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Ascites Incidences and Related Growth Responses in Feed-restricted Broilers Raised Under Cold High-altitude Conditions in Papua New Guinea

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Abstract

Modern broilers are highly susceptible to ascites syndrome under high-altitude environments in Papua New Guinea. Severe ascites results in economic losses which undermines the viability of broiler enterprises, hence the need for counteractive measures. This study evaluated the influence of feed restriction on ascites incidence and growth responses of broilers under high-altitude conditions. A total of 180 one-day-old Ross 308 broilers were randomly assigned to four treatments (RT) consisting of three replicates with 15 birds each. Broilers subjected to RT1 had feed available for eight hours daily throughout the 49-day rearing period. Birds under RT2 were offered feed eight hours daily from 1-21 days and then unrestricted feeding at day-22 onwards. RT3 had feed available ad libitum from 1-7 days, followed by restricted feeding at eight hours daily from 8-28 days: then unrestricted feeding from 29-49 days. Broilers exposed to the control regime (C100) had unlimited access to feed. Data on feed conversion, weight gain, ascites incidences, and associated costs were subjected to a one-way analysis of variance. Broilers on C100 consumed more feed, gained more weight, and were heavier than RT1, RT2, and RT3 ($p<0.05$). In contrast, lower weight gain and final weights were noted in broilers on RT1 ($p<0.05$). Broilers under RT3 and RT2 attained better weight gain and final weights than RT1 ($p<0.05$). Irrespective of feeding regime, feed conversion ratios were similar ($p>0.05$). Feed restriction programs lowered overall mortality to less than 8 % and all ascites-related deaths by 86 to 100 % ($p<0.05$). Accordingly, feed-restricted broilers attained better benefit-cost ratios than C100 ($p<0.05$). Ascites incidences may be reduced by feed restriction however, the severity and duration can adversely impact compensatory growth. Metabolic testing may be required for optimizing the duration over which feed restriction is imposed to encourage sufficient compensatory growth in broilers.

Keywords: Broiler, Feed Restriction, Ascites, Growth Response, High-altitude

Introduction

Broiler chicken (Gallus gallus domesticus) production has become crucial to socio-economic growth and development in developing countries [1]. Its typically quick turnover and low investment need makes it an enviable venture. In Papua New Guinea (PNG), smallholder farmers operate separately from vertically integrated commercial entities and raise around 6 million broilers annually for the informal live meat-bird market. This enterprise is gradually becoming an important income activity for over 50,000 households that are actively involved [2]. Growth in the smallholder sector is further constrained by additional costs of freighting feed and stock from producers and hatcheries to other centres nationwide. While prevailing challenges include rising feed prices and ageing infrastructure, ascites is fast becoming a threat to raising broilers under high-altitude conditions (1,600 - 2,800 m above sea level).

Broilers are largely selected for large muscle mass and increased growth rate at the expense of visceral organs associated with the cardiovascular and respiratory systems [3-5]. This weakens normal organ functions thereby, exposing modern broilers to ascites [6]. As explained by Hunter et al., broilers with limited lung capacities struggle to maintain blood oxygen levels necessary to support its fast growth. In order to maximize oxygen levels reaching the growing muscles, the number of circulating oxygenated blood cells increases drastically [7]. This makes the blood thicker and more viscous, making it difficult in passing through the small capillaries of the lung, thus increasing the workload of the right aorta. Eventually succumbing to the increased pressure, the heart then dilates, and its function becomes impaired. Blood backs up in the liver and eventually fluid leaks through the liver capsule and oozes down into the abdominal cavity. This condition is termed ascites or water-belly and can cause significant bird losses during growth.

Any condition that increases its oxygen needs will predispose broilers to ascites e.g., raising broilers in cold high-altitude environments. Anecdotal evidence suggests ascites-related mortalities to be as high as 50 % being reported on numerous farms in the Highlands region. The ensuing economic losses often impede the long-term sustainability of broiler enterprises, needing appropriate counteractive measures to abate this. Studies on ascites in PNG are regrettably minimal but reports from investigations elsewhere are extensive. The addition of water pills, gut-beneficial bacteria, fats, and antioxidants in broiler rations have shown great promise in reducing ascites [8-10]. These methods aim to reduce broiler metabolism thereby reducing its oxygen demand and consequent risk of ascites. However, such approaches are costly and less attractive for PNG's small-scale broiler keeping domains.

Management of ascites in broilers through cost-efficient interventions have been successful. For instance, some studies have recommended mashed diets and restrictive feeding as potential low-cost ascites management strategies. Providing mashed diets, instead of pelleted, to broilers saw a decline in ascites cases [11, 12]. However, Baghbanzadeh et al., argued that this method has some side-effects with reports of broilers developing distorted crops overtime. A more suitable option involves raising broilers under feed restriction regimes. As described by Sahraei, "feed restriction is a method of feeding where time, duration and amount of feed are limited, and it has an impact on whether a bird is capable of achieving the same body weights as unrestricted birds" [13, 14].

Feeding broilers excessively triggers a surge in their metabolism thereby increasing both their oxygen needs and the probability of ascites development. In contrast, restricted feeding encourages low metabolism, less oxygen demand and thereby reduced ascites risks. However, a right balance between restriction levels and the time broilers need to reach maturity is crucial. This study was undertaken to investigate ascites incidences and related growth responses of feed-restricted broilers under PNG's high-altitude conditions.

Materials and Methods

Study Area

This study was implemented from September to November of 2022 at the National Agricultural Research Institute (NARI) High-altitude Highlands Regional Centre (5.942° S, 144.0113° E, 2,200 m above sea level) in Tambul (Western Highlands Province), PNG. The prevailing climate is typically cold and wet with mean annual rainfall and temperatures ranging between 2,300 – 4,000 mm and 18 - 20 °C accordingly, and relative humidity (RH) levels of 65 – 75 % [15]. The total rainfall, average ambient temperature range, and RH levels recorded during the study period were 220 mm, 15-18 °C and 70 - 90 % respectively.

Experimental Birds, Housing, and Design

A total of 180 mixed-sex day-old chicks (Ross-308) were obtained from a commercial hatchery (Zenag© Chickens, Mumeng, Morobe Province). The study was conducted in a naturally ventilated shed made of corrugated iron roofing with a concrete floor and outer v-crimp walls. All enclosures have equal floor area of 5 m2 each and were partitioned with mesh wire. Dry wood shavings were spread as bedding material up to a depth of 10 cm on the floors of each pen. A complete randomized layout was used in this experiment and involved four feeding regimes represented by three replicates; each stocked with 15 birds randomly distributed across 12 experimental pens. Irrespective of feeding regime, all birds were fed a conventional broiler starter and finisher ration (Table 1) at starting (1-21 days) and finishing (22-49 days) phases accordingly. The starter diet was offered as crumbles while the finisher ration was administered in pelleted form.

Table 1: Nutrient levels of the starter and finisher rations [16].

Nutrient component	Starter	Finisher
Dry matter (%)	89.8	89.7
Ash (%)	9.81	5.89
Crude fibre (%)	4.1	5.0
Fat (%)	7.7	7.5
Crude protein (%)	21.0	19.0
Calcium (%)	1.26	1.28
Phosphorus (%)	0.7	0.71
Nitrogen free extract (%)	47.19	52.31
Metabolizable energy (MJ, kg-1)	12.13	12.2

Restrictive Feeding Regimes

Broilers were exposed to three feed restriction regimes (Table 2) at different stages of growth. Broiler chickens on RT1 had feed available for eight hours daily throughout the rearing period. Broilers on RT2 were offered feed at eight hours daily from 1-21 days and then returned to ad libitum or unrestricted feeding from

22 – 49 days. The RT3 regime had feed available ad libitum from 1-7 days, followed by provision of feed at eight hours daily from 8-28 days, and then back to ad libitum feeding from 29-49 days. Birds subjected to the control diet (C100) were provided unrestricted access to feed throughout the experimental period. Additionally, clean fresh water was provided ad libitum to all birds, through bell drinkers over the course of this study.

Table 2: Restrictive feeding regimes evaluated in this study (including the control).

Abbreviation	Description of feeding regime
C100	The control: broilers fed ad libitum throughout the experimental period (day 1-49).
RT1	Broilers had access to feed for only eight hours daily throughout the experimental period.
RT2	Broilers fed eight hours daily from 1– 21 days, then ad libitum from day 22 – 49.
RT3	Fed ad libitum from 1-7 days; eight hours daily from 8-28 days; then ad libitum afterwards.

Note. RT = restricted feeding treatment

Carcass Yield Measurements and Ascites Incidences

The final weights were recorded on day 49 after starving the birds for eight hours prior to slaughter. Pre-slaughter weights were obtained before birds were humanely decapitated, and exsanguinated [16]. The slaughtered birds were submerged in hot water for 30 seconds to loosen feathers which were manually removed. The birds were eviscerated, and internal organs (gizzard, heart, liver) and abdominal fat were removed and weighed separately with a kitchen scale (5,000 g ± 1 g). Non-carcass components were discarded, and the resulting carcasses weighed and rinsed for chilling. Similar to the method used by Das and Deka, ascites incidences during experimental phase were determined either visually or through palpation to see whether broilers have a dilated abdomen. Moreover, ascites-related mortalities were diagnosed by the presence of a clear yellow fluid in the abdominal cavity, and an enlarged liver through post-mortem [17].

Data Collection and Analysis

Data on ascites incidences and associated growth responses were recorded over 49 days. The quantity of feed provided, and its corresponding residuals were recorded daily with a kitchen-scale (10 kg ± 0.025 kg). Weekly weights of broilers were also obtained using a smaller kitchen scale (5,000 g ± 0.025 g). Data on all variables; feed conversion, weight gain, final body weights, and carcass yield were sorted using MS Excel® 2007 version. Feed intake (FI) was obtained as the difference between feed provided and its residue. Weight gains and final live weights were derived as weight differences of birds at start and end of study, and end weights of broilers at conclusion of trial period respectively. Feed conversion ratio (FCR) was computed as the amount of feed converted to body mass while benefit-cost ratios were determined as total returns divided by total costs of production.

1. FI (g) = [feed offered] – [feed residual]
2. $\text{FCR} = \frac{\text{Feed consumed (g)}}{\text{Weight gained (g)}}$
3. Weight gain (g) = ["weight of bird at end of week] – [weight of bird at start of week]"
4. $\text{Benefit-cost ratio} = \frac{\text{Total returns (PGK)}}{\text{Total costs (PGK)}}$

The data was tested for normality using Shapiro-Wilk test and Bartlett's test for homogeneity of variances using the distribution platform and analysed using a one-way analysis of variance (ANOVA) in R [18] to determine the main effects of restrictive feeding regime on ascites incidence and growth parameters. Tukey's honest significant difference (HSD) test, at 95 % confidence interval, was then used to separate means where significant main effects were detected in the ANOVA.

Results

Gowth Performances and Ascites Incidences

The effect of restrictive feeding regimes on growth performances and mortality rates are presented in Table 3. The initial body weights of broilers prior to exposure to the treatment programs were statistically similar (p=0.167). Feed consumption and weight gain of broilers under all treatments were positively linear to growth stage i.e., overall feed intake, and weight gain gradually increased as broilers advanced in age (Figure 1). Feed restriction had a significant impact (p<0.05) on feed consumption; a general decline in cumulative feed intake was observed for broilers exposed to RT1, RT2, and RT3. Feeding regimes, however, did not have any significant effects (p=0.721) on FCR.

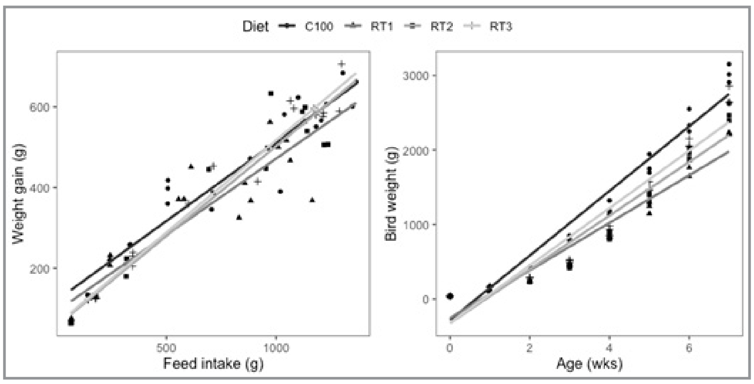

Figure 1: Weight gain as a function of feed intake, and broiler weight by age and feeding regime.

Reduced feed intake led to significant ($p<0.05$) declines in weight gain and subsequently lower final weights in broilers under RT3, RT2, and RT1 regimes in that order. In contrast, overall feed consumption, weight gain and final weight of broilers on C100 were significantly ($p<0.05$) higher than RT1, RT2, and RT3 regimes. Additionally, ad libitum fed broilers attained marketable weights (2,000 g,) earlier, from 35 days onwards, followed by RT3 and RT2 at 42 days, and RT1 thereafter (Figure 1).

Table 3: Effect of feeding regime on feed intake and conversion, weight gain, final weights, and bird mortalities.

Variable	Feeding regime				S.E.M	P-value
	RT1	RT2	RT3	C100		
IBW (g-1)	38.63 a	38.60 a	38.46 a	38.70 a	0.37	0.167
FI (g)	4,093.81 a	4,609.07 b	4,925.52 c	5,480.38 d	92.47	<0.001
BWG (g)	2,182.62 a	2,454.58 b	2,671.17 b	2,997.61 c	107.0	<0.001
FCR (g, g-1)	1.85 a	1.85 a	1.88 a	1.83 a	0.05	0.721
FBW (g-1)	2,569.17 a	2,754.25 b	2,963.33 b	3,413.33 c	262.2	<0.001
Overall mortality (%)	8.92 a	5.42 b	5.65 b	16.87 b	0.40	<0.001
Ascites-related mortality (%)	0.0 a	10.81 b	10.77 b	76.93 c	0.41	<0.001

Note. IBW = initial body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio, FBW = final body weight, S.E.M = standard error of mean. Means in rows with different superscripts (a, b, c, d) differ significantly at $p<0.05$ using Tukey's HSD test.

The overall mortality rate (Table 3) was statistically ($p<0.05$) higher for broilers under C100 having ad libitum access to feed. More importantly, nearly 77 % of these bird mortalities were directly associated with ascites. While ascites-related mortalities in RT2 and RT3 were 86-87 % lower than C100, no mortalities associated with ascites were observed in RT1 (ascites-related mortalities were 100 % lower than C100).

Carcass Components and Production Costs

The effects of feed restriction on selected broiler carcass components and production costs are shown in Table 4. Broilers exposed to the restricted feeding regimes attained significantly ($p<0.05$) lower carcass weights than birds on C100 at 49 days-of-age. Similar trends were observed for liver and heart weights; both the liver and heart weights of broilers on RT1 were statistically ($p<0.05$) lower than birds with ad libitum access to feed. Likewise, Figure 2 generally indicated a directly proportionate association between liver and heart weights of broilers. Moreover, the mean gizzard weights of broilers subjected to C100 was significantly ($p<0.05$) heavier than for birds on RT1. Irrespective of feeding program, however, the variation in the abdominal fat content of all broilers was not significant ($p=0.112$).

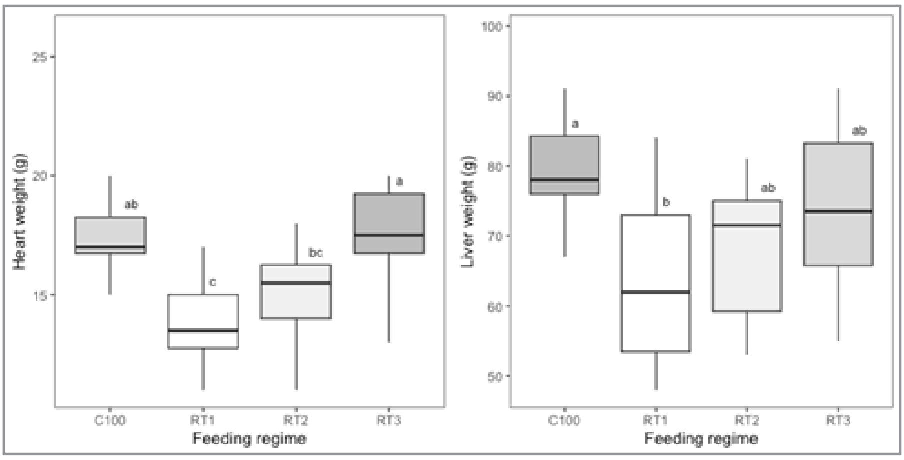

Figure 2: Shows the mean heart and liver weights of broilers in response to feeding regime.

The overall production costs varied significantly ($p<0.05$) across all feed restriction regimes imposed in this study. Broiler chickens subjected to RT1 were less costly to produce compared to the other two restricted feeding regimes and the control (Table 4). Similarly, broilers under RT1 attained significantly ($p<0.05$) higher benefit-cost ratios than broilers on RT2, RT3, and C100 regimes. Moreover, reduced production costs and comparably better benefit-cost ratios were observed in broilers under RT2 and RT3. Broilers with ad libitum access to feed were notably more expensive to raise over the 49-day study period.

Table 4. Effect of feeding regime on selected broiler carcass components and associated production costs.

Variable	Feeding regime				S.E.M	P-value
	RT1	RT2	RT3	C100		
CWT (g-1)	2,375.08 a	2,602.67 ab	2,825.25 b	3,269.92 c	247.70	<0.001
Gizzard (g-1)	33.00 a	35.08 ab	35.50 ab	40.75 b	6.31	<0.05
Liver (g-1)	63.00 a	68.17 ab	74.08 bc	79.58 c	10.47	<0.01
Heart (g-1)	13.83 a	15.33 ab	18.17 c	17.58 bc	2.44	<0.001
AbFAT (g-1)	25.08 a	31.83 a	36.25 a	32.00 a	11.00	0.112
TCOST (PGK, b-1)	18.62 a	20.50 b	21.54 c	23.38 d	0.31	<0.001
Benefit-cost ratio (PGK)	2.15 a	1.95 b	1.86 c	1.71 d	0.03	<0.001

Note. CWT = carcass weight, AbFAT= abdominal fat, TCOST = total cost per bird at 49 days-of-age PGK = PNG Kina. S.E.M = standard error of mean. Means in rows with different superscripts (a, b, c, d) differ significantly at p<0.05 using Tukey's HSD test.

Discussion

Growth Performances

The ANOVA results indicated a positive linear relationship between feed intake and weight gain of broilers. Regardless of feeding regime, weight gain increased simultaneously with feed consumption (Figure 1). However, cumulative feed intake, weight gain, and the ensuing final weights of broilers were adversely impacted by feed restriction [18]. As anticipated, broilers on C100 consumed significantly more feed, gained more weight and were heavier than broilers subjected to all restricted feeding regimes combined (Table 3). This observation was similar to studies by Balog et al., Boostani et al. and Butzen et al. who reported significantly lower feed consumption, weight gain, and final weights in feed-restricted broilers [19, 20]. Broilers on RT3 and RT2 regimes attained comparably better weight gains and final weights than RT1. This is because RT2 and RT3 involved alternating between restrictive and ad libitum feeding during the growth period. Compared to RT1 and RT2, broilers exposed to RT3 attained generally better weight gain and final weights. Despite this, broilers under RT3 and RT2 were unable to achieve sufficient compensatory growth i.e., similar weight gain and final weights as full-fed broilers. This assessment is consistent with the views of Saleh et al., Ponte et al., and Boostani et al. in separate studies involving feed-restricted broilers [21, 22].

Several studies have pointed out that restrictive feeding, and the severity of restriction suppresses bird growth during the restriction period [23-26]. On the contrary, Balog et al. observed compensatory weight gains and comparable final weights in broilers that were feed-restricted for three weeks followed by another three weeks of ad libitum feeding. Similarly, Butzen et al. observed no marked differences in cumulative weight gain and final weights of full-fed versus feed-restricted broilers. However, the disparities in these studies should be viewed with some caution as the duration and intensity of feed restriction vary between studies. Nevertheless, broilers subjected to RT1 demonstrated poor compensatory growth due to the severity of restriction. Essentially, a sudden change to restricted feeding is less acceptable to broilers than a gradual reduction in feeding levels.

The lowest cumulative weight gain and final weights were recorded in broilers under RT1. Similarly, inferences from studies by Balog et al. and Boostani et al. indicated reduced performances in broilers exposed to full feed restriction, and three weeks of feed restriction plus three weeks of ad libitum feeding, accordingly. On the other hand, Balog et al. and Omosebi et al. reported cumulative weight gains and final weights that were relatively similar between feed-restricted and full-fed broilers. The differing observations are indicative that the severity and duration of restriction can be optimized to attain sufficient compensatory growth in broilers. Additionally, the feed restriction regimes evaluated here did not have any notable influence on FCR. All broilers attained reasonably similar FCRs irrespective of feeding regime. This reiterates the observations of Saleh et al. and Balog et al. who noted no distinct differences between FCRs of feed-restricted and full-fed broilers kept under high-altitude conditions. In contrast, Ozkan et al. and Boostani et al. observed considerably improved FCRs in feed-restricted broilers than in full-fed broilers [27].

Ascites Incidences

Restricting feed availability to just eight hours daily during the earlier stages of growth was effective in reducing ascites-related mortalities [28]. Similarly, Mohammadalipour et al. observed no mortalities in broilers exposed to early feed restriction from 7 – 14 days-of-age. Although ascites-related mortalities in RT2 and RT3 were similar, these were 86-87 % lower compared to full-fed broilers [29]. This implies that whilst promoting greater weight gain in broilers, ad libitum feeding exacerbates ascites incidences in tandem under cold high-altitude environments. Interestingly, all ascites incidences observed in broilers under C100, RT2, and RT3 occurred at finishing-phase from 22 – 49 days-of-age. More importantly, the reduction in cumulative weight gains and final weights of broilers on RT2 and RT3 were not that severe compared to RT1. Despite zero mortalities i.e., 100 % lower than full-fed broilers, the lack of response in compensatory weight gain and cumulative final weights in broilers on RT1 makes it less attractive. As explained by Sahraei and Hadloo, the extent of compensatory growth is often dependant on the duration of feed restriction. The key outcome is that despite having minimal impact on compensatory growth, all feed restriction programs imposed in this study had noticeably lower ascites-related mortalities than the control group [30]. Evidently, subjecting broilers to feed restriction programs can reduce ascites incidences and therefore ascites-related mortalities.

Similar trends were observed by Boostani et al. and Camacho-Escobar et al. who reported low ascites incidences and ascites-related mortalities in feed-restricted broilers as compared to others with unlimited access to feed. Furthermore, Arce et al. , Fontana et al. , and Acar et al. noted overall declines in ascites-related mortalities in broilers subjected to early feed restriction [31, 32]. The decline in ascites-related mortalities is attributed to reduced growth rates, decline in metabolism, and thereby less ascites incidences [33]. The findings in this study further assert that feed restriction limits growth rate and thereby reduces ascites-related mortalities but, with varying degrees of impact on compensatory growth.

Carcass Components

Broiler carcass weights at 49 days-of-age were directly proportional to feed consumption and final weights (Table 4). The carcasses of broilers on C100 were heavier than others on RT3, RT2, and RT1 accordingly. In line with the observation of Boostani et al. carcass weights of feed-restricted broilers were markedly lower compared to others with ad libitum access to feed. Likewise, in a study by Jahanpour et al., exposing broilers to a 50 % feed restriction program was shown to reduce carcass weights significantly [34]. As anticipated, the lowest carcass weights were noted in broilers exposed to RT1. On the contrary, Zhan et al. observed no differences in carcass yields of full-fed broilers and broilers feed-restricted for four hours daily from 1 – 21 days-of-age. Further, the carcass weights of full-fed broilers and others on a 30 % feed restriction regime were reportedly similar [35, 36].

The gizzard and liver weights of feed-restricted broilers were lower compared to birds subjected to ad libitum feeding. Gizzard weights of broilers exposed to all feed restriction programs in this study were more or less similar. Likewise, no marked differences were observed in the mean gizzard weights of broilers under RT2, RT3, and C100 regimes. Studies by Fontana et al., Novele et al., and Novel et al. also reported no variations in the gizzard weights of feed-restricted and full-fed broilers. In this study, however, the mean gizzard weights of broilers under RT1 were significantly lower than full-fed broilers [37-39]. This suggests that the feed restriction program imposed here did not allow for a full utilization, and development of the gizzard hence its subsequently low weight.

Imposing a 50 and 75 % feed restriction on broilers did not have any notable influence on liver weights. Moreover, Novel et al. and Azouz et al., observed no substantial differences in the liver weights of feed-restricted and full-fed broilers [40]. However, the liver weights of all feed-restricted broilers were distinctly lower compared to the control group in this study. A similar investigation by Velele, also reported lower liver weights in feed-restricted broilers. As explained by Jones, “feed restriction reduces [the] metabolic efficiency of the liver; thus, the effect of the intensity and duration of restriction may cause a reduction in liver weights” [41, 42]. Restricting feed for eight hours daily throughout the rearing period had a profound impact on heart weight. The heart weights of broilers exposed to the RT1 regime were considerably lower than birds on RT3 and C100. In contrast, broilers subjected to RT1 and RT2 attained relatively similar heart weights. Additionally, no noticeable differences in heart weights of broilers were detected between RT3 and C100 regimes. This coincides with Kamely et al. and Azouz et al. who reported no significant variations in heart weights of full-fed versus feed-restricted broilers [43].

Consumers in PNG generally prefer live meat-birds that are heavier with high fat content. The restrictive feeding regimes administered in this study had no observable influence on abdominal fat. The abdominal fat contents of all broilers were relatively similar regardless of feeding regime. This is related to reports by Yu et al. and Fontana et al. who observed no variations in abdominal fat contents of feed-restricted versus full-fed broilers. In contrast, notable differences in abdominal fat were observed between broilers exposed to three weeks of feed restriction and full-fed broilers [44]. Likewise, an earlier study by Zhan et al. reported significant differences in the abdominal fat of full-fed broilers and others feed-restricted for four hours daily during the first three weeks of growth. Yet, inferences from other studies further determined that feed restriction reduces abdominal fat in broilers. These observations are analogous with this study as the abdominal fat content of broilers on RT1, though not significant, was observably lower than the other feeding regimes. Generally, the dissimilarities across separate studies corresponding to different growth parameters and various carcass components discussed here could be explained by differences in the duration and severity of feed restriction, and broiler strains.

Production Costs

Regardless of lower weight gains and final weights, broilers under RT1, RT2, and RT3 regimes were less costly in terms of unit costs and attained better benefit-cost ratios compared to full-fed broilers (Table 4). As expected, the lowest cost per bird and highest benefit-cost ratio was recorded in broilers under RT1. However, this feeding regime had very little impact on compensatory growth as demonstrated by low weight gain and final bird weights at the conclusion of this study. In comparison, birds exposed to RT2 and RT3 were able to recover slightly through compensatory growth in terms of cumulative weight gain and final weights. Further, broilers under C100 reached marketable weights earlier than all feed-restricted birds. However, the elevated ascites cases and consequently low benefit-cost ratio renders it a less viable option.

Broilers under RT2 and RT3 attained low production costs and better benefit-cost ratios as compared to C100. These indicate that in addition to low ascites-related mortalities, benefit-cost ratios can be improved through the adoption of restricted feeding regimes. These findings concur with the observations of Saleh et al. and Omosebi et al. who reported marked reductions in production costs per bird and improved benefit-cost ratios in feed-restricted broilers. Moreover, a similar trend was observed in Ross-strain broilers subjected to a late feed restriction program by Azouz et al. Essentially, feed accounts for nearly 70 % of overall production costs hence, a cost-effective alternative for raising broilers is through the utilization of restrictive feeding [45]. In agreement with Arce et al., the modest reduction in cumulative weight gains and final weights of broilers subjected to RT2 and RT3 are reasonably sound compromises for improved benefit-cost ratios and reduced ascites incidences, particularly under high-altitude conditions. Importantly, these restricted feeding regimes can be optimized to encourage adequate compensatory growth in broilers during growth.

Conclusion

Ascites incidences and consequent bird losses under high-altitude conditions can be reduced through the utilization of restricted feeding programs. Technically, feed restriction slows down bird growth and reduces its metabolism; subsequently reducing broiler susceptibility to ascites and hence, ascites-related mortalities. Yet, the severity and duration of feed restriction can adversely impact compensatory growth as observed in full feed-restricted broilers. Despite this, compensatory growth can be achieved by alternating between feed restriction and ad libitum feeding during the growth period. As demonstrated in this study, RT3 and RT2 feeding regimes allowed for moderate compensatory growth with comparable benefit-cost ratios and reduced ascites-related mortalities. More notably, the modest reduction in cumulative weight gain and final weights of broilers under both feeding regimens are deemed as reasonable trade-offs for reduced ascites incidences and successively better benefit-cost ratios. Still, this assessment places more importance on optimizing the duration, severity, and age at which feed restriction programs are imposed to allow for sufficient compensatory growth in broiler chickens.

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