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Chapter 2

The Effect of Age on Growth Performance and Carcass Quality Parameters in Different Poultry Species

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Abstract

In recent years, a steady increase in global poultry meat production has been witnessed, accompanied by an increase in a major portion of a poultry carcass, referred to as the inedible portion. In poultry, edible components include meat, skin with subcutaneous fat and giblets (gizzard, liver, and heart) and sometimes also abdominal fat in waterfowl. Age, together with species and environmental conditions, is one of the key factors affecting body growth rate. In four poultry species, chickens, turkeys, Pekin ducks, and geese, an increase in body weight is accompanied by an increase in edible weight and a decrease in inedible weight in the carcass, and more significant age-related changes occur in turkeys and broiler chickens than in ducks and geese. The highest increase in the content of edible components expressed as a percentage of total body weight is noted in turkeys (20% in males, 25% in females), followed by broiler chickens (19.4%), ducks (17.1%), and geese (only 8.2%). Gallinaceous birds have also a higher content of muscle tissue and a lower content of skin (including subcutaneous fat) and bones than waterfowl.

Keywords: tissue components, edible components, non-edible components, poultry species

1. Introduction

Age, together with species and environmental conditions, belongs to the key factors affecting the growth rate of birds. Age has a significant effect also on carcass tissue composition, and the most profound changes, both qualitative and quantitative, occur at early life stages which are relatively short (compared with the lifespan) and characterized by rapid growth.

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Selection progress in meat-type poultry (particularly in broiler chickens and turkeys) has contributed to an increase in their body weight, improved carcass composition, a shorter production period, and a substantial rise in carcass dressing percentage, which results from an increase in the content of edible portions in the total body weight of birds, accompanied by a decrease in the content of inedible components treated as slaughter offal [1]. The total percentage content of edible and inedible components in the carcasses of different poultry species is an important economic consideration since the waste load from meat processing plants has to be effectively managed or disposed of [2–7].

In poultry, edible components include meat, skin with subcutaneous fat, and giblets (gizzard, liver, and heart), sometimes also abdominal fat in waterfowl. Fast-growing birds need concentrated feeds in an adequate amount and appropriate form. Changes in the nutritional regime affect the function of gastrointestinal tract segments and the weight of internal organs [8–10]. The growth rate of muscle tissue—the most valuable edible component—is faster than the growth rates of internal organs and other body parts classified as inedible, such as feathers, blood, head, and others [11–16].

In growing birds, significant age-related changes can be observed not only in carcass tissue composition but also in the location of lean meat, skin with a fat layer, and bones in the carcass [11, 17–20]. Carcass quality is also determined by the distribution of tissue components. Lean meat should be located in the most valuable carcass parts—the breast and legs, rather than in the neck, wings, and back, which are less valuable. The tissue composition of poultry carcasses changes with age because the growth rates of tissue components vary across species.

Carcass parts and tissue components can be classified as edible and nonedible. Methodological differences in carcass preparation (carcass with or without the neck and wing tips) and the classification of abdominal fat as an edible or a nonedible component make it difficult to compare the research findings reported by various authors. The present report summarizes mostly the results of own studies due to the uniform methodological approach to carcass processing and classification of edible and nonedible carcass components in the analyzed poultry species, that is, Ross 308 broiler chickens [13], Pekin ducks [14], BIG 6 turkeys [15, 20], and Koluda® White geese [16, 21].

2. The effect of age on the growth rates of tissues and organs in broiler chickens, turkeys, ducks, and geese

Selective breeding carried out over many generations has resulted in specialized poultry meat and egg production based upon specialized meat stock and egg stock, including single-purpose strains and lines selected separately. Breeds and strains of meat-type poultry are intensely selected for fast growth rate, high body weight, high carcass dressing percentage, and lean tissue deposition. Dual-purpose birds, raised for both meat and eggs, are less cost-effective than specialized layers and broilers in large-scale commercial poultry farming.

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2.1. Body weight and carcass weight

Body weight is highly heritable and easy to measure [22, 23]. Body weight variation over time considerably affects production effectiveness in meat-type poultry. The growth rates of birds vary with age and across species. In comparison with ducks and geese, chickens and turkeys grow slower in the first weeks of life. The growth rates of ducks and geese decrease at 7 and 10 weeks of age, respectively. Migratory birds such as ducks and geese have to be capable of flight within a short time after hatching, so they gain weight rapidly during early life stages. Despite domestication and long-term selection aimed at eliminating atavistic features, adjustments enhancing flight capabilities can still be observed in modern ducks and geese [24, 25]. Broiler chickens have been raised since the 1920s, but initially only surplus cockerels from the laying stock were used as a source of poultry meat. In 1923, the average body weight of meat-type cockerels at 16 weeks of age was 1 kg [26]. Today, the average slaughter age of broiler chickens is 35–42 days at a body weight of 2.10–2.80 kg [27]. Between 1 and 10 weeks of age, the body weight and carcass weight of broiler chickens increase nearly 30-fold and over 40-fold, respectively [13] (**Figure 1a**). If the rearing period is longer than 35–42 days, the produced broilers have higher body weight and muscle yield, but also higher carcass fat content.

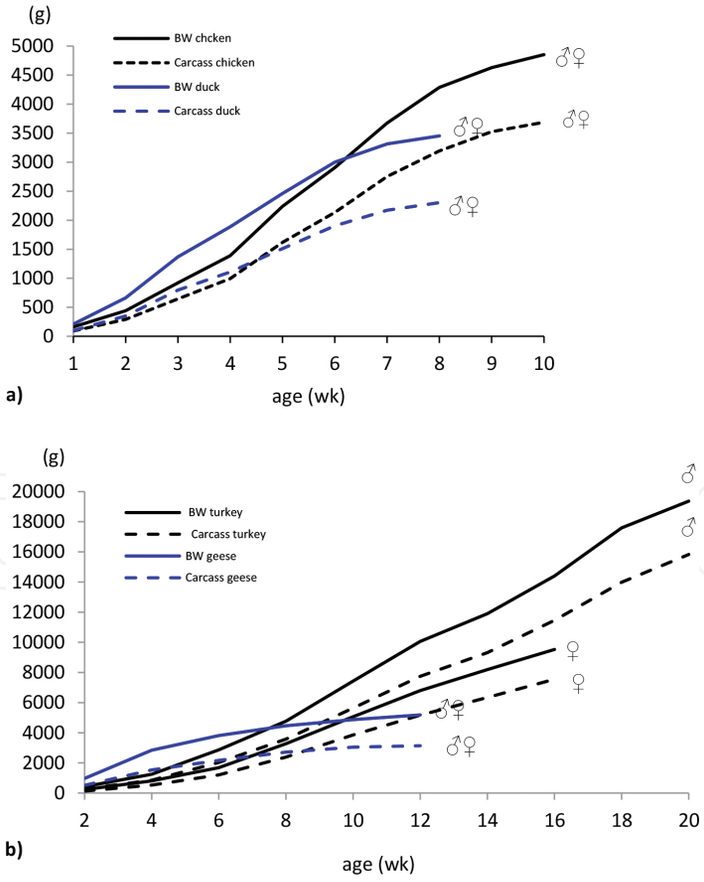

Figure 1. Arithmetic means (x) for the body weight and carcass weight of (a) chickens and ducks, (b) turkeys and geese (g).

Turkeys are the second most popular meat-type poultry species, after broiler chickens. Turkeys are heaviest among the four most common poultry species raised for meat. In comparison with other poultry species, turkeys are characterized by the highest carcass dressing percentage and high feed efficiency [4–6]. Turkey carcasses have high lean content and relatively low fat content [28]. Based on their body weight, modern commercial hybrid turkeys can be divided into heavy type, medium-heavy type, and medium type. Depending on the type, the body weight of males and females at 20 weeks of age ranges from 16.8 to 21 kg and from 9.3 to 11 kg, respectively. Due to considerable sexual dimorphism in the body weight of turkeys, males are reared over a longer period of time than females. Turkeys are characterized by the highest carcass dressing percentage among all poultry species, which reaches 81% in 16-week-old females and 84% in 21-week-old males [29].

The average body weight of male and female BIG 6 turkeys increases 45.6-fold between 2 and 20 weeks of age, and 40.8-fold between 2 and 16 weeks of age, respectively. The respective values for carcass weight are 58.3-fold (♂) and 57.7-fold (♀). A nearly 58-fold increase in carcass weight is observed already at 16 weeks of age in females and at 20 weeks of age in males, as compared with initial carcass weight at 2 weeks of age [15, 20] (**Figure 1b**).

Ducks can be divided into meat type, egg-layer type, and dual purpose. Broiler ducks are raised to 7–8 weeks of age and slaughtered at a body weight of approximately 3.5 kg. Hybrid Pekin ducks are used commercially for meat production [9]. Between 1 and 8 weeks of age, the average body weight and carcass weight of Pekin ducks increase 16.5-fold and 23.3-fold, respectively [14] (**Figure 1a**).

Geese are also raised mostly for meat, whereas egg, feather, and down production remains marginal. Geese are slaughtered at different ages, depending on breed and management system [30, 31]. Broiler-type geese are raised intensively to 10–12 weeks of age, and they are slaughtered at a body weight of approximately 5.2 kg. Geese have a fast initial growth rate. From 1 day to 12 weeks of age, their body weight increases over 34-fold [21], compared with a 5.3-fold increase in body weight and a 6.2-fold increase in carcass weight between 2 and 12 weeks of age [16] (**Figure 1b**).

Broiler chickens intended for grilling, with carcass weight of approximately 1 kg, can be slaughtered at 28 days of age. Medium-heavy female turkeys that are to be roasted whole can be slaughtered at 12 weeks of age. However, market demand for such products tends to be seasonal and remains low. Large carcasses that can be divided into retail and market-ready cuts or used for further processing are preferred, and this applies also to ducks and geese.

2.2. Growth rates of tissue components

The whole-body growth rate of birds varies over time, similarly as the growth rates of tissue components, which affects the proportions between carcass parts and tissue components [11, 17–19]. Chicks, poults, ducklings, and goslings are characterized by relatively slow growth of muscle tissue and adipose tissue, and fast growth of bones and internal organs. The content of muscle tissue and skin (including subcutaneous fat) increases significantly with age,

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whereas the content of giblets (liver, heart, gizzard), bone, and slaughter offal (excluding abdominal fat and feathers) decreases [13–16].

2.2.1. Lean meat

In birds raised specifically for meat production, both the percentage and the distribution of lean tissue in the carcass are important consideration. In poultry, breast and leg muscles constitute the most valuable carcass portion. The growth rates of muscle groups vary across poultry species. Similar age-related changes in muscle growth can be observed in chickens and turkeys, and in ducks and geese.

In broiler chickens, carcass lean content increases approximately 49-fold between 1 and 10 weeks of age. Over this period, the percentage of muscle tissue increases from 30.9 to 51.3% of total body weight, by 16.5% until week 6, and by approximately 4% between 6 and 10 weeks of age [13] (**Figure 2a**). In the carcasses of 2-week-old broiler chickens, approximately 36 and 35% of lean meat is located in the breast and legs, respectively. As birds grow older, the percentage of lean tissue increases in the breast (to 44%) and decreases insignificantly in the legs (to 32%), relative to the total lean content of the carcass [17].

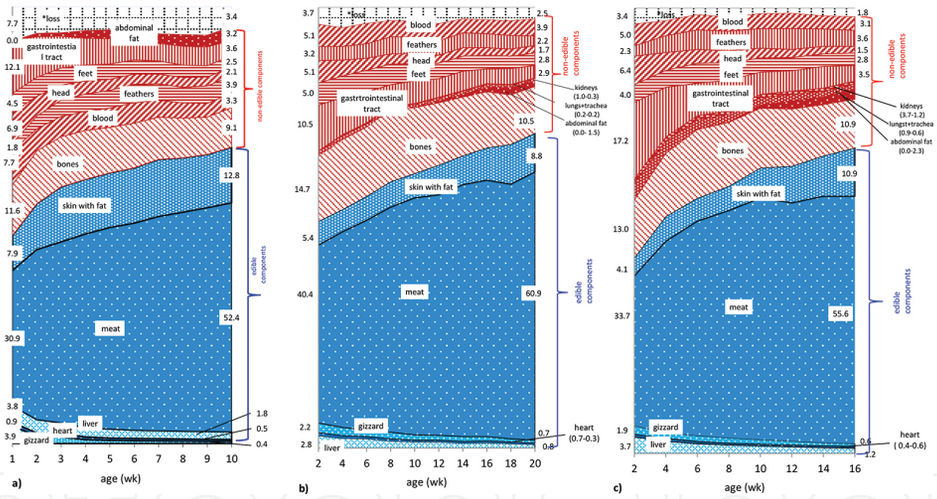

Figure 2. Percentage content of particular components in the body weight of (a) broiler chickens and turkeys, (b) males, (c) females. *loss = body weight loss during post-slaughter processing and dissection (%) [13, 15].

Turkey carcasses have high lean content [5, 6]. The growth rates of muscle tissue vary between carcass parts. In male BIG 6 turkeys, the weight of breast muscles increases approximately 77.1-fold between 2 and 20 weeks of age, the weight of leg muscles increases 75.4-fold, and the combined weight of the remaining muscles is only 54.4-fold. In female BIG 6 turkeys, the weights of breast muscles and leg muscles increase 66.7-fold and 70.5-fold, respectively, between 2 and 16 weeks of age, whereas the combined weight of the remaining muscles increases 60.5-fold [15, 20]. Muscle tissue accounts for approximately 40 and 34% of the total body weight in 2-week-old males and females, respectively, and increases to approximately 61 and 56%, respectively, at slaughter, that is, at 20 weeks of age in males and 16 weeks in females

[15]. Changes in the distribution of lean meat in the carcass can be observed in growing turkeys. In males, lean meat content (relative to total lean weight in the carcass) increases in the breast (by 3.4%) and legs (by 1.8%), and decreases in the wings (by 2.8%), back (by 1.5%), and neck (by 1%). In females, muscle tissue distribution in the carcass is similar, with a higher (by 4.2%) percentage of lean meat located in the breast. The most valuable muscles, that is, breast and leg muscles, account for 72 and 74% of total meat weight in males and females at slaughter age, respectively [20].

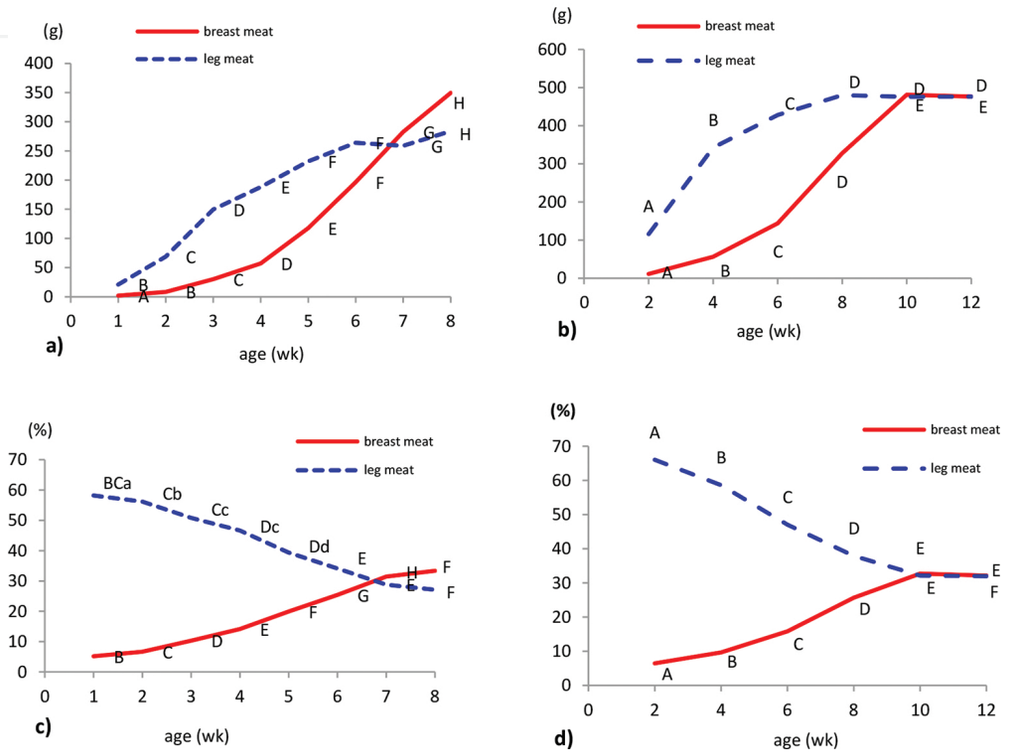

Figure 3. Arithmetic means ($\bar{X}$) for weight of breast muscles and leg muscles (g): (a) ducks, (b) geese and percentage share of breast muscles and leg muscles in total lean weight, subject to the age of birds (%), (c) ducks, and (d) geese. Values followed by different letters (age) differ significantly: capital letters $\alpha = 0.01$, small letters $\alpha = 0.05$ [14, 16].

Ducklings and goslings have well-developed leg muscles and poorly developed breast muscles. In Pekin ducks, the weight of muscle tissue increases 29.3-fold between 1 and 8 weeks of age. The percentage of lean meat increases from 17.1 to 30.4% of the total body weight over this period. The growth rate of breast muscles increases, and the growth rate of leg muscles decreases with age. Between 1 and 8 weeks, breast muscle weight increases 188-fold, whereas leg muscle weight only 13.6-fold. In 1-week-old ducklings, breast muscles and leg muscles account for approximately 5 and nearly 60% of total muscle weight, respectively. At 8 weeks of age, the proportion of breast muscles increases to approximately 33%, whereas the proportion of leg muscles decreases to 27% of total muscle weight (**Figure 3a** and **c**) [14].

In geese, muscle tissue weight increases 8.5-fold between 2 and 12 weeks of age. Age-related changes in lean meat weight in different carcass parts are similar in geese and ducks. The

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growth rate of leg muscles decreases, and the growth rate of breast muscles increases between 2 and 10 weeks of age. Over this period, the weights of breast muscles and leg muscles increase 42-fold and only 4-fold, respectively. As a result, the percentage of lean meat increases rapidly in the breast and decreases in the legs [19]. In 2-week-old geese, lean meat accounts for 18.0% of the total body weight, and it increases to nearly 29.0% at 12 weeks of age. In 2-week-old geese, leg muscles and breast muscles account for approximately 66.0% and only 7% of total muscle weight in the carcass, respectively. At 12 weeks of age, the proportion of breast muscles and leg muscles (expressed as a percentage of total lean weight) is comparable, that is, approximately 33 and 32%, respectively (**Figure 3b** and **d**) [16].

2.2.2. Skin with subcutaneous fat

Unlike Pekin ducks [9, 18] and geese [30, 31], chickens and turkeys are characterized by relatively low fat content [17, 20, 32]. The weight of fat and skin increases, at a different rate, throughout the growing period of birds. In waterfowl, subcutaneous fat can account for up to 76% of total body fat content [33]. At slaughter age, the percentage share of skin and subcutaneous fat in the total body weight is approximately 13% in broiler chickens, 10 (♂ 21 weeks) to 12% (♀ 16 weeks) in turkeys, 23% in Pekin ducks, and 19% in geese [29]. The results of research investigating different waterfowl species indicate that fat deposition as a reserve of energy is still observed in modern commercial duck and goose lines despite selective breeding aimed at eliminating atavistic features [9, 34].

In broiler chickens, the weight of skin with subcutaneous fat increases 48-fold between 1 and 10 weeks of age. Over this period, the percentage of skin and subcutaneous fat in the total body weight increases from approximately 8% in week 1 to 13% in week 3, and it remains stable until 10 weeks of age. In the analyzed period, the weight of skin and subcutaneous fat increases, but their percentage share remains at a stable level, which results from a fast growth rate of muscle tissue [13]. The distribution of skin fat and subcutaneous fat varies with age. The percentage of skin with a fat layer increases in the back (by 7%) and legs (by approx. 4%), and decreases in the breast (by approx. 4%), wings (by approx. 3%), and neck (by approx. 3.5% [17], relative to the total weight of this tissue component in the carcass. Increased fat deposition in the body cavity can also be observed in growing broiler chickens. Adipose tissue is deposited as abdominal fat, periorgan fat, and peri-intestinal fat, thus increasing the weight of slaughter offal [13].

In BIG 6 turkeys, the weight of skin and subcutaneous fat increases over 75-fold in males (from 2 to 20 weeks of age) and approximately 108-fold in females (from 2 to 20 weeks of age) [15]. Over this period, the percentage content of skin and subcutaneous fat increases by approximately 3.5% in males (from 5.4 to 8.8 %) and by 5.8% in females (from 41 to 10.9%). In males, the percentage share of skin and subcutaneous fat increases in the breast (by 7.6%), legs (by 7.9%), and back (by 1.7%), and decreases in the wings (by 11.6%) and neck (by 5.6%). In females, the percentage share of skin and subcutaneous fat increases in the legs (by 7.5%) and back (by 7.9%), decreases in the wings (by 12.1%) and neck (3.6%), and remains unchanged in the breast [20].

In Pekin ducks, between 1 and 8 weeks of age, the weight of skin with subcutaneous fat increases 25.7-fold, whereas their percentage share of the total body weight increases from 15.5% in week 1 to 24.5% in week 8. Until 3 weeks of age, the content of skin with a fat layer increases by approximately 8%, and between 3 and 8 weeks by only 1% [14]. The distribution of skin with subcutaneous fat in the carcass varies with age, with a rising tendency in the back (5% increase) and wings (4%), and a falling tendency in the neck (7% decrease) and breast (2%) [18].

In geese, the weight of skin and subcutaneous fat increases 5.4-fold from 2 to 12 weeks of age, whereas the percentage of skin with a fat layer in the total body weight remains at a similar level of approximately 19.1–19.6% [16]. The distribution of skin and subcutaneous fat in the carcass undergoes smaller changes with age than the distribution of lean meat. A rising tendency can be observed in the back (4% increase) and wings (2.5%), and a falling tendency in the breast (3.5% decrease), legs (2.5%), and neck (0.5%) [19].

2.2.3. Bones

The growth of bone tissue is completed earlier than the growth of tissue and adipose tissues. Bones are inedible components of the carcass, and the decrease in their proportion observed with age is highly desirable. However, rapid growth of muscles (in particular breast muscles) in the early life stages of birds may negatively affect their health status due to a higher incidence of leg abnormalities and deformities that result in reduced walking ability and feed utilization, followed by increased mortality [35–37].

In Ross 308 broiler chickens, between 1 and 10 weeks of age, bone weight increases approximately 23.4-fold and decreases from 11.5 to 9% when expressed as a percentage of the total body weight [13] (**Figure 2a**). Unlike the growth rates of muscle tissue and adipose tissue, the growth rate of bone tissue in different carcass parts of broiler chickens is uniform and comparable [17].

In BIG 6 turkeys, bone weight increases approximately 33-fold in males (weeks 2–20) and 34-fold in females (weeks 2–16), and the share of bones in the total body weight decreases by 4.2% in males (from 14.7 to 10.5%) and by 2.1% in females (from 13.0 to 10.9%) [15] (**Figure 2b** and **c**). Age-related changes are also observed in bone distribution in the carcass. In males, bone content expressed as a percentage of the total bone weight in the carcass increases significantly in the back portion (by 3.1%), and decreases in the wings (by 1.3%) and neck (by 2.0%). In females, bone content increases only in the back (by approx. 1%) and decreases in the neck (by approx. 1.5%) [20].

In Pekin ducks, between 1 and 8 weeks of age, bone weight increases 15.2-fold. Minor changes are noted in bone content—bones account for 12 and 11% of the total body weight in weeks 1 and 8, respectively [14] (**Figure 3a**). Significant age-related changes are observed in the distribution of bones in carcass parts. Until 7 weeks of age, bone content expressed as a percentage of the total bone weight in the carcass decreases in the legs (from 35.5 to 24.0%), and increases in the neck (from 9.0 to 18%) and breast (from 12% in week 2 to 16% in week 7).

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The percentage of bones located in the wings, relative to the total bone weight in the carcass, remains stable (approx. 17%) [18].

In Koluda White geese, the patterns of growth in body weight and bone weight are similar until 12 weeks of age (5.3-fold and 5.2-fold increase, respectively). The proportion of bones remains at a stable level (approx. 11.9–11.5%) [16] (**Figure 4b**). Similar to Pekin ducks, also in growing geese bone content expressed as a percentage of the total bone weight in the carcass undergoes greater changes than the content of skin and subcutaneous fat. From 2 to 12 weeks of age, bone content increases rapidly in the wings (from 5.7 to 39.5%) and breast (from 9.0 to 12.9%). Until 8 weeks of age, the proportion of bones decreases rapidly in the legs (from 34.9 to 17.0%) and remains stable in the neck (approx. 9%) [19].

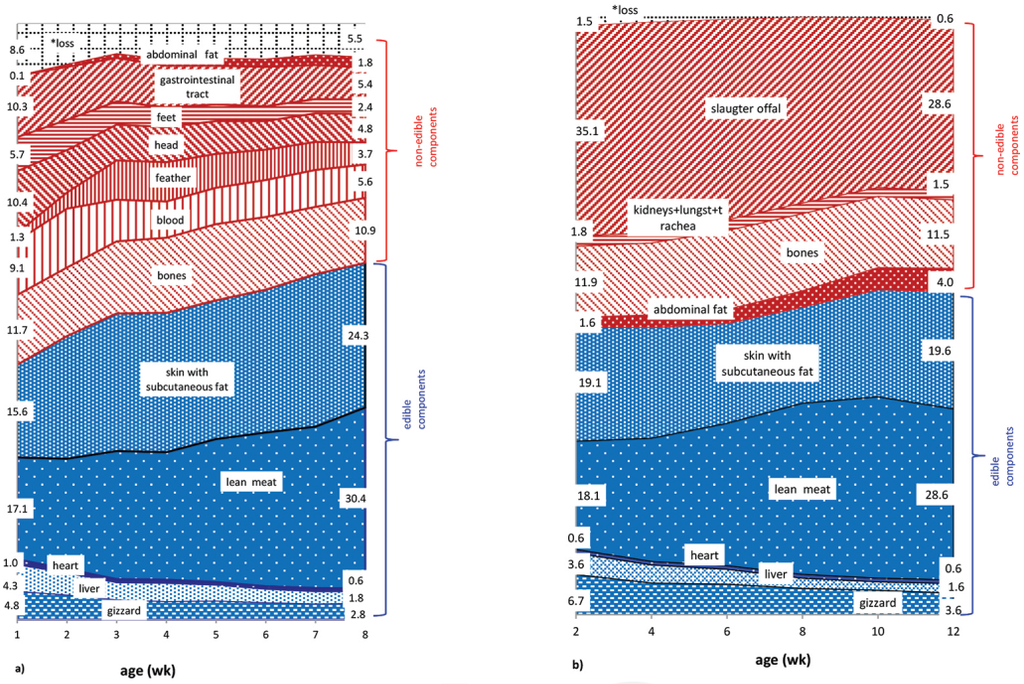

Figure 4. Percentage content of particular components in the body weight of (a) ducks and (b) geese (%). *loss = body weight loss during post-slaughter processing and dissection [14, 16].

2.3. Growth rates of organs/giblets

Full expression of the genetic potential of modern poultry lines is largely dependent on feed intake and feed conversion efficiency, which is why the composition and physical form of diets, in particular those offered to gallinaceous birds, are subject to constant modifications. Therefore, the function once performed by gastrointestinal tract segments, in particular the gizzard, has changed. In gallinaceous birds, the storage capacity and grinding activity of the gizzard have been limited. In modern broilers, the gizzard "works" less intensively due to considerable modifications in the composition and structure of feed, which is why this organ gradually diminishes in size [8]. Fast weight gain accompanied by insufficient development of some

organs, for example, the heart and lungs, may lead to metabolic diseases, skeletal system diseases, and increased fat deposition [36–39].

In broiler chickens, between 1 and 6 weeks of age, heart weight increases 11.3-fold, liver weight increases 9.3-fold, and gizzard weight only 3.4-fold. In weeks 1, 6, and 10, the total weight of giblets (heart, gizzard, and liver) accounts for 8.2, 3.0, and only 2.4% of the total body weight, respectively. In 1-week-old chickens, the gizzard has a nearly 4.0% share of the total body weight, similar to the liver. Until 10 weeks of age, the percentage content of the gizzard, liver, and heart decreases over 8-fold, 2.5-fold, and 2-fold, respectively. A rapid decrease in the percentage content of the gizzard (from 4.0 to 1.5%) is noted between 1 and 2 weeks of age, and the percentage content of the liver decreases (from 3.8 to 2.1%) from 4 weeks of age. The percentage content of the heart decreases from 0.9% in week 1 to 0.4% in week 10 [13] (**Figure 2a**).

In BIG 6 turkeys, the total weight of giblets increases 13.9-fold in males (weeks 2–20) and 14-fold in females (weeks 2–16). The growth rates of individual organs vary with age. Heart weight increases 22.2-fold in males and 27.2-fold in females. Liver weight increases 15.5-fold in males and 13.5-fold in females. Gizzard weight increases 13.4-fold in males and 14.0-fold in females. At 2 weeks of age, giblets have a 5.7 and 6.1% share of the total body weight in males and females, respectively. The total percentage content of giblets decreases to 1.7% in males at 20 weeks of age, and to 2.2% in females at 16 weeks of age. The share of individual organs decreases as follows in males: gizzard, by 1.5% (from 2.2 to 0.7%); liver, by 1.0% (from 2.8 to 0.8%); heart, by 0.5% (from 0.7 to 0.3%); and in females: gizzard, by 1.3% (from 1.9 to 0.6%); liver, by 2.5% (from 3.7 to 1.2%); heart, by 0.2% (from 0.6 to 0.4%) [15] (**Figure 2b** and **c**).

According to Lilja [40], digestive organs (esophagus, gizzard, intestines, and liver) and leg muscles belong to the group of supplying organs in geese. The supplying organs are characterized by rapid embryonic development and a fast growth after hatching, which is natural since goslings need mature legs to find food and mature digestive organs to process it efficiently.

In Pekin ducks, the total weight of giblets increases 8.9-fold between 1 and 8 weeks of age. Over this period, the weight of the liver, heart, and gizzard increases 6.9-fold, 10.4-fold, and 9.5-fold, respectively. Giblet weight expressed as a percentage of the total body weight decreases from 10.1% in week 1 to 5.3% in week 8. The percentage content of individual organs decreases as follows: liver, by 2.5% (from 4.3 to 1.9%); gizzard, by 2.0% (from 4.8 to 2.8%); heart, by 0.4% (from 1 to 0.7%) [14] (**Figure 4a**).

The growth rates of visceral organs classified as giblets vary with age also in geese. Between 2 and 12 weeks of age, the total weight of giblets increases 2.8-fold, including a 2.3-fold increase in liver weight, a 2.9-fold increase in gizzard weight, and a 4.7-fold increase in heart weight. A statistically significant increase in liver weight, gizzard weight, and heart weight is observed until 4, 6, and 8 weeks of age, respectively. The percentage content of giblets in the total body weight decreases with age, from 10.9% in week 2 to 5.8% in week 12. Over this period, the share of the gizzard and liver decreases by 3.1% (from 6.7 to 3.6%) and 2.0% (from 3.6 to 1.6%),

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respectively, whereas the share of the heart in the total body weight remains stable at around 0.6% [16] (**Figure 4b**).

2.4. Growth rate of the slaughter offal portion

During post-slaughter processing, offal is separated from the carcass. In poultry, the slaughter offal portion includes blood, feathers, feet, head, trachea, lungs, intestines (including the contents and peri-intestinal fat), spleen, pancreas, testes, components of the female reproductive system, and abdominal fat. In some regions of the world, abdominal fat and feet are classified as edible components, but they are generally considered as offal. Contemporary consumers prefer low-fat products; therefore, abdominal fat is treated as slaughterhouse waste [41]. However, the fat of waterfowl is used in regional cuisines for the production of specialty foods. Geese have higher abdominal fat content than other poultry species [31]. Fat deposition in the lower parts of the body in waterfowl is a natural adaptation to the environmental conditions. Duck and goose fat is considered to be healthier than pork fat, due to higher concentrations of essential unsaturated fatty acids [33, 42]. However, some researchers emphasize the lower durability of the former. In ducks and geese, the abdominal fat weight increases over the entire growing period, thus increasing both the weight of undesirable offal and overall production costs. Feathers are a by-product of poultry production. Today, the economic importance of the feathers of gallinaceous birds is relatively low [3]. Plumage development is particularly important in ducks and geese because carcass quality deteriorates during the feathering process, which affects the processing suitability of raw material. Feathers account for approximately 4.2, 4.0–4.5, and 5.4% of the total body weight in turkeys, chickens and ducks, and geese at slaughter age, respectively. The rate of feathering is species-specific, affected by nutrition and determined genetically [43].

In broiler chickens, the total weight of slaughter offal increases 17-5-fold between 1 and 10 weeks of age, including a 83-fold increase in feathers weight, a 41-fold increase in abdominal fat weight, a 19-fold increase in the weight of feet, a 14-fold increase in blood weight, an 11-fold increase in the weight of the gastrointestinal tract, and a 10-fold increase in head weight. The growth rates of the above components are slower than the whole-body growth rate, and their percentage content decreases with age, from 33.0% to approximately 19% in broiler chickens. The proportions of most offal components decrease during the growing period, except for abdominal fat and feathers (3.2 and 1.8% increase, respectively). Between 1 and 10 weeks of age, the smallest changes are noted in the percentage content of feet (2% decrease, from 4.5 to 2.5%), and the greatest changes are observed in the percentage content of the gastrointestinal tract (8.5% decrease, from 12.1 to 3.6%). The carcasses of 1-week-old chickens contain low amounts of abdominal fat, whereas at 10 weeks of age abdominal fat content reaches 3.2% and is almost equal to that of gastrointestinal tract [13] (**Figure 2a**).

In male turkeys, the weight of slaughter offal increases 23.5-fold between 2 and 20 weeks of age. Over this period, blood weight increases approximately 35-fold, feathers weight increases approximately 31-fold, and the combined weight of the lungs and trachea nearly 38-fold. The growth rates of the remaining nonedible components are slower; gastrointestinal tract weight increases only 14.5-fold. The percentage content of slaughter offal decreases in males from

30.1% at 2 weeks of age to 15.8% at 20 weeks of age. The greatest decrease is noted in the percentage share of the gastrointestinal tract (by approx. 7%), head (3%), and feet (2%). In female turkeys, the weight of slaughter offal increases 20-fold between 2 and 16 weeks of age. The fastest growth rate is observed in feathers weight (approx. 64-fold increase), followed by the weight of feet (29-fold), lungs and trachea (27-fold), and blood (25-fold). Similar to males, the growth rate of the gastrointestinal tract is relatively slow (approx. 10-fold increase). The percentage content of slaughter offal decreases in females from 38.5% at 2 weeks of age to 18.0% at 16 weeks of age. Age-related changes in the content of individual offal components are similar to those noted in males [15] (**Figure 2b** and **c**).

In Pekin ducks, offal content expresses as a percentage of the total body weight decreases from 37% in week 1 to 24% in week 8. The weights of feathers and abdominal fat change to the greatest extent. Between 1 and 8 weeks of age, feathers weight increases approximately 65-fold. The carcasses of 1-week-old ducks contain low amounts of abdominal fat, but its weight increases nearly 200-fold by 8 weeks of age. The growth rates of the remaining nonedible components are slower; from 1 to 8 weeks of age, the weights of blood, head, feet, and gastrointestinal tract increase 11-fold, 7.7-fold, 7.2-fold, and 9.1-fold, respectively. Changes in the growth rates of the above components and the body weight of birds contribute to an increase in the percentage content of feathers and abdominal fat (by 2.4 and 1.5%, respectively), and a decrease in the percentage content of gastrointestinal fat (5%), blood (3.3%), head (5.4%), and feet (3.3%) [14] (**Figure 4a**).

In geese, between 2 and 12 weeks of age, the total weight of slaughter offal increases 4.2-fold or 4.6-fold, depending on the classification of abdominal fat as an edible or inedible component, respectively. Over this period, abdominal fat weight increases approximately 13.6-fold. The increase in offal weight in geese aged 2–12 weeks is not uniform. The total weight of slaughter offal increases rapidly (2.9-fold) in weeks 2–4, it stabilizes and remains relatively unchanged until week 10, and increases again in weeks 10–12. The main reason for the increase in slaughter offal weight in geese aged 10–12 weeks is enhanced peri-intestinal fat deposition. Despite the increase in slaughter offal weight, its proportion in the total body weight decreases from 35% in week 2 to 29% in week 12 [16] (**Figure 4b**).

3. The effect of age on the percentage content of edible and nonedible components

The total weights of edible and nonedible components in the carcasses of different poultry species are an important economic consideration since edible carcass parts are used as raw materials for the manufacture of processed meat products, and the waste load from meat-processing plants has to be effectively managed or disposed of. In view of the fact that global poultry meat production continues to increase, the ratio between edible and inedible weights in poultry carcasses deserves particular attention [2, 3, 7]. The whole-body growth rate of birds varies over time, similarly as the growth rates of internal organs and tissue components, which affects the proportions between edible and nonedible components in the carcass. Research

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results show that the rate of age-related changes in the content of edible and nonedible carcass portions varies across poultry species [13–16].

3.1. Percentage content of the edible portion

In chickens slaughtered at 1 week of age, the ratio between edible and nonedible parts is estimated at 1:1, whereas a more desirable value of 2.2:1 is noted in birds slaughtered at 10 weeks of age. From weeks 1–10, the total weights of edible and nonedible components in broiler carcasses increase 42-fold and only 20-fold, respectively. In 1-week-old broiler chickens, edible components account for approximately 47.0% of the total body weight, and their content increases to 63.0 and 67% at 6 and 10 weeks of age, respectively [13] (**Figure 2a**).

Similar to chickens, age-related changes in the weights and percentages of edible and nonedible components are also observed in turkeys. In males, between 2 and 20 weeks of age, the weights of edible and nonedible portions increase 63.5-fold and approximately 26.5-fold, respectively. In 2-week-old males, edible components account for nearly 52% of the total body weight, compared with 72% in 20-week-old birds. In the group of edible components, muscle tissue is characterized by the highest growth rate (40.4% in week 2, 60.9% in week 20), followed by skin and subcutaneous fat (5.4% in week 2, 8.8% in week 20). The content of giblets, expressed as a percentage of the total body weight, decreases with age (in contrast to the remaining edible components), from 5.7% in week 2 to 1.8% in week 20. A similar trend can be observed in female turkeys. Until 16 weeks of age, edible and inedible weights increase approximately 63.7-fold and 23.7-fold, respectively. The share of muscle tissue in the total body weight increases from 33.7% in week 2 to 55.6% in week 16, the share of skin with subcutaneous fat increases from 4.1% to 10.9%, and the share of giblets decreases from 6 to 2.4% [15] (**Figure 2b** and **c**).

In 1-week-old ducks, the weight of edible components is lower than the weight of nonedible components (0.8:1). In Pekin ducks, between 1 and 8 weeks of age, edible and inedible weights increase 23-fold and 12.1-fold, respectively, and the ratio between edible and nonedible components reaches 1.6:1 in 8-week-old birds. Edible components account for 42.8% of the total body weight in week 1 and for 59.9% in week 8. The most significant changes are observed in the percentage content of muscle tissue (10.5% increase) and giblets (5.1% decrease). The share of skin and subcutaneous fat remains stable at 19.3% throughout the growing period. As a result, the proportions between tissue components change. In 1-week-old ducks, muscle tissue, skin with a fat layer, and giblets account for 40, 37, and 24% of total edible weight, respectively. More desirable values are noted in 8-week-old birds, where muscle tissue, skin with fat, and giblets account for 50, 41, and only 9% of total edible weight, respectively [14] (**Figure 4a**).

In geese, the ratio between edible and inedible weights is 1:1 at 2 weeks of age, and 1.4:1 (variant I, abdominal fat classified as an edible component) or 1.2:1 (variant II, abdominal fat classified as a nonedible component) at 12 weeks of age (Murawska 2013b). The most valuable edible component, muscle tissue, has an 18% share of the total body weight in week 2 and 29% in week 12. Between 2 and 12 weeks of age, the percentage content of skin and subcutaneous fat

in the total body weight of geese remains stable at 19.5%, whereas the share of giblets decreases from 10% in week 2 to 6% in week 12 [16] (**Figure 4b**).

3.2. Percentage content of the nonedible portion

The nonedible portion of poultry carcasses comprises slaughter offal and bones. The content of those components, expressed as a percentage of the total body weight of birds, decreases with age.

In 1-week-old broiler chickens, nonedible components account for 45.3% of the total body weight on average, and their content decreases to 34.4 and 30.2% at 6 and 10 weeks of age, respectively. Over this period, a greater decrease is observed in the share of slaughter offal (by 12.5%, from 33.7% in week 1 to 21.2% in week 10), in comparison with bones (by 2.5 %, from 11.6 in week 1 to 9.1% in week 10) [13] (**Figure 2a**).

In 2-week-old turkeys, nonedible components have a 44.7 (♂) and a 49.9% (♀) share of the total body weight, and their content decreases to 26.0 (♂, week 20) and 29% (♀, week 16) at slaughter age. Similar to broiler chickens, slaughter offal content decreases by over 15% (from 29.7 to 14.5%) in males and by 19% (from 36.9 to 17.9%) in females, whereas bone content decreases at a slower rate (♂ 4.2% decrease, from 14.7 to 10.5%; ♀ 2.1% decrease, from 13.0 to 10.9%) [15] (**Figure 2b** and **c**].

In ducks, nonedible components account for 48.6% of the total body weight in week 1, and decrease to 34.6% in week 8. Slaughter offal accounts for 39.7 and 27.2% of the total body weight in weeks 1 and 8, respectively. Bone content decreases from 11.7% in week 1 to 10.9% in week 8 [14] (**Figure 4b**).

In geese, between 2 and 12 weeks of age, the percentage content of inedible components decreases mostly due to a decrease in the share of slaughter offal (approx. 6.5%) because the proportion of bones remains at a stable level (approx. 11.9–11.5%). In variant I (abdominal fat classified as an edible component), the share of nonedible parts decreases from 48.08 to 41.6%, and in variant II (abdominal fat classified as a nonedible component) from 50.2 to 45.4% [16] (**Figure 4b**).

4. Conclusion

The research findings presented in this chapter can be used in an analysis of potential health threats resulting from the undesirable differences between the growth rates of individual organs and the whole-body growth rate of birds. The relationship between the growth rates of muscle tissue and adipose tissue is also an important consideration for carcass quality and poultry production efficiency. Due to the specific structure of subcutaneous adipose tissue in poultry, analyses of carcass fat content should include both skin with a subcutaneous fat layer and abdominal fat. Information on age-related changes in the weight and content of edible and inedible carcass components may contribute to the effective processing of poultry meat and

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the effective management of slaughter offal, including bones separated from muscle tissue in the mechanical deboning process.

A prolonged rearing period contributes to higher final body weight and higher muscle yield, but overall production costs increase because older birds are characterized by a slower growth rate and a higher feed intake per kg of body weight gain. Those factors should be taken into account when determining the optimal slaughter age.

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