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Physical Body Deformity Effects on Differential Growth and Body Traits Development in Commercial Broilers

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SUMMARY
Physical deformities have been a recurrent challenge on broiler production in the tropics. The effect of physical body deformity (PBD) on differential growth of 550 commercial broiler chicks of Ross308 strain from day-old to 56 days were evaluated. Experimental design was completely randomized Design (CRD), while treatment groups were normal birds (NB), crooked neck (CN), twisted Leg (TL) and crooked neck+twisted leg (CN+TL). Data were collected on body weight (BWT, g), drumstick length (DST, cm), wing length (WGL, cm), shank+toe length (STL, cm) and leg length (LEL, cm); and were subjected to General Linear model (GLM), $\alpha_{=0.05}$, regression and Tukey's Honestly Significant Difference (HSD) procedures of Statistical Analytical Systems software, SAS® v8 (2008). Physical body deformity depressed broiler growth and development significantly (P<0.05) with small to large effects sizes (*ds* = -1.40 to 0.70). The differences in latent growth between deformity groups were significant (P<0.05), of practical (d_S>0.5) and large (f^2>0.4) importance from age 35 to 56 days. The CN+TL broiler group was most significantly depressed by physical deformity with linear growth speed of 0.43, and quadratic late growth speed of -0.19. Most adverse impact of the deformity conditions on growth and body development spanned from 35 to 56 days, and could lead to rejection of live birds at maturity and low profitability of small flock enterprises in the tropics
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Keywords: Commercial broilers, Physical abnormalities, Growth and development, Torticollis, Valgus-varus angulation

INTRODUCTION
As consumers demand for more chicken, breeders were challenged to produce strains with improved genetics, fast growth rate and high meat yield for maximum economic returns. Due to intense selection pressure applied on parent breeder stock, broiler growth increased by over 400% between 1957 and 2005 (Zuidhof *et al.*, 2014). The increased growth rate resulted in broilers with larger breast muscles than their ancestors (Tallentire *et al.*, 2016) but associated with physiological stresses and increased incidences of deformities such as skeletal, leg, nervous and other temporary and permanent disorders (Knowles, *et al.*, 2008; Shim *et al.*, 2012). Clinical and anatomical evidences suggest that

deformities could be linked to distinct causes (Le Bihan-Duval *et al.,* 1996). Skeletal disorders result in lameness or biomechanical dysfunction which leads to poor growth, culled birds, increased mortality from starvation and dehydration, increased carcass condemnation and downgrading at slaughter. Dinev (2012) reported that most leg abnormality in chickens could be overcome by selection, and improvement of production systems by the end of the 20th century, but current experiences reveal persistence of leg problems in broiler. All broiler flocks contain birds with skeletal abnormalities in varying degrees such as twisted legs (Dunkley, 2017), twisted necks etc, and theses are related to chicken's growth potential (Shim *et al.,* 2012). Developmental disorders of long bones are affected by genetics and environmental stressors throughout the life-cycle of the broiler (Bradshaw *et al.,* 2002; Oviedo-Rondón *et al.,* 2006, Oviedo-Rondón, 2008).

Twisted legs or valgus-varus angulation in broilers is reportedly associated with tibial deviation and rotation of the shallow distal condyle groove of the tibiotarsus (Shim *et al.,* 2012). Crooked neck or torticollis is a muscular disorder characterized by curved neck and limited head mobility in poultry birds, with heads and necks that appear twisted and tilted, and may be unable to feed and drink leading to starvation or eventual death (Wry neck, 2020). Despite increased leg and other abnormalities in commercial broiler birds over decades, reports on effects on growth and development of broilers are limited. This study on commercial broilers is important because outcome could reveal impact of physical body disorders on post-hatch growth and development in commercial broilers. Physical body disorders also have grave financial implications on commercial broiler profitability. Findings from study could re-focus managers to innovative management for reduction of body deformity in commercial broiler flocks in the Tropics. The objective of the experiment was to investigate the effect of physical deformity on differential growth and development in broilers. Hypothesis of study was that there shall be no differences in growth and body development among physical body deformity (PBD) groups.

MATERIALS ASND METHODS

The protocol and procedures for experiment were ethically reviewed and approved by the Federal University Oye-Ekiti Research ethics committee, and is also in line with national guidelines and regulations for the care and use of animals, ARRIVE 2.0 (Percie du Sert, *et al.,* 2020) and PREPARE guidelines for planning animal research and testing (Smith *et al.,* 2018). Thus experimental subjects were cared for under guidelines comparable to those laid down by the Canadian Council on Animal Care.

Location of study:

Experiment was conducted at the Teaching and Research Farm, Federal University Oye-Ekiti, Ikole campus, Nigeria. It is located on latitude of 7.798^0N and longitude 5.514^0E, with average annual temperature of 24.2^0C and humid tropical conditions.

Housing and management of chicks:

The poultry house was open-sided with dwarf wall, side-netting and asbestos roofing sheets cover. House repairs, cleaning and disinfection with a disinfectant agent - Izal (Guanlang Group, Shijiazhuang, China) - were done; and installation of side curtains for brooding were completed before chicks' arrival. Five hundred and fifty (550), mixed-sex, day-old commercial chicks of Ross308 broiler strain were purchased from Agritech hatchery in Ibadan, Nigeria. On arrival, chicks were tagged on the left wing for identification and reared for 56 days on deep litter system placed with wood shavings bedding managed with high level of hygiene. A stocking density of 10 birds/m^2 was adopted. Cold-room brooding of chicks was acomplished with mechanical coal-pots, placed at equidistant intervals during the first four weeks of life, to provide additional heat. Temperature of heat (35^0C at day old, and reduced weekly to 26.5^0C at end of 4th week) was maintained with side curtains, monitored with wall thermometers fixed at convenient intervals close to the floor. This was combined with chicks' behavioural responses to adjust the temperature of the heat source. Oral vaccinations were administered against Infectious bursal disease (IBD) at day-old (spray), and 21 days; and Newcastle disease (ND LaSota) at 7, 14 and 28 days. Feed and water were made available ad-libitum. Birds were fed daily with commercial (VITAL FEEDS) pelletized broiler starter and finisher mash feeds (Table 1) purchased within Ikole-Ekiti metropolis. Medicated feed at 10mg/kg of caprofen was offered on two days weekly to reduce handling stress and pain (Hocking *et al*, 2005). Twelve hours (6.30-18.30 hrs) of light was provided through natural day-light.

All chickens received standard management throughout experimental period. At the end of the 4th week, the chicks were examined and assigned to four (4) physical body deformity groups namely: normal birds (without observed defects, NB), crooked neck (twisted neck or torticollis group, CN), twisted leg (valgus-varus angulation, TL) and crooked neck+twisted leg (composed of birds showing both deformities, CN+TL) groups. Subsequently, experimental birds were separated into observed groups, and their effects on body development to 4 weeks of age (when they were clearly observed and classified) was examined. Although broilers with observed deformities were to be culled from the flock, but ANOVA revealed no significant effect of deformity on body weight and growth at 4 weeks of age; therefore, study was furthered till commercial maturity at 8 weeks to uncover the full effect of conditions and impplications on body development. Treatment groups had replicates 199, 106, 128 and 117 chicks respectively.

TABLE I: Nutrient and energy composition of feed types

Feed Type	broiler starter	broiler finishers
Duration	1-4 weeks	5-8 weeks
Crude Protein	22.0 %	19.0 %
Crude Fiber	5.0 %	8.0 %
Calcium	1.2 %	0.85%
Available Phosphorus	0.50 %	0.42 %
Metabolizable Energy	3100 Kcal/Kg	3225 Kcal/Kg

Defintion of Treatment groups:

Experimental birds were grouped based on above classifications. Normal broilers (NB) were taken as birds with typical broiler body conformation such as broad concave back shape, wide spreading feet, broad fleshy chest and balanced gait (Plate 1). Birds classified as showing torticollis or crooked neck condition (CN) displayed abnormal neck and head positioning, inability to hold the neck erect, stiffness, inability to control the head and feed normally (Plate 2). Broiler birds with valgus-varus angulation or twisted legs (TL) were regarded as those showing splayed legs, angular leg twist, bowed in and out legs, swollen hocks, lameness, impaired walking ability or gait (Plate 3). Birds showing both crooked neck and twisted legs (CN+TL) displayed both physical deformity conditions.

Plate 1: An experimental normal female broiler. The typical broiler composite conformation include: broad concave back shape, wide spreading feet, broad fleshy chest and balanced gait.

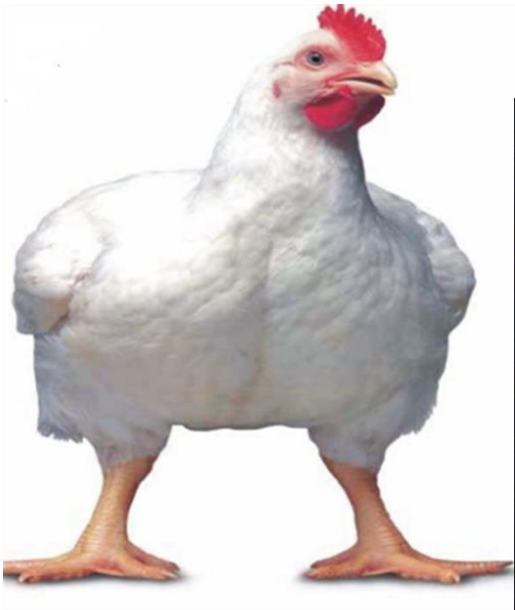

Plate 2: An experimental broiler bird showing torticollis or crook neck condition. Signs of crooked neck condition include: abnormal neck and head positioning, inability to hold the neck erect, stiffness, pain, inability to move and feed normally, and loss of typical broiler conformation.

Plate 3: An experimental broiler bird with valgus angulation (twisted legs). Signs of valgus-varus angulation include: splayed legs, angular leg twist, bowed in and out legs, swollen hocks, lameness, impaired walking ability (gait), and loss of typical broiler conformation.

Data collection:

Data were collected on weekly basis from day-old to eight weeks. Traits investigated were body weight (BWT, g), wing length (WGL, cm), shank+toe length (STL, cm), drumstick length (DST, cm), leg length composed of drumstick+shank+toe (LEL, cm). Three index traits derived were growth rate (g/d), body-wing index (BWI, BWT÷WGL, g/cm) and body-drumstick index (BDI, BWT÷DST, g/cm). Wing length was taken as the length of the wing from the scapula joint to the last digit of the wing, shank+toe length was taken as length from the hock joint to the last phalange on the toe (Fayeye *et al.*, 2006), drumstick length was taken as distance from the upper femur joint to the tibia joint, including the patella, while leg length was composed of drumstick+shank+toe length. Body weight was estimated at day-old and weekly thereafter with Camry electronic scale (1g sensitivity) while linear traits were measured in cm at 6 to 8 weeks with metric tape rule. Treatment groups CN, TL and CN+TL were compared to the NB group which was taken as standard.

Experimental design and analytical procedures:
Experimental design was completely randomized design (CRD, unbalanced) as in model equation below (1):

$$Y_{ij} = \mu + \tau_i + \mathcal{E}_{ij} \quad (1)$$

where Y_{ij}= trait response in ith body deformity group and jth replicate; i=body deformity treatment group; j=number of replicates within group; μ=strain mean; T_i=fixed effect of ith physical body deformity (i=1,….,4); $\mathcal{E}_{ij}$=common error, assumed to be normally and independently distributed, NID, (0, σ^2) in ith body deformity group and jth replicate. The hypothesis tested was: H_0: $T_1=T_2=T_3=T_4$. Data generated were subjected to General Linear Model (GLM), Tukey's Honestly Significant Difference (HSD) $\alpha_{=0.05}$, and regression procedures with SAS®v8 software (2008).
Data were transformed to percentage of NB broiler values before regression; while linear curves were plotted using Microsoft excel procedures (Ms, 2010). The regression models were as in Eq. (2) and (3):

$Y = a + bX + \mathcal{E}$ (Linear regression model) (2)

$Y = a + bX + cX^2 + \mathcal{E}$ (Quadratic regression model) (3)

Where, Y = body weight/growth rate, a = constant (latent/genetic potential), b = slope (early body weight/growth speed), c = power of second function for body weight or growth (late body weight/growth speed) and Ɛ = residuals component. Effect sizes were determined with Cohen's f^2 classification scheme for multiple regression (Cohen, 1988, Bowman, 2017, Kotrlik *et al*., 2011) and Glass's delta formular for estimating and clasifying effect size between independent group means as in Eq. (4) and (5).

Cohen's effect size (f^2) = $R^2 / (1 - R^2)$ (4)

Glass' Δ, *(ds)* = $(X_1 - X_2) / SD_2$ (5)

Where, R^2 = coefficient of determination for a regression equation, X_1 = mean of an independent group, X_2 = mean of independent control group, and SD_2 = standard deviation of the control group.

RESULTS
Table II reveals that NB, CN and TL groups were superior to CN+TL group (P<0.0322), but similar in body weight, growth rate, wing length, drumstick length, shank+toe length, leg length, BWI and BDI values. Compared to the NB group, the CN group recorded very small effect size *(ds)* of -0.07 to 0.04 on all traits. The TL group recorded low effect *ds* of -0.21 to 0.22 on body weight, growth rate, WGL and DST; and medium effect *ds* of 0.50 to 0.70 on LEL, BDI, STL and BWI. The CN+TL group returned *ds* of -0.19 to -0.21 on growth and BWT; high effect *ds* of -0.55 to -0.94 on WGL, DST, BDI, LGL, BWI and a huge effect *ds* of -1.40 on STL.

TABLE II: Effect of physical deformity on body weight and other traits in Ross308 broilers from day-old to 56 days in Ikole, Nigeria

	Physical Deformity Conditions						
Body Traits	Normal Broilers	Crooked Neck	Twisted Leg	CN + T L	*SEM*	*P-level*	CV
N	199	106	128	117		-	550
Body weight, g	599.67[a]	590.49[a]	679.59[a]	489.96[b]	16.17	<0.0322	93.37
Growth, (g/d)	21.24[a]	21.35[a]	23.95[a]	18.82[b]	0.34	0.0128	55.31
Wing length, cm	16.14[a]	16.08[a]	15.78[a]	15.21[b]	0.11	0.0141	10.50
Drumstick length, cm	13.28[a]	13.16[a]	13.58[a]	12.14[b]	0.12	0.0015	13.21
Shank+Toe length, cm	14.21[a]	14.17[a]	14.75[a]	12.99[b]	0.07	0.0001	7.22
Leg Length, cm	27.43[a]	27.12[a]	28.33[a]	25.17[b]	0.17	0.0001	9.18
BWI, (g/cm)	78.11[a]	77.97[a]	89.05[a]	63.39[b]	1.10	0.0001	20.44
BDI, (g/cm)	94.92[a]	95.60[a]	104.05[a]	80.22[b]	1.25	0.0001	19.51

[a,b] Mean with different superscripts across row indicate significant differences<0.05. CN+TL=Crooked neck+Twisted leg. SEM= standard error of mean, Signif. Level=significance level, CV=coefficient of variation

TABLE III: Effect of physical deformity on weekly body weight and growth in Ross308 broilers from day-old to 56 days in Ikole Nigeria

		Physical Deformity Conditions						
Age (days)	Body Traits	Normal Broilers	Crooked Neck	Twisted Leg	CN+T L	*SEM*	*Signif. level*	CV
1	Body weight, g	41.42	41.40	41.33	41.25	*0.81*	*0.9928*	6.24
	Growth (g/d)	40.94	41.40	41.33	41.25	*0.39*	*0.9811*	10.97
7	Body weight, g	96.25	95.90	100.33	94.07	*1.00*	*0.7433*	11.80
	Growth (g/d)	13.28	13.70	14.33	12.96	*0.25*	*0.8113*	21.72
14	Body weight, g	194.39	184.30	214.00	187.08	*3.35*	*0.5128*	19.06
	Growth (g/d)	12.77	13.16	15.29	12.41	*0.38*	*0.7365*	34.15
21	Body weight, g	361.83	348.40	415.67	343.43	*6.82*	*0.3860*	21.48
	Growth (g/d)	16.84	16.59	19.79	16.35	*0.37*	*0.6054*	25.16
28	Body weight, g	504.33	483.10	579.00	453.29	*10.03*	*0.1022*	22.54
	Growth (g/d)	17.40	17.25	20.68	16.19	*0.42*	*0.3971*	27.82
35	Body weight, g	693.23[ab]	667.40[ab]	846.33[a]	581.67[b]	*14.85*	*0.0042*	23.64
	Growth (g/d)	18.91[ab]	19.07[ab]	24.18[a]	16.03[b]	*0.52*	*0.0421*	31.57
42	Body weight, g	1073.12	939.20	1101.67	766.63	*77.8*	*0.4495*	85.50
	Growth (g/d)	23.81	22.36	26.23	17.60	*1.81*	*0.5707*	92.35
49	Body weight, g	1159.89[ab]	1183.50[ab]	1329.33[a]	911.57[b]	*25.88*	*0.0002*	24.16
	Growth (g/d)	23.67[b]	24.15[b]	27.13[a]	18.60[c]	*0.53*	*0.0002*	24.16
56	Body weight, g	1353.15[b]	1371.20[b]	1488.67[a]	1008.04[c]	*29.83*	*0.0001*	22.98
	Growth (g/d)	24.16[ab]	24.49[ab]	26.58[a]	18.00[c]	*0.53*	*0.0001*	22.98

[a, b, c, d] - suprscripts in rows with different letters differ significantly (P≤0.05), CN+TL=Crooked neck+Twisted legs, *SEM= standard error of mean Signif. Level=significance level, CV=coefficient of variation*

Table III reveals that body weight and growth among PBD groups differed significantly (P<0.05) at weeks 5 to 8, although these traits were similar at early life weeks 1 to 4. The CN+TL group showed lower BWT and growth rate than NB, CN and TL treatment groups (P<0.05) from week 5 upwards. The CN, TL and CN+TL groups differed from NB in body weight by 18.05, 135.52, -345.11 g; and in growth rate at 56 days old by 0.33, 2.42 and -6.16 g/day respectively. Figure 1 reveals the comparative linear growth equations of NB, CN, TL and CN+TL groups. These equations revealed latent growth abilities of 62.25, 63.40, 72.90 and 65.31 g/day, and linear growth speeds of 0.95, 0.92, 1.07 and 0.43 g/day for respective groups. The R^2 values were 29.8, 27.5, 27.6 and 7.3 % for growth rate-age models of NB, CN, TL and CN+TL respectively.

Table IV presents the effect of PDC on other body and index traits at 42, 49 and 56 days of age (weeks 6 to 8). There were no significant differences (P>0.05) among broiler groups at 42 and 49 days of age, but important differences were observed on all traits at 56 days of age. Compared to normal broilers, CN group trait-averages revealed *ds* of -0.31 to 0.22 on all traits, TL returned *ds* of -0.01,-0.04 on LGL and DST; small *ds* of 0.37, 0.45, 0.45,-0.49 on STL, BWT, growth and WGL; and medium *ds* of 0.73 and 0.76 on BDI and BWI respectively. All traits in CN+TL group returned delta's effect size (*ds)* range of 2.25 to 14.33.

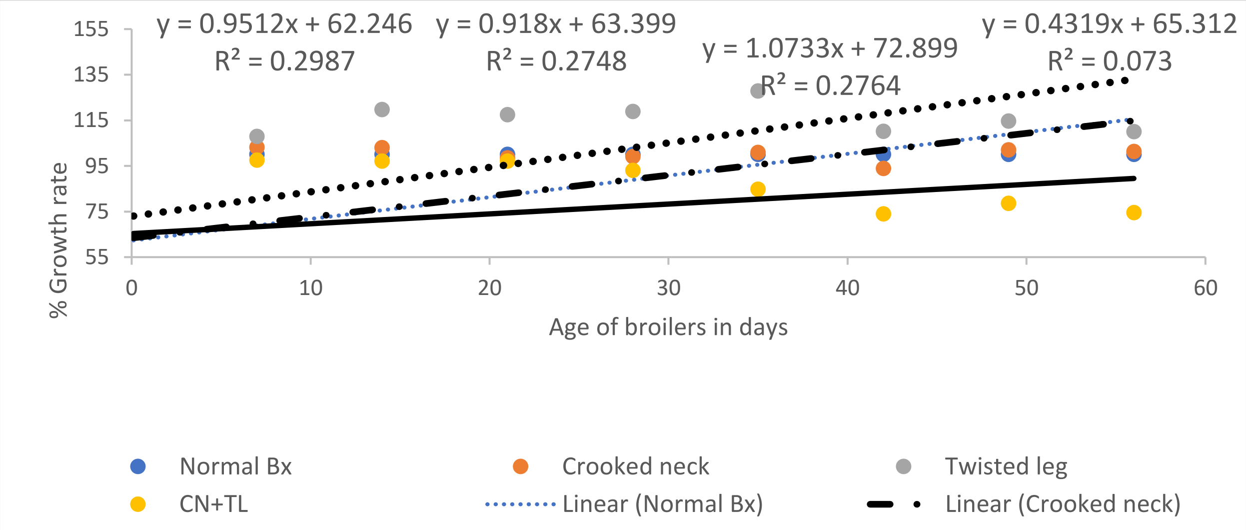

FIGURE 1: Comparative linear growth curves and equations from day-old to 56 days of age in physical body deformity groups of Ross308 broiler in Ikole Nigeria.* Equations in graph above are in order of NB, CN, TL and CN+TL broiler groups respectively

TABLE IV: Effect of physical deformity on body and index traits in Ross308 broilers at 42, 49 and 56 days in Ikole Nigeria

Age (days)	Body Traits	Physical Deformity Conditions Normal Broilers	Crooked Neck	Twisted Leg	CN +TL	SEM	Signif. level	CV
42	Wing length, cm	12.50	12.45	12.62	12.75	0.53	0.8943	13.45
	Drumstick length, cm	7.00	7.41	7.23	8.50	0.38	0.2402	13.22
	Shank+Toe length, cm	11.40	11.22	11.76	11.25	0.37	0.9091	10.61
	Leg Length, cm	17.40	17.16	20.52	19.75	0.70	0.3200	10.62
	BWI, (g/cm)	49.68	45.44	60.16	56.67	4.28	0.2350	22.50
	BDI, (g/cm)	70.86	72.34	95.45	85.01	5.89	0.4874	21.82
49	Wing length, cm	14.83	15.15	14.67	14.85	0.08	0.6303	5.17
	Drumstick length, cm	12.15	12.30	13.17	12.38	0.08	0.1810	6.67
	Shank+Toe length, cm	14.13	13.85	14.83	14.06	0.08	0.2644	5.34
	Leg Length, cm	26.16	25.75	28.00	26.56	0.16	0.1536	5.92
	BWI, (g/cm)	79.60	78.02	89.89	73.99	1.62	0.5338	20.56
	BDI, (g/cm)	97.03	96.00	102.38	88.67	1.85	0.6200	19.31
56	Wing length, cm	17.49[a]	17.12[a]	16.90[a]	16.01[b]	0.12	0.0001	7.00
	Drumstick length, cm	14.49[a]	14.11[ab]	14.00[ab]	13.11[b]	0.13	0.0001	9.04
	Shank+Toe length, cm	14.33[ab]	14.53[a]	14.67[a]	13.18[b]	0.10	0.0001	7.19
	Leg Length, cm	28.84[a]	28.64[a]	28.67[a]	26.33[b]	0.20	0.0001	6.60
	BWI, (g/cm)	77.10[a]	77.92[a]	88.21[a]	62.28[b]	1.44	0.0001	19.44
	BDI, (g/cm)	93.12[a]	95.16[a]	105.71[a]	76.44[b]	1.72	0.0001	19.41

[a, b, c, d] – superscripts in rows with different letters differ significantly (P≤0.05), CN+TL=Crooked neck+Twisted legs, *BWI=body-winglength index, BDI=body-drumstick index, SEM= standard error of mean, Signif. Level=significance level, CV=coefficient of variation,*

Table V gives the standardized quadratic growth equations showing asymptotic behaviour of body weight development and body mass growth with increasing age for all groups. The NB, CN, TL and CN+TL groups demonstrated increasing early weight development speed, a= 0.41, 0.37, 0.56, and 0.69; and decreased variability (CV=22.50 – 19.31) on index traits. These same groups revealed lower late weight development speed, b=0.36, 0.61, 0.37 and 0.22 at 42 to 56 days of age, except CN group. The R^2 values were 0.81, 0.83, 0.55 and 0.94 giving Cohen's f^2 values of 1.22, 16.86, 4.95 and 4.83 respectively. Similarly, early-life growth rate was higher than late growth in all groups. Growth increased early-life from CN, NB, CN+TL to TL at (a= 0.50, 0.80, 1.16, 1.36), but decreased later at 5 to 8 weeks (b= 0.47, 0.16, -0.19, -0.37) respectively. The R^2 ranged from 0.91 to 0.99, and translated to Cohen's f^2 values of 10.24, 12.51, 199.00 and 14.38 for respective broiler groups.

TABLE V: Quadratic growth equations covering day-old to 56 days in normal and deformity groups of Ross308 broiler chicks in Ikole Nigeria

	Standardized quadratic growth model $Y = \mu + bX + cX^2 + \varepsilon$			
Trait	Normal birds	Crooked neck	Twisted leg	CN+TL
BWT	$-4.48+0.41X+0.36X^2$	$16.35+0.37X+0.61X^2$	$-18.81+0.56X+0.37X^2$	$3.51+0.69X+0.22X^2$
R^2	0.549	0.944	0.832	0.812
GRH	$0.74+0.80X+0.16X^2$	$3.51+0.50X+0.47X^2$	$-5.32+1.36X-0.37X^2$	$-5.81+1.16X-0.19X^2$
R^2	0.911	0.926	0.995	0.935

* Y = Body weight response, μ = basal group mean, b= linear function growth speed, c = second function growth speed, X = Age in days, *BWT=Body weight,GRH= Growth rate.*

DISCUSSION

The crooked neck+twisted leg condition revealed severely checked or highly depressed growth and body traits development. The CN, TL and CN+TL deformity groups revealed body weight, growth rate and body traits development of small, medium and large practical importance respectively. The CN+TL group was most negatively affected than NB, CN and TL groups at 56 days. Researchers reported relatively high incidence of growth-associated leg weakness in broilers (Garner *et al.*, 2002; Sanotra *et al.*, 2002, Brickett, 2007). Sherlock *et al.* (2010) reported that twisted leg or valgus-varus deformation (VVD) in broiler chickens was developmental, due to abnormal intertarsal joint and tibiotarsus or femur rotation. This condition causes walking difficulties, increased risk of injury during catching, causing downgrading and rejection of live birds by processors (Aviagen, 2001). Twisted leg (TL) lead to altered load bearing and lack of activity (Bradshaw *et al.*, 2002). Thorp (1994) reported that bone deformity conditions in poultry reflect genetic and production stresses applied to the skeleton. Sherlock (2010) reported that poor leg health lead to reduced bone quality (weakness) in rapid growing broilers.

Growth and body weight between groups was highest on TL group and least on CN+TL group, while the CN and NB groups were in-btween at 35 to 56 days. Nilsson *et al.*, (2005) identified pathologies and abnormalities in the endocrine regulation of the growth plate as primary causes of most skeletal growth disorders in growing broilers. The CN condition, which variably could be caused by genetic factors, head injury, vitamin deficiency or disease (Amanda, 2018) make broilers lose control of their necks, unable to hold the necks erect; and thus affecting their ability to feed properly. However, this condition did not reduce growth and body weight (Table III) significantly below that obtained in NB group.

The cause of the insignificant differences among PDC groups on body weight and growth at 42 days (week 6) was not clearly understood, but this probably may be because the CN+TL group showed some compensatory growth at this period. But at 56 days old, body weights in present study were comparable to 1353 to 1391g for 8-week old broilers reported by Jiang and Yang (2007), although the twisted leg group had body weight higher than above range. Shukla (2011) had proposed a linear model for growth studies wherever phenomenon exhibit asymptotic behavior. Kaufmann (1981) measured growth rate as function of size, because growth rate (as independent variable) at many different sizes (body dimensions) can be measured at same time. The quadratic body weight and growth curves revealed the innate or latent ability, the early and the late performance attributes of broiler groups. The CN group displayed most superior latent body weight development and latent growth rate; and fastest late body weight development and growth rate compared to other deformity groups. Thus, crooked neck condition had medium effect on latent and late body weight development and growth. The TL broilers showed low latent ability for body weight developmemt and growth, but fast early life growth rate which declined later towards commercial maturity. Although the TL condition did not appear to influence early life growth negatively, but it exerted higher negative effect with increasing age of birds; as late growth showed a drastic decline (Table V) towards commercial maturity. Similarly, the CN+TL condition revealed low positive effect on early body weight development and growth; with further declined in growth rate as it approaches commercial maturity at 8 weeks. Early-life body weight development in CN+TL was numerically better than in CN and TL groups (Table 4), probably because the effect of CN+TL condition did not manifest early in the short life-cycle of the experimental group. Both early body weight development and early growth were believed to be lowly negatively influenced by the PDC conditions, and so exerted no noticeable effects at this period compared to normal birds.

The linear curves (Figure 1) revealed that growth abilities were similar among experimental groups, but actual linear growth among PDC groups differed in relation to the intensity of defect suffered. Growth abilities were severely checked as revealed by the R^2 of PDC equations. Furthermore, the pattern of overall growth among experimental groups show that the CN+TL condition adversely affected both latent and overall growth, while the TL condition produced the best latent and linear growth among broiler groups. This meant that TL (valgus-varus angulation) did not adversely affect overall development and growth when compared to the effect of crooked neck (torticollis) or the combination of both crooked neck and twisted legs condition. The NB and CN groups followed the TL group in descending order of overall performance. The linear curve thus reveals that rate of growth was best in TL and higher than in CN and BN; but least in CN+TL group. Twisted legs and other PBD conditions in present study might be associated with poor leg genetics, fast early-growth and management stresses. The growth rate-age model approach applied thus removed environmental effects from observed body weight development and growth patterns, since size is closely related to growth rate than numerical increase in age.

Overall, wing length, drumstick length, shank+toe length, leg length, BWI, BDI were similar among NB, CN and TL groups but differed from CN+TL group.

Thus, the CN+TL defect manifested more severe defects on above-mentioned traits, depicting the double-deformity condition suffered (Table 2). The negative effects on body traits among NB, CN and TL conditions were less severe compared to the effect of the CN+TL group at 56 days. The effect of these differences on body traits development were very large, medium and small in CN+TL, TL and CN groups; and therefore economically important at 56 days of age than at lower ages (Table IV). The large negative effect of CN+TL condition on differential body weight and growth were specifically revealed at days 35, 49 and 56 among broiler groups (Table III).

Growth in birds involve complex physiological and morphological processes from egg-hatching to chick-maturity, and involves increase in weight and volume of organs or body dimensions over time (Kaplan and Gürcan, 2018; Topal and Bölükbaşı 2008). It exhibits asymptotic, non-linear, behaviour towards maturity stage when it becomes fixed. Late growth increased positively with age in normal looking control birds and CN birds, but decreased in birds with the TL and CN+ TL conditions. Similarly, both TL and CN+TL conditions were negatively related to growth rate (Table V). The decrease in growth with increasing age support report by Shim *et al.,* (2012) that growth rate was negatively correlated with twisted leg syndrome. Ricklefs (1985) pointed that curve fitting describes the course of body mass increase with age by simple equations with few parameters, although the Gompertz equation had been in use for describing growth in broilers (Darmani *et al.,* 2003). The quadratic curves fitted adequately described the course of early and late body weight development and growth with age (R^2 = 0.55-0.99), but could not have depicted the full asymptotic behaviour for body development and live growth due to limited experimental period of eight weeks employed in present study. The depression in growth suffered by the CN+TL birds could have been induced by the joint action of the nervous and twisted legs condition suffered which severely hampered normal feeding activity in birds. Study revealed that 36%, 19%, 23% and 22% of experimental units displayed the normal broiler conformation, crooked neck, twisted legs and crooked neck+twisted legs conditions (ratio 2:1:1:1). Therefore, in small fast-growing broiler flocks, farmers may experience similar incidence of physical body deformity at commercial maturity point, which could lead to high level of mid-life culling, rejection of live birds at commercial maturity by buyers and processing plants, and low profitability. Nevertheless, high growth rate of broilers will continue to present challenges of physical deformities worldwide, while commercial managers could continue to apply adequate nutrition, biosecurity and good management to reduce the degree of observed malformations.

CONCLUSION

Study revealed differences in growth and body development among physical body deformity (PBD) groups. Physical deformity caused different levels of severity on growth and development of broilers. Overall growth performance was severely affected in the crooked neck +twisted leg birds than others. It is recommended that further research should investigate best management practices that could - at 29 to 56 days - mitigate the impact of physical deformity on broiler growth and development in the tropics.

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