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Comparative study of gastrointestinal tract size in three parent breeds for the production of dual-purpose organic chickens

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Abstract

An alternative to culling male hatchlings of layers is breeding dual-purpose chickens. One breeding objective is the ability to digest low-quality feed. Certain measurements of the gastrointestinal tract may be useful indicators of this ability. The present study compared the gastrointestinal tract of adult hens of two layer-type breeds (White Rock (WR), New Hampshire (NH)) and the meat-type ÖTZ (Ökologische Tierzucht gGmbH) Bresse Gauloise (BR), used for the production of dual-purpose organic chickens. Flocks had the same housing and feeding conditions. At slaughter at 19 months, the body weight and gastrointestinal organs of 134 hens (51 WR, 55 NH and 28 BR) were measured. The muscle thickness of the proventriculus and ventriculus and the length and width of the duodenum, jejunoileum, caeca and colorectum were measured and variances between the groups were analysed using a one-factor covariance analysis. Significant differences between the breeds were found in total intestine length and the lengths and/or widths of single gastrointestinal segments. For example NH showed the highest mean total intestinal length and BR showed the lowest mean (NH: 186.73 cm, WR 185.86 cm, BR 157.91 cm; $p = 0.001$). To our knowledge, this is the first study comparing the gastrointestinal tract size of adult female layer- and meat-type chicken breeds kept under the same feeding and housing conditions. Given the possible relationship between intestinal length parameters and chicken performance, measurement of the gastrointestinal tract may be a simple, quick and inexpensive additional method to help select layer-, meat-type and dual-purpose chickens suitable for organic production when a selection process using genetic markers is not possible.

KEYWORDS
broiler, gut morphology, intestinal morphology, layers, poultry

1 | INTRODUCTION

The breeding of dual-purpose chicken lines with high-performance females for egg production and males being raised for meat production is an alternative to the culling of male day-old chicks from laying lines (Alshamy et al., 2018). In Germany, the White Rock (WR), New Hampshire (NH) and ÖTZ (Ökologische Tierzucht gGmbH) Bresse Gauloise (BR) breeds are currently used in dual-purpose organic chicken production. One of the two layer-type breeds (WR or NH) is crossbred with the meat-type breed BR. A

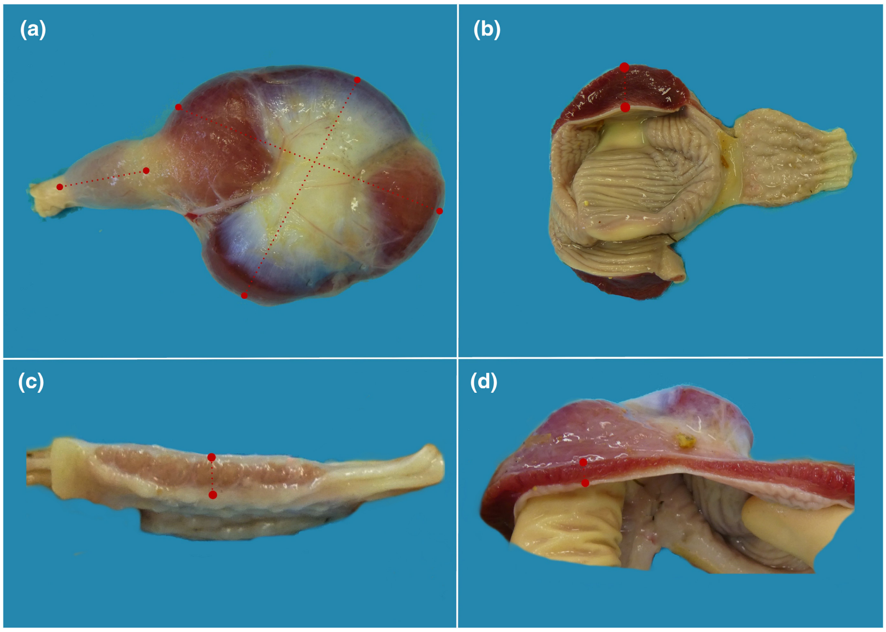

FIGURE 1 Measurement points (a) proventriculus and ventriculus: length and width, (b) ventriculus: muscle thickness of musculus crassus cranioventralis, (c) proventriculus: muscle thickness, (d) ventriculus: muscle thickness of musculus tenuis caudoventralis.

breeding objective for dual-purpose chickens is the ability to optimally digest organic or low-quality feed. Therefore, an important factor is nutrient absorption, for which both functional anatomical and histological characteristics are of critical importance (de Verdal et al., 2010).

The chicken's digestive tract includes the rostral cavity, pharynx, oesophagus, stomach, the intestinal tract (intestinum) and the cloaca. The stomach is divided into two compartments: the glandular stomach (GS: proventriculus, pars glandularis) and the gizzard (G: ventriculus, pars muscularis). The intestine is divided into the small and large intestine (intestinum tenue, intestinum crassum). The small intestine, which is the main site of nutrient absorption, is divided into the duodenum, the jejunum (which has Meckel's diverticulum (diverticulum vitellinum) about halfway along its length) and the ileum. The jejunum is the longest segment of the small intestine. Because the divisions of the small intestine are not as well differentiated in birds as in mammals, many authors divide the small intestine into the duodenum and jejunoileum (Gäbel & Loeffler, 2018; Hodges, 1974). The ileum is the posterior part of the small intestine and ends with the confluence of the two caeca in the rectum. The large intestine of the birds is short compared to that of mammals and consists of the paired caeca and the rectum, which ultimately ends in the cloaca (Gäbel & Loeffler, 2018; Salomon, 1993). According to various authors, the length of the intestine in birds is relatively short compared to mammals and is only about five times the body length (Mangold, 1950). The length of the intestine depends on age and breed, as well as the type, structure, amount and frequency of feed intake (Ege et al., 2019; Schwarze et al., 1972).

Since there is very little reliable data on the size of the gastrointestinal tract of chickens, the aim of this study was to investigate whether there are differences in the size of the stomach and the length and width of the intestine between the different layer- and meat-type breeds kept under the same (organic) housing and feeding conditions. We speculate that larger intestinal segments provide more surface area for nutrient absorption and may improve productivity. Hence measuring the gastrointestinal tract may be a simple and inexpensive method to monitor breeding progress in dual-purpose organic chicken lines.

2 | MATERIALS AND METHODS

The birds examined originated from three parent breeds, WR, NH and ÖTZ BR, which are currently used in Germany to breed dual-purpose organic chickens. WR and NH are layer-type breeds and BR is a meat-type breed. All birds were individually marked with wing tags during rearing. At the breeding site the hens were kept under organic feeding and housing conditions according to the current EU regulations (EU VO 834/2007 and EU VO 889/2008), except no pasture was offered. After one laying period, the birds were slaughtered in a certified organic slaughterhouse, and marketed as fresh organic meat. Samples were taken at this slaughterhouse on the regular slaughter date. At the time of the study the hens were 19 months old. Sixty birds per flock were randomly sampled according to the principle of 'systematic selection with random onset'. Flock sizes were 200 (WR, NH) and 350 (BR) hens at the time of sampling. Data from the birds were only included when the carcass could be allocated to the extracted gastrointestinal tract at slaughter. Allocation was possible if at least one wing tag number per bird was legible.

The hens were weighed with a manual poultry scale BAT1 (VEIT Electronics, Moravany, Czech Republic) with an accuracy of 1 g, and a total of 150 gastrointestinal tracts (GITs) were collected. A total of 134 (51WR, 55 NH, 28 BR) fulfilled all inclusion criteria and were included in the analysis. Twenty-three variables were evaluated. As a result of the slaughtering process, which involved removing the giblets from the carcass by cutting the cloaca and pulling on the intestines, the colorectal region of 23 chickens was incomplete or missing, and thus not all variables could be evaluated.

After slaughter, the giblets (lung, liver, spleen, ovary, oviduct and gastrointestinal tract) were cooled to 4°C, transported to the dissection hall and stored at 4°C until further processing the following day. After separation from the other organs, GITs were weighed and measured. They were not emptied for this purpose. Measurements (Figure 2) were always performed by the same person according to the methods described by Berenfeld (2011), Alshamy et al. (2018) and de Verdal et al. (2010). During measurement, care was taken to avoid stretching or damaging the intestines. The small and large intestine segments were spread out lengthwise to measure the length and width. The lengths of the intestinal segments were measured with measuring tape with an accuracy of 0.05 cm. The parameters of the proventriculus and ventriculus and the width of the intestinal segments were measured with a manual vernier calliper using the metric main scale with an accuracy of 0.05 cm. The measurement areas of the gizzard and the glandular stomach are shown in Figure 1 and described below. The measurement areas of each segment of the intestine are shown in Figure 2 and described below.

2.1 | Measurements of glandular stomach (GS, proventriculus)

Measurement of length and width as well as muscle thickness in centimetres. Measurement points:

1. Length: Proximal entrance of the proventriculus from the oesophagus (to the middle between the glandular stomach and gizzard [Isthmus gastris]).
2. Width: Measured at the widest point.
3. Muscle thickness: Measured at the thickest point.

2.2 | Measurements of the gizzard (G, ventriculus)

Measurement of length and width as well as muscle thickness of musculi crassus and musculi tenues in centimetres. Measurement points:

1. Length: Measured at the longest distance between the musculi crassus (cranioventralis and caudodorsalis) and musculi tenues (craniodorsalis and caudoventralis).
2. Width: Measured at the widest point.
3. Muscle thickness: Measured at the thickest point of the musculus crassus cranioventralis and musculus tenuis caudoventralis.

2.3 | Measurements of the duodenum

Measurement of length and width in centimetres. The duodenum was first separated from the gizzard and the jejunoileum. Measurement points:

1. Length: Gizzard junction (ostium pyloricum) to the end of the pancreatic loop at the junction to the jejunoileum, which is characterized by the vascular sheath of the arteria coeliaca and arteria mesenterica cranialis.
2. Width: Measured at the widest point.

2.4 | Measurements of the jejunoileum

Measurement of length and width in centimetres. Measurement points:

1. Length: From the vascular sheath of the arteria coeliaca and arteria mesenterica cranialis to the ileocaecal junction (ostium caeci).
2. Width: Measured at the widest point.

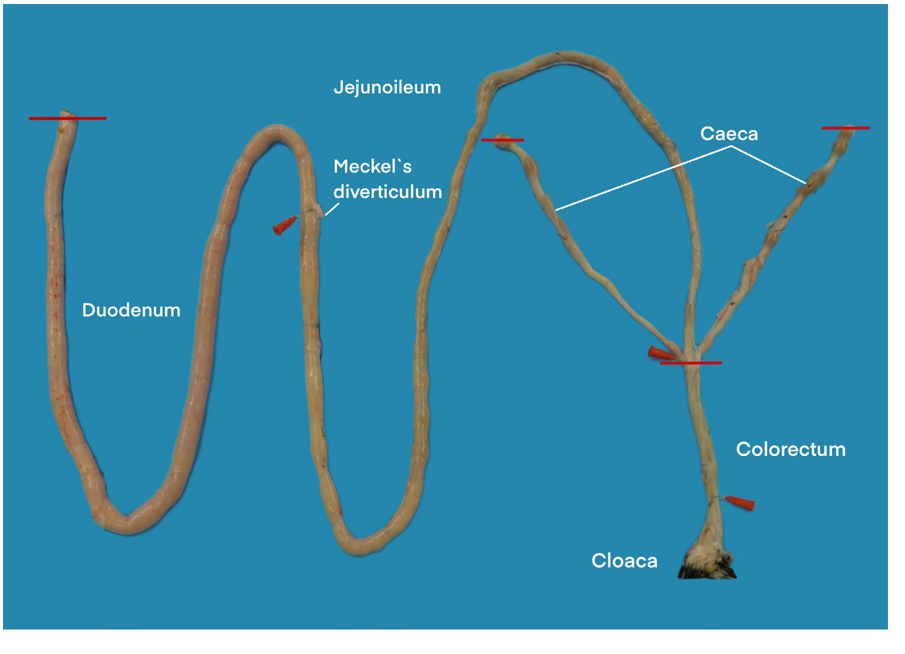

FIGURE 2 Overview of measurement points of individual intestinal segments.

2.5 | Measurements of the large intestine

The large intestine consists of the two ceaca and the colorectum. Measurement of length and width in centimetres. Measurement points:

1. Length Colorectum: From the ostium caeci to the cloaca, measured at the plicarectocoprodealis.
2. Length Caeca: From the ostium caeci to the apex caeci.
3. Width: Measured at the widest point of the corpus caeci.

2.6 | Statistical analysis

To compare the length and width of the gastrointestinal segments between the three breeds, statistical analyses were performed using the software BMDP/Dynamic, Release 8.1 (Dixon, 1993). The normal distribution of traits was tested using a histogram. A one-factor covariance analysis (ANCOVA) was performed on the approximately normally distributed characteristics to statistically test the group influence for significance. For all analyses, α was set at 0.05.

Using single-factor analysis of covariance, body mass was considered as a covariate in the evaluation of the data, so that the results were adjusted for body mass (Table 1). The dependent variables evaluated were GI tract mass, length, width and muscle thickness of the glandular stomach, length and width of the gizzard and muscle thicknesses of the musculi tenues and Mm. crassus, length and width of the duodenum, length and width of the jejunoileum and position of Meckel's diverticulum, if present (data not shown), length and width of both caeca, length and width of the rectum and the total length of the intestine (Table 1).

3 | RESULTS

The body mass of the NH varied between 1.85 and 2.80 kg, with a range of 0.95 kg. The arithmetic mean was 2.34 kg. The body mass of the WR hens ranged from 1.62 to 2.26 kg (arithmetic mean: 1.93 kg, range: 0.64 kg) and that of the BR from 2.22 to 3.80 kg (arithmetic mean: 3.14 kg, range: 1.58 kg).

Significant breed differences were found in total intestinal length and in the lengths and/or the widths of various segments of the gastrointestinal tract. The results of the one-factor analysis of covariance are presented in Table 1. Figure 3 compares the length of all measured organs of the gastrointestinal tract of the three breeds and indicates the level of significance.

When comparing the results adjusted for body mass between the breeds, NH hens showed the largest mean glandular stomach and gizzard values in length, followed by WR and BR hens (GS: NH 5.07 cm, WR 4.92 cm, BR 4.43 cm; G: $p=0.001$; G: NH 6.86 cm, WR 6.75 cm, BR 6.19 cm; $p \leq 0.001$). Regarding the width of the two stomach compartments, NH also showed the largest mean values in the glandular stomach area (NH 2.49 cm; WR 2.31 cm, BR 2.07 cm; $p \leq 0.001$). The gizzard, in contrast, was widest in WR (WR 6.39 cm; $p > 0.05$). Regarding the length of the duodenum, the longest lengths were found in WR and NH, and the smallest in BR (WR 32.14 cm, NH 31.86 cm, BR 30.50 cm; $p=0.5$). With regard to the width of the duodenum, WR and NH hens had the lowest and BR hens the highest mean values (BR 1.27 cm, WR 1.25 cm, NH 1.18 cm; $p=0.08$). The mean lengths of the jejunoileum were significantly longer in NH hens, while BR hens had the shortest mean lengths among breeds (length: NH 144.27 cm, WR 142.98 cm, BR 122.53 cm; $p=0.001$). No significant difference was found regarding the width of the jejunoileum. Looking at the mean values of the caecal measurements, the NH had the longest (left caecum 19.83 cm, right caecum 20.79 cm) and the BR (left caecum 17.77 cm, right caecum 18.56 cm) had the shortest caeca, with a significant difference ($p < 0.001$) in the case of the left caecum. On the other hand, the greatest width was found in BR hens (left caecum 1.38 cm, $p < 0.001$) and the smallest width in NH hens (left caecum 1.05 cm, $p < 0.001$). In relation to the length and width of the colorectum, it can be noted that NH hens had the longest and BR hens the shortest colorectal segments on average (NH 9.09 cm, WR 8.51 cm BR 7.99 cm; $p=0.037$). Again, BR hens had the widest rectal segments among the three breeds ($p=0.714$). Regarding total intestinal length, NH hens had the longest and BR hens the shortest intestine, with the difference being significant (adjusted group mean values: NH 186.73 cm, WR 185.85 cm, BR 157.91 cm; $p=0.001$).

4 | DISCUSSION

Breeding of dual-purpose chickens is an alternative to culling day-old male hatchlings from highly selected layer-type lines. Different projects and companies use several different lines, basically crossing layer-type and meat-type lines, one example being the Lohmann Dual line from Lohmann Breeders. The hens used in the present study were from two parent breeds with good feed-conversion and laying qualities: New Hampshire (NH) and White (Plymouth) Rock (WR) (Schmidt, 1985). The Bresse Gauloise (BR), a French meat-type breed, was also used in the present study. The NH and WR layer-type breeds are found in most commercial white and brown layer lines.

Sample sizes ranged from 27.5% in NH (55/200) to 25.5% in WR (51/200) to 8% in BR (28/350) birds. All three sampled flocks were a homogeneous population with respect to species, line, parents, age, rearing, husbandry and feeding, so the total size of the flocks could be largely ignored when choosing random samples. In flock diagnostics, at least 29 evaluable samples are needed to detect a prevalence of 10% and to detect traits, e.g. pathogens, with a confidence level of 95% (Cannon, Cannon & Roe, 1982). Considering the small flock sizes and the expected low variance of the parameters, we considered the sample sizes from all three breeds to be sufficient.

The BR breed had a higher mean body weight (3.14 kg) than NH (2.34 kg) and WR (1.93 kg). The NH hens were above the breed standard weight of 2–2.25 kg (Schmidt, 1985) and WR were below the Plymouth Rock standard weight of 2.5–3 kg. The BR hens were

TABLE 1 Statistical characteristics of the gastrointestinal tract of females from three parent breeds at the age of 19 months.

Variable	Breed	Group mean	Equality of slopes *p*-value	Regression coefficient (*r*)	Regression coefficient *p*-value	Adjusted group mean	Adjusted mean *p*-value
Mass of GIT[a] [g]	NH	254.90	0.636	78.630	<0.001**	256.20	<0.001*
	WR	219.10				252.69	
	BR	283.89				219.78	
Proventriculus length (cm)	NH	5.06	0.171	0.584	0.003**	5.07	0.001*
	WR	4.68				4.92	
	BR	4.89				4.43	
Proventriculus width (cm)	NH	2.49	0.721	0.131	0.214	2.49	<0.001*
	WR	2.26				2.31	
	BR	2.17				2.07	
Proventriculus muscle thickness (cm)	NH	0.39	0.776	0.086	0.005**	0.39	0.643
	WR	0.36				0.39	
	BR	0.43				0.36	
Ventriculus length (cm)	NH	6.86	0.503	0.388	0.032**	6.86	<0.001*
	WR	6.58				6.75	
	BR	6.50				6.19	
Ventriculus width (cm)	NH	6.23	0.361	0.245	0.180	6.24	0.410
	WR	6.28				6.39	
	BR	6.46				6.27	
Thickness musculus crassus (cm)	NH	2.08	0.599	0.010	0.930	2.08	0.049*
	WR	2.26				2.66	
	BR	2.09				2.08	
Thickness musculus tenuis (cm)	NH	0.21	0.856	−0.002	0.932	0.21	<0.001*
	WR	0.22				0.22	
	BR	0.32				0.32	
Duodenum length (cm)	NH	31.84	0.148	1.861	0.103	31.86	0.500
	WR	31.36				32.14	
	BR	31.97				30.50	
Duodenum width (cm)	NH	1.18	0.093	0.006	0.937	1.18	0.079
	WR	1.25				1.25	
	BR	1.28				1.27	
Jejunoileum length (cm)	NH	144.16	0.336	10.288	0.075	144.27	0.001*
	WR	142.98				142.98	
	BR	122.53				122.53	
Length till Meckel's Divertikel (cm)	NH	72.37	0.696	3.794	0.177	72.42	0.007*
	WR	71.94				73.55	
	BR	66.24				63.22	
Jejunoileum width (cm)	NH	1.11	0.130	0.009	0.888	1.11	0.507
	WR	1.10				1.10	
	BR	1.06				1.05	
Left ceacum length (cm)	NH	19.83	0.692	0.428	0.657	19.83	0.005*
	WR	18.45				18.63	
	BR	18.11				17.77	
Left ceacum width (cm)	NH	1.05	0.485	0.156	0.131	1.05	0.001*
	WR	1.06				1.13	
	BR	1.50				1.38	

(Continues)

TABLE 1 (Continued)

Variable	Breed	Group mean	Equality of slopes *p*-value	Regression coefficient (*r*)	Regression coefficient *p*-value	Adjusted group mean	Adjusted mean *p*-value
Right caecum length (cm)	NH	20.79	0.748	0.650	0.574	20.80	<0.001*
	WR	18.32				18.59	
	BR	19.08				18.56	
Right caecum width (cm)	NH	1.07	0.865	0.177	0.111	1.07	0.055
	WR	1.04				1.11	
	BR	1.45				1.31	
Colorectum length (cm)	NH	9.09	0.664	0.871	0.19	9.10	0.037*
	WR	8.14				8.51	
	BR	8.73				7.99	
Colorectum width (cm)	NH	0.98	0.994	0.025	0.714	0.98	0.787
	WR	0.94				0.95	
	BR	1.02				1.00	
Total intestine length (cm)	NH	186.46	0.618	16.933	0.025**	186.73	0.001*
	WR	178.58				185.86	
	BR	172.37				157.91	

Note: Mean body mass: NH: 2.34 kg, WR 1.93 kg, BR 3.14 kg.

Abbreviations: BR, ÖTZ Bresse; NH, New Hampshire; WR, White Rock.

*Statistically significant difference in breed. **Statistically significant influence of body mass.

[a]Measure without emptying.

above the mean weight of purebred BR of 2.817 kg ± 330 g measured at 75 weeks of age in a study by Lambertz et al. (2018).

When the values of the glandular stomach (Proventriculus) and gizzard (Ventriculus) were compared among the three breeds, NH had the highest and BR the lowest values in both stomach compartments. The gizzard is responsible for mechanical grinding of feed and has been described by some authors as a temporary food store in broilers (Scanes, 2022). The weight of the gizzard can be influenced by the structure of the diet. For example, some authors have reported that gizzard weight decreases by an average of 8% and 16% when finely ground and pelleted diets are fed (Bozkurt et al., 2020). In their study, Alshamy et al. (2018) demonstrated larger gizzards in slow-growing Lohmann Dual (LD) chickens compared to the fast-growing Ross 308 line (Table 2). The authors concluded that the large gizzards in LD chickens likely increased the degree of food processing and improved nutrient availability in the oral part of the intestine. Because the duration of the study was limited to an average bird weight of 2 kg, which was reached in 5 weeks for Ross and 9 weeks for LD chickens, effects in adult birds were not tested. Coarser feed grinding was found to have a positive effect on gizzard weight by Ege et al. (2019). The present study was conducted with hens aged 21–52 weeks in enriched cages. Xu et al. (2015) studied broilers at 49 days of age and found that dietary inclusion of 50% coarse corn significantly increased absolute and relative gizzard weight and the gizzard to proventriculus ratio, but decreased jejunum unit weight. The authors concluded that broilers may be able to adapt their digestive function to diet structure and nutrient composition. The hens in our study were all fed the same grain-based diet with both coarse and fine particles and were offered grit. The hens in our study had access to other sources of fibre such as hay, straw and wood shavings, which were probably consumed by some individuals. As the diet differed from that used in other studies and we used size rather than weight as a reference, direct comparison with the results of other authors is difficult. By feeding the same diet to all breeds, the comparison within the three breeds in our study was not biased by this factor.

Our values for the total intestinal length were within the range described by several authors (Table 2) (Alshamy et al., 2018; Mangold, 1950; Proszkowiec-Weglarz, 2022; Schwarze et al., 1972). Longer intestines were only measured in one study, with means of 212.9 cm in 70-week-old Rosa (Rhode Island Red x Sussex; dual-purpose breed) and 254.0 cm in 62-week-old Ross 308 broiler breeders (= meat-type breed) (Włodarczyk et al., 2022). The length of the Jejunoileum in our study was longer (NH 144.16 cm, WR 142.98 cm, BR 122.53 cm) than the value of 120 cm given by Hodges (1974; Proszkowiec-Weglarz, 2022). We can only speculate that feed composition may have influenced this parameter, as Hodges (1974) did not provide details on feeding or housing. The combined jejunum and ileum length reported by Włodarczyk et al. (2022) was 129.7 cm in the Rosa chicken, which was comparable to our BR values. The length of 163.2 cm in the Ross 308 broiler-breeders was above all values measured in our study and attributed by Włodarczyk et al. (2022) to the different directions of selection.

Significant differences were found between NH, WR and BR in the total length of the intestine as well as in the length and/or width of individual segments of the GIT. Overall, NH had the highest and

FIGURE 3 Mean lengths of the different segments of the gastrointestinal tract in the different breeds. NH, New Hampshire; WR, White Rock; BR, ÖTZ Bresse.

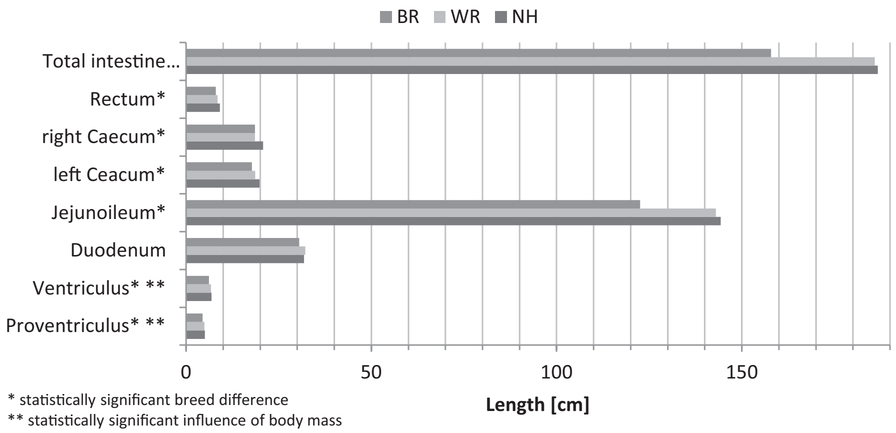

TABLE 2 Overview of intestine lengths in the domestic chicken (*Gallus gallus domesticus*).

Author (publication year)	Intestinal segment	Length (cm)	Diameter (cm)
Mangold (1950)[a]	Duodenum	22–35	n.d.
	Jejunum	85–120	n.d.
	Ileum	13–18	n.d.
	Caeca, each	14–23	n.d.
	Rectum	8–11	n.d.
	Total length	117–260	n.d.
Bergner and Ketz (1969)[a]	Duodenum	22–35	n.d.
	Jejunum	85–120	n.d.
	Ileum	13–18	n.d.
	Total length	210	n.d.
Schwarze, Schröder, and Michel (1972)[a]	Duodenum	22–35	0.8–1.2
	Jejunum	85–120	0.6–1.0
	Ileum	13–18	0.7–1.0
	Caecum	12–25	n.d.
	Colorectum (including cloaca)	8–11	n.d.
	Total length	152–234	n.d.
Hodges (1974)[a]	Jejunoileum	120	n.d.
Alshamy et al. (2018)[b]	Total length LD	152.23/182.95	n.d.
	Total length Ross 308	217.28/-	n.d.
Xu et al. (2015)[c]	Total length	186.46	n.d.

Abbreviations: LD, Lohmann Dual; n.d., not determined

[a]No exact information about age, breed, sex, husbandry and feeding.

[b]Ross = Ross 308, age 35/63 days; housed under same husbandry conditions; mash diet ad libitum; male chicken.

[c]Ross 344 × 708 (Aviagen, Huntsville, AL), 42 day old, male broiler, 50% coarse corn diet.

BR the lowest measurements. Exceptions were the widths of the duodenum and caeca, where BR had the highest values.

In our study, the average total intestine length varied from 186.73 cm (NH) to 157.91 cm (BR). In contrast to our study Proszkowiec-Weglarz (2022) reported higher values for broilers (217.1 cm) than for Leghorn layers (137.2 cm). Body weight was reported to be 3.0 kg in broilers and 1.2 in Leghorn layers, which is higher than in our study and may explain some of the differences. Since the primary source of these values was not given and could not be traced, too much relevant data such as broiler breed, housing and feeding is missing to be able to thoroughly discuss the contrasting results. A second study with contrasting results was conducted by Włodarczyk et al. (2022). Here the total intestinal length of Ross 308 broiler breeders was higher than in dual-purpose Rosa chickens.

The mean carcass weight of the dual-purpose chickens was 1.23 kg, while the Ross 308 broiler breeders had a mean carcass weight of 3.12 kg, which again may explain some of the differences regarding total intestinal length. Basic housing and feeding data were provided, revealing minimal differences between the two groups. No data were provided on crude fibre in the feed or potentially restricted feeding, which is common practice in broiler breeders to avoid excessive weight gain. The form, structure and ingredients of the diet may influence the development of the gastrointestinal organs. Frikha et al. (2009) studied the influence of dietary energy content and feed form on production performance and digestive tract characteristics of High Line Brown (layer-type) pullets. They found that at 45 days of age, feeding pellets decreased the relative weight and the relative length of all the different segments of the GIT. However, the observed differences in the relative length of the different GIT segments were no longer apparent at 120 days of age. They concluded that increasing the energy concentration of the diet or pelleting the diet over the period of 1 to 45 days of age reduces the relative weight of the gizzard and that this must be taken into account in the rearing of young hens, as poor gizzard development could affect productive performance at the beginning of the egg-laying phase. Particle size and diet form can affect the length of intestinal components (Amerah et al., 2007). When the total intestinal length was compared between the three parent lines, the BR had the shortest mean values. Alshamy et al. (2018) reported that the relative length of the gastrointestinal tract was greater in the slow-growing Lohmann Dual birds than in the fast growing Ross 308 broilers. As BR is a meat-type breed with a fast growth rate, the results of this study are consistent with the results of the study by Alshamy et al. (2018). Similar findings were also observed by de Verdal et al. (2010), who reported longer and heavier small intestines in broilers selected for a low ability to digest a wheat-based diet compared to broilers with a high ability to digest this diet at 35 days of age. One explanation for the longer small intestines in slower growing birds may be differences in genetic selection between meat-type and layer-type chickens.

Genetic selection for growth has altered the morphology of the villi in meat-type breeds, which show more developed protuberances of epithelial cells on the apical surface to the duodenal villi than layer-type breeds (Yamauchi & Isshiki, 1991). Another effect of selective breeding appears to be less dense intestines (de Verdal et al., 2010). The authors measured the weight: length ratio of the intestines of meat-type chickens selected for high or low ability to digest wheat after being fed a wheat-based diet. The group selected for better digestion had lower values in all segments. The authors tentatively attributed their findings to an adaptation of the lower digestive tract to greater nutrient availability, likely involving hormonal regulatory processes. With both a higher surface area for nutrient absorption and better passage through more permeable tissues, shorter intestines still result in adequate nutrient delivery. The feed intake capacity of chickens is limited, so higher energy intake for rapid growth in meat-type chickens means feeding diets with higher energy and protein concentrations than those fed to layer-type pullets (Leeson, 2009). The addition of lipid (Sell et al., 1983) or protein (Sibbald, 1979), as well as higher environmental temperatures (Proszkowiec-Weglarz, 2022), to birds' diets can increase passage time. With the increased passage time of higher protein and energy broiler diets, again shorter intestines would not interfere with adequate nutrient delivery. This theory is supported by the results of our study, where the width of the duodenum and caeca were the only measurements where the highest values were found in the meat-type line BR. As such differences are likely to be genetically determined, in practice, adapted feeding should be considered for the different breeds to achieve the best possible performance. Whether optimized feeding regimes result in improved performance needs to be evaluated in further studies.

Our study showed significant differences in the measurements between the layer-type (NH, WR) and meat-type (BR) breeds, so this method may be useful as a simple, fast and inexpensive additional method to assist in the selection of layer-, meat- and dual-purpose chickens in situations where a selection process using genetic markers is too expensive or not desired. To obtain more data to further support or refute our theory, this study should be repeated at least 5 years after starting the breeding programme.

AUTHOR CONTRIBUTIONS

Conceptualization: Franca Möller Palau-Ribes, Michael Lierz; *Data curation*: Nicole Neuhaus. *Formal analysis*: Nicole Neuhaus; *Investigation*: Franca Möller Palau-Ribes, Nicole Neuhaus; *Methodology*: Franca Möller Palau-Ribes, Nicole Neuhaus; *Project administration*: Franca Möller Palau-Ribes; *Resources*: Franca Möller Palau-Ribes; *Supervision*: Michael Lierz; *Validation*: Franca Möller Palau-Ribes, Michael Lierz; *Writing—original draft*: Nicole Neuhaus; *Writing—review and editing*: Michael Lierz, Franca Möller Palau-Ribes, Nicole Neuhaus.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in copyright at the institutional data repository of the Justus-Liebig-University, JLUpub https://jlupub.ub.uni-giessen.de/home under the following DOI: https://doi.org/10.22029/jlupub-18494.

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