management practices, organizing farmers and involving them in participatory breed improvement programs.

## RECOMMENDATIONS

There is need to strengthen the conservation efforts for the various ecotypes of indigenous cattle of Rwanda. Particularly, the Bashi cattle appear to be severely substituted by the Holstein Friesian and is almost absent in Rwanda. The goal of dairy farming in Rwanda is to boost milk production but this is cognizant of a very limited land resource. In view of this and the now recognised climate change, a balance is needed betweenconservation of the five ecotypes of indigenous cattle, and controlled crossbreeding of these ecotypes with exotic commercial dairy breeds. The Rwanda Agriculture Board should strengthen the conservation efforts since private farmers who are currently involved will keep a growing interest in productivity and better marketable breeds. Advocacy for specialised cuisine based on dairy and meat from indigenous cattle will also boost the commercial value of these cattle. Training of cattle farmers in various aspects of herd management should ultimately cause improvements in productivity of these ecotypes in particular and for the Ankole cattle

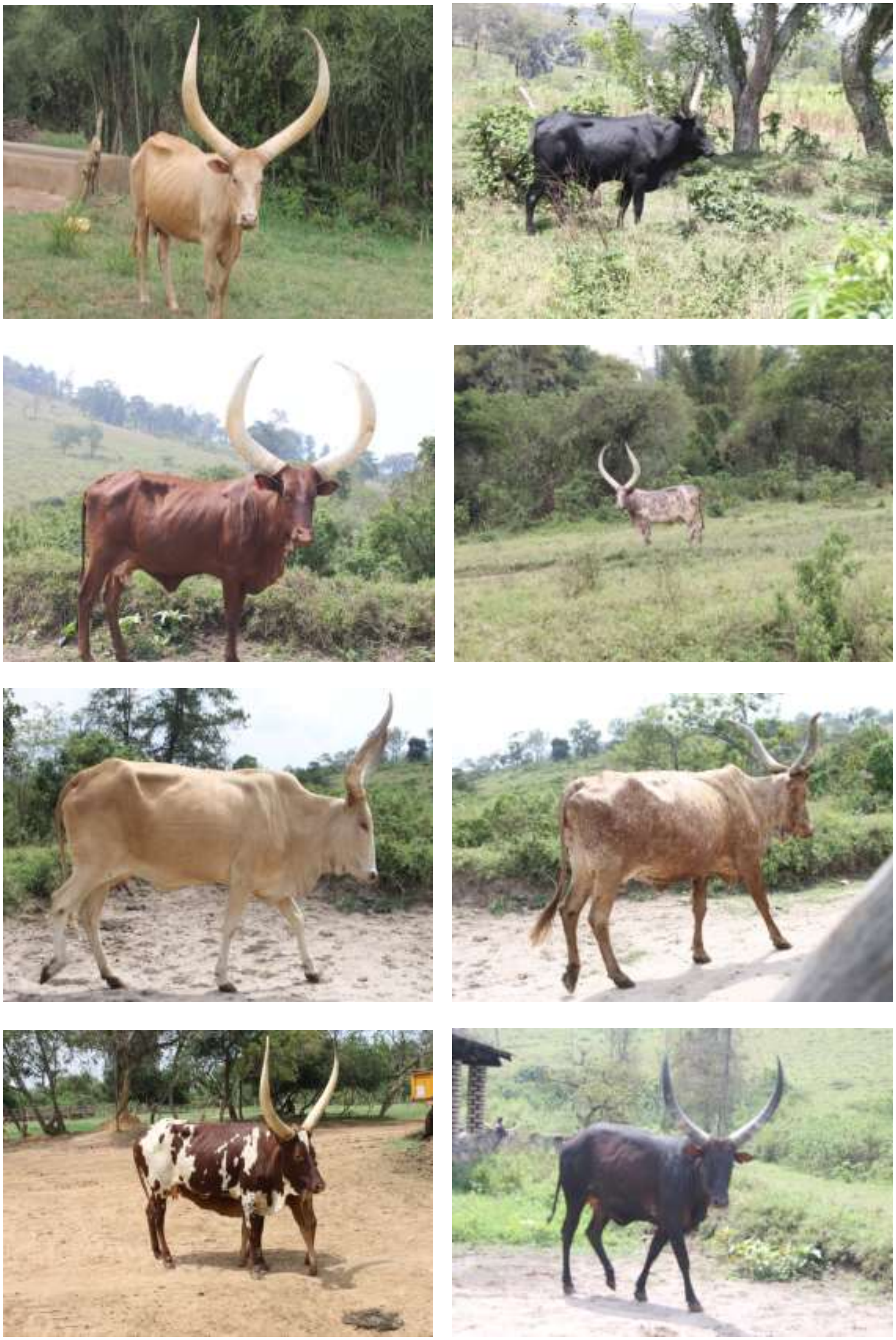

**Figure 10.** Body coat colours and patterns in indigenous cattle of Rwanda.

breed in general. Extension services for cattle farming should be strengthened through increasing the number of public and private service providers through affirmative action.

## Abbreviations

BL, Body length; **HW,** height at withers; **LH,** leg height; **HG,** heart girth; **BW,** body weight: **TL,** tail length: **DL,** Dewlap length: **DW,** Dewlap width; **RW,** Rump width: **EL,** ear length; **MC,** muzzle circumference; **HL,** horn length; **HS,** distance between horns; **HuL,** hump length; **HuW,** hump width; **ND,** navel depth; **UL,** udder length; **UD,** udder depth; **TL,** teat length; **BCS,** body condition score.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The African Union-InterAfrica Bureau for Animal Resources (AU-IBAR) for developing the Animal Genetic Resource - Characterisation, Inventory and Monitoring Tool (AnGR-CIM) that was customized for this study. The authors are grateful to the research partners who participated in data collection, particularly Musoni Fidel, Diane Uwumukiza and Olive Umunezero. Gratitude is also due to the farmers who assiduously participated in the study and continue to be are very supportive of the conservation efforts of the indigenous cattle breeds of Rwanda.

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academicJournals

Vol. 8(7), pp. 113-124, July 2017
DOI: 10.5897/IJLP2017.0371
Article Number: 0597B7165000
ISSN 2141-2448

http://www.academicjournals.org/IJLP

International Journal of Livestock Production

Full Length Research Paper

# Evaluation of different processing methods of soya beans (*Glycine max*) on its nutritive value and the performance of broilers: A qualitative selection approach for extension

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Received 1 March, 2017; Accepted 26 May, 2017

**Several trials has been conducted by poultry nutritionist in evaluating effects of soybean processing on its nutritive value and the performance of broilers without clearly declaring the best processing method to be adopted by farmers that will give them on the average a cumulative best result output. A qualitative selection approach was thus adopted in the evaluation of different processing methods of soya beans (*Glycine max)* on its nutritive value and the performance of broilers using published results from the same authors who conducted an experiment using four thermal processing methods (extrusion, cooking, toasting and roasting -dry heating); four fermentation processing methods (fermentation with culture organisms, cooking and fermentation, daddawa, cooking and fermentation + potash) and four alkaline processes methods (soaking in water, sodium carbonate ($Na_2CO_3$), potassium carbonate ($K_2CO_3$) and sodium hydroxide -NaOH) A quantitative evaluation of both nutritive values and performance of experimental birds were undertaken as basis for selection of best means from each processing method after the selected best from each of the processing methods were compared to select the overall best. Cooking, cook and ferment and 1% potassium carbonate respectively emerged as the representative best for thermal, fermentation and alkaline processing. The comparative evaluation of the representative best processing methods showed that cook and ferment from fermentation group was the overall best. This processing method showed the best potentials for essential nutrients preservation, better performance of broilers and greater economic returns on investment. This confirmed the superiority of fermentation process in increasing the viability of soya beans utilization in broiler feeds resulting from microbial organisms activities.**

**Key words:** Broilers, farmers, qualitative selection, soybeans, processing.

## INTRODUCTION

Soybean utilization in the monogastric animals (poultry) Feed industry will continue to draw the attention of all

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actors in the feed supply chain. This is accountable by the nutritional benefits of this oil seed to the feed industry and thus, the reason for continues search for best ways of enhancing utilization of different forms (raw fullfat ) are still a major research focus.

Several soybean processing techniques that are aimed at improving the nutritive values and removing anti nutritional factors (ANFs) have been documented. These includes: Drying, toasting, cooking, extraction, autoclaving, fermenting, alkaline treatment, use of enzyme (Asiedu, 1989; IITA, 1997; ASA, 1993; Kaankuka et al., 1996; Qin et al., 1996; Caine et al., 1998; Ayanwale, 1999; Mellor, 2002; Ayanwale and Kolo, 2011). These soyabean processing techniques uniquely present different opportunities and challenges in both the nutritional profile and nutrient availability of soya beans for utilization by animals.

Thermal processing of soyabean such as hydrothermal, autoclaving, extrusion, micronization is acknowledged for being very successful in enhancing the nutritional value of soyabean and in reducing ANFs. It is however affected by many and varied reports on the influence of temperature time combinations on the ANFs and amino acids profile of soya bean as well as high energy and technology cost requirement, lack of standardization of cooking time and temperature regimes and associated cost (Lovell, 1990; Kaankuka et al., 1996; Qin et al., 1996; Ebrahimi-Mahmoudabad and Taghinejad-Roudbaneh, 2011; Ari et al., 2012a) poses greater challenge in the nutritional status of thermally processed soya beans and its utilization by broilers.

The use of microbial cultures in the treatment of soya bean meal in order to achieve enhancement of total soluble mater, crude protein and reduced ANFs have been reported by Caine et al. (1998). This process however, required complex process of inoculation with microbial substrates. Other solid state fermentation processes adopted for soya beans include daddawa fermentation; cooking and fermentation (Campbel-Platt, 1980; Water-Bayer, 1998; Ayanwale and Kolo, 2001; Ari et al., 2012b); *in vitro* cytotoxicity of soybean agglutinin has also been demonstrated (Babot et al., 2016).

In spite of the associated benefits of fermentation, cooking time and prolong period of fermentation above 72 h is reported to have deleterious effects on the nutritive value of soya beans and consequently on the performance of broilers. Similarly, the use of enzymes in the improvement of the availability of nutrients from plant sources has resulted in the development of highly effective heat stable phytases that ensures maximum phosphorous release from plant phytase especially in soya beans (Mellor, 2002). However, the exogenous supply of enzymes significantly affects the ability of birds to produce endogenous phytase. A novel approach was also adopted in improving the potential utilization of raw soya bean (Erdaw et al., 2016; Iji et al., 2016) in poultry feeds using different dosing rates of cocktails of new generation enzymes with relatively good outcomes in terms of feed quality improvement and response of fed chickens to raw soya bean based diets. The justification for the use of enzymes must also be measured on the optimum enzyme dose rate required to maximize economic returns from enzyme use (Hruby, 2002).

The use of alkaline treatment of soya beans is dependent on the concentration levels and type of the alkaline used (Friedman and Master, 1984; Ayanwale, 1999; Ari et al., 2012c). The use of strong alkaline salts in the processing of soya beans often result in decreased protein quality, loss of amino acids and the formation of amino acids lysinoalanine complex. This leads to reduced nutrient availability especially lysine.

The small holder farmer/feed miller is faced with even greater challenge of selecting for adoption of any of these processing methods as each of these methods manifest differently in the nutritive value and performance parameters evaluated for broilers (Ari et al., 2012d, e, 2013).

It is envisaged that a comparative evaluation of these processing techniques on the performance of broilers, the nutritional value of the processed soya beans and the effectiveness of the systems should provide a base for the adoption of a more effective method of maintaining the quality, and providing the best economic returns to poultry farmers and the feed mill industry (Dudley-Cash, 2004)

This study is therefore aimed at undertaking a comparative evaluation of the effects of the best treatments of each of the soya beans processing methods and its utilization by broilers. Specifically a qualitative evaluation of each of the experimented soya beans processing methods was envisaged to support farmers and extension staff in decision making.

## MATERIALS AND METHODS

### Experimental site

This study was conducted at the Livestock Complex of College of Agriculture, Doma Road, Lafia which is located between latitude 8 and 9× North and longitude 80 and 90° East. The minimum temperature is 21.9°C and maximum temperature of 37.6°C between January to June and the average annual rainfall is 823 mm.

### Soya beans processing

Soya beans seeds *(Glycine max)* were procured from a local market in Lafia metropolis of Nasarawa State, Nigeria. The collected seeds were cleaned by winnowing and hand picking of stones and debris and were subjected to four thermal and hydrothermal processing methods (extrusion, cooking, toasting and roasting -dry heating); four (4) fermentation methods (fermentation with culture organisms, cooking and fermentation, daddawa and cooking and ferment + potash fermentation methods) and four alkaline treatments soaking in water (HOH) sodium carbonate

($Na_2CO_3$), potassium carbonate ($K_2CO_3$) and sodium hydroxide (NaOH) according to the methods described by Ari et al. (2012a, b, c).

### Chemical evaluation of processed soya beans

The proximate composition of each the processed soya beans were determined according to AOAC (2000); determination of amino acid profile using the methods described by Spackman et al. (1958); Trypsin Inhibitor Activity (TIA) determined according to the method described by Gupta and Deodhar (1975) and Hammerstrand et al. (1981); Phytic acid determination was done according to the modified method described by Wheeler and Ferrell (1971) and Stewart (1974); Protein Solubility Index method described by Araba and Dale (1990) was adopted and the determination of pH was done using urease assay as a measure of protein quality (Dudley-Cash, 2004).

### Experimental treatment and diet preparation

A total of 240 day-old Anak broilers randomly divided into four (4) experimental groups of three replicate were used in each of the thermal and hydrothermal; fermentation methods; and alkaline treatments based experiments. Dietary treatments were as follows: Extrusion T1, cooking T2, toasting T3 and roasting - dry heating T4 for thermal and hydrothermal processing methods; fermentation with culture organisms F1, cooking and fermentation F2 , and daddawa F3 cooking and ferment + potash F4 for fermentation methods and soaking in water A1, sodium carbonate ($Na_2CO_3$) A2, potassium carbonate ($K_2CO_3$) A3 and sodium hydroxide (NaOH) A4 for alkaline treatments at both starter and finisher phases using completely randomized design having the test ingredients incorporation as the main source of variation.

The starter diets were formulated to give approximately 3000 Kcal of energy and 24% CP for all the experimental groups using a least cost feed formulation software *Feedwin* and were fed for five (5) weeks (1 to 35 days) brooding phase and the finisher diets were similarly formulated to give approximately 3000 Kcal of energy and 22% CP and were fed for four weeks (36-63 days). All management practices were similarly conducted.

### Statistics

#### *Quantitative evaluation*

The data collected for the following parameters viz: Chemical composition of soya bean seed, amino acid profile of test soya beans, anti-nutritional factor analysis, chemical composition, performance traits, carcass characteristics, organ morphology, cooking yields and loss, serum profile and economics of each of the individual experiments were subjected to analysis of variance (ANOVA), means were separated where there were significant differences using Duncan's multiple range test (Duncan, 1955) using SPSS 16.0.

#### *Qualitative evaluation*

This experiment adopted qualitative evaluation techniques Likert scaling (Asika, 1991) was used to weigh the treatment means for each parameter measured in each of the experiment. The treatment group with the best cumulative means in each of the experiment (thermal, fermentation and alkaline treatment) was selected to represent the group in the comparative evaluation process.

### Selection process for best means

The selection process was based on a four point score evaluation for the means of each of the parameters assessed in the three soya bean processing experiments. This four point score evaluation is irrespective of means similarities ($P<0.05$) within the same parameter and the cumulative average points score for each of the experimental treatment groups were ranked according to the methods described by Ajayi (2005) and Rahman and Ogungbile (2006). The scores were as follows: 1 = Fair; 2 = Good; 3 = Better and 4 = Best mean.

### Selection process for processing methods

The selection process was based on a three point score evaluation for the overall means of each of the parameters assessed in the three soya bean processing experiments. The cumulative average points score for each of the experimental treatment groups were pooled and ranked according to the methods described by Ajayi (2005) and Rahman and Ogungbile (2006). The scores are as follows: 3 = Good; 2 = Better; and 1 = Best mean.

## RESULTS AND DISCUSSION

Results of the quantitative evaluation are presented in Tables 1 to 4. The overall ranking for the selection of the best treatment group within the three experiments are presented in Tables 5 to 8 for thermal, fermentation and alkaline processing experiments, respectively.

The overall best performances recorded in the cooking, cook and ferment and 1% potassium carbonate ($K_2CO_3$) groups respectively confirmed these processes of soya beans as the best representatives of thermal, fermentation and alkaline processing methods that will guarantee the preservation of essential nutrients and remove ANFs for greater performance of broilers

This finding was in agreement with the findings of Balloun (1980) who reported better nutrient profile and better reduction values of TIA and other ANFs (Cheva-Isarakul and Tangtawaeewipat, 1995) of hydrothermaly processed soya beans as against the deleterious effects of excessive dry heating on the nutrient composition and bio-availability for utilization by broilers as observed by ASA (1993) and Tiamiyu (2001).

The chemical compositions, removal of anti-nutritional factors as well as the performance of broilers fed all the fermented soya beans were on the average, these are indicators that fermentation processes are advantageous processing methods when compared to thermal and alkaline treatments. This confirmed the reports of Ayanwale and Kolo (2001), Mellor (2002) and Kalavathy et al. (2003) among other workers.

Although all the fermentation process gave good performance especially in the removal of ANFs, the overall best performance recorded in the cooked and ferment group confirmed the potentials of the process as the best processing method that will guarantee the preservation of essential nutrients, better performance of broilers and yield of greater economic returns on

**Table 1.** Effect of different processing methods on the chemical and amino acid composition and anti-nutritional factors of soya bean.

| Parameter | Thermal | | | | Fermentation | | | | Alkaline | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | F1 | F2 | F3 | F4 | A1 | A2 | A3 | A4 |
| **Proximate composition** | | | | | | | | | | | | |
| DM | 79.00 | 89.83 | 91.25 | 90.57 | 91.12 | 89.57 | 93.77 | 90.11 | 90.02 | 90.02 | 90.17 | 89.83 |
| CP | 40.20 | 39.27 | 35.47 | 37.53 | 40.35 | 32.91 | 37.90 | 37.86 | 39.7 | 38.34 | 40.27 | 39.64 |
| CF | 19.50 | 12.51 | 28.34 | 24.29 | 4.96 | 14.34 | 10.32 | 17.22 | 13.76 | 14.64 | 22.87 | 12.37 |
| EE | 9.72 | 19.27 | 18.03 | 16.92 | 9.32 | 19.41 | 16.82 | 20.22 | 21.85 | 18.58 | 6.72 | 21.31 |
| T Ash | 4.27 | 4.39 | 4.41 | 4.46 | 6.33 | 4.21 | 2.64 | 4.57 | 3.61 | 5.29 | 4.80 | 5.05 |
| NFE | 26.31 | 24.56 | 13.75 | 16.8 | 39.04 | 29.13 | 32.32 | 20.13 | 21.08 | 23.15 | 25.34 | 21.63 |
| Ca | 0.45 | 0.56 | 0.44 | 1.08 | 0.38 | 0.50 | 0.51 | 0.48 | 0.39 | 0.44 | 0.37 | 0.42 |
| P | 0.33 | 0.29 | 0.28 | 0.29 | 0.25 | 0.23 | 0.22 | 0.29 | 0.36 | 0.23 | 0.23 | 0.23 |
| **Amino acid composition (g/100 g protein)** | | | | | | | | | | | | |
| Lysine | 2.40 | 5.30 | 3.60 | 5.71 | 5.25 | 5.60 | 3.99 | 5.09 | 5.23 | 5.5 | 5.78 | 4.79 |
| Histidine | 3.21 | 2.60 | 3.00 | 2.90 | 3.43 | 2.93 | 2.06 | 3.20 | 3.4 | 2.93 | 3 | 2.96 |
| Arginine | 4.52 | 4.95 | 4.48 | 4.72 | 5.58 | 5.73 | 4.01 | 5.19 | 5.5 | 5.82 | 5.82 | 4.8 |
| Aspartic acid | 11.80 | 11.57 | 10.49 | 10.60 | 11.46 | 10.72 | 10.03 | 11.00 | 11.23 | 12.03 | 12.08 | 12.15 |
| Threonine | 1.47 | 2.99 | 2.80 | 2.49 | 3.29 | 2.99 | 2.72 | 3.08 | 3.18 | 3.24 | 3.48 | 3.16 |
| Serine | 2.45 | 2.59 | 1.90 | 2.38 | 2.50 | 2.29 | 1.62 | 2.62 | 2.59 | 2.66 | 2.78 | 2.64 |
| Glutamic acid | 12.01 | 11.28 | 14.94 | 12.01 | 12.90 | 12.23 | 15.01 | 12.01 | 12.15 | 12.89 | 13.62 | 12.67 |
| Proline | 3.45 | 3.47 | 3.08 | 3.34 | 3.59 | 3.47 | 2.82 | 3.47 | 3.59 | 3.59 | 3.72 | 3.47 |
| Glycine | 2.71 | 3.21 | 3.35 | 2.84 | 3.21 | 2.86 | 2.10 | 2.91 | 3.00 | 3.45 | 3.49 | 2.68 |
| Alanine | 3.47 | 3.70 | 3.04 | 3.14 | 3.60 | 3.33 | 2.81 | 3.43 | 3.50 | 3.93 | 3.99 | 3.33 |
| Cystine | 0.71 | 0.64 | 0.70 | 0.88 | 1.12 | 0.88 | 1.04 | 0.96 | 1.07 | 0.80 | 0.88 | 0.96 |
| Valine | 1.69 | 2.65 | 2.85 | 3.05 | 3.53 | 3.20 | 3.39 | 3.32 | 3.37 | 2.75 | 2.8 | 3.69 |
| Methionine | 0.52 | 1.01 | 0.88 | 1.14 | 1.34 | 1.16 | 0.70 | 1.10 | 1.23 | 0.90 | 0.99 | 1.30 |
| Isoleucine | 1.81 | 2.41 | 2.32 | 2.89 | 3.32 | 2.99 | 2.81 | 2.97 | 3.10 | 2.53 | 2.65 | 2.78 |
| Leucine | 2.94 | 6.80 | 6.00 | 6.73 | 7.44 | 6.74 | 5.79 | 7.00 | 7.44 | 5.99 | 6.19 | 7.01 |
| Tyrosine | 1.69 | 2.90 | 2.63 | 2.49 | 3.46 | 2.91 | 2.49 | 3.04 | 3.18 | 2.91 | 2.77 | 2.63 |
| Phenylalanine | 3.31 | 3.60 | 3.06 | 4.26 | 4.50 | 4.34 | 3.30 | 4.42 | 4.42 | 3.78 | 3.79 | 4.26 |
| **Anti-nutritional factors** | | | | | | | | | | | | |
| TIA (mg/k) | 6.05 | 2.30 | 7.30 | 7.10 | Trace | Trace | Trace | Trace | 9.40 | 0.90 | 1.20 | 1.15 |
| Reduction in TIA (%) | 60.59 | 85.02 | 52.44 | 53.75 | 100 | 100 | 100 | 100 | 38.76 | 94.14 | 92.18 | 92.51 |
| PA (mg/100 g) | 102.00 | 113.90 | 178.90 | 97.61 | 126.98 | 276.60 | 113.90 | 146.40 | 325 | 66 | 48.8 | 48.6 |
| Reduction in PA (%) | 70.73 | 67.25 | 48.12 | 71.71 | 63.19 | 19.83 | 66.99 | 57.57 | 5.80 | 80.87 | 85.86 | 85.86 |
| UA (∆pH) | 0.06 | 0.09 | 0.02 | 0.06 | 0.06 | 0.18 | 0.04 | 0.16 | 0.07 | 0.09 | 0.03 | 0.04 |
| PSI (%) | 76.20 | 83.40 | 77.40 | 64.80 | 84.85 | 78.12 | 84.81 | 75.43 | 81.95 | 76.44 | 76.65 | 74.6 |

**Table 1.** Contd.

| | |
|---|---|
| *Thermal | T1-Extrusion; T2-Cooking;T3-Toasting;T4-Roasting |
| Fermentation | F1- Lactobaccillus; F2- Cook and ferment; F3- daddawa; F4-Cook and ferment+ potash |
| Alkaline | A1-0 % Alkaline; A2-1% $Na_2CO_3$;A3-1% $K_2CO_3$; A4-1%NaOH |

**TIA: Trypsin inhibitor factor; PA: Phytic acid; UA: Urase assay; PSI: Protein solubility index.

**Table 2.** Effect of different processing methods on the chemical composition of diets and nutrient digestibility in broilers.

| Parameter | T1 | T2 | T3 | T4 | F1 | F2 | F3 | F4 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chemical composition (starter Diets)** | | | | | | | | | | | | |
| DM | 92.69 | 92.87 | 92.73 | 92.72 | 90.47 | 92.78 | 91.40 | 92.05 | 92.10 | 92.10 | 91.30 | 92.42 |
| CP | 22.00 | 21.77 | 23.47 | 20.53 | 22.91 | 22.30 | 22.47 | 20.13 | 21.14 | 21.86 | 23.36 | 23.36 |
| CF | 4.75 | 6.40 | 7.36 | 7.60 | 6.78 | 6.06 | 6.74 | 6.82 | 7.15 | 6.58 | 6.88 | 6.24 |
| EE | 10.48 | 13.40 | 12.72 | 12.11 | 9.88 | 12.01 | 13.50 | 9.48 | 11.75 | 9.52 | 10.32 | 8.86 |
| Ash | 14.75 | 15.19 | 15.10 | 12.55 | 12.79 | 17.25 | 17.76 | 17.21 | 11.49 | 10.55 | 11.20 | 11.25 |
| NFE | 40.71 | 36.11 | 34.08 | 39.93 | 45.60 | 35.08 | 38.53 | 46.36 | 37.57 | 43.59 | 39.49 | 42.71 |
| Ca | 2.24 | 2.48 | 1.76 | 2.94 | 5.39 | 2.26 | 1.35 | 2.89 | 2.23 | 2.93 | 1.70 | 1.35 |
| P | 1.35 | 1.26 | 1.26 | 1.43 | 2.68 | 1.35 | 0.72 | 1.36 | 0.69 | 0.90 | 0.64 | 0.63 |
| **Chemical composition (finisher Diets)** | | | | | | | | | | | | |
| DM | 93.43 | 92.95 | 92.83 | 92.62 | 92.93 | 92.43 | 94.19 | 92.57 | 91.81 | 92.12 | 92.73 | 91.99 |
| CP | 20.83 | 22.99 | 20.12 | 20.41 | 21.23 | 21.66 | 21.06 | 23.24 | 20.44 | 23.63 | 20.56 | 20.62 |
| CF | 7.15 | 5.19 | 6.94 | 7.26 | 5.67 | 6.90 | 6.93 | 5.91 | 7.06 | 7.01 | 7.41 | 6.80 |
| EE | 12.42 | 10.59 | 14.47 | 13.44 | 11.50 | 11.23 | 13.30 | 11.53 | 12.45 | 11.16 | 13.52 | 11.93 |
| Ash | 9.31 | 9.96 | 9.68 | 9.44 | 15.03 | 12.11 | 8.76 | 11.19 | 5.72 | 6.80 | 14.03 | 7.76 |
| NFE | 43.72 | 44.22 | 41.62 | 42.07 | 38.50 | 47.47 | 44.14 | 40.70 | 46.14 | 43.52 | 37.21 | 44.88 |
| Ca | 0.80 | 2.24 | 1.72 | 1.92 | 2.69 | 2.09 | 1.49 | 1.22 | 1.20 | 1.74 | 2.00 | 1.52 |
| P | 0.54 | 1.68 | 0.74 | 0.74 | 0.74 | 1.35 | 0.73 | 0.68 | 0.61 | 0.54 | 1.22 | 0.72 |
| **Nutrient digestibility (Starter)** | | | | | | | | | | | | |
| DM | $71.10^{b}$ | $77.01^{a}$ | $73.42^{ab}$ | $57.50^{c}$ | $83.57^{ab}$ | $81.94^{b}$ | $84.58^{a}$ | $82.28^{b}$ | $69.22^{b}$ | $83.46^{a}$ | $69.77^{b}$ | $74.52^{b}$ |
| CP | 89.11 | 85.94 | 86.07 | 81.24 | 92.91 | 90.73 | 92.51 | 88.84 | 80.63 | 80.96 | 82.50 | 81.39 |
| CF | $60.52^{c}$ | $87.93^{a}$ | $88.06^{a}$ | $83.80^{b}$ | 71.10 | 85.70 | 87.66 | 86.49 | 89.98 | 72.30 | 75.37 | 82.81 |
| EE | 89.42 | 88.83 | 90.25 | 76.71 | 91.81 | 92.11 | 90.38 | 94.84 | 82.79 | 80.27 | 79.15 | 76.30 |
| Ash | 71.72 | 86.04 | 67.75 | 77.67 | 76.05 | 81.56 | 86.74 | 83.12 | 79.58 | 71.25 | 73.41 | 71.49 |
| NFE | 95.90 | 87.23 | 93.50 | 95.89 | 96.62 | 95.20 | 92.83 | 95.33 | 84.45 | 93.78 | 94.18 | 92.17 |
| Ca | 87.63 | 74.98 | 60.11 | 83.31 | 87.56 | 79.81 | 82.12 | 92.43 | 82.30a | 79.45a | 59.81b | 58.28b |
| P | 84.27 | 84.29 | 80.48 | 87.24 | 82.50 | 85.87 | 88.13 | 89.94 | 54.78c | 75.73a | 61.24b | 43.30c |

**Table 2.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nutrient digestibility (Finisher)** | | | | | | | | | | | | |
| DM | 85..01 | 84.91 | 85.00 | 85.10 | 86.91 | 87.08 | 87.11 | 87.08 | 82.29 | 82.44 | 82.38 | 82.43 |
| CP | 83.03 | 83.62 | 81.86 | 81.72 | 85.91 | 87.07 | 86.55 | 85.91 | 80.62 | 79.26 | 80.96 | 75.10 |
| CF | 67.88 | 70.00 | 69.87 | 78.63 | 72.12 | 77.25 | 72.04 | 68.14 | 72.16 | 83.19 | 65.52 | 74.17 |
| EE | 92.80 | 95.70 | 95.82 | 95.36 | 95.58 | 95.64 | 95.35 | 95.73 | 94.62 | 93.32 | 95.06 | 94.63 |
| Ash | 65.53 | 58.83 | 34.07 | 58.49 | 68.30 | 67.01 | 60.66 | 67.32 | 18.90 | 44.50 | 67.55 | 40.34 |
| NFE | 93.14 | 93.16 | 92.45 | 88.28 | 91.77 | 97.18 | 96.53 | 96.35 | 85.97 | 85.49 | 88.54 | 94.83 |
| Ca | 97.52 | 78.41 | 62.67 | 78.58 | 76.54 | 79.63 | 84.12 | 69.57 | 40.20 | 73.56 | 73.60 | 56.54 |
| P | 68.40 | 70.68 | 68.69 | 75.81 | 76.84 | 89.93 | 79.13 | 65.80 | 55.56 | 46.50 | 80.85 | 67.03 |

$^{abc}$Means with the same superscripts on the same row are not significantly different (p>0.05); SEM: Standard error of mean.

**Table 3.** Effect of different processing methods on the performance parameters and cost implications of broilers.

| Performance parameter | T1 | T2 | T3 | T4 | F1 | F2 | F3 | F4 | A1 | A2 | A3 | A4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Starter phase** | | | | | | |
| IBW | 47.67 | 40.67 | 44.33 | 45.00 | 42.67 | 40.33 | 40.00 | 40.33 | 42.67 | 40.33 | 40 | 39 |
| ABW | 537.6 | 642.37 | 582.8 | 514.67 | 535.20$^{c}$ | 749.30$^{a}$ | 709.33$^{b}$ | 710.80$^{b}$ | 423.13 | 429.2 | 494.67 | 501.33 |
| FI (g) | 374.00$^{a}$ | 490.67$^{a}$ | 415.67$^{b}$ | 260.67$^{c}$ | 693.00$^{ab}$ | 607.67$^{c}$ | 730.00$^{a}$ | 629.00$^{bc}$ | 373.00$^{b}$ | 661.33$^{a}$ | 371.00$^{b}$ | 425.00$^{b}$ |
| ABWG(g) | 210.33$^{b}$ | 285.33$^{a}$ | 279.67$^{a}$ | 186.67$^{b}$ | 244.00$^{b}$ | 264.33$^{b}$ | 370$^{a}$ | 255.33$^{b}$ | 121.33 | 144.33 | 153 | 120.33 |
| FCR | 1.78$^{c}$ | 1.72$^{bc}$ | 1.49$^{ab}$ | 1.41$^{a}$ | 2.84$^{b}$ | 2.31$^{a}$ | 2.04$^{a}$ | 2.48$^{ab}$ | 3.06$^{ab}$ | 4.63$^{c}$ | 2.45$^{a}$ | 3.55$^{b}$ |
| PER | 2.56$^{a}$ | 2.67$^{a}$ | 2.87$^{a}$ | 3.50$^{b}$ | 1.54$^{a}$ | 1.95$^{ab}$ | 2.27$^{b}$ | 2.03$^{ab}$ | 1.55$^{bc}$ | 1.00$^{a}$ | 1.76$^{c}$ | 1.22$^{ab}$ |
| EER | 17.77$^{a}$ | 19.24$^{a}$ | 19.57$^{a}$ | 24.31$^{b}$ | 10.29$^{b}$ | 13.84$^{ab}$ | 15.93$^{a}$ | 12.71$^{ab}$ | 11.32$^{a}$ | 6.41$^{b}$ | 12.48$^{a}$ | 8.78$^{b}$ |
| Survl (%) | 95.33 | 95.33 | 94.00 | 94.00 | 97.00 | 96.67 | 97.00 | 95.33 | 97.00 | 97.67 | 97.00 | 98.00 |
| P Index | 112.88$^{b}$ | 158.58$^{a}$ | 177.07$^{a}$ | 125.89$^{b}$ | 81.91$^{b}$ | 111.25$^{b}$ | 188.96$^{a}$ | 100.29$^{b}$ | 38.17$^{b}$ | 31.03$^{b}$ | 61.59$^{a}$ | 33.55$^{b}$ |
| | | | | | | **Finisher phase** | | | | | | |
| IBW | 537.6 | 642.37 | 582.8 | 514.67 | 535.20$^{c}$ | 749.30$^{a}$ | 709.33$^{b}$ | 710.80$^{b}$ | 423.13 | 429.2 | 494.67 | 501.33 |
| ABW | 1853.33$^{b}$ | 2127.50$^{a}$ | 2197.50$^{a}$ | 1645.00$^{c}$ | 2029.17$^{ab}$ | 2220,83$^{ab}$ | 2425.00$^{a}$ | 1526.67$^{c}$ | 1366.67$^{b}$ | 1529.33$^{ab}$ | 1614.33$^{a}$ | 1422.10$^{ab}$ |
| FI (g) | 844.00$^{a}$ | 902.33$^{a}$ | 894.00$^{a}$ | 648.33$^{ab}$ | 1315.33$^{ab}$ | 1257.33$^{b}$ | 1451.67$^{a}$ | 1314.33$^{ab}$ | 984.33$^{ab}$ | 928.00$^{b}$ | 1140.67 | 1144.67$^{a}$ |
| ABWG(g) | 466.67$^{a}$ | 424.33$^{a}$ | 436.67$^{a}$ | 337.33$^{b}$ | 383.33$^{b}$ | 438.67$^{b}$ | 661.00$^{a}$ | 422.33$^{b}$ | 285.00$^{bc}$ | 329.67$^{a}$ | 303.33$^{ab}$ | 249.67$^{c}$ |
| FCR | 1.81 | 2.13 | 2.05 | 1.97 | 3.44$^{b}$ | 2.90$^{ab}$ | 2.20$^{a}$ | 3.24$^{b}$ | 3.46$^{a}$ | 2.83$^{a}$ | 3.75$^{ab}$ | 4.62$^{b}$ |
| PER | 2.66$^{c}$ | 2.05$^{a}$ | 2.43$^{ab}$ | 2.55$^{ab}$ | 1.37$^{c}$ | 1.62$^{ab}$ | 2.17$^{b}$ | 1.39a$^{b}$ | 1.43$^{b}$ | 1.51$^{b}$ | 1.30$^{ab}$ | 1.07$^{a}$ |
| EER | 18.64$^{a}$ | 20.72$^{a}$ | 13.88$^{b}$ | 14.09$^{b}$ | 9.74$^{b}$ | 11.5$^{ab}$ | 13.24$^{a}$ | 9.4$^{b}$ | 8.40$^{b}$ | 10.73$^{a}$ | 7.79$^{b}$ | 6.79$^{b}$ |
| Survl (%) | 98.93$^{a}$ | 98.67$^{a}$ | 99.00$^{a}$ | 97.33$^{b}$ | 95.00$^{ab}$ | 96.00$^{a}$ | 93.33$^{b}$ | 96.00$^{a}$ | 97.67 | 97 | 98.67 | 98.33 |
| P Index | 255.86$^{a}$ | 196.39$^{ab}$ | 211.48$^{a}$ | 175.02$^{b}$ | 106.60$^{b}$ | 149.16$^{b}$ | 282.68$^{a}$ | 135.79$^{b}$ | 81.63$^{b}$ | 114.04$^{a}$ | 80.00$^{b}$ | 54.08$^{b}$ |

**Table 3.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Cost implication** | | | | | | | |
| **feed cost** | 71.10$^{b}$ | 77.01$^{a}$ | 73.42$^{ab}$ | 57.50$^{c}$ | 21,393.00 | 21,538.20 | 24,739.20 | 21,858.00 | 69.22$^{b}$ | 83.46$^{a}$ | 69.77$^{b}$ | 74.52$^{b}$ |
| **Income** | 89.11 | 85.94 | 86.07 | 81.24 | 92.91 | 50,853.00 | 57,387.00 | 60,142.50 | 38,709.0 | 80.96 | 82.50 | 81.39 |
| **Cost/benefit ratio** | 60.52c | 87.93a | 88.06a | 83.80b | 71.10 | 85.70 | 87.66 | 86.49 | 89.98 | 72.30 | 75.37 | 82.81 |

$^{abc}$Means with the same superscripts on the same row are not significantly different (p>0.05); SEM: Standard error of mean; IBW: Initial body weight; ABW: Average body weight; FI- Feed intake; ABWG: Average body weight gain; FCR: Feed conversion ratio; PER: Protein efficiency ratio; EER: Energy efficiency ratio; Survl (%): Survival percentage; P Index: Performance index

**Table 4.** Effect of different processing methods on carcass characteristics, organ morphology, cooking yield and serum profile.

| Carcass characteristics | Thermal | | | | Fermentation | | | | Alkaline | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T1** | **T2** | **T3** | **T4** | **F1** | **F2** | **F3** | **F4** | **A1** | **A2** | **A3** | **A4** |
| Live weight (g) | 1853.3$^{b}$ | 2400.0$^{a}$ | 2462.7$^{a}$ | 1933.3$^{b}$ | 2776.0 | 2833.0 | 2833.0 | 2500.0 | 160.0$^{c}$ | 195.0$^{b}$ | 226.67$^{a}$ | 190.00$^{b}$ |
| Pluck weight (g) | 2162.7$^{a}$ | 2172.70$^{a}$ | 2263.30$^{a}$ | 1810.00$^{b}$ | 262.30 | 267.03 | 271.00 | 228.30 | 189.67$^{b}$ | 156.00$^{c}$ | 220.67$^{a}$ | 185.0$^{bc}$ |
| Pluck percentage (g) | 94.19 | 90.77 | 91.81 | 93.75 | 94.43 | 94.25 | 95.72 | 91.61 | 97.20 | 97.57 | 97.23 | 97.36 |
| Eviscerated weight (g) | 210.00$^{a}$ | 187.67$^{ab}$ | 203.33$^{a}$ | 158.67$^{b}$ | 165.67$^{b}$ | 209.00$^{a}$ | 213.33$^{a}$ | 171.67$^{b}$ | 163.7$^{ab}$ | 125.0$^{bc}$ | 186.67$^{a}$ | 116.67$^{c}$ |
| Head (%) | 0.98 | 1.01 | 1.01 | 1.10 | 0.81 | 0.90 | 0.85 | 0.86 | 1.50 | 0.96 | 1.02 | 0.93 |
| Neck (%) | 1.87$^{b}$ | 1.48$^{b}$ | 2.34$^{a}$ | 2.22$^{ab}$ | 1.38$^{b}$ | 2.03$^{a}$ | 1.44$^{b}$ | 1.50$^{b}$ | 2.01$^{a}$ | 1.67$^{ab}$ | 1.80$^{ab}$ | 1.38$^{b}$ |
| Wing (%) | 3.05 | 1.77 | 2.56 | 2.99 | 2.87$^{b}$ | 2.99$^{ab}$ | 2.67$^{b}$ | 3.37$^{a}$ | 3.35$^{a}$ | 3.17$^{a}$ | 3.29$^{a}$ | 2.10$^{b}$ |
| Breast (%) | 6.92$^{ab}$ | 3.71$^{b}$ | 8.64$^{ab}$ | 9.54$^{a}$ | 7.04$^{c}$ | 9.34$^{a}$ | 8.81$^{ab}$ | 8.41$^{b}$ | 9.17$^{a}$ | 9.17$^{a}$ | 9.20$^{a}$ | 7.00$^{b}$ |
| **Organ morphology** | | | | | | | | | | | | |
| Intestine (g) | 1.99 | 1.48 | 1.43 | 2.21 | 1.64$^{a}$ | 1.67$^{a}$ | 1.39$^{b}$ | 0.86$^{c}$ | 2.22$^{b}$ | 3.15$^{a}$ | 2.55$^{b}$ | 2.29$^{b}$ |
| Lungs (g) | 0.28$^{ab}$ | 0.81$^{a}$ | 0.43$^{ab}$ | 0.11$^{b}$ | 0.14 | 0.20 | 0.13 | 0.20 | 0.11$^{b}$ | 0.11$^{b}$ | 0.18$^{a}$ | 0.10$^{b}$ |
| Liver (g) | 0.74$^{ab}$ | 1.02$^{a}$ | 0.86$^{ab}$ | 0.65$^{b}$ | 0.78$^{a}$ | 0.66$^{b}$ | 0.53$^{c}$ | 0.66$^{b}$ | 0.92$^{a}$ | 0.65$^{b}$ | 0.73$^{b}$ | 0.63$^{b}$ |
| Hearts (g) | 0.44$^{ab}$ | 0.82$^{a}$ | 0.37$^{ab}$ | 0.21$^{b}$ | 0.20 | 0.23 | 0.08 | 0.22 | 0.27$^{a}$ | 0.15$^{b}$ | 0.23$^{ab}$ | 0.18$^{ab}$ |
| Kidney (g) | 0.02$^{b}$ | 0.64$^{a}$ | 0.01$^{b}$ | 0.01$^{b}$ | 0.03 | 0.13 | 0.03 | 0.03 | 0.03 | 0.01 | 0.02 | 0.02 |
| Spleen (g) | 0.18 | 0.35 | 0.35 | 0.04 | 0.04 | 0.14 | 0.02 | 0.03 | 0.03 | 0.01 | 0.02 | 0.02 |
| Gizzard (g) | 1.38$^{a}$ | 1.12$^{b}$ | 1.04$^{b}$ | 1.10$^{b}$ | 1.13$^{a}$ | 0.92$^{ab}$ | 0.62$^{b}$ | 0.79$^{b}$ | 1.94$^{a}$ | 0.01$^{b}$ | 1.21$^{a}$ | 0.88$^{a}$ |
| Gall bladder (g) | 1.16 | 0.33 | 0.18 | 0.04 | 0.04 | 0.13 | 0.01 | 0.10 | 0.11$^{b}$ | 0.90$^{a}$ | 0.19$^{b}$ | 0.04$^{b}$ |
| Abdominal fat (g) | 0.51$^{a}$ | 0.85$^{b}$ | 0.91$^{b}$ | 0.81$^{b}$ | 0.39 | 0.41 | 0.15 | 0.44 | 0.96$^{a}$ | 0.25$^{b}$ | 0.85$^{a}$ | 0.36$^{b}$ |
| Crop oesophagus (g) | 10.33$^{a}$ | 4.93$^{b}$ | 14.00$^{a}$ | 10.00$^{ab}$ | 12.33$^{b}$ | 5.17$^{c}$ | 16.67$^{a}$ | 4.50$^{c}$ | 12.30$^{a}$ | 7.83$^{d}$ | 10.67$^{b}$ | 9.43$^{c}$ |
| Proventiculus (g) | 0.60$^{ab}$ | 1.63$^{a}$ | 0.61$^{ab}$ | 0.30$^{b}$ | 0.50 | 0.50 | 0.23 | 0.45 | 0.50$^{a}$ | 0.17$^{c}$ | 0.39$^{ab}$ | 0.30$^{bc}$ |
| Duodenum fold length (cm) | 12.17$^{b}$ | 23.33$^{a}$ | 14.73$^{ab}$ | 10.00$^{b}$ | 14.50$^{b}$ | 16.00$^{b}$ | 17.67$^{a}$ | 16.00$^{b}$ | 14.67$^{a}$ | 9.17$^{c}$ | 13.67$^{b}$ | 13.67$^{b}$ |
| Duodenum width (cm) | 4.13$^{b}$ | 18.67$^{a}$ | 4.40$^{b}$ | 1.99$^{b}$ | 2.97$^{a}$ | 2.92$^{a}$ | 1.50$^{b}$ | 2.68$^{a}$ | 3.50 | 2.63 | 2.97 | 5.90 |
| Jejunum width (cm) | 12.65$^{ab}$ | 24.00$^{a}$ | 3.20$^{b}$ | 0.99$^{b}$ | 2.57$^{a}$ | 2.15$^{ab}$ | 1.68$^{b}$ | 2.04$^{ab}$ | 3.40$^{a}$ | 2.13$^{b}$ | 2.73$^{ab}$ | 2.30$^{b}$ |
| Ileum length (cm) | 2.16 | 7.80 | 1.74 | 1.47 | 2.11$^{a}$ | 1.90$^{ab}$ | 1.08$^{c}$ | 1.68$^{b}$ | 1.09$^{d}$ | 1.76$^{b}$ | 1.63$^{c}$ | 1.91$^{a}$ |
| Ceacum Length (cm) | 18.67 | 15.03 | 18.50 | 15.27 | 23.17 | 26.17 | 21.00 | 24.00 | 21.00 | 19.00 | 18.67 | 21.00 |
| Ceacum width (cm) | 4.34 | 2.13 | 5.50 | 2.67 | 3.83 | 3.33 | 6.67 | 3.33 | 4.33$^{a}$ | 1.73$^{c}$ | 3.38$^{b}$ | 2.43$^{c}$ |

**Table 4.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Small intestine (cm) | 61.67$^{a}$ | 43.73$^{ab}$ | 44.33$^{ab}$ | 18.60$^{b}$ | 70.00 | 86.67 | 66.67 | 70.00 | 25.00$^{a}$ | 9.50$^{b}$ | 11.83$^{b}$ | 10.00$^{b}$ |
| Colo-recticulum length (cm) | 11.67$^{a}$ | 4.57$^{b}$ | 14.93$^{a}$ | 10.67$^{ab}$ | 12.43 | 13.00 | 16.00 | 12.50 | 11.00$^{a}$ | 7.33$^{d}$ | 13.00$^{a}$ | 9.33$^{c}$ |
| Colo-recticulum width (cm) | 2.10$^{b}$ | 1.47$^{b}$ | 3.23$^{a}$ | 1.93$^{b}$ | 2.70 $^{a}$ | 1.57 $^{b}$ | 2.90 $^{a}$ | 2.07 $^{ab}$ | 2.33$^{b}$ | 10.20$^{ab}$ | 2.17$^{b}$ | 12.67$^{d}$ |
| Colo-gizzard length (cm) | 27.60$^{a}$ | 18.97$^{c}$ | 21.10$^{b}$ | 19.77$^{bc}$ | 25.10 $^{a}$ | 24.33 $^{ab}$ | 19.83 $^{c}$ | 20.53 $^{bc}$ | 22.37$^{b}$ | 20.50$^{c}$ | 19.07$^{d}$ | 23.50$^{a}$ |
| Intestine (g) | 1.99 | 1.48 | 1.43 | 2.21 | 1.64$^{a}$ | 1.67 $^{a}$ | 1.39 $^{b}$ | 0.86 $^{c}$ | 2.22$^{b}$ | 3.15$^{a}$ | 2.55$^{b}$ | 2.29$^{b}$ |
| **Cooking yield and loss** | | | | | | | | | | | | |
| Cooking yield | 55.98$^{a}$ | 55.53$^{ab}$ | 53.33$^{b}$ | 53.02$^{b}$ | 63.25$^{a}$ | 64.77$^{a}$ | 63.57$^{a}$ | 60.25$^{b}$ | 53.63$^{a}$ | 53.59$^{a}$ | 53.05$^{a}$ | 51.32$^{b}$ |
| Cooking loss | 44.02$^{a}$ | 44.47$^{ab}$ | 46.67$^{b}$ | 46.98 | 36.75 $^{a}$ | 35.23$^{a}$ | 36.43$^{a}$ | 39.75$^{b}$ | 46.37 $^{a}$ | 46.41$^{a}$ | 46.95$^{a}$ | 48.68$^{b}$ |
| **Serum profile** | | | | | | | | | | | | |
| Urea (mmn/1) | 3.55$^{a}$ | 3.33$^{a}$ | 3.43$^{a}$ | 2.13$^{b}$ | 2.83$^{b}$ | 2.83$^{b}$ | 2.07$^{c}$ | 3.00$^{a}$ | 3.0$^{a}$ | 2.17$^{c}$ | 2.73$^{b}$ | 2.27$^{c}$ |
| Cholesterol (mmn/1) | 2.57$^{b}$ | 2.27$^{c}$ | 2.83$^{a}$ | 2.27$^{c}$ | 2.70 | 2.80 | 2.97 | 2.87 | 2.17$^{d}$ | 3.13$^{b}$ | 3.47$^{a}$ | 2.43$^{c}$ |
| Creatine (mn/1) | 122.67$^{a}$ | 111.33$^{b}$ | 122.67$^{a}$ | 97.33$^{c}$ | 85.33 $^{a}$ | 98.67 $^{b}$ | 85.33 $^{a}$ | 115.33 $^{a}$ | 102.00$^{a}$ | 83.33$^{b}$ | 82.33$^{b}$ | 89.00$^{ab}$ |
| Packed Cell Volume (PCV) | 32.67$^{a}$ | 31.33$^{a}$ | 32.33$^{a}$ | 28.33$^{b}$ | 29.33 $^{b}$ | 32.33 $^{a}$ | 25.33 $^{a}$ | 27.33$^{c}$ | 30.67 | 30.33 | 31.00 | 25.67 |

$^{abc}$Means with the same superscripts on the same row are not significantly different ($p>0.05$) SEM: Standard error of mean.

**Table 5.** Overall scoring of parameters measured in the different thermal processing methods of soyabeans.

| Parameter | Thermal processing methods | | | |
|---|---|---|---|---|
| | Extrusion | Cooking | Toasting | Roasting |
| Chemical composition of soyabean seed | 3 | 1 | 4 | 2 |
| Amino acid profile of test soya beans | 3 | 1 | 4 | 2 |
| Anti-nutritional factor analysis | 2 | 1 | 4 | 3 |
| Chemical composition of starter diets | 1 | 2 | 3 | 4 |
| Chemical composition of finisher diets | 3 | 1 | 2 | 1 |
| Nutrient digestibility starter | 1 | 2 | 3 | 4 |
| Nutrient digestibility finisher | 3 | 1 | 4 | 2 |
| Performance traits starter | 2 | 1 | 3 | 4 |
| Performance traits finisher | 2 | 3 | 1 | 4 |
| Carcass characteristics | 1 | 4 | 3 | 2 |
| Organ morphology | 4 | 1 | 3 | 2 |
| Cooking yields and loss | 1 | 2 | 3 | 4 |
| Serum profile | 1 | 3 | 2 | 4 |
| Economics | 3 | 2 | 2 | 4 |
| Means | 2.1 | 1.8 | 2.93 | 3.0 |
| Score | 2 | 1 | 3 | 4 |

1 = Fair; 2 = Good; 3 = Better; 4 = Best mean.

**Table 6.** Overall scoring of parameters measured in the different fermentation methods of soyabeans.

| Parameter | Fermentation method | | | |
|---|---|---|---|---|
| | Lactobacillus | Cook and ferment | Daddawa | Cook + potash and ferment |
| Chemical composition of soyabean seed | 2 | 1 | 3 | 4 |
| Amino acid profile of test soya beans | 1 | 3 | 4 | 2 |
| Anti-nutritional factor analysis | 1 | 3 | 2 | 4 |
| Chemical composition of starter diets | 1 | 2 | 3 | 3 |
| Chemical composition of finisher diets | 2 | 3 | 1 | 1 |
| Nutrient digestibility starter | 3 | 4 | 1 | 2 |
| Nutrient digestibility finisher | 3 | 1 | 2 | 4 |
| Performance traits starter | 2 | 3 | 1 | 4 |
| Performance traits finisher | 4 | 3 | 1 | 2 |
| Carcass characteristics | 4 | 1 | 2 | 3 |
| Organ morphology | 2 | 1 | 3 | 4 |
| Cooking yields and loss | 3 | 1 | 2 | 4 |
| Serum profile | 1 | 1 | 3 | 2 |
| Economics | 3 | 1 | 2 | 4 |
| Means | 2.3 | 2.0 | 2.1 | 3.1 |
| Score | 3 | 1 | 2 | 4 |

1 = Fair; 2 = Good; 3 = Better; 4 = Best mean.

**Table 7.** Overall scoring of parameters measured in the different alkaline treatment of soyabeans.

| Parameter | Alkaline treatment | | | |
|---|---|---|---|---|
| | 0 % Alkaline | 1% $Na_2CO_3$ | 1% $K_2CO_3$ | 1%NaOH |
| Chemical composition of soyabean seed | 2 | 1 | 3 | 1 |
| Amino acid profile of test soya beans | 2 | 4 | 1 | 3 |
| Anti-nutritional factor analysis | 4 | 1 | 3 | 2 |
| Chemical composition of starter diets | 4 | 1 | 2 | 3 |
| Chemical composition of finisher diets | 2 | 3 | 1 | 4 |
| Nutrient digestibility starter | 2 | 3 | 1 | 3 |
| Nutrient digestibility finisher | 4 | 3 | 1 | 2 |
| Performance traits starter | 4 | 1 | 3 | 2 |
| Performance traits finisher | 3 | 3 | 1 | 2 |
| Carcass characteristics | 1 | 3 | 2 | 4 |
| Organ morphology | 3 | 2 | 1 | 4 |
| Cooking yields and loss | 1 | 2 | 3 | 4 |
| Serum profile | 1 | 2 | 1 | 2 |
| Economics | 3 | 2 | 1 | 4 |
| Means | 2.6 | 2.2 | 1.7 | 2.9 |
| Score | 3 | 2 | 1 | 4 |

1 = Fair; 2 = Good; 3 = Better; 4 = Best mean.

investment.

The results obtained from the use of different alkaline salts in this experiment confirmed the advantages associated with alkaline treatment in the nutritional improvement of soya beans for broiler utilization (Omoeti et al., 1992; Ayanwale, 1999; Aregheore et al., 2003).

Although the results of the various chemical analysis performed on both the alkaline treated soya beans seeds and alkaline treated soya beans based diets and other performance parameters were better in the sodium carbonate treated group, biological assay using performance traits measurements of the broilers and other indices like economic benefit and cost analysis cumulatively placed the 1% potassium carbonate ($K_2CO_3$)

**Table 8.** Overall scoring of parameters measured in the comparative evaluation of the best processing methods in thermal, fermentation and alkaline processing of soyabeans.

| Parameter | Processing methods | | |
|---|---|---|---|
| | Thermal- cooking | Fermentation-cook and ferment | Alkaline-1% potash |
| Chemical composition of soyabean seed | 1 | 3 | 2 |
| Amino acid profile of test soya beans | 3 | 2 | 1 |
| Anti-nutritional factor analysis | 2 | 1 | 2 |
| Chemical composition of starter diets | 2 | 1 | 2 |
| Chemical composition of finisher diets | 2 | 3 | 1 |
| Nutrient digestibility starter | 2 | 1 | 3 |
| Nutrient digestibility finisher | 2 | 1 | 3 |
| Performance traits starter | 2 | 1 | 3 |
| Performance traits finisher | 2 | 1 | 3 |
| Carcass characteristics | 3 | 2 | 1 |
| Organ morphology | 1 | 3 | 2 |
| Cooking yields and loss | 2 | 1 | 3 |
| Serum profile | 3 | 2 | 3 |
| Economics | 3 | 2 | 1 |
| Means | 2.1 | 1.7 | 2.1 |
| Score | 2 | 1 | 2 |

1 = Fair; 2 = Good; 3 = Better; 4 = Best mean.

group as the overall best in the alkaline processing experiment.

The relative poor results associated with the sodium hydroxide treatment of soya beans may be associated with the type and possibly the strength of the alkaline salt which led to mineral and nutrient chelating as earlier reported by Ayanwale (1999) and leaching of nutrients (Ku et al., 1976) as well as reduction in nutritional value and bioavailability.

The overall ranking for the selection of the best processing method among the different processing methods experimented on is presented in Table 4. The ranking in this table summarized the pooled ranks of best means of the three selected experimental bests (cooking for thermal processing, cook and ferment for fermentation methods and 1% potassium carbonate ($K_2CO_3$) for the alkaline treatment) as described in the research methodology.

Although the three selected processes presented good nutrient profile, 1% potassium carbonate ($K_2CO_3$) was scored best in terms of nutrient composition as indicated in Table 1. This confirmed that biological assay rather than chemical analysis was the best assessor of nutrient quality in any feed ingredient required for broilers, since nutrient mobilization and utilization was found to be best in the cook and ferment group.

The outstanding score of the cook and ferment group in the removal of anti-nutritional factors especially trypsin inhibitor activity confirmed the superiority of fermentation in the removal of ANFs as earlier documented by Fagbemi et al. (2005) who stated that fermentation was the most effective processing method that drastically reduced phytic acid and trypsin inhibitor activity in oilseeds. This view was also shared by Doell et al. (1981) whose examination of some traditional oriental soya foods revealed that most of the TIA had been removed or inactivated during fermentation processing and the rest were further removed through cooking. Phytic acid reduction has also been reported in fermented soya beans by Sudarmadji and Markakis (1977) and Sutardi and Buckle (1985).

The best scores observed in the cook and ferment group when compared with the other groups in nutrient digestibility, performance parameters such as average weight gain, feed conversion ratio, protein efficiency ratio and performance index among others in both the starter and finisher phases observed in this comparative evaluation was supported by Roozen and De Groot (1985), Matsui (1996), Caine et al. (1998), Ayanwale and Kolo (2001) and Barde and Ari (2004) who reported that fermentation provided a major means of nutritional improvement of feedstuff for utilization by farm animals.

The emergence of the cook and ferment group as the overall best in spite of similarities or even better performance in some trails measured confirmed that fermentation process converts food compounds into structurally related but financially more viable food through the activities of microbial cells as reported by Stanbury and Whitaker (1984).

## Conclusions

The findings of this study revealed that significant variations in the effect of different thermal, fermentation and alkaline processing methods on the chemical composition, amino acid profile, ANFs removal and the performance of broilers. The best performance recorded in the cooking group confirmed hydrothermal processing of soya beans as the best thermal processing method that will guarantee the preservation of essential nutrients and removal of ANFs for greater performance of broilers, while the poor performance recorded in the roasting group confirmed the process as not an ideal soya bean processing method for broiler feeds. The cook and ferment group presented the best performance recorded under fermentation process. However, controlled fermentation using selected culture organisms (*Lactobacilus bulgricus, Saccharomyces cerevisiae* and *Streptococcus lactis*) helps in the improvement and preservation of nutrient quality without necessarily impacting better performance of broilers than uncontrolled fermentation processes. The use of potassium carbonate (1% $K_2CO_3$) and sodium carbonate (1% $Na_2CO_3$) in the processing of soya bean recorded greater improvement in the removal of ANFs and preservation of nutrient quality, gave better performance traits, serum profile and economic returns. These factors accounted for the best performance recorded in 1% $K_2CO_3$ treatment of soya beans when compared with other alkaline treatment methods investigated in this study.

The comparative evaluation of all the processing methods showed that cook and ferment group was the overall best in spite of similarities or even better performance in some traits measured when compared with the other methods. The potentials of this processing method in the preservation of essential nutrients, better performance of broilers and yield of greater economic returns on investment observed in this comparative evaluation has confirmed that fermentation process converts food compounds into structurally related but financially more viable food through the activities of microbial organisms. Thus, the qualitative tool used to arrive at this decision has provided the farmer an aggregated selection criterion for choosing the right processing method to adopt for optimum benefit.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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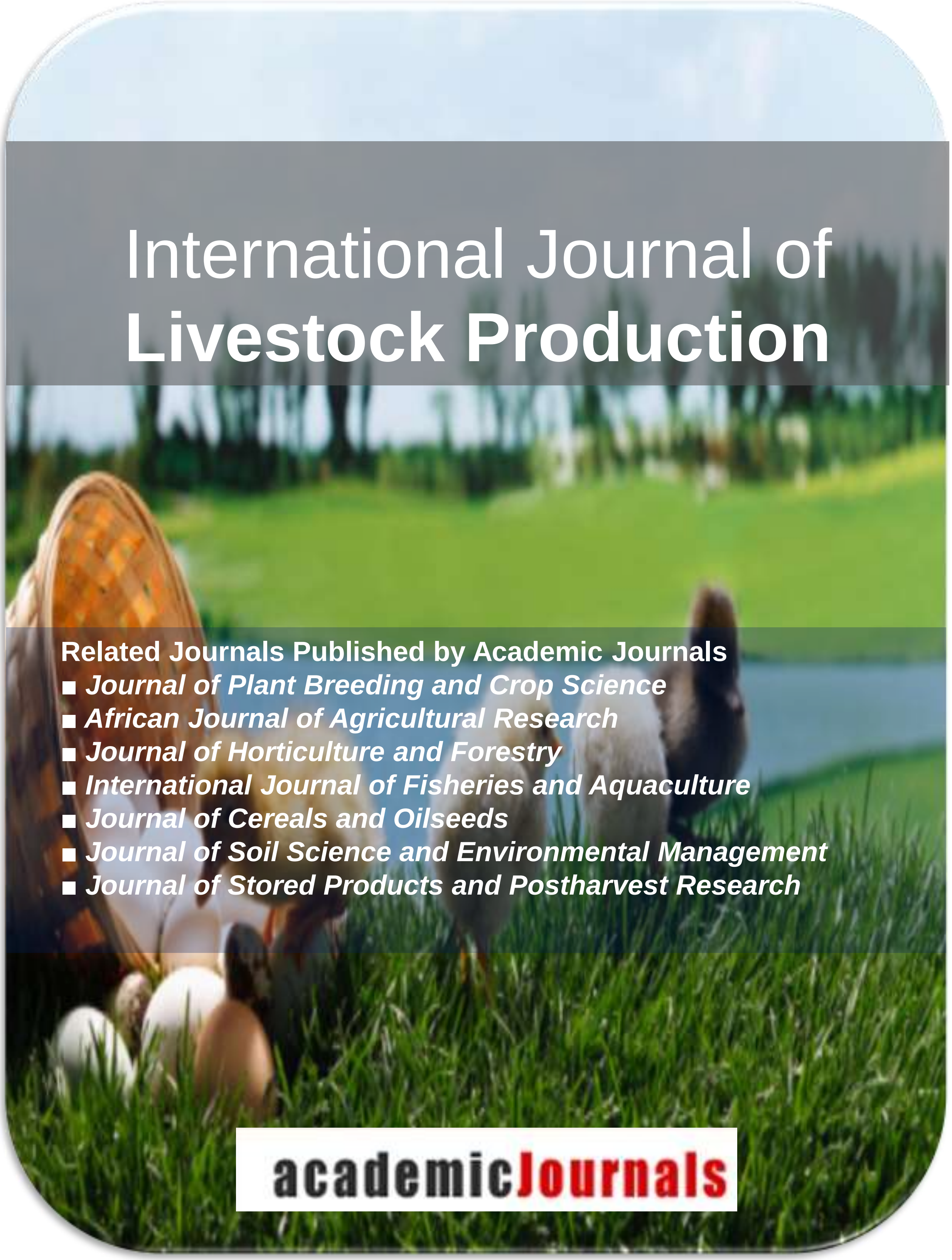

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