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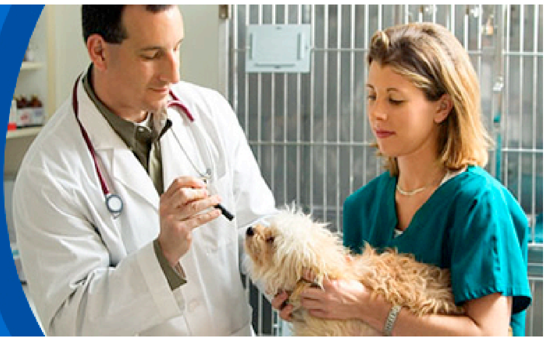

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Development of bio-economic models and application to indigenous chicken production systems in south Sudan

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Abstract
The profitability of indigenous chickens (IC) reared in different production systems in South Sudan was evaluated using a bio-economic model. Three production systems considered were free-range system (FRS), where chickens foraged for feed through scavenging without any form of supplementation; intensive system (IS), in which chickens were housed and fed with limited feeds and healthcare; and semi-intensive system (SIS), where chickens were confined but allowed to scavage within runs where supplementary rationed feeds were provided. The revenues in South Sudanese Pounds (SSP) came from sells of eggs not selected for incubation, surplus growers not retained for flock replacement and culled birds. The costs accrued from brooding of chicks, feeding, labour, veterinary services and marketing. The total costs and revenues were SSP 19437.0 and SSP 22322.9 for FRS, SSP 123462.5 and SSP 33239.59 for SIS and SSP 163916.5 and SSP 59,059.4 for IS, giving profits of SSP 2885.9, SSP -90222 and SSP -104857.1, respectively. The results indicated that utilisation of IC under FRS is more profitable when compared to SIS and IS of production.

Keywords: Management system, poultry, productivity, profitability

1. Introduction

Small-scale indigenous chicken production is practiced by majority of farmers in rural areas of most developing countries and are reared under free-range and semi-intensive production systems (Besbes *et al.*, 2012) [2]. Among local poultry, indigenous chickens account for 80% of the total population in developing countries and forms an important part of socio-economic well-being of poor households (Halimariam *et al.*, 2010; Hailu, 2019) [5, 6]. They are very important in provision of animal protein in terms of eggs and meat to the rural households (Mohanta *et al.*, 2018) [19]. Indigenous chicken also help in diversification of household diets, incomes, act as a bank and insurance and help to improve the resilience of their livelihoods. The birds are easily converted into cash for acquisition of food, medicine and other essential household needs, and they significantly contributed to the religious and socio-cultural life of most communities (Kingori *et al.*, 2010; Kryger *et al.*, 2010; Okeno *et al.*, 2012) [9, 10, 24].

Indigenous chicken production experiences numerous constraints such as lack of feeds, disease, poor genetic potential for eggs and meat production, inappropriate housing, poorly developed marketing channels and lack of well-defined breeding objectives. These factors significantly limit the contribution of IC to the livelihoods of rural households (Magothe *et al.*, 2010; Okeno *et al.*, 2013; Mahoro *et al.*, 2017) [12, 25, 14]. Despite these constraints, IC possess great genetic diversity for growth, egg production and adaptation traits. Ngeno (2011) [22] found that their exists variation in body weight at various ages among IC ecotypes in Kenya. Muasya *et al.*, (2015) [21], reported sexual dimorphism for body weight at 12 weeks of age in IC. The study by Muasya et al. (2015) also demonstrated a genetic gain of 56g in BW12 after one round of selection. Nicknafs *et al.* (2013) [23] reported gain of 4.78g. Meanwhile Larivière *et al.* (2009) [11] reported average gain of 518.9g and 362.48 g for males and females in three generation, respectively. The existence of such high genetic diversity imply that selection can be successfully employed to improve performance of IC.

Well defined breeding objectives are a key pre-requisite to implementation of successful genetic improvement because it provides the set as well as the relative importance of traits to select for (Åby *et al.*, 2012; Wolc *et al.*, 2011) [1, 28]. In development breeding objectives, traits that have influence on the costs and income in a given system of production are identified (Okeno *et al.*, 2012) [24]. When developing the breeding objective, the production conditions and economic environment within which the animals are reared are a key consideration (Okeno *et al.*, 2013; Mbuthia *et al.*, 2015) [25, 16]. The complexity and variation in management, climatic and economic conditions under which IC are raised developing countries hinder the development of general breeding objectives. Under such circumstances, bio-economic models provide a production system-specific biological and economic aspects (Åby *et al.*, 2012) [1]. Such models are used to estimate economic values for traits of economic importance and evaluate profitability of IC in different production systems (Menge *et al.*, 2005; Okeno *et al.*, 2013; Henning *et al.*, 2013; Mahoro *et al.*, 2018) [17, 25, 7, 15], pigs (Mbuthia *et al.*, 2015) [15], sheep (Gebre *et al.*, 2012) [4], beef cattle (Rewe *et al.*, 2006) [27] and dairy cattle (Åby *et al.*, 2012) [1]. In South Sudan similar studies are not available and therefore a bio-economic model that incorporates the productive and functional traits under the prevailing production circumstances should be developed and applied. Therefore, the aim of this study was to develop and apply a bio economic model to evaluate the profitability of IC production systems in South Sudan.

2. Material and Methods

2.1 Description of the bio-economic model

In the present study, a bio-economic model was designed and applied to evaluate the economic and biological characteristics of production systems for IC in South Sudan. Table 1 shows the biological traits which were deemed to influence revenues and costs for all categories of chicken. The IC production systems in South Sudan as well as in other tropical countries have been characterized on the basis of levels of management and outputs (Moges *et al.*, 2010; Okeno *et al.*, 2012; Mahoro *et al.*, 2018) [18, 24, 15]. The identified production systems were extensive (free range), semi-intensive and intensive. In the free-range system (FRS) chickens scavenge for feed during day time and housed at night, feed supplementation is minimal or lacking while housing and health care are poor. Semi-intensive system (SIS) is a blend of FRS and the IS in which are allowed to scavenge and receive supplementary feeds within the homestead or runs. Health care and house are provided. In the intensive system (IS), chicken were housed at all times and supplied with a balanced ration of feed. Heath care measures that include vaccination against disease and control of Ecto- and Endo-parasites are carried out under this system of production.

Table 1: Biological traits influencing revenue and costs for indigenous chickens in South Sudan

Traits	Units	Abbreviation
Number of eggs per clutch	count	NECL
Weight of egg	g	WE
Fertility of eggs	%	FERTE
Hatchability of eggs	%	HAE
Number of clutches per year		NCLY
Chick hatching weight	g	CHW
Setting percentage	%	SPERC
Number of settings per year	count	N SETT
Survival rate of chicks	%	SRC
Survival rate of growers	%	SRG
Survival rate of breeding stock	%	SRB
Expected live weight at 21 weeks (cockerels)	kg	EW COCK
Expected live weight at 21 weeks (growers)	kg	E WHEN
Age of hen at first egg	weeks	AFE
Productive lifetime of hen	days	PLT

The management, production and nutritional variables used in the current study were obtained from farm level field survey at carried out in Bahar El Ghazel, Upper Nile and Equatoria regions of South Sudan. Where information could not be obtained from the current study, values were obtained from previous studies conducted in the tropics. Within a production system, the profitability depended on inputs and outputs was calculated on a per hen basis as the difference between annual revenues and costs. The main categories of inputs were feeds, husbandry (vaccinations, disease treatments, labour) and marketing costs. Revenue sources were sale of surplus eggs not selected for incubation, surplus growers (those which were not selected for replacement) and culled breeding hens and cocks. Such input and output parameters reflected the production and actual performance of IC in the three production systems in South Sudan. To ease calculations, an important assumption for this study was that some of the parameters were the same for all three production systems, even though it is expected that levels of inputs and therefore production may differ between the production systems. Calculation of economic variables was based on the actual average prices of inputs and outputs. The prices were in South Sudanese Pound (SSP) where US$ 1= SSP 30 and Ksh1= 3 SSP according to exchange rates of 2019.

2.2 Flock management

The mating ratio in the three production systems was pegged at 1 cock to 5 hens. Incubation and brooding were by natural method where the hens were used to hatch the eggs and brood chicks to weaning. The hens were assumed to lay 14, 19, 25 eggs per clutch in the free range, semi-intensive and intensive production systems, respectively. For each laying cycle of 15 weeks, 12 eggs were incubated per hen translating into 3 clutches per year (Okeno *et al.*, 2012) [24]. In the three systems, chick hatching weight was fixed at 30g. fifty percent of the old breeding stock was replaced each year. Maturity weights for females and males were assumed to be 1.9 and 2.22 kg, respectively (Menge *et al.*, 2005; Dana *et al.*, 2010; Kingori *et al.*, 2010; Magothe *et al.*, 2012; Okeno *et al.*, 2012*;* Mahoro *et al.*, 2018) [17, 3, 9, 13, 24, 15]. Selection of replacement pullets and cockerels was carried out at 21 weeks of age. Surplus cockerels and pullets were sold off when they reached sexual maturity. Estimated levels of production variables used in the present study to model the production systems are shown in Table 2.

Table 2: Estimated levels of production and management variables considered in the model for indigenous chicken in South Sudan

	Units	Production system		
Variables		**Free range**	**Semi-intensive**	**Intensive**
Production variables				
Number of eggs per clutch	count	14.0	19.0	25.0
Weight of egg	g	42.0	42.0	42.0
Fertility of eggs	%	87.0	87.0	87.0
Hatchability of eggs	%	93.0	93.0	93.0
Clutches per year	count	3.0	3.0	3.0
Chick hatching weight	g	30.0	30.0	30.0
Proportion of eggs set per clutch	%	66.0	50.0	40.0
Number of settings per year	count	3.0	3.0	3.0
Survival rate of chicks	%	53.0	64.0	83.0
Survival rate of growers	%	63.0	70.0	93.0
survival rate of breeding stock	%	70.0	75.0	95.0
Live weight of cocks at 21 weeks	kg	1.87	2.00	2.22
Live weight of hens at 21 weeks	kg	1.60	1.75	1.99
Age of hen at first egg	weeks	24.00	24.00	24.00
Productive lifetime	weeks	104.00	104.00	104.00
Management variables				
Mothering period	weeks	15.00	15.00	15.00
Sale age of surplus birds	weeks	21.00	21.00	21.00
Nutritional variables (Metabolizable energy), Kcal/kgDM				
Chick's mash	-	-	2784	2784
Growers' mash	-	-	2417	2920
Layers' mash	-	-	2417	2500
Scavenged feed		2417	2417	-

Source: Field data; Menge *et al.*, 2005; Dana *et al.*, 2010; Kingori *et al.*, 2010; Magothe *et al.*, 2012; Okeno *et al.*, 2012; Mahoro *et al.*, 2018) [17, 3, 9, 13, 24, 15]

2.3 Marketing and prices

Farmers normally sold birds and eggs directly to consumers at farm gate or to primary traders who then sold the birds at the village markets. The primary traders also sold live birds to secondary traders operating in secondary markets in towns and cities. The secondary traders then sold the birds directly to individual consumers and institutions such as hotels and restaurants or to other traders (Mahoro *et al.*, 2018) [15]. Sale of chicken was based on live weight. However, this study assumed that marketing cost and price of chicken were constant regardless of the size. Mature cock and hen were sold at SSP 4000 and SSP 3000, respectively, while one kilogram of IC was sold at SSP 1200. Eggs not selected for incubation sold at SSP 60 each. Cost of marketing per bird was equated to the levies charged for each at the market. No levies were charged on eggs. The unit input cost and output prices considered in the model are shown Table 3.

Table 3: Unit cost of inputs and price of outputs for indigenous chicken in South Sudan

Economic variables	Symbols	Units	Production system		
			Free range	**Semi-intensive**	**Intensive**
Prices (SSP)					
Eggs	PEGG	SSP/egg	60	60	60
Mature cock	PMCOCK	SSP/cock	4000	4000	4000
Mature hen	PMHEN	SSP/hen	3000	3000	3000
Meat	PMEAT	SSP/kg	2500	2500	2500
Costs (SSP)					
Chick mash	CHMASH	SSP/kg	0.00	500	500
Grower mash	CGMASH	SSP/kg	0.00	400	400
Layer mash	CLMASH	SSP/kg	0.00	500	500
Scavenging feed	PSF	SSP/kg	100	100	0.00
Labour	LABW	SSP/day	540	540	540
Marketing	MARKC	SSP/bird	50	50	50
Veterinary	VETCOST	SSP/bird	0.00	30	30
Fixed	FCOST	SSP/system	0.00	10000	20000

2.4 Estimation of cost, revenue and profitability

2.4.1 Revenue

The revenue accrued from eggs not selected for incubation (surplus eggs), surplus growers and culled breeding hens and cocks were calculated as follows

Surplus eggs

$$R_{eggs} = Necl \times (1 - Sperc) \times Ncly \times P_{egg}$$

Where Necl is the number of eggs per hen per clutch; Sperc is the setting percentage, Ncly is the number of clutches per year and P_{egg} price per egg (SSP).

Surplus growers not selected as replacements stock

$$R_{growers} = \{(N_{pcul} \times EWpul) + (N_{crlcul} \times EWcock) \times P_{lc}\}$$

Where N_{pcul} = number of pullet and N_{crlcul}= number of cockerels; EWpul =liveweight of pullets at 21 weeks of age; EWcock = live weight of cockerels respectively at 21 weeks of age; and P_{lc} = price per kg live weight in (SSP), with

$$N_{pcul} = N_p - N_{psel}$$

Where N_P =all available pullets; N_{psel} =the number of selected pullets. N_P was computed:

$$N_P = 0.5 \times N_{chicks} \times SRC \times SRG$$

Where N_{Chicks} =number of chicks that were hatched; SRC =survival rate of chicks up to 6 weeks; SRG =survival rate of growers to 21 weeks of age. N_{psel} was computed as:

$$N_{psel} = N_p \times H_{rt}$$

Where H_{rt} = replacement rate of hens.
N_{crlcul} was computed using the formula described for N_{pcul}, by replacing H_{rt} was replaced with the replacement rate of cocks (C_{rt}).

Culled breeding cocks and hens

$$R_{breedcul} = \{(N_{ckcul} \times LW_{ck}) + (N_{hncul} \times LW_{hn}) \times P_{lc}\}$$

Where N_{ckcul} = the number of culled breeding cocks; N_{hncul} = number of culled breeding hens; LW_{ck} =liveweight of culled breeding cock; LW_{hn} =liveweight of culled breeding hens. N_{crcul} and N_{hncul} were estimated as:

$$N_{crcul} = N_{crlsel} \times SRB$$

$$N_{hncul} = N_{psel} \times SRB$$

Where SRB = The rate of survival of breeding stock.

2.4.2 Costs
The costs considered were those associated with brooding activity of the hen, feeding, labour, veterinary services and marketing cost.

Brooding cost (CBROOD)
The cost of brooding was equated to the value of eggs lost as a result of the incubation and brooding activities. It was assumed that hens spend a total of 15 weeks when incubating eggs and brooding chicks to weaning. The brooding cost was calculated as:

$$C_{brood} = \left\{(Necl \times S_{perc}) \times (1 - (FERTE \times HAE)) + \left(EN \times \frac{105}{365}\right)\right\} \times Necl \times P_{egg}$$

Where FERTE = Egg fertility; and HAE = hatchability of eggs.

Cost of feeding (chicks)
The cost of feeding chicks (Cfchicks) was calculated as:

$$C_{fchicks} = N_{chicks} \times TFI_{chicks} \times 42 \times P_{sf}$$

Where TFI_{chicks} =daily feed intake per chick; P_{sf} =cost of scavenging feed resources (for free range and semi-intesive systems). For the intensive system, P_{cmash} was used instead of P_{sf} where P_{cmash} = price per kg DM.

Cost of feeding growers ($C_{fgrowers}$)
The feed intake for growers from the 7th week to 21st week was calculated as:

$$C_{fgrowers} = \{(N_p \times TFI_p) + (N_{crl} \times TFI_{crl}) \times 150 + (N_{psel} \times TFI_p \times 21)\} \times P_{sf}$$

Feeding costs for breeding stock
The annual cost of feeding per hen and cock was calculated as:

$$C_{fbreed} = \left\{(SRB \times TFI_{hn}) + \left(\frac{SRB \times TFI_{ck}}{5}\right)\right\} \times 365 \times P_{sf}$$

Where TFI_{hn} = daily total feed intake per hen; TFI_{ck} = daily feed intake per cock.

Veterinary services costs
Cost associated with health management, C_{vet} of the birds was calculated as:

$$C_{vet} = N_i \times SR_i \times D_i \times C_{health}$$

Where *i* =bird category (either chick, grower or breeding flock); N_i = the number of birds in each category; D_i =the duration a bird remains in each category (such that chicks = 0-6 weeks, growers = 7-12 weeks, breeding stock = 22nd week to time of exiting the flock through culling or death); C_{health} veterinary cost per day.

Cost of labour
Labour cost (C_{lab}) was based on the time spend attending the chicken per day. Previously this time had been estimated to be ten minutes (Menge *et al.*, 2005; Okeno *et al.*, 2013) [17, 25].

$$C_{lab} = 0.17 \times t \times 365 \times 0.125 \times C_{wages}$$

Where T = The proportion of time for each production system (such that Free range= 10%, Semi intensive = 50% and Intensive = 100%); 0.17 = hours spent attending to each bird daily; and C_{wages} =daily cost of labour for a eight-working-hours day.

Cost of marketing
Marketing cost was derived from the levies charged per bird at the market as:

$$C_{mkt} = (N_{hncu} \times N_{cokcul} + N_{pcul} \times N_{cokul}) \times C_{levy}$$

Where C_{levy} = The cost levy charge in the market. Eggs were not charged any levy.

2.4.3 Profitability
The annual profitability of the flock for each production system was estimated as:

$$P = R - C$$

Where P is the profit per flock per year, R is the revenue per flock per year and C is the cost per flock per year.

3. Results and Discussion
Results of revenue, cost and profitability of the three indigenous chicken production systems estimated using a deterministic bio-economic model are presented in Table 4. The *in-silico* process was important because such parameters are very difficult to collect under field conditions. During the simulation process, the outputs were simulated for the base situation and then verified to determine whether they reflected the reality of indigenous chicken farming or not. The values of revenues, costs and profitability were estimated based on the flock structure within each production system. The results in Table 4 indicate that the sales of surplus eggs, pullets and cockerels not selected for breeding and culled hens and cocks positively influenced profitability in all the production systems.

Table 4 also shows revenues and variable costs for FRS, SIS and IS in South Sudan. Sale of surplus growers accounted for 89.9%, 89.9% and 91.9% of the total revenues in free rang, semi-intensive and intensive production systems, respectively. In Kenya, Okeno *et al.* (2013) [25] reported that surplus growers accounted for 74.4%, 67.0% and 58.3% of the total revenues in free range, semi-intensive and intensive production systems, respectively.

Table 4: Estimates of revenues, costs and profitability (in SSP) for indigenous chicken production systems in South Sudan

Variables	Production system		
	Free range	Semi-intensive	Intensive
***Revenues* (SSP)**			
Eggs	856.8	1710.0	2700.0
Growers	20083.6	29915.2	54297.9
Culled hens and cocks	1382.5	1614.4	2061.5
Total revenue (a)	22322.9	33239.59	59059.4
Costs (SSP)			
Feeding chicks	3291.4	19748.5	14709.4
Feeding growers	12312.7	71672.5	97192.1
Feeding breeding stock	2705.1	18324.9	25409.7
Labour	418.8	2094.2	4188.4
Veterinary	0.00	706.4	1055.2
Marketing	361.4	479.2	815.4
Brooding cost	347.5	436.8	546.0
Total variable costs (b)	19437.0	113462.5	143916.5
Fixed cost (c)	0.0	10000.0	20000.0
Total costs (b+c)	19437.0	123462.5	163916.5
Profit (a-(b+c)) (SSP)	2885.9	-90222.9	-104857.1

The prices are in South Sudanese Pounds (SSP) where US$ 1= SSP 300 and Ksh1= SSP 3

In Rwanda the sale of surplus growers accounted for 83.7%, 83.2% and 82.6% of the total revenue in intensive, free range and semi-intensive operations (Mahoro 2017) [14]. Sale of culled hens and cocks were also an important source of revenue and accounted for 6.2% in free range, 4.9% in semi-intensive and 3.5% in intensive production systems. Eggs accounted for 3.8%, 4.5% and 6.9% of the total revenues in semi-intensive, intensive and free-range systems, respectively. The diminished contribution of eggs to total revenue could be because of the higher number of settings and egg setting percentage used as inputs in the model to cater for the farmers' need for chicks. The revenues from sales of surplus hens, cocks and egg were similar to those reported by Menge *et al.* (2005) [17] and Mahoro (2017) [14].

Cost of feed for all the classes of indigenous chicken accounting for 88.9% and 83.8% of the total cost in semi-intensive and intensive systems, respectively, which were slightly higher than those reported by Mahoro (2017) [14] of 78.3% and 79.3% in semi-intensive and intensive systems, respectively. In Kenya, Okeno *et al.* (2013) [25] reported that feeds accounted for 55.8% and 78.5% of the total costs in semi-intensive and intensive production operations, respectively. The reason that the feeds costs were higher in this study could be attributed to the fact that all production in puts including feeds are imported from neighbouring countries in hard currency. Various studies carried in different production systems revealed that feeds were the major component of the total production costs for different livestock species (Kahi & Nitter, 2004; Rewe *et al.*, 2011; Gebre *et al.*, 2012; Okeno et al., 2013; Mbuthia *et al.*, 2015) [8, 26, 4, 25, 16] . Labour and veterinary costs (husbandry costs) contributed 2.2%, 2.2% and 3.2% of the production cost in free range, semi-intensive and intensive production systems, respectively. Marketing and brooding costs accounted for an even smaller proportion of the production cost.

Cost of brooding, calculated as the opportunity cost for using hens to incubate eggs and brooding chicks to weaning was the least of all sources of cost. This is in agreement to simulated results of Mahoro (2017) [14] in Rwanda and Menge *et al.* (2005) [17] in Kenya. In these studies, labour contributed a larger proportion of the total costs in all systems followed by marketing than brooding cost. However, the study by Okeno *et al.* (2013) [25] reported that the marketing costs accounted for a smaller proportion of the total production costs compared to the brooding cost. Raising the chicks artificially after natural incubation using hens can help to minimise brooding cost. This practice has additional benefits of increasing the number of clutches per hen per year, the number of eggs produced and reduction in chick mortality (Okeno *et al.*, 2013) [25]. In the current study inclusion of family labour and marketing costs in the bio-economic model resulted in increased production cost. Similar results were reported by Okeno *et al.* (2013) [25], Mbuthia *et al.* (2015) 16] and Mahoro (2017) [15] where inclusion of cost of family labour in the bio-economic models resulted in inflated costs.

Profits from this simulation study were obtained as the difference between total revenue and total production cost. The results indicated that the utilisation of IC under free range generated higher profits when compared to semi-intensive and intensive production systems (Table 4). The profitability of IC under free range could partly be explained by the failure to include feed costs. On the other hand, for the semi-intensive and intensive systems, feeds were considered, resulting to negative profits for these two systems. This failure to include feed costs under free range systems was due to the difficulty of quantifying the cost of scavenging feed resources, even though it has been established that ignoring such costs may lead to overestimated profitability (Okeno *et al.*, 2013; Mahoro 2017) [25, 14]. In free range the veterinary and the fixed cost variables were set to be zero. This may also help in reduction of the production cost when compared to SIS and IS (Mahoro, 2017) [14]. Under intensive and semi-intensive systems, cost of feeds can be reduced by utilisation locally available feed sources in IC feeding. This would also result in improved productivity and consequently increased profitability (Okeno *et al.*, 2013; Mahoro 2017) [25, 14]. Although the higher profitability of free range compared to semi-intensive and intensive systems agrees with the findings of Menge *et al.* (2005) [17] and Mahoro (2017) [14], its contrary to the positive profitability of semi-intensive system reported by Okeno *et al.* (2013) [25]. This might have been due differences in parameters used in the bio-economic models by Okeno *et al.* (2013) [25] where commercial feeds and scavenging feeds accounted for 50% each of feeds used in the semi-intensive system.

Although IC utilized under the semi-intensive and intensive systems reported negative profitability, increased demand due to increasing human population and diminishing land acreage call for a shift from subsistence to commercial production systems. Therefore, simple and practical breeding objectives for IC production under the prevailing circumstances is very important and should be based on farmer's traits of preferences (Okeno *et al.*, 2013) [25]. Development of breeding objectives should always endeavour to describe prevailing production conditions, documentation of traits that influence costs and revenue, bio-economic modelling to establish the profitability IC flocks and estimation of economic values for traits of economic importance (Mosnier *et al.*, 2009; Åby *et al.*, 2012; Okeno *et al.*, 2013) [20, 1, 25]. The model used in the current study has succeeded estimating the profitability of IC production systems in South Sudan. Consequently, economic values for the traits of economic importance should be derived and their influence on genetic gain determined.

4. Conclusion
The current study successfully developed a bio-economic model that was able to estimate the cost, revenues and profits of different production systems utilising IC in South Sudan. The results of the simulation model revealed that IC can be utilised profitably under free range production system while profits were negative for semi-intensive and intensive systems. The next step is to derive economic values for the traits that influence profitability and to determine their influence on genetic gain for IC in South Sudan.

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