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Age and Gender Depending Growth of Feathers and Feather-Free Body in Modern Fast Growing Meat-Type Chickens

Christian Wecke, Daulat Rehman Khan, Angela Sünder, Frank Liebert

Division Animal Nutrition Physiology, Department of Animal Sciences, Georg-August-University of Göttingen, Göttingen, Germany
Email: flieber@gwdg.de

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Abstract

Two growth experiments with fast growing meat type chickens (Ross 308) were conducted to assess the growth of feathers and feather-free body dependent on age and gender (male:female ratio = 1:1). Birds were reared under uniform management and feeding conditions (floor pens; 15 pens per gender; 5 birds per pen) during the starter (day 1 to 22) and grower period (day 22 to 36). Diets were based on corn, wheat, soybean meal, soybean protein concentrate and balanced with feed amino acids to ensure an equal feed protein quality close to the ideal amino acid ratio by a constant mixture of the feed proteins. At start of the experiment and further on weekly up to the end of the 5^{th} week, 15 birds per gender (each 3 pens of 5 birds) were selected and 24 h fasted before quantitative de-feathering. Both feather and feather free body fractions were significantly increased with increasing age of the birds ($p <$ 0.001). Feather percentage as related to the empty body weight increased non-linearly from approximately 2% at the end of the first week to about 4% at the end of the experiment. Feather percentage and dry matter content of the feather-free body was significantly higher in female birds ($p < 0.001$) as compared to males. Further investigations will show how this varying proportions impact on nutrient deposition of modern meat-type chickens dependent on age and gender, respectively.

Keywords

Growing Chickens, Feather Percentage, Feather-Free Body, Age, Gender

1. Introduction

Investigations about whole body composition of current broiler genotypes provide preconditions for valid evaluation of energy and nutrient requirements, namely when factorial methods are applied. In this context, both maintenance requirement and nutrient deposition data are needed for valid conclusions. Consequently, changes of the proportion between feather and feather-free body fractions during growth are of special importance for revision of such requirement data when based on factorial methods. According to our knowledge, first detailed investigations about feather and feather-free body mass both depending on genotype and age were reported by Lehmann [1] [2]. However, corresponding data of actual broiler genotypes are missed.

Several studies are indicating that feathers achieve their mature state earlier than the remaining body fractions [3] [4] [5]. Wylie *et al.* [6] concluded that feather growth was apparently maintained in preference to muscle and body development. Generally, the growth rate of any body tissue is resulting from balance between synthesis and degradation of proteins, but once formed feather protein is not underlying turnover processes. Therefore, inadequate nutrient supply impacted on the proportionate feather covering by lower gain of the remaining body mass. Wylie *et al.* [7] pointed out that dietary crude protein (CP) was preferentially partitioned for feather production rather than for muscle growth in a modern turkey line. It was concluded that feather growth is maintained as high as possible on the expense of body growth when feed supply was below the need for optimal performance data. Consequently, the nutrient consumption for feather development is a significant factor of high nutritional priority during the period of rapid growth.

As reviewed both by Deschutter and Leeson [8] and Leeson and Walsh [9], several factors of influence like animal, nutritional, environmental and management factors may respond on feather growth and development. Accordingly, significant differences in feather development and rate of feathering between genotypes of growing chicken and laying hens were reported [1] [2] [10]-[17]. Among nutritional factors, the dietary CP and amino acid (AA) supply is the most important [17]-[25]. Reduced feather development as well as abnormal feather structure and pigmentation was observed due to suboptimal AA supply [26]-[32]. In addition, feather coverage of birds with naked-neck and fizzle gene is considerably lower as compared to their "fully-feathered" counterparts [16] [20] [33]-[40]. Furthermore, time-dependent plumage development of birds with early and late feathering genes is to be taken into account [41] [42].

The present study aimed to generate a revised database of feather and feather-free body mass development in modern meat-type chickens which may contribute to explain variation in age and gender depending nutrient requirements.

2. Materials and Methods

Two consecutive growth experiments utilized 180 growing chicken (male to female birds = 1:1) and were conducted at the facilities of the Division Animal Nutrition Physiology, Department of Animal Sciences of Georg-August-University

Gottingen. Each experiment lasted 5 weeks and was approved by the Lower Saxony Federal Office for Consumer Protection and Food Safety (LAVES), Germany.

2.1. Animals and Housing

Day old meat-type chickens (ROSS 308) were obtained from a commercial hatchery and kept in floor pens on wood shavings. Free supply of a standard diet and water was provided. Next day (d1), averaged weighed birds were randomly allotted to 15 pens per gender (1.2 sqm; 5 birds per pen) and kept under uniform management and feeding conditions (starter period: 1 to 22 d, grower period: 22 to 36 d). Room temperature was gradually reduced from 32˚C to 20˚C with increasing age of the birds. Humidity was maintained between 60% and 70% and light was provided for 23 hours per day.

2.2. Diets and Feeding

The starter and grower diet (Table 1) was based on corn, wheat, soybean meal,

Table 1. Composition of experimental diets (g/kg as fed).

	Starter diet (d1 to d22)	Grower diet (d22 to d36)
Corn	270.0	249.2
Wheat	200.0	184.6
Soybean meal	330.0	304.6
Soybean protein concentrate	80.0	73.8
Soybean oil	75.0	73.0
DCP	13.5	11.0
$CaCO_3$	10.0	7.3
NaCl	2.6	2.2
Premix[1]	10.0	10.0
Wheat starch	4.50	8.02
DL-Methionine	3.10	2.86
L-Lysine·HCl	1.20	1.11
L-Threonine	0.10	0.09
AMEn, MJ/kg[2]	12.81	13.01
Crude protein	229.9	212.2
Lysine	13.0	12.0

Dietary amino acid ratio (*Lys* = 100):

Lys	Met+Cys	Thr	Trp	Arg	His	Ile	Leu	Phe	Val
100	74	65	21	114	43	68	132	80	71

[1]Provided (per kilogram of diet): vitamin A, 12,000 IU; vitamin D3, 3500 IU; vitamin E, 40 mg; thiamin, 2.5 mg; riboflavin, 8.0 mg; vitamin B6, 6.0 mg; vitamin B12, 32 µg; vitamin K3, 4.5 mg; nicotinic acid, 45 mg; $CaCO_3$, 15 mg; folic acid, 1.2 mg; biotin, 50 µg; choline chloride, 550 mg; Mn,100 mg; Zn, 80 mg; Fe, 30 mg; Cu, 20 mg; I, 1.2 mg; Co, 0.4 mg; Se, 0.4 mg; butylated hydroxytoluene, 100 mg. [2]Nitrogen corrected apparent metabolizable energy, calculated according to WPSA [46].

soybean protein concentrate and crystalline feed AA as main ingredients. Diet formulation aimed to meet current recommendations of NRC [43] and GRRS [44]. A constant mixture of the dietary protein sources yielded equal feed protein quality during both of the feeding periods. Based on the analysed AA content of the individual feed ingredients (see 2.4.), the AA composition of final diets was adjusted close to the ideal AA ratios (IAAR) as proposed by Wecke and Liebert [45]. In case of histidine, leucine and phenylalanine the observed individual AA ratios to lysine exceeded the IAAR due to the elevated content in the ingredients.

Birds had free access both to drinking water and pelletized starter and grower diets.

2.3. Collection and Sampling

Both at start of the experiment and weekly up to the end of the 5th week 15 male and female birds (3 pens per week and gender) were selected by body weight (BW) and fasted for 24 hours with full access to drinking water. Selected birds were euthanized by CO_2 inhalation according to animal welfare regulations. Fresh feather mass from manual individual feather plucking was quantified by weight before and after plucking. Each sample of quantitatively collected feathers and of feather-free body was separately stored in plastic bags at −20˚C for further processing. Differing from this procedure, the removed down from day-old chickens were pooled due to the low individual feather quantity.

Feather sample bags were perforated and freeze dried for 48 h. Following freeze drying, feathers were weighed, roughly cut with scissors and milled with added dry ice in a laboratory mill. Finally, the samples were grinded in a hammer mill with dry ice to pass a 1 mm sieve. These powdered feather samples were applied for proximate chemical analyses.

The feather-free empty bodies were carefully defrosted, autoclaved for 4 h at 110˚C (HMC Europe GmbH, Germany) and pooled in three replicates of 5 birds per pen. Pooled samples were cut into small pieces to pass through the meat chopper. The resulting mince was carefully homogenized and a representative sample was taken for further analyses.

2.4. Chemical Analyses

Feed ingredients, diets, feathers and feather-free empty bodies were analysed in duplicates according to the German standard procedures [47]. N analyses were conducted by DUMAS-method (LECO® TruMac, LECO Instrument GmbH, Kirchheim, Germany) and CP was calculated with factor 6.25. AA composition of the feed protein sources (except tryptophan) was analysed by ion-exchange chromatography (Biochrom® 30, Biochrom Ltd. Cambridge, England) following acid hydrolysis without and with application of an oxidation step for quantitative determination of sulphur containing AA (SAA). Tryptophan was quantified by reverse phase high performance liquid chromatography and fluorometric detection following alkaline hydrolysis with barium hydroxide during autoclaving (16 h, 120˚C).

2.5. Statistical Analyses

Statistical analyses run with SPSS software package (Version 23.0 for Windows; IBM SPSS Statistics Inc., Chicago, IL, USA). Individual outlier data were identified ($p \le 0.05$) by explorative data analysis using the interquartile range (IQR) for outliers (values between 1.5 IQR's and 3 IQR's from the end of a box) and extreme values (more than 3 IQR's from the end of a box) of the boxplot function. Two-way analysis of variance (ANOVA) was performed to compare means of variables depending both on age and gender of broiler chickens as main effects, inclusive their interactions. Verification of variance homogeneity (evaluated by Levene-Test) and identification of significant differences ($p \le 0.05$) applied Games-Howell test and Tukey post-hoc test, respectively. Nonlinear regression analysis was utilized to demonstrate the age-dependent variation of both the feather percentage and the dry matter (DM) content of the body fractions.

3. Results

Data of BW, feather weight and feather percentage in male and female birds of the two hatches are summarized in Table 2. According to the biological process of growth, both body and feather mass were significantly increased with increasing age of the birds ($p < 0.001$). At the end of the first week of age, feather

Table 2. Body and feather weight data and feather percentage depending on age and gender of fast growing broiler chickens[1].

Age (d)	Whole body weight (g)		Empty body weight[2] (g)		Feather weight (g)		Feathers (% of empty body)	
	Female	Male	Female	Male	Female	Male	Female	Male
1	45.1	46.6	42.0	43.0	1.4	1.3	3.34	2.95
8	180	195	154	170	2.9	4.3	1.85	2.54
15	437	516	392	475	9.7	16.3	2.38	3.42
22	952	1045	866	964	28.3	35.9	3.26	3.72
29	1749	1655	1632	1534	53.8	62.6	3.28	4.10
36[3]	2499	2437	2305	2278	83.1	91.7	3.61	4.04
Mean	990	975	910	904	30.3	35.1	2.97	3.47
	ANOVA significance levels (p)							
Age (A)	<0.001		<0.001		<0.001		<0.001	
Gender (G)	=0.746		=0.433		<0.001		<0.001	
A x G	=0.006		=0.003		=0.011		<0.001	

[1]n = 15 per age period and gender. [2]Body weight following 24 h feed deprivation. [3]Final body weight of male birds was determined at 35 d of age.

weight and relative feather percentage data of female birds were significantly higher ($p < 0.001$) as compared to their male counterparts. For both criteria, highly significant two-way interaction between age and gender was identified. Means of feather percentage as related to the empty BW increased from approximately 2% at the end of the first week to about 4% at the end of the experiment.

In Figure 1, the individual feather percentage data are summarized. In spite of the high individual variation and except day 1, the rate of feathering is obviously higher in female birds. Fitted plots of feather percentage as function of empty BW depending on gender yielded very similar curve approximations. Superior adaptation of both trend-lines and highest correlation were observed when the data from day old broiler chickens were excluded and a non-linear power function was approximated.

DM related data (Table 3) show a significant increase of feather percentage from 4.6% at the end of the 1st week to approximately 7% at the end of the 5th week ($p < 0.001$). However, no significant gender effect was observed ($p > 0.05$) when data were DM related. This observation can be explained by high standard deviations and different DM content in feathers and de-feathered body fractions. Except at d1, the DM content of feathers varied between 40% and 60%, but only 20% to 32% DM were analysed in feather-free body fractions. Superior DM contents were found in the down feathers of birds at d1 (approximately 70%), but contents declined subsequently up to the end of the 3rd week. A continuous increase of DM content in feathers was observed up to the end of the 5th week. The age-dependent differences were significant ($p < 0.001$), but no significant gender effect was observed for DM content of feathers ($p > 0.05$).

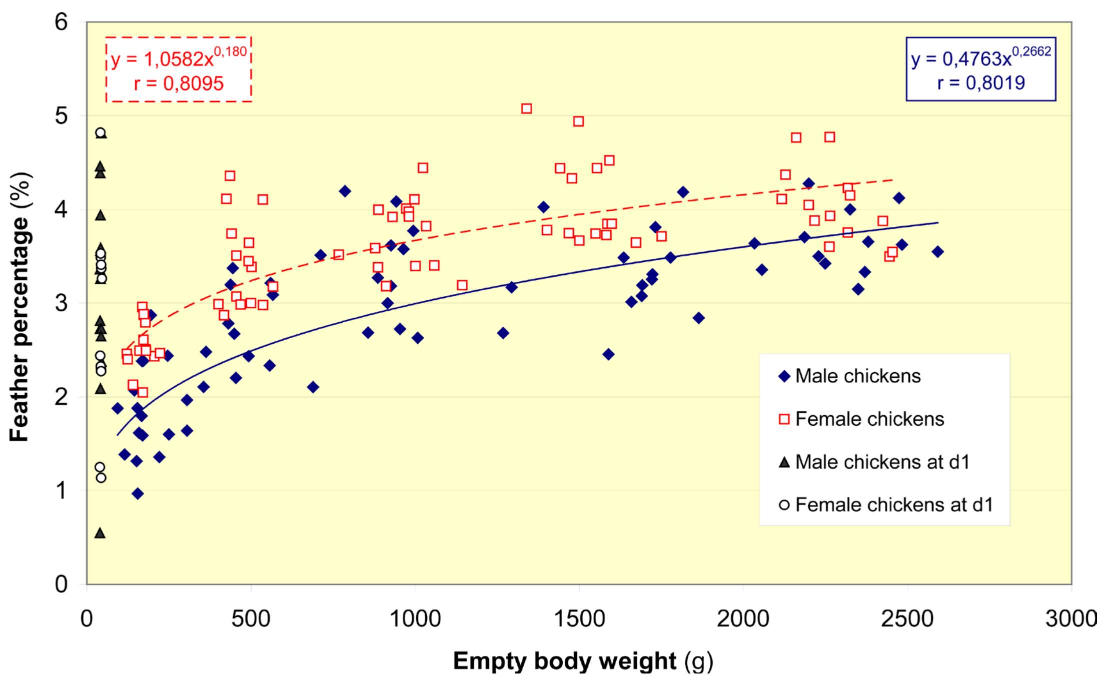

Figure 1. Feather weight as a proportion of the empty body weight of male and female broiler chickens.

Table 3. Dry matter (DM) content of body fractions and feather DM percentage depending on age and gender of fast growing broiler chickens[1].

Age (d)	Empty body[2] (%)		Feather-free body (%)		Feathers[3] (%)		Feather DM (% of empty body DM)	
	Male	Female	Male	Female	Male	Female	Male	Female
1	21.43	21.37	19.62	20.02	76.78	65.98	11.32	9.09
8	25.38	26.15	24.70	25.62	56.72	45.74	4.67	4.57
15	27.20	29.08	26.86	28.56	40.85	43.62	3.70	5.13
22	28.64	30.21	28.16	29.68	42.39	43.81	5.00	5.40
29	30.28	32.10	29.69	31.33	47.34	50.39	5.20	6.41
36[4]	30.62	33.46	29.79	32.31	52.07	60.38	6.30	7.41
Mean	27.98	29.65	27.33	28.91	49.68	49.86	5.37	5.99
SD[5]	2.64	3.38	2.82	3.35	9.44	7.86	1.86	1.32
ANOVA significance levels (p)								
Age (A)	<0.001		<0.001		<0.001		<0.001	
Gender (G)	<0.001		<0.001		=0.205		=0.094	
A x G	=0.004		=0.074		<0.001		=0.001	

[1]n = 3 pooled samples of each five birds per age period and gender. [2]Body weight following 24 h feed deprivation. [3]At 1 d of age only one pooled feather sample of each gender due to the low feather yield per bird. [4]Final body weight of male birds was determined at 35 d of age. [5]Standard deviation.

Consequently, all feather DM data related to the empty BW were plotted in Figure 2. Superior correlation between DM content of feathers and empty BW was achieved by application of a quadratic function, but only when data from d1 and d8 were excluded. Due to the limited quantity of collected down feathers at d1 and only one sample available for DM analysis per gender, these data need further validation. In addition, including data of male and female birds at d8 yielded a strong decline of the coefficient of the regression function (r = 0.7308).

Contrary, the DM content both in the feather-free and whole empty body (Table 3) increased continuously from 20% - 21% at start up to 31% - 32% at the end of the experiment ($p < 0.001$). The body of female birds contained significantly more DM as compared to the males ($p < 0.001$). The gender-specific correlations between DM content in the feather-free body and the empty BW are summarized in Figure 3.

4. Discussion

The nonlinear increase of feather growth with increasing age of actual fast growing meat-type chickens seems to be higher as compared to previous genotypes which yielded about 50 g feather per bird at market age, as reviewed by Leeson and Walsh [48]. According to our results (Table 2), a total of 80 to 90 g feathers per bird can be expected at the commercial slaughter age of 5 weeks. Higher individual feather yields between 110 and 130 g were observed in older birds (Table 4).

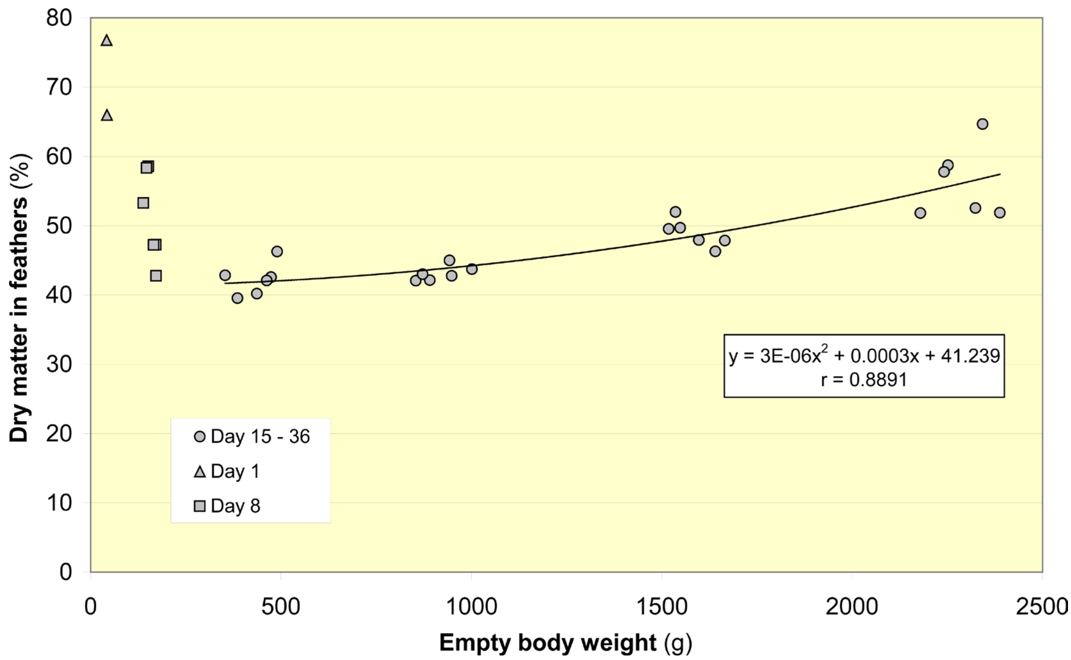

Figure 2. Dry matter content of feathers related to the empty body weight of male and female broiler chickens.

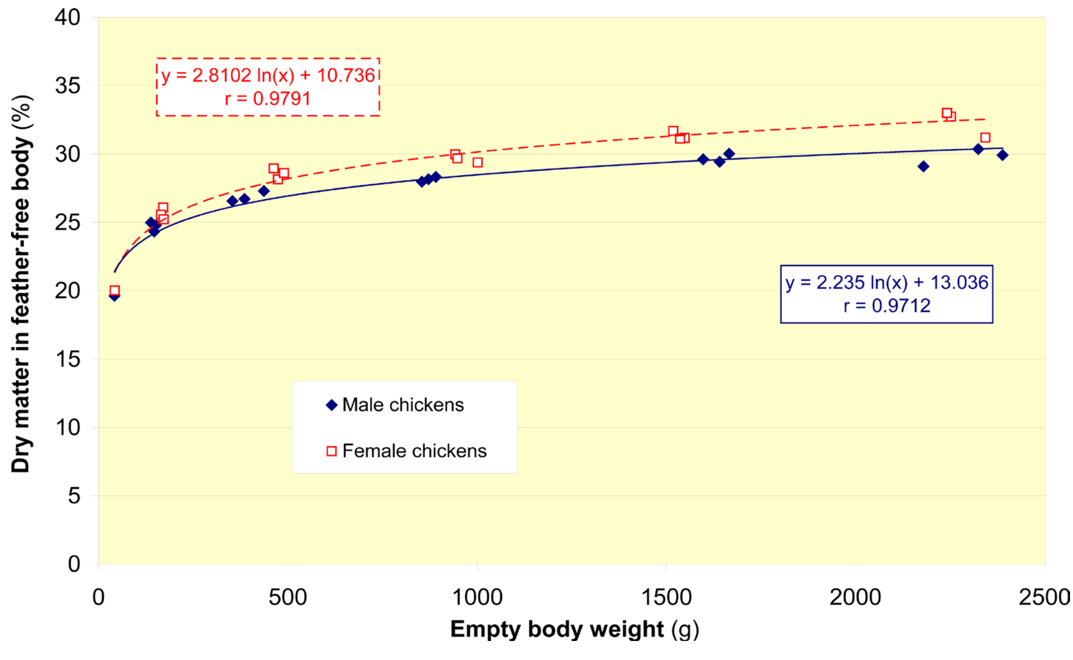

Figure 3. Dry matter content of the feather-free body related to the empty body weight of broiler chickens dependent on gender.

Wheeler and Latshaw [49] observed the beginning of rapid feather growth up to the end of the 2nd week of age. Sheridan and McDonald [41] stated the competition between feather and body growth as most pronounced during the first weeks of life. However, to our knowledge reliable quantitative data on feather weight of male and female chicken up to the 2nd week of age are scarcely reported. The growth rate of feathers is reported to be the highest during the first 6

Table 4. Summarized feather percentage data of normally feathered male (M) and female (F) broiler chickens depending on age taken from reported experimental data.

Age	Gender	Total body weight[1] (g)	Feather weight[1] (g)	Feather percentage (%)	Reference basis[2]	Literature source
49 d	M + F	1624 - 1708		3.4 - 4.0	… starved BW	[18]
45 d	M	1783 - 1803	121 - 124	6.7 - 6.9	… full-fed live weight	[19]
52 d	F	1692 - 1722	125 - 128	7.3 - 7.5		
44 d	M	1769 - 1771	116 - 121	6.6 - 6.8		
52 d	F	1700 - 1714	116 - 122	6.9 - 7.1		
39 d	M	1929 - 2065	71 - 81 (DM)	5.91 - 6.00[4]	… empty BW after 18 h food removal	[12]
49 d	M	2510 - 2727[3]		5.66 - 6.07[4]		
48 d	M	1992 - 2212		4.73 - 6.10	… starved live weight	[42]
48 d	F	1683 - 1783		5.19 - 5.75		
6 wk	M + F	1895	111.5 61.5 (DM)	5.92 3.26 (DM)	… final whole BW	[35]
28 d	M	656	38.8[5]	5.91		[20]
42 d		1301[5]	86.8[5]	6.67[5]		
7 wk	M	1954 - 2576		4.45 - 4.80	… final whole BW	[15]
	F	1700 - 2167		4.92 - 5.36		
49 d	M + F	2003		4.66	… final whole BW	[36]
7 wk		1771		5.7	… BW at slaughter	[16]
8 wk		2151		6.0		
6 wk		1895	111.5 61.5 (DM)	5.92 3.26 (DM)	… final whole BW	[37]
7 wk	M	1786		5.34	... BW after 24 h without feed	[38]
7 wk	F	1462		6.11		
21 d	M	710 - 779	71.0 - 75.7	9.51 - 10.10	… final whole BW	[21]
21 d	M		5.1 - 10.1	1.0 - 1.5	… final whole BW	[22]
37 d	M	2006	112	5.6[5]	… BW at slaughter	[39]

[1]Lowest and highest average body weight (BW) and feather weight data of the experimental groups. [2]Feather weight expressed as a percentage of …. [3]Empty body weight (BW). [4]2.86% - 3.01% and 2.60% - 3.03% feather dry matter (DM), respectively. [5]Calculated values based on published body weight and feather weight data.

weeks of age [19] [20] [50]. Consequently, Yalcin *et al.* [15] stated full feathered birds at 7 wk of age. As reviewed by Leeson and Walsh [48], most estimates of feather percentage in adult birds range between 3% and 6% of BW. In laying hens, 6.4% to 7.0% feather DM of BW is reported [33]. Depending on age growing turkeys yielded 2.0% to 6.3% feathers as related to BW [51] or empty BW [52].

According to our present results, a very high individual variability of feather percentage can be expected in day old growing chickens. Similar data (**Table 5**) were calculated from earlier results as published by Lehmann [1], Stilborn *et al.* [50] and Sklan and Noy [53] [54]. In terms of fresh feather weight percentage related to the empty BW, feather proportion in fast growing chickens was

Table 5. Feather percentage as related to the weekly final body weight (BW) of normally feathered broiler chickens dependent on age and gender.

Age (d)	1	7	14	21	28	35	42	Literature source
Female	2.1				5.2			[1][1,2]
Male		1.4	1.2	1.7	2.4	2.4	2.5	[57][1,3]
Female		1.2	1.7	2.3	2.9	3.1	3.0	
Male	3.0		3.1		4.9		5.2	[50][1,4]
Female	3.4		3.2		5.4		5.4	
Male		0.9	2.9	4.4	4.6	5.0	5.8	[55][1,5]
Female		1.3	3.2	4.9	5.2	5.6	6.8	
Male	0.9		2.4	4.7	3.9		5.1	[53]
Male	0.9	1.7	2.3	3.7	4.9	5.0	5.2	[54]

[1]Calculated, based on reported body weight and feather weight data. [2]Feather weight expressed as a percentage of the empty BW (Means of three different genotypes). [3]Feather dry matter weight expressed as a percentage of the BW. [4]Feather weight expressed as a percentage of the BW (Means of two different genotypes). [5]Feather weight expressed as a percentage of the BW (Means of six different genotypes).

elevated non-linearly with increasing age and ranged between 1% and 3% at d8 to 3% and 5% at d36, respectively (**Figure 1**). These results are in general agreement with literature data (**Table 5**). According to Sklan and Noy [54], the feather proportion of BW in male broiler chickens is approximated by following equation: Feathers (% of BW) = $0.26 \cdot BW^{0.38}$.

Generally, literature data in normally feathered growing chickens vary markedly. In addition to individual differences, both the absolutely certain description of bird`s age and basis of reference (BW resp. feather-free BW) are the main factors responsible for high variation of feather percentage data. In consequence, data comparability is very limited. In majority of reported experiments feather weight was estimated by difference between BW before and after plucking. However, this procedure implies inaccuracies due to dry or wet de-feathering. Furthermore, the process of feather drying or the feather DM analysis and/or the analyses of feather-free body fraction are factors of influence. **Table 2** and **Table 3** provide an additional overview about the importance of reliable reference data impacting on derived feather percentage.

In line with Deschutter and Leeson [8], Moran [19] and Hancock *et al.* [55], feather growth of growing chicken also depends on gender (**Table 2**, **Figure 1**). The observed higher feather weight and feather percentage in female birds is in agreement with several reports [10] [41] [56] and gender-specific data [15] [19] [38] [42] [50] [55] [57] as summarized in **Table 4** and **Table 5**. However, age dependent also similar or even less feather yields of female growing chickens are reported [3] [50]. But, due to the lower feather-free body mass and the lower surface area of female birds their feather mass per unit BW was higher as compared to their male counterparts of equal age. Otherwise, according to sex-linked different rate of feathering, feather loss of female birds during growth was observed to increase [57] [58].

As reviewed by Leeson and Walsh [9], the nutrient supply impacts on feather growth and development. Stimulated feather growth was observed with increasing dietary CP and SAA supply [18] [20] [22], mainly due to varying body proportion of feathers, connective tissue and muscle tissue [59]. Additionally, more feathers were found on the litter following a high protein diet [58] indicating faster feather development with subsequent moult. Otherwise, deficient feed and CP supply or imbalanced dietary AA composition created opposite effects on the rate of feathering of young birds [6] [7] [9] [21]. Feather percentage was significantly higher in restrictive fed birds as compared to birds fed on free choice level [6].

At d1, an elevated DM content in the feathers of freshly hatched chickens was observed (**Table 3**). Lehmann [2] indicated that down feathers are exceptional as related to age-depending changes of feather composition due to their high DM contents between 73% and 80% [1]. Smith and Bath [60] suggested that individual feathers of growing chickens reached maximum weight when the dry feather mass was 50% of the total mass. At 2 weeks of age all the feathers were half feather (50% to 55% DM) and half pulp (13-15% DM) with approximately 38% to 40% DM content in the entire feather [60]. According to Lehmann [1] [2] and Hancock *et al.* [55] the DM content of the feathers increased steadily throughout the growing period from 38% at week 1% to 63% DM at week 8 - 10 indicating an apparent drying out of feathers with age [14]. Several reports [12] [35] [37] [61] underline our observed age-depending effect (**Figure 2**), but missing related data about the influence of gender on DM content in feathers.

Carcass DM content in the modern strain birds was significantly higher than in previous genotypes [62] [63] [64]. Significantly different DM contents of the feather-free or whole body of varying genotype broiler chickens are reported [1] [2] [42] [65] [66]. Increased DM content in fat-type chickens can be expected [67]. Accordingly, elevated body DM contents were observed with increasing age [1] [2] [61] [63] [65] [68] [69] [70] and in female versus male birds [3] [42] [62] [64].

Finally, energy and protein supply as well as dietary AA balance impact on DM content of the feather-free or total body of broiler chickens [42] [67]-[73], but eliminated in the current study by standardized diets.

5. Conclusion

Within the growth period of growing chickens, the feather coverage as a proportion of the total or empty body mass increases with increasing age of the birds. Due to larger relative feather percentage in female vs. male birds, gender-specific differences were observed and also validated by literature data. With increasing age, the DM content in feathers and in feather-free or whole empty body raised continuously, but DM content of feathers differed not significantly between male and female birds. However, the whole body of female birds contained significantly more DM as compared to their male counterparts. The observed age and gender-specific proportion between feather and feather-free body fractions and modulation of DM contents during growth are of special importance for evaluating energy and nutrient requirements based on factorial procedures. For this purpose, additional data are needed to specify the database. In consequence, further detailed data about nutrient composition of feathers and feather-free body, but also about nutrient deposition depending on age and gender in modern genotype growing chickens are required. Actually, a consecutive publication is prepared to provide such a database for re-evaluation of requirement data in modern genotype meat-type chickens.

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