Ann. Anim. Sci., Vol. 16, No. 3 (2016) 653–678 *DOI: 10.1515/aoas-2016-0032*

AVIAN CROP FUNCTION – A REVIEW*

Bartosz Kierończyk[1], Mateusz Rawski[1], Jakub Długosz[1], Sylwester Świątkiewicz[2], Damian Józefiak[1♦]

[1]Department of Animal Nutrition and Feed Management, Poznań University of Life Sciences, Wołyńska 33, 60-637 Poznań, Poland
[2]Department of Animal Nutrition and Feed Science, National Research Institute of Animal Production, 32-083 Balice n. Kraków, Poland
♦Corresponding author: damjo@up.poznan.pl

Abstract

The aim of this review is to present and discuss the anatomy and physiology of crop in different avian species. The avian crop (ingluvies) present in most omnivorous and herbivorous bird species, plays a major role in feed storage and moistening, as well as functional barrier for pathogens through decreasing pH value by microbial fermentation. Moreover, recent data suggest that this gastrointestinal tract segment may play an important role in the regulation of the innate immune system of birds. In some avian species ingluvies secretes "crop milk" which provides high nutrients and energy content for nestlings growth. The crop has a crucial role in enhancing exogenous enzymes efficiency (for instance phytase and microbial amylase, *β*-glucanase), as well as the activity of bacteriocins. Thus, ingluvies may have a significant impact on bird performance and health status during all stages of rearing. Efficient use of the crop in case of digesta retention time is essential for birds' growth performance. Thus, a functionality of the crop is dependent on a number of factors, including age, dietary factors, infections as well as flock management. It is important to expand knowledge about the crop functions to use them effectively in poultry production. Furthermore, more scientific data is needed in the scope of immunological function of the crop as well as its microecosystem for a better understanding of the avian immune system and enhancing the health of the birds.

Key words: ingluvies, avian crop, crop anatomy, crop physiology, crop microbiology

Crop anatomy

Crop (ingluvies) is a tubular organ which is an enlarged part of the esophagus. Depending on its anatomy it is classified as rudimentary crop (e.g. Anseriformes), i.e. long and narrow, occupying a small space, either "false crop" – simple diverticulum of the esophagus (e.g. *Gyps fulvus*) or "real crop" (e.g. Galliformes) – well-developed and round-shaped bilobed enlargement (Farner, 1960). In the case of *Gallus*

*The article was supported by the grant: "Bacteriocins – innovative supplements for poultry diets" UDA-POIG 01.03.01-30-179/09. Innovative Economy Programme, as well as Grant NCN PRELUDIUM no. UMO-2014/15/N/NZ9/01529, financed by National Science Center (Poland).

gallus var. *domesticus*, ingluvies is characterized by thin wall, 4.5–5.0 cm of length and 8–10 cm^3 capacity. The crop wall is attached to the skin and to the clavicle (*clavicula s. furcular*) by the loose connective tissue as well as to the sternum by *musculus compressor ingluvialis* (Langenfeld, 1992). Furthermore, *m. cucullaris capitis pars clavicularis* forms a surface i.e. *m. levator ingluviei* which supports crop position (McLelland, 1993). Through the crop entrance (*ostium ingluviale*), the feed is transferred to the singular diverticulum (Galliformes) and then down to *fundus ingluvialis* (Kobryń and Kobryńczuk, 2004). Anatomical topography of the crop strictly depends on species. Ingluvies lies mainly to the right of the trachea, e.g. Galliformes and Falconiformes crop is located at the thoracic inlet; in Psittaciformes it is stretched transversely across the neck. Pigeons have two large lateral diverticula on both sides of the trachea and small enlargement in the median side (*diverticulum ingluviale sinistrum, dextrum et medianum*). In parrots crop lies at the caudal-cervical part of esophagus and has two pouches – bigger on the right and smaller on the left; the filled crop of some nectivoro-insectivorous birds as well as nestlings of *Chloris chloris* and *Taeniopygia guttata* is located dorsally over the vertebral column; *Opisthocomus hoazin* has the largest crop, which consists of cervical and thoracic parts of esophagus (Niethammer, 1933; Eber, 1956; McLelland, 1990; McLelland, 1993; Lumeij, 1994). A cross section through the entire chicken crop wall allows distinguishing the following parts: incompletely keratinized stratified squamous epithelium, lamina propria, mucous glands – *gll. ingluviales* (near esophageal area or their lack, depends on the authors), muscular mucosae, submucosa, inner circular muscle layer and longitudinal muscle layer (McLelland, 1990; Doneley, 2010). *Tunica mucosae ingluviei* contains *plicae et rugae ingluviei* (McLelland, 1993). The crops' muscular layer in *Strigops habroptila* and *Opisthocomus hoazin* is well developed and may play a role in mechanical grind of food (Szarski and Grodziński, 1987). Despite the fact that birds do not develop esophageal sphincters like mammals (Klasing, 1999), in the case of parrots and pigeons it is possible to identify a functionally similar structure which is located at the junction of the crop and the thoracic esophagus, which allows portioning of feed formation (Taylor, 2000).

The crop in different avian species

The size of the crop and its shape constitute species-specific features (Figure 1) (Godoy-Vitorino et al., 2008). This fact is determined by the birds' evolutionary adaptation to their diet, environment and behavior, i.e. through the rapid feed ingestion in stressful conditions and then digestion in a safety refuge (Gelis, 2006). Stevens and Hume (1998) point out that omnivores and herbivores, including granivorous birds, are characterized by a larger crop than carnivorous predators. Particularly noteworthy is the hoatzin (*Opisthocomus hoazin*), whose enlarged esophagus is the largest part of its digestive tract (Figure 2). Zheng et al. (2011), based on studies carried out on fossils at the Tianyu Museum of Nature, hypothesize that the development of the crop together with adaptation to the intake of a specific diet (e.g. gastroliths) had a significant impact on the reduction or total deprivation of teeth in birds from the Cretaceous period. However, not all present representatives of birds (Aves), for example, seagulls, penguins, geese and ostriches, have a developed esophagus forming the crop (Table 1) (Denbow, 2000; López-Calleja and Bozinovic, 2000). On the other hand, some species, e.g. European goldfinch (*Carduelis carduelis*), developed an extensible esophageal pouch which is able to play a feed storage function like the crop (Klasing, 1999). Furthermore, esophageal diverticula or enlargements (*saccus esophagealis*) may be involved in courtship as resonating chambers and/or display devices, e.g. in several species of grouse, cranes and pigeons (Farner, 1960; Lumeij, 1994; Kobryń and Kobryńczuk, 2004). However, it should be noted that great bustard (*Otis tarda*), as well as frigatebird (*Fregata magnificens*) have a gular pouch which has the same function but another structure (Farner, 1960; Madsen et al., 2007).

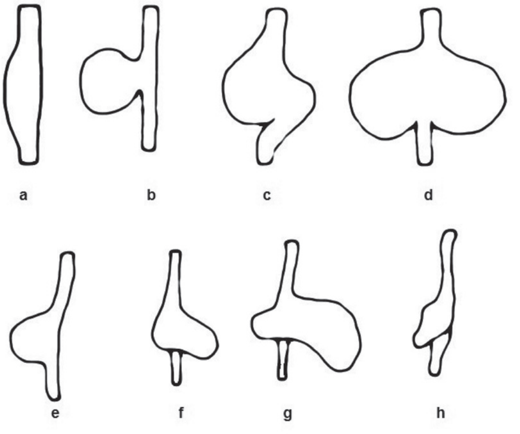

Figure 1. Shape of crop in selected bird species: a) cormorant (*Phalacrocorax carbo*) – rudimentary crop, b) peacock (*Pavo* sp.) – "true" crop, c) budgerigar (*Melopsittacus undulatus*), d) pigeon (*Columbidae*), e) "false" crop, e-h) different shapes of crop in Cacatuidae (King and McLelland, 1984)

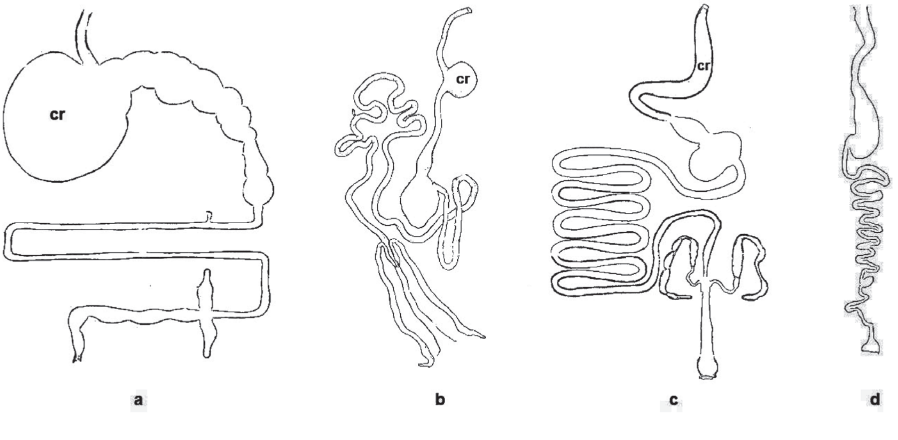

Figure 2. Diagram of the gastrointestinal tract: a) hoatzin (*Opisthocomus hoazin*), b) turkey (*Meleagris gallopavo*), c) goose (*Anser anser*), d) striated heron (*Butorides striatus*); cr – indicating the crop (based on Godoy-Vitorino et al., 2008; Montaner et al., 1997; Clemens et al., 1975; Duke, 1989)

Table 1. Presence of crop among the different taxa of birds

Order	Presence of the crop	Comments	Literature
Accipitriformes		With the exception of the bearded vulture (Gypaetus barbatus), which does not have the crop.	Duke (1997) Houston and Copsey (1994)
Anseriformes		Rudimentary crop.	Backues (2015) Taylor and Murray (1999)
Family: Apodidae	–	No caeca. There is a gall bladder.	Pye (2003) Sibley and Ahlquist (1990)
Caprimulgiformes			Charles (1995) Mayr (2010)
Charadriiformes		Crop and stomach are characterized by simple and often reduced structure.	McCain (2015)
Genus: *Ciconia*			Ziswiler and Farner (1972)
Columbiformes		Secretion of crop (i.e. crop milk) is produced by both males and females under the influence of prolactin.	Schultz (2003)
Falconiformes			Duke (1997) Aguilar et al. (2012)
Galliformes			Duke (1986)
Genus: *Gracula*	–	Ventriculus has a moderately muscular wall.	Dorrestein (2009)
Gruiformes	–		Taylor and Murray (1999)
Musophagiformes	–	Relatively short gastrointestinal tract with a muscular glandular stomach (proventriculus) and thin-walled gizzard (ventriculus). Well-developed liver.	Johnston (1999)
Passeriformes		In most species the caecum is rudimentary or missing. The most characteristic feature of pelicans is a skin gular sac (gular pouch), which allows hunting and subsequent draining off the prey (not to be confused with crop).	Smith (2015)
Pelecaniformes	–	Proventriculus and ventriculus are thin-walled and flexible.	Redrobe (2015) Montaner et al. (1997)

Genus: *Phalacrocorax*		Rudimentary crop	Ziswiler and Farner (1972)
Phoenicopteriformes		Chicks are fed with high-energy secretion of crop, containing canthaxanthin, leukocytes and erythrocytes.	Lang (1963)
Procellariformes			Hendriks et al. (2000) Miskelly et al. (2009) Padilla (2015)
Psittaciformes		Caeca are rudimentary or missing.	Taylor and Murray (1999)
Family: *Ramphastidae*	–		Leger et al. (2012) Del Hoyo et al. (2002)
Ratitae	–		Deeming (1999) Tully (2009)
Sphenisciformes	–	Glandular stomach (proventriculus) stores food, which is further used to feed the young.	Kirk Baer (1999)
Strigiformes	–	Food can be stored along the entire length of the esophagus.	McLelland (1979) Duke (1997)
Family: Tinamidae			Chikilian and de Speroni (1996)
Family: Trochilidae		Complete emptying of the crop takes approx. 4 minutes. No caeca or gall bladder. Presence of a thin-walled, flexible esophagus reaching up to 12 cm in length.	Karasow et al. (1986) Del Rio et al. (2001)
Trogoniformes		Cuban trogon (*Priotelus temnurus*) – has gizzard of considerable size (1.8 cm in diameter), also caeca measuring 18–26% of the total length of the intestines.	Wheelwright (1983) Clark (1918)

The crop functions

Crop in the case of nestlings' growth

In many avian species, crop plays an important role in the rearing of nestlings (e.g. pigeons, parrots, finches) (Lumeij, 1994). On the one hand, it stores initially ingested feed that is passed on or obtained directly by the young, and on the other hand in individual species, i.e. pigeons (Columbiformes) and flamingos (e.g. *Phoenicopterus ruber*), it secretes so-called crop milk (Studer-Thiersch, 1967; Gillespie et al., 2012). This substance is also produced by emperor penguins (*Aptenodytes forsteri*), however, it is synthesized through the esophagus due to the lack of an anatomically separated crop (Prévost et al., 1963; Kirk Baer, 1999).

The phenomenon of crop milk presence and secretion was first described by Hunter in 1786 (Hunter, 1840). It involves the secretion of prolactin causing hyperplasia of the mucosa (Riddle et al., 1933). Further, on account of the holocrine secretion, the exfoliating epithelium is mixed with the previously collected food forming a semi-solid substance (Kirk Baer, 1999). The composition of crop milk is species-specific (Table 2) and is characterized by a protein content of 50–60% (in dry matter), 32–45% of fat (including triglycerides, phospholipids, cholesterol, free fatty acids and cholesterol esters and diglycerides), and carbohydrates (1–3%) which, due to low concentration levels, are often overlooked (Davies, 1939; Desmeth and Vandeputte-Poma, 1980; Kirk Baer, 1999). Furthermore, this secretion is rich in keratinocytes and macroelements, i.e. calcium, phosphorus, sodium, and potassium (crude ash: 4.4–4.8%) (Davies, 1939). Due to the biology of short-term rearing of pigeon nestlings (10-40 days, depending on the species) the milk constitutes a food that is easily digestible, highly energetic and rich in immunoglobulin A (Goudswaard et al., 1979). In addition, this secretion contains bioactive substances such as: transferrin, glycoproteins (with the same sequence as lactoferrin) and a specific growth factor – Pigeon Milk Growth Factor (PMGF) (Frelinger, 1971; Shetty et al., 1992; Shetty and Hegde, 1993; Wally and Buchanan, 2007). It has been shown that this secretion, in the case of the flamingo, is characterized by the abundance of canthaxanthin, leukocytes and erythrocytes (Lang, 1963). It is also interesting that the introduction of substitute crop milk into chicks of pigeons led to their death or abnormal growth of young birds (Guareschi, 1936). This suggests the presence of immune-modulating factors such as immunoglobulins and cytokines, like in the case of mammals milk (Wagstrom et al., 2000; Stelwagen et al., 2009), which is necessary during post-hatching period.

Research work related to the supplementation of broiler chicken diets with pigeon crop milk resulted in an increased rate of growth when compared with the control group without its addition (Pace et al., 1952; Hegde, 1973). It is believed that the reason for this could be the higher energetic value of the feed and the beneficial effects of bacteria and bioactive substances contained in crop milk. The research of Gillespie et al. (2012) showed that pigeon crop milk supplemented to broiler chicken diet have a significant impact on their immune system by gene expression in the GALT (gut-associated lymphoid tissue), regulation of cytokine production and activation and proliferation of B-lymphocytes. Furthermore, the impact of crop milk was proven on beneficial diversification of the composition of the microbiota of chickens, due to its pre- and probiotic properties. Therefore, it was suggested that crop milk is characterized by analogous properties to the milk secreted by mammals (Gillespie et al., 2012). At the same time, the fact of evolutionarily independent development process of the formation of this secretion is fascinating.

Table 2. Comparison of crop or esophagus secretion composition in selected species of birds (adapted from Campbell and Lack, 2011)

	Pigeon[1]	American flamingo (*Phoenicopterus ruber*)[2]	Emperor penguin (*Aptenodytes forsteri*)
Protein	58.4	32.5	59.3
Fat	35.1	65.3	28.3
Carbohydrates	–	0.8	7.8
Minerals	6.5	1.4	4.6

[1]Water content 74%.
[2]Water content 73%.

The role of the crop in scope of feed intake

Due to the relatively low volume of the glandular stomach and gizzard in comparison to body mass, birds (as the only vertebrates) developed an organ for transitional digesta storage. It was noted that up to 50% of the diet consumed in the morning and the afternoon goes directly to the crop of turkeys (Jackson and Duke, 1995). However, broiler chickens fed *ad libitum* do not use the maximum capacity of this organ due to a continuous manner of feed intake (Nielsen, 2004). It was experimentally documented by cropectomy that crop does not play a crucial role in controlling feed intake in *ad libitum* fed birds (Fisher and Weiss, 1956). Moreover, in the case of cropectomized Japanese quails (*Coturnix coturnix japonica*), birds may store feed in the esophagus at the same amount as a crop (Savory, 1985). Therefore, from the practical point of view, the crop acts as a storage of food in a situation when the feed is provided in an intermittent feeding system, but is not involved in the regulation of feed intake in a continuous manner (Jackson and Duke, 1995; Svihus et al., 2013). It must be noted that crop usage is linked with natural foraging behavior, e.g. least frequency and a large amount of feed intake (Savory, 1985), as well as day length (Irving et al., 1967). The same results of decreasing of filling crop were noticed in diluted diet with application of an indigestible filler (Fisher and Weiss, 1956; Slater, 1974). These data are contrary to reports discussing the impact of mechanoreceptors located in the wall of the crop as regulators of feed intake (Richardson, 1970; Hodgkiss, 1981). Explanation of this process should be traced, like in the case of other animals, including mammals, to the mechanism of stimulating the vagus nerve through the work of stomach muscles (Denbow, 1994), as well as humoral effects (ghrelin, gastrin, cholecystokinin) (Richards and Proszkowiec-Weglarz, 2007). Thus, the filling of the crop is closely dependent on the volume of food in the two-part stomach (proventriculus and ventriculus), whose capacity in chickens is estimated at up to 5–10 g of feed (Svihus, 2014). When this organ is filled up completely, storage of feed in the crop takes place (Jackson and Duke, 1995). After a while, when the gizzard is emptied, muscle contractions cause the passage of content to further sections of the intestinal tract (Langenfeld, 1992). Therefore, the functions of the anterior digestive tract are closely linked, and affect the peristalsis of further sections of the digestive system. The time which is needed for the bolus to pass from the crop to the gizzard is around 5–30 seconds (Henry et al., 1933), moreover, the pressure used in this process (in laying hens) is in the range from 7 to 18 cm H_2O (Groebbels, 1932). Furthermore, it is possible, especially in the carnivorous birds (e.g. *Accipiter gentilis*) that the crop fills first, and after a few minutes the peristaltic movements push a prey into the stomach (Dedič, 1930).

In chickens the volume of the crop is closely related to body weight, gender, as well as its breed. It has been shown that with increasing body weight of laying hens (Quisenberry, 1971) and broiler chickens (Wehner and Harrold, 1982) its crop volume increases proportionally. Moreover, reduced sizes of this section have been observed in hens. Further, males of broiler chickens are characterized by a much higher crop volume when compared with the Single Comb White Leghorns (Table 3).

Table 3. Dependence of the crop volume on body weight, sex, and breed of chickens (adapted from Wehner and Harrold, 1981)

Type	Average body weight (kg)	Average crop volume (cm^3)	Crop volume to body weight ratio (cm^3/kg)
SCWL laying hens	1.8	71.1 a	38.7 a
Lightweight roosters SCWL	1.9	95.8 b	51.2 b
Heavyweight roosters SCWL	3.2	169.3 c	52.9 c
Broiler cockerels	3.2	214.3 d	67.4 d

a, b, c, d – values differ at the significance level of $P \leq 0.05$.
SCWL – Single Comb White Leghorn.

Feeding *ad libitum* results in reduced physical use of the crop by chickens (Svihus et al., 2010) due to the fact of adjusting the frequency of feed intake (on average every half hour) to the rate of passage of the digesta (Svihus et al., 2013). Boa-Amponsem et al. (1991) confirmed that filling the crop in slow- and fast-growing chickens varies depending on the feeding system. It was also reported that the chickens adapting to environmental conditions (two feedings per day) could collect up to 40% of the daily dose at once, while using the crop, glandular stomach and gizzard as organs that store the feed (Barash et al., 1992; Buyse et al., 1993). In addition, free range farming caused an increase in the use of storage functions of the crop (Mwalusanya et al., 2002; Mekonnen et al., 2010). Therefore, it is possible that access to additional structural feeds results in increased feed intake, through which the crop is stimulated to intensified work. However, studies that were conducted on the use of various forms of physical feeds (pellets, coarsely ground, fine) for broiler chickens, did not show statistically significant differences in the impact of the structure of the diet on the mass of the crop content (Sacranie et al., 2012). The reduction in pH value was observed (5.1 vs. 5.6) in the crop of birds fed finely ground (1 mm) diet (Svihus et al., 2013). It should be emphasized that in clinical condition (fluid therapy), the optimal amount of feed directly placed into the crop is within the 3–5% of bird's normal body weight (Quesenberry and Hillyer, 1994).

The crop and the efficiency of feed additives

Effective use of the crop organ is closely related to its filling and the rate of passage content. Therefore, the retention time of digesta during restrictive feeding of chickens should be noted. In an interval of 1 hour after the last feeding as much as 40 g DM of feed was observed in the crop. A significant amount of content was noticed even 4 or 5 hours after feeding, but it amounted to an average of 10 g (Buyse et al., 1993; Svihus et al., 2002). It is believed that due to the lack of endogenous enzymes secretion by the crop, it does not fulfill important functions in the digestion of feed. However, the study by Ponte et al. (2008) mentioned the possibility of synthesizing *β*-glucanase of bacterial origin in this segment, which may affect the activity of exogenous feed enzymes. In addition, the crop plays an important role in moistening the feed, which supports enzymatic degradation in subsequent sections of the digestive tract. At the same time, other substances activated by moistening, including exogenous feed enzymes, can potentially positively affect the nutrient's digestibility. The crop is the only part of the bird's gastrointestinal tract where the activity of digestive enzymes depends on the water content. Moreover, retention of a wet digesta takes prolonged time in comparison to short-term remaining of dry feed in the crop (Sturkie, 1976 a). Thus, the moistening time of feed is an important factor in determining the effectiveness of exogenous enzymes; however, this only applies to a situation where the crop is the place of their main activity. So, gradual moistening of the crop content in time was observed, increasing even by 50% within 60 minutes (Svihus et al., 2010). Furthermore, the light schedule changes from continuous to intermittent may enhance the effectiveness of exogenous enzymes by elongation of feed retention in the crop (Ao, 2005). Svihus et al. (2010) proved that the use of restricted feeding, thanks to the use of the crop by birds as a transitional feed storage, may have an impact on better growth performance of chickens. This is because of an increase in the efficiency of exogenous phytase. There was a 50% reduction in digesta phytic acid at 100 minutes retention of digesta in this segment of the gastrointestinal tract. In the *in vitro* experiment by Denstadli et al. (2006), degradation of phytic acid (IP6) reached up to 86% during 45 min of incubation in conditions similar to those in the crop. It has been repeatedly proven that the crop plays a major role in creating an environment for phytase activity synthesized, among others, by *Aspergillus niger*, *Mitsuokella jalaludinii* or *Peniophora lycii* (Liebert et al., 1993; Onyango et al., 2005; Lan et al., 2010).

The acidic environment of the crop is crucial to optimal efficacy of the exogenous enzymes added to the chicken diets. It is well-documented that bacterial or fungal enzymes show the highest activity at pH 4.0–6.0 (Coughlan, 1985; Ademark et al., 2001; Beauchemin et al., 2003; Greiner and Konietzny, 2011). In the situation where pH value is above 6.5 (up to 3 h after feeding) the enzymes activities are decreased to 10–15% of effectiveness at pH 4.5 or 5.5 (Baas and Thacker, 1996). Thus, the crop allows for a thorough utilization of exogenous enzymes by decreasing the pH value of digesta through the *Lactobacilli* fermentation. It should be noticed that disturbances of microbial composition may be a limiting factor for maximizing the enzyme activity.

Another feature of ingluvies, through the blood vessels presence, is absorption of nutrients (Bolton, 1965). This property is frequently overlooked due to the fact of minimal intensity of this process or its absence. Some authors indicated that glucose (Bolton, 1965; Pritchard, 1972), threonine (Teekell et al., 1967) and β-carotene (in the presence of bile) (Sibbald and Hutcheson, 1959) could be absorbed directly from the crop. In contrast to that, botulinus toxin is not absorbed through the crop (Leasure and Foltz, 1940).

The environment of the crop and its functioning

The digesta in crop is characterized by a high variability of pH (Table 4), which according to various scientific reports of healthy birds ranges from 4.0 to 7.8 (*Gallus gallus* var. *domesticus*) (Herpol and van Grembergen, 1967; Józefiak et al., 2008, 2011, 2014). In the case of sour-crop the pH value can be as low as 3.7 (Bolton, 1965). Feeds for nonruminants usually have pH values around 6.0 (Ao, 2005). Therefore, it may be assumed that when the content begins to be stored, the pH will be formed at a similar level (Ao et al., 2008). However, prolonged retention is associated with a significant increase in the fermentation activity of the endogenous microbiota. Organic acids synthesized by the bacteria effectively reduce the pH value (Hilmi et al., 2007). Thus, the different storage time of the content is associated with a different intensity of fermentation, and hence the concentration of hydrogen ions and other products of microbial activity. Bolton (1965) confirmed that the pH value decreases with prolonged retention time of feed in the crop, but it concerned only broiler chickens. In the case of laying hens similar effects were not observed due to the high dietary content of limestone characterized by a high buffering capacity. Moreover, the addition of acidifiers (formic and propionic acids) to the diets for laying hens did not affect pH change in the crop. In contrast, it had negative effects by reducing the number of lactic acid bacteria and decreased the concentration of short-chain fatty acids (Thompson and Hinton, 1997). Besides, addition of 25 g/kg of the propionate ion to the hen diet resulted in chronic damage of the crop epithelium (Bolton and Dewar, 1965). Insufficient activity of the fermentation of carbohydrates by lactic acid bacteria in the crop, for example, through lack of feeding during transport, reduces their population and the concentration of the product, i.e. lactic acid.

It has to be emphasized that complete emptying of the crop in broiler chickens takes less than four hours (May and Deaton, 1989), although this may be dependent on feeding and management. This affects the sudden drop in bacterial activity and, consequently, an increase in pH. The most preferred conditions for the reproduction of *Salmonella* sp. are in the range of pH 6.0–7.5, for the remaining Enterobacteriaceae, including *E. coli*, this range is slightly wider, i.e. from 6.0 to 8.0 (Banwart, 1979). In this case, the crop's ability to resist pathogen invasion significantly decreases. This allows the colonization and stabilization of Enterobacteriaceae and *Salmonella* spp. in the gastrointestinal tract of the host (Fuller, 1977).

To conclude, the functionality of the crop will be dependent not only on the feeding system of animals and their behavior, but also on alimentary factors, as well as the presence of buffering substances.

Table 4. The crop pH value in selected avian species and poultry breeds

Breed	pH value	References
Broiler chickens		
ROSS 308	4.5–5.8	Józefiak et al. (2012) Svihus et al. (2013) Amerah et al. (2014)
COBB-Vantress male broiler	3.4–6.8	Ao et al. (2009) Fonseca et al. (2010) Alali et al. (2013)
COBB 500	4.3–5.1	Rubio-García et al. (2015) Józefiak et al. (2005)
Feed withdrawal broilers	5.3–6.5	Hinton et al. (2000 a) Hinton et al. (2000 b)
Laying hens		
Hy-Line® W-36	4.1–5.9	Gordon and Roland (1997) Moore et al. (2004)
Single Comb White Leghorn hens	4.1–6.0	Kubena et al. (2005) Woodward et al. (2005)
Medium-weight hens (Warren)	4.8–6.0	Mongin (1976)
Indigenous Venda chickens	4.9±0.210	Mabelebele et al. (2014)
Laying hens fed molt diet	4.6–6.2	Donalson et al. (2008)
Turkey	5.3–6.2	Farner (1942) Bennett et al. (2002) Giannenas et al. (2014)
Duck	4.8–5.1	Farner (1942)
Goose	4.1–5.0	Clemens et al. (1975)
Others:		
Pigeon	4.1–4.4 6.3	Farner (1942) Sturkie (1976 b)
Pheasant	5.6–6.0	Farner (1942)
Hoatzin	6.0–6.8	Grajal et al. (1989) Grajal (1995)

The crop microbiota composition and its properties

The environment of ingluvies is favorable to bacterial growth, it is maintained at a temperature of 40°C, as well as essentially anaerobic conditions (Bolton, 1965). The microbiota of bird crops develops together with age and the changing diet (Godoy-Vitorino et al., 2010). The majority of the microbiome inhabiting the crop are bacteria assigned to the *Lactobacillus* spp. (Table 5, 6) (Salminen et al., 1993; Mackie et al., 1997). The most frequently isolated representatives of this type include *Lactobacillus salivarius, L. fermentum, L. reuteri and L. acidophilus*. However, for *L. acidophilus*, due to reclassification two homologous groups have been separated (A and B) containing six species, i.e. *L. acidophilus* (A1), *L. crispatus* (A2), *L. amy-*

lovorus (A3), *L. gallinarum* (A4) *L. gasseri* (B1) and *L. johnsonii* (B2) (Lauer et al., 1980; Fujisawa et al., 1992; Jensen et al., 1993). Flora is very stable and permanently attached to the crop, as evidenced by the colonization of these bacteria in just 1 hour after hatching. At the same time, there were no effects of the diet and rearing conditions on the process of bacterial colonization in the first hours of life (Fuller, 2001). In addition, the crop is also inhabited by the representatives of *Bifidobacterium, Enterococcus,* and *Enterobacter* (Yeoman et al., 2012). Generally, bacteria in the crop are concentrated at a high level of about 10^9/g (Figure 3) (Oakley et al., 2014).

Table 5. Identification of bacterial isolates (n=300) from the crop of broiler chickens through partial sequencing the 16S RNA gene (Hilmi et al., 2007)

Species	Number of isolates	% of isolates	Number of isolates detected in 8 crop samples
L. acidophilus/L. johnsonii	5	1.7	4
L. crispatus	56	18.7	7
L. gallinarum	1	0.3	1
L. helveticus	1	0.3	1
L. pentosus	1	0.3	1
L. reuteri	99	33.0	7
L. salivarius	40	13.3	7
Lactobacillus sp. oral clone CX36	6	2.0	3
Lactobacillus sp. strain CLE-4	1	0.3	1
Lactobacillus spp.[a]	83	27.7	8
P. acidilactici	7	2.3	2
Total	300	100	**8**

[a] Bacteria of the genus *Lactobacillus* not assigned to species.

In the case of adult individuals of *Opisthocomus hoazin,* the microbial content of the crop closely resembles the rumen of ruminant animals and is dominated by Bacteroidetes, Firmicutes and Proteobacteria (Godoy-Vitorino et al., 2012). In addition, there are relatively high concentrations of Spirochaetes, Synergistes or Acidobacteria, and for the first time for vertebrates Aquificae, Coprothermobacteria, Thermodesulfobacteria and Caldithrix (Godoy-Vitorino et al., 2010). In the critically endangered (126 individuals) (IUCN, 2015), endemic for New Zealand, flightless and heaviest of parrots – kakapo (*Strigops habroptilus*)*,* bacterial flora of the crop is limited to Gammaproteobacteria and Firmicutes (Waite et al., 2012). Moreover, in 95% of cases, the microbiome of the gastrointestinal tract of this species belongs to the genera *Escherichia* and *Streptococcus* (Waite and Taylor, 2015). It is believed that this difference is caused by the specific behavior of food intake consisting in the "chewing" of plant material and then leaving out the fibrous fraction (Horrocks et al., 2008). However, not all parrots are characterized by such a little differentiated microbiota of the gastrointestinal tract. For the green-rumped parrotlet (*Forpus passerinus*) the crop is populated by gram-positive bacteria of the genera *Lactobacillus, Streptococcus, Enterococcus, Pediococcus* and *Propionibacterium,* and gram-negative, i.e. *Enterobacter, Klebsiella,* and *Escherichia coli* (Pacheco et al., 2004).

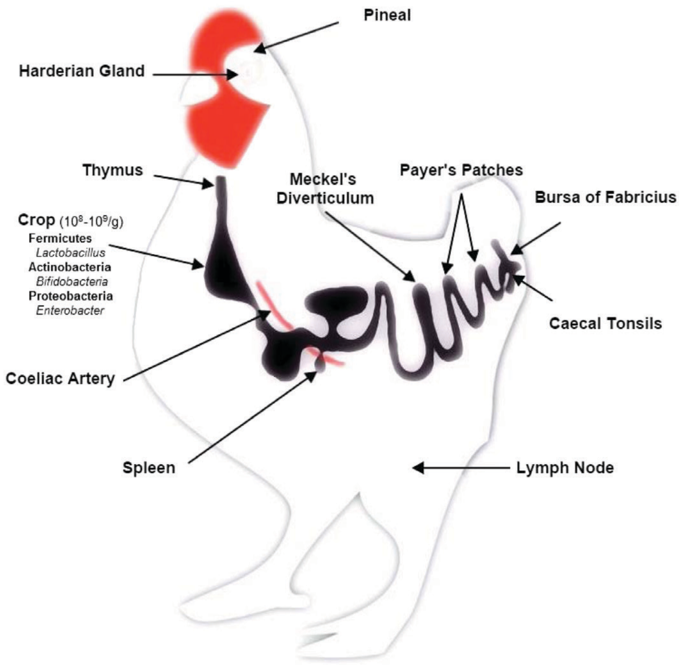

Figure 3. Primary and secondary immunological tissues, indicating the crop (based on Glick, 2000; Yeoman et al., 2012)

In the case of most birds, including chickens (*Gallus gallus* var. *domesticus*), helmeted guinea fowl (*Numidia meleagris*), great bustard (*Otis tarda*) and North African ostrich (*Struthio camelus*), the main fermentation of carbohydrates takes place in the caeca (Józefiak et al., 2004, 2005, 2007, 2010). Species collecting plant food and not having this organ had to develop alternative mechanisms. The green-rumped parrotlet (*Forpus passerinus*) uses the ability of microorganisms naturally present in the crop (*Lactobacillus* and *Streptococcus*) for the production of amylase which decomposes starch into maltose, maltotriose and glucose (Champ et al., 1983; Kotarski et al., 1992). This process greatly simplifies the distribution of carbohydrates in the subsequent sections of the digestive tract. In addition, glucose may simultaneously be absorbed by the mucous membrane of the crop or used as a substrate for the production of volatile fatty acids (*E. coli, Klebsiella* spp., and *Enterobacter*), which constitute one of the sources of energy for the bird and maintains an acidic environment (Soedarmo et al., 1961; Stevens and Hume, 2004). Due to the hard-digestible diet of the parrotlet, the retention time of the content will play an important role in increasing the efficiency of the microbiota. Moreover, due to the intake of feed poor in protein, the flora of the crop takes part in increasing the level of this nutrient in the diet (Pacheco, 2000, Ph.D. dissertation).

Table 6. Identification of bacterial isolates from the crop of laying hens using the fragments V6-V8 and V2-V3 of the 16S rRNA gene sequence (Janczyk et al., 2009)

V6-V8		V2-V3	
Species	No.	Species	No.
Acinetobacter sp.	EF111248	*Lactobacillus salivarius*	AJ508721
Aeromonas hydrophila ssp. *hydrophila*	AY422755	*Lactobacillus vaccinosterus*	DSM 20634; AJ417735
Bacillus subtilis ssp. *subtilis*	AJ288302	*Lactobacillus suebicus*	DSM 5008; AJ417734
Lactobacillus amylovorus	AJ241720	*Lactobacillus paracasei*	MBRG 1.4; AJ508362
Lactobacillus crispatus	EF439685	*Lactobacillus mucosae*	AJ508724
Lactobacillus gasseri	AY339167	*Lactobacillus jensenii*	5L08; DQ317562
Lactobacillus helveticus	FJ749687	*Lactobacillus ingluviei*	JCM 11423; AB289169
Lactobacillus plantarum	FJ604851	*Lactobacillus iners*	AM117145
Lactobacillus salivarius	DSM 20555; DQ901733	*Lactobacillus gasseri*	BJ H36-3b; AY339179
Pseudomonas putida	KCTC1639; AY750859	*Lactobacillus gallinarum*	JCM 1036; AB289121
Staphylococcus delphini	EU157199	*L. gallinarum*	ATCC 33199; X97898
Staphylococcus saprophyticus ssp. *saprophyticus*	EU816968	*Lactobacillus frumenti*	JCM11122; AB289119
Uncultured bacterium	AY667924	*Lactobacillus fermentum*	AJ617543
Uncultured bacterium	DGGE gel band 10; AY509585	*Lactobacillus delbrueckii* ssp. *bulgaricus*	ATCC 11842; AJ414693
		Lactobacillus crispatus	180; AJ421225
		Lactobacillus casei	AJ507644

The crop as the first barrier to the colonization of microbiota is particularly important in terms of integrity and homeostasis of the microbiome of further sections of the gastrointestinal tract. Bayer et al. (1974) due to the structure of the mucosa and biodiversity of the microbiome, compares the crop of chickens to the rumen. Microbiota of the digestive tract and crop are divided into two groups in terms of their environmental niche: bacteria residing in its lumen, and bacteria closely associated with the mucosa (Dubos et al., 1965). The close link between endogenous microorganisms and the host causes it to have a significant impact on bird's metabolism and health. This thesis is confirmed by the fact that bacteria, e.g. *Escherichia coli*, to cause pathological conditions, must first bind to the host's epithelial mucosa (Fuller and Brooker, 1974). The same situation was observed for *Vibrio cholerae,* which even in substantial numbers in the intestinal lumen did not cause disease symptoms (Freter, 1969).

The concentrations and biodiversity of different microbiota populations are significantly correlated with filling the crop. Fasting chickens before being transported to the slaughterhouse may contribute to the growth of bacteria of the genus *Salmonella* in the crop and caeca (Hargis et al., 1995; Ramirez et al., 1997). Subsequently, during technological processes there is a high probability of contamination of chicken carcasses (Hinton et al., 2000 b). The natural defense of the host against the colonization of Enterobacteriaceae is competitive exclusion by populations of probiotic commensal bacteria, as well as decreasing the pH by the increase in the activity of microbial fermentation (Hinton et al., 1990). However, fasting may cause physical, chemical and microbiological changes in the crop of broiler chickens, which will reduce the natural resistance of birds to the potentially pathogenic bacteria. However, it should be emphasized that some representatives of Enterobacteriaceae (e.g. *E. coli)* are an integral part of the microbiota of the digestive system of animals and only in certain situations, when homeostasis wavers, negative effects on health status of their presence occur.

It has been reported many times that both gram-positive and gram-negative organisms are capable of secreting bacteriocins (Józefiak and Sip, 2013). Bacteriocins are ribosome-synthesized peptides not exceeding the molecular weight of a dozen kDa, which are characterized by antimicrobial properties (Stern et al., 2006). Jack et al. (1995) and Montville et al. (1995) classify microorganisms naturally present in the crop, i.e. *Lactobacillus, Bifidobacterium, Enterococcus,* and *Enterobacter* to bacteriocinogenic bacteria. This activity effectively limits potentially pathogenic strains in the crop of the bird host. Stern et al. (2006) observed that bacteriocin produced by *Lactobacillus salivarius* (NRRL B-30514) reduces the number of four strains of *Campylobacter jejuni.* It has been shown that Bifidocin B (*Bifidobacterium bifidum*) may exhibit antagonistic activity towards *Listeria, Enterococcus, Leuconostoc* and *Pediococcus* (Yildirim and Johnson, 1998). Bacteriocinogenic activity of *Enterococcus faecium* results in the inhibition of growth of *Listeria monocytogenes* (Strompfova and Laukova, 2007). Lauková et al. (1993) observed that Enterocin A (*E. faecium*) effectively limits the concentration of *Salmonella dusseldorf* SA31 in the gastrointestinal tract of Japanese quail.

The crop is the most important GIT segment for bacteriocins activity due to the specific environment and lack of endogenous proteolytic enzymes such as pepsin or trypsin (Józefiak et al., 2013). However, bacteriocins are not the only antimicrobial factors present in this section of the gastrointestinal tract. *Lactobacillus reuteri,* by far the most numerous bacteria of the genus *Lactobacillus* in the crop, i.e. 33% of the total, due to anaerobic fermentation of glycerol, is able to produce reuterin (Axelsson et al., 1989). Reuterin is resistant to degradation with the use of endogenous proteolytic and lipolytic enzymes; its activity remains in a wide pH range and it dissolves in water (El-Ziney et al., 1999). Its biocidal mode of action includes the reduction of gram-positive and gram-negative bacteria, yeasts, molds, protozoa and viruses (Axelsson et al., 1989; Casas and Dobrogosz, 2000).

In the available literature there is information concerning the biocidal effects of *β*-defensin on *Salmonella enterica* serovar typhimurium and *Clostridium perfringens.* The latter is responsible for the pathogenesis of necrotic enteritis in poultry annually generating the greatest financial losses globally (2 billion USD) (Van Immerseel et al., 2009). In the case of chickens gallinacin-6 (*AvBD9*) plays an important role in the bird's innate immunity to the pathogens of the gastrointestinal tract (van Dijk et al., 2007). The research of the team Hong et al. (2012) suggests that the crop can perform the function of local expression of *β*-defensins (*AvBD1, 7, 9*) towards *Eimeria maxima* and *C. perfringens.* However, further research is needed for a detailed understanding of the host-pathogen relationship in this aspect.

The immunological function of the crop

The composition of the specific immune system of birds includes primary lymphoid tissues, i.e. the thymus and bursa of Fabricius. The secondary, peripheral tissues include, among others, the spleen (Gallego et al., 1993), Harderian gland (Olah et al., 1996), esophageal and glandular stomach tonsils (Matsumoto and Hashimoto, 2000), Peyer's patches (Befus et al., 1980), Meckel's diverticulum (Olah et al., 1984) and lymphoid follicles in the cecum (Olah and Glick, 1979), as well as lymphoid tissues of the gastrointestinal tract, i.e. GALT (gut-associated lymphoid tissue) (Glick and Olah, 1981) and BALT (bronchial-associated lymphoid tissue) (Figure 3) (Bienenstock and McDermott, 2005). Furthermore, studies by Holt et al. (2006) clearly indicate the possibility of immunological response of the crop in the presence of *Salmonella enterica* serovar Enteritidis (strain SE89-8312). The experiment was carried out with White Leghorn line raised gnobiotically (specific pathogen free). During infection of chickens (1 ml *per os*, 9×10^6 *S. enteritidis*), an increase of IgA specific for the used pathogen in the crop was observed. At the same time, there was the presence of lymphoid aggregates within the lamina propria of mucous membrane of the crop (Holt et al., 2002). In many cases it was shown that immunoglobulins A have an inhibiting effect towards bacteria present in the gastrointestinal tract of animals (Michetti et al., 1992; Iankov et al., 2002). Moreover, they are defined as the first line of immunological defense by limiting the adhesion of pathogens to the mucosal epithelium and its penetration (Michetti et al., 1994). In the lymphoid tissue of the crop, plasma cells and lymphocytes-B were also isolated. So, the local humoral immunity located in the crop may constitute a specific diagnostic indicator used to detect disease of the gastrointestinal tract of chickens (Seo et al., 2003). Simultaneously, it is a cheap method, non-invasive and simple in execution (Vaughn, 2007, Ph.D. dissertation).

Conclusions

In conclusion, feed storage is a basic and direct role of the crop. However, from the point of view of productivity and the health of birds, the most important functions of this organ are: feed moistening and creating a favorable environment for the development of probiotic microbiota. Indirectly, the crop is involved in the suppression of potentially pathogenic bacteria and reduces contamination of further sections of the gastrointestinal tract by substances with antimicrobial properties and those regulating the digesta pH. However, the composition of the microbial populations of the crop may change under the influence of dietary factors (Knarreborg et al., 2002; Hammons et al., 2010), age (Hilmi et al., 2007), antibiotics (Knarreborg et al., 2002) and other feed additives (Józefiak et al., 2011; Józefiak et al., 2012; Ptak et al., 2015) supplementation or infection (Kimura et al., 1976). Therefore, it is necessary to better understand the different processes occurring in the crop in order to use it as efficiently in poultry production.

Acknowledgments

The authors thank Prof. Birger Svihus for his advice and review of the paper.

References

Ademark P., Larsson M., Tjerneld F., Stålbrand H. (2001). Multiple α-galactosidases from *Aspergillus niger*: purification, characterization and substrate specificities. Enzyme Microb. Tech., 29: 441–448.

Aguilar R.F., Yoshicedo J.N., Parish C.N. (2012). Ingluviotomy tube placement for lead-induced crop stasis in the California condor (*Gymnogyps californianus*). J. Avian Med. Surg., 26: 176–181.

Alali W., Hofacre C., Mathis G., Faltys G. (2013). Effect of essential oil compound on shedding and colonization of *Salmonella enterica* serovar Heidelberg in broilers. Poultry Sci., 92: 836–841.

Amerah A., Plumstead P., Barnard L., Kumar A. (2014). Effect of calcium level and phytase addition on ileal phytate degradation and amino acid digestibility of broilers fed corn-based diets. Poultry Sci., 93: 906–915.

Ao T., Cantor A., Pescatore A., Pierce J. (2008). *In vitro* evaluation of feed-grade enzyme activity at pH levels simulating various parts of the avian digestive tract. Anim. Feed Sci. Tech., 140: 462–468.

Ao T., Cantor A., Pescatore A., Ford M., Pierce J., Dawson K. (2009). Effect of enzyme supplementation and acidification of diets on nutrient digestibility and growth performance of broiler chicks. Poultry Sci., 88: 111–117.

Axelsson L., Chung T., Dobrogosz W., Lindgren S. (1989). Production of a broad spectrum antimicrobial substance by *Lactobacillus reuteri*. Microb. Ecol. Health D., 2: 131–136.

Baas T., Thacker P. (1996). Impact of gastric pH on dietary enzyme activity and survivability in swine fed β-glucanase supplemented diets. Can. J. Anim. Sci., 76: 245–252.

Backues K.A. (2015). Anseriformes. In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 116–126.

Barash I., Nitsan Z., Nir I. (1992). Metabolic and behavioural adaptation of light-bodied chicks to meal feeding. Brit. Poultry Sci., 33: 271–278.
Bayer R., Bird F., Musgrave S., Chawan C. (1974). A simple method of preparation of gastro-inestinal tract tissues for scanning electron microscopy. J. Anim. Sci., 38: 354–356.
Beauchemin K., Colombatto D., Morgavi D., Yang W. (2003). Use of exogenous fibrolytic enzymes to improve feed utilization by ruminants. J. Anim. Sci., 81: E37–E47.
Befus A.D., Johnston N., Leslie G., Bienenstock J. (1980). Gut-associated lymphoid tissue in the chicken. I. Morphology, ontogeny, and some functional characteristics of Peyer's patches. J. Immunol., 125: 2626–2632.
Bennett C., Classen H., Schwean K., Riddell C. (2002). Influence of whole barley and grit on live performance and health of turkey toms. Poultry Sci., 81: 1850–1855.
Bienenstock J., McDermott M.R. (2005). Bronchus- and nasal-associated lymphoid tissues. Immunol. Rev., 206: 22–31.
Boa-Amponsem K., Dunnington E., Siegel P. (1991). Genotype, feeding regimen, and diet interactions in meat chickens. 2. Feeding behavior. Poultry Sci., 70: 689–696.
Bolton W. (1965). Digestion in the crop of the fowl. Brit. Poultry Sci., 6: 97–102.
Bolton W., Dewar W. (1965). The digestibility of acetic, propionic and butyric acids by the fowl. Brit. Poultry Sci., 6: 103–105.
Buyse J., Adelsohn D., Decuypere E., Scanes C. (1993). Diurnal-nocturnal changes in food intake, gut storage of ingesta, food transit time and metabolism in growing broiler chickens: A model for temporal control of energy balance. Brit. Poultry Sci., 34: 699–709.
Campbell B., Lack E. (2011). A dictionary of birds. Poyser Monographs, UK, pp. 120.
Casas I.A., Dobrogosz W.J. (2000). Validation of the probiotic concept: *Lactobacillus reuteri* confers broad-spectrum protection against disease in humans and animals. Microb. Ecol. Health D., 12: 247–285.
Champ M., Szylit O., Raibaud P., Aïut-Abdelkader N. (1983). Amylase production by three *Lactobacillus* strains isolated from chicken crop. J. Appl. Bacteriol., 55: 487–493.
Charles J. (1995). Organochlorine toxicity in tawny frogmouths. Proc. Australian Committee of the Association of Avian Veterinarians, Dubbo, Australia, pp. 135–141.
Chikilian M., de Speroni N.B. (1996). Comparative study of the digestive system of three species of Tinamou. I. *Crypturellus tataupa*, *Nothoprocta cinerascens*, and *Nothura maculosa* (Aves: Tinamidae). J. Morphol., 228: 77–88.
Clark H.L. (1918). Notes on the anatomy of the Cuban Trogon. Auk, 35: 286–289.
Clemens E., Stevens C., Southworth M. (1975). Sites of organic acid production and pattern of digesta movement in the gastrointestinal tract of geese. J. Nutr., 105: 1341–1350.
Coughlan M.P. (1985). The properties of fungal and bacterial cellulases with comment on their production and application. Biotechnol. Genet. Eng., 3: 39–110.
Davies W. (1939). The composition of the crop milk of pigeons. Biochem. J., 33: 898.
Dedič S. (1930). Über physiologische Formierung und Motiliät der Verdauungsorgane bei Habichten (*Aster palumbarius*). Fortschr. Geb. Roentgenstr., 43: 367–371.
Deeming D.C. (1999). The ostrich: biology, production and health. Wallingford, UK, CABI Publishing University Press, pp. 39–42.
Del Hoyo J., Elliott A., Sargatal J. (2002). Handbook of the birds of the world, vol. 7. Lync Edicions, Barcelona, Spain.
Del Rio C.M., Schondube J.E., McWhorter T.J., Herrera L.G. (2001). Intake responses in nectar feeding birds: digestive and metabolic causes, osmoregulatory consequences, and coevolutionary effects. Am. Zool., 41: 902–915.
Denbow D. (2000). Gastrointestinal anatomy and physiology. In: Sturkie's Avian Physiology, 5th ed., Whittow G.C. (ed.). San Diego, Academic Press, pp. 299–325.
Denbow D.M. (1994). Peripheral regulation of food intake in poultry. J. Nutr., 124, Suppl. 8: 1349S–1354S.
Denstadli V., Vestre R., Svihus B., Skrede A., Storebakken T. (2006). Phytate degradation in a mixture of ground wheat and ground defatted soybeans during feed processing: Effects of temperature, moisture level, and retention time in small- and medium-scale incubation systems. J. Agr. Food Chem., 54: 5887–5893.

Desmeth M., Vandeputte-Poma J. (1980). Lipid composition of pigeon cropmilk – I. Total lipids and lipid classes. Com. Biochem. Phys. B., 66: 129–133.
Donalson L., McReynolds J., Kim W., Chalova V., Woodward C., Kubena L., Nisbet D., Ricke S. (2008). The influence of a fructooligosaccharide prebiotic combined with alfalfa molt diets on the gastrointestinal tract fermentation, *Salmonella enteritidis* infection, and intestinal shedding in laying hens. Poultry Sci., 87: 1253–1262.
Doneley B. (2010). The digestive tract. In: Avian medicine and surgery in practice: Companion and aviary birds. Manson Publishing Ltd., London, UK, pp. 16–19.
Dorrestein G.M. (2009). Passerines and exotic softbills. In: Handbook of avian medicine, Tully T.N., Dorrestein G.M., Jones A.K. (eds), Elsevier/Saunders, pp.145–179.
Dubos R., Schaedler R.W., Costello R., Hoet P. (1965). Indigenous, normal, and autochthonous flora of the gastrointestinal tract. J. Exp. Med., 122: 67–76.
Duke G. (1986). Alimentary canal: secretion and digestion, special digestive functions, and absorption. In: Avian Physiology, Sturkie P.D. (ed.). Springer-Verlag, New York, pp. 289–302.
Duke G.E. (1989). Avian gastrointestinal motor function. In: Handbook of physiology – the gastrointestinal system, Wood J.T. (ed.). Oxford University Press, New York, USA, pp. 1283–1300.
Duke G.E. (1997). Gastrointestinal physiology and nutrition in wild birds. Proc. Nutr. Soc., 56: 1049–1056.
Eber G. (1956). Vergleichende Untersuchungen über die Ernährung einiger Finkenvögel. Biol. Abh., 13: 1–60.
El-Ziney M., Van Den Tempel T., Debevere J., Jakobsen M. (1999). Application of reuterin produced by *Lactobacillus reuteri* 12002 for meat decontamination and preservation. J. Food Protect., 62: 257–261.
Farner D.S. (1942). The hydrogen ion concentration in avian digestive tracts. Poultry Sci., 21: 445–450.
Farner D.S. (1960). Digestion and the digestive system. In: Biology and comparative physiology of birds, Vol. 1, Marschall H.J. (ed.). Academic Press, New York, USA, pp. 411–467.
Fisher H., Weiss H.S. (1956). Feed consumption in relation to dietary bulk and energy level: The effect of surgical removal of the crop. Poultry Sci., 35: 418–423.
Fonseca B.B., Beletti M.E., Silva M.S.d., Silva P.L.D., Duarte I.N., Rossi D.A. (2010). Microbiota of the cecum, ileum morphometry, pH of the crop and performance of broiler chickens supplemented with probiotics. Rev. Bras. Zootec., 39: 1756–1760.
Frelinger J.A. (1971). Maternally derived transferrin in pigeon squabs. Science, 171: 1260–1261.
Freter R. (1969). Studies of mechanism of action of intestinal antibody in experimental cholera. Tex. Rep. Biol. Med., 299.
Fujisawa T., Benno Y., Yaeshima T., Mitsuoka T. (1992). Taxonomic study of the *Lactobacillus acidophilus* group, with recognition of *Lactobacillus gallinarum* sp. nov. and *Lactobacillus johnsonii* sp. nov. and synonymy of *Lactobacillus acidophilus* group A3 (Johnson et al., 1980) with the type strain of *Lactobacillus amylovorus* (Nakamura, 1981). Int. J. Syst. Bacteriol., 42: 487–491.
Fuller R. (1977). The importance of lactobacilli in maintaining normal microbial balance in the crop. Brit. Poultry Sci., 18: 85–94.
Fuller R. (2001). The chicken gut microflora and probiotic supplements. J. Poultry Sci., 38: 189–196.
Fuller R., Brooker B. (1974). Lactobacilli which attach to the crop epithelium of the fowl. Am. J. Cli. Nutr., 27: 1305–1312.
Gallego M., Olah I., Del Cacho E., Glick B. (1993). Anti-S-100 antibody recognizes ellipsoid-associated cells and other dendritic cells in the chicken spleen. Dev. Comp. Immunol., 17: 77–83.
Gelis S. (2006). Evaluating and treating the gastrointestinal system. In: Clinical avian medicine, vol. 1, Harrison G.J., Lightfoot T.L. (eds). Palm Beach, Spix Publishing Inc., pp. 411–440.
Giannenas I., Papaneophytou C., Tsalie E., Pappas I., Triantafillou E., Tontis D., Kontopidis G. (2014). Dietary supplementation of benzoic acid and essential oil compounds affects buffering capacity of the feeds, performance of turkey poults and their antioxidant status, pH in the digestive tract, intestinal microbiota and morphology. Asian Australas. J. Anim. Sci., 27: 225–236.
Gillespie M.J., Stanley D., Chen H., Donald J.A., Nicholas K.R., Moore R.J.,

Crowley T.M. (2012). Functional similarities between pigeon 'milk' and mammalian milk: induction of immune gene expression and modification of the microbiota. PLoS ONE, 7: e48363.

Glick B. (2000). Immunophysiology. In: Sturkie's Avian Physiology, Whittow G.C. (ed.). Academic Press, San Diego, pp. 657–670.

Glick B., Olah I. (1981). Gut-associated-lymphoid tissue of the chicken. Scan. Electron Micros., 3: 99–108.

Godoy-Vitorino F., Ley R.E., Gao Z., Pei Z., Ortiz-Zuazaga H., Pericchi L.R., Garcia-Amado M.A., Michelangeli F., Blaser M.J., Gordon J.I. (2008). Bacterial community in the crop of the hoatzin, a neotropical folivorous flying bird. Appl. Environ. Microb., 74: 5905–5912.

Godoy-Vitorino F., Goldfarb K.C., Brodie E.L., Garcia-Amado M.A., Michelangeli F., Domínguez-Bello M.G. (2010). Developmental microbial ecology of the crop of the folivorous hoatzin. ISME J., 4: 611–620.

Godoy-Vitorino F., Goldfarb K.C., Karaoz U., Leal S., Garcia-Amado M.A., Hugenholtz P., Tringe S.G., Brodie E.L., Dominguez-Bello M.G. (2012). Comparative analyses of foregut and hindgut bacterial communities in hoatzins and cows. ISME J., 6: 531–541.

Gordon R., Roland D. (1997). The influence of environmental temperature on *in vivo* limestone solubilization, feed passage rate, and gastrointestinal pH in laying hens. Poultry Sci., 76: 683–688.

Goudswaard J., van der Donk J., van der Gaag I., Noordzij A. (1979). Peculiar IgA transfer in the pigeon from mother to squab. Dev. Comp. Immunol., 3: 307–319.

Grajal A. (1995). Structure and function of the digestive tract of the hoatzin (*Opisthocomus hoazin*): a folivorous bird with foregut fermentation. Auk, 112: 20–28.

Grajal A., Strahl S.D., Parra R., Dominguez M.G., Neher A. (1989). Foregut fermentation in the hoatzin, a neotropical leaf-eating bird. Science, 245: 1236–1238.

Greiner R., Konietzny U. (2011). Phytases: Biochemistry, enzymology and characteristics relevant to animal feed use. In: Enzymes in farm animal nutrition, Bedford M.R., Partridge G.G. (eds). CAB Intl. Publishing, Oxfordshire, UK, pp. 96–128.

Groebbels F. (1932). Der Vogel: Atmungswelt und Nahrungswelt. Berlin: Verlag von Gebruder, Borntraeger.

Guareschi C. (1936). Necessita di fattori alimentari materni per l'accrescimento del giovanissimi colombi. Boll. Soc. Ital. Biol. Sper., 11: 411–412.

Hammons S., Oh P.L., Martínez I., Clark K., Schlegel V.L., Sitorius E., Scheideler S.E., Walter J. (2010). A small variation in diet influences the *Lactobacillus* strain composition in the crop of broiler chickens. Syst. Appl. Microbiol., 33: 275–281.

Hargis B., Caldwell D., Brewer R., Corrier D., DeLoach J. (1995). Evaluation of the chicken crop as a source of *Salmonella* contamination for broiler carcasses. Poultry Sci., 74: 1548–1552.

Hegde S. (1973). Composition of pigeon milk and its effect on growth in chicks. Indian J. Exp. Biol., 11: 238–239.

Hendriks W., O'Conner S., Thomas D., Rutherfurd S., Taylor G., Guilford W. (2000). Nutrient composition of the crop contents of growing and adult grey-faced petrels (*Pterodroma macroptera*): A preliminary investigation. J. Roy. Soc. New Zeal., 30: 105–111.

Henry K., MacDonald A., Magee H. (1933). Observations on the functions of the alimentary canal in fowls. J. Exp. Biol., 10: 153–171.

Herpol C., van Grembergen G. (1967). La signification du pH dans le tube digestif de *Gallus domesticus*. Ann. Biol. Anim. Bioch., 7: 33–38.

Hilmi H.T.A., Surakka A., Apajalahti J., Saris P.E. (2007). Identification of the most abundant *Lactobacillus* species in the crop of 1- and 5-week-old broiler chickens. Appl. Environ. Microb., 73: 7867–7873.

Hinton A., Buhr R., Ingram K. (2000 a). Physical, chemical, and microbiological changes in the crop of broiler chickens subjected to incremental feed withdrawal. Poultry Sci., 79: 212–218.

Hinton A., Buhr R., Ingram K., (2000 b). Reduction of *Salmonella* in the crop of broiler chickens subjected to feed withdrawal. Poultry Sci., 79: 1566–1570.

Hinton Jr. A., Corrier D.E., Spates G.E., Norman J.O., Ziprin R.L., Beier R.C., De-

Loach J.R. (1990). Biological control of *Salmonella typhimurium* in young chickens. Avian Dis., 34: 626–633.

Hodgkiss J.P. (1981). Distension-sensitive receptors in the crop of the domestic fowl (*Gallus domesticus*). Comp. Biochem. Phys. A., 70: 73–78.

Holt P.S., Vaughn L.E., Gast R.K., Stone H.D. (2002). Development of a lavage procedure to collect crop secretions from live chickens for studying crop immunity. Avian Pathol., 31: 589–592.

Holt P.S., Vaughn L.E., Moore R.W., Gast R.K. (2006). Comparison of *Salmonella enterica* serovar Enteritidis levels in crops of fed or fasted infected hens. Avian Dis., 50: 425–429.

Hong Y.H., Song W., Lee S., Lillehoj H. (2012). Differential gene expression profiles of *β*-defensins in the crop, intestine, and spleen using a necrotic enteritis model in 2 commercial broiler chicken lines. Poultry Sci., 91: 1081–1088.

Horrocks M., Salter J., Braggins J., Nichol S., Moorhouse R., Elliott G. (2008). Plant microfossil analysis of coprolites of the critically endangered kakapo (*Strigops habroptilus*) parrot from New Zealand. Rev. Palaeobot. Palyno., 149: 229–245.

Houston D., Copsey J. (1994). Bone digestion and intestinal morphology of the Bearded Vulture. J. Raptor Res., 28: 73–78.

Hunter J. (1840). Observations on certain parts of the animal oeconomy: Inclusive of several papers from the philosophical transactions. Etc. New Orleans: Haswell, Barrington, and Haswell.

Iankov I.D., Petrov D.P., Mladenov I.V., Haralambieva I.H., Mitov I.G. (2002). Lipopolysaccharide-specific but not anti-flagellar immunoglobulin A monoclonal antibodies prevent *Salmonella enterica* serotype Enteritidis invasion and replication within HEp-2 cell monolayers. Infect. Immun., 70: 1615–1618.

Irving L., West G.C., Peyton L.J. (1967). Winter feeding program of Alaska willow ptarmigan shown by crop contents. Condor, 69: 69–77.

Jack R.W., Tagg J.R., Ray B. (1995). Bacteriocins of gram-positive bacteria. Microbiol. Rev., 59: 171–200.

Jackson S., Duke G.E. (1995). Intestine fullness influences feeding behaviour and crop filling in the domestic turkey. Physiol. Behav., 58: 1027–1034.

Janczyk P., Halle B., Souffrant W. (2009). Microbial community composition of the crop and ceca contents of laying hens fed diets supplemented with *Chlorella vulgaris*. Poultry Sci., 88: 2324–2332.

Jensen M.A., Webster J.A., Straus N. (1993). Rapid identification of bacteria on the basis of polymerase chain reaction-amplified ribosomal DNA spacer polymorphisms. App. Environ. Microb., 59: 945–952.

Johnston G.B. (1999). Comparative anatomy of Musophagidae (Turacos). AFA Watchbird, 26: 43–45.

Józefiak D., Sip A. (2013). Bacteriocins in poultry nutrition – a review. Ann. Anim. Sci., 13: 449–462.

Józefiak D., Rutkowski A., Martin S. (2004). Carbohydrate fermentation in the avian ceca: a review. Anim. Feed Sci. Tech., 113: 1–15.

Józefiak D., Kaczmarek S., Rutkowski A., Józefiak A., Jensen B., Engberg R. (2005). Fermentation in broiler chicken gastrointestinal tract as affected by high dietary inclusion of barley and beta-glucanase supplementation. J. Anim. Feed Sci., 14: 695.

Józefiak D., Rutkowski A., Jensen B.B., Engberg R.M. (2007). Effects of dietary inclusion of triticale, rye and wheat and xylanase supplementation on growth performance of broiler chickens and fermentation in the gastrointestinal tract. Anim. Feed Sci. Tech., 132: 79–93.

Józefiak D., Kaczmarek S., Rutkowski A. (2008). A note on the effects of selected prebiotics on the performance and ileal microbiota of broiler chickens. J. Anim. Feed Sci., 17: 392–397.

Józefiak D., Kaczmarek S., Rutkowski A. (2010). The effects of benzoic acid supplementation on the performance of broiler chickens. J. Anim. Physiol. An. N., 94: 29–34.

Józefiak D., Sip A., Rawski M., Rutkowski A., Kaczmarek S., Hojberg O., Jensen B.B., Engberg R.M. (2011). Dietary divercin modifies gastrointestinal microbiota and improves growth performance in broiler chickens. Brit. Poultry Sci., 52: 492–499.

Józefiak D., Sip A., Rutkowski A., Rawski M., Kaczmarek S., Wołuń-Cholewa M., Engberg R.M., Højberg O. (2012). Lyophilized *Carnobacterium divergens* AS7 bacteriocin preparation improves performance of broiler chickens challenged with *Clostridium perfringens*. Poultry Sci., 91: 1899–1907.

Józefiak D., Kierończyk B., Juśkiewicz J., Zduńczyk Z., Rawski M., Długosz J., Sip A., Højberg O. (2013). Dietary nisin modulates the gastrointestinal microbial ecology and enhances growth performance of the broiler chickens. PloS one, 8: e85347.

Józefiak D., Kierończyk B., Rawski M., Hejdysz M., Rutkowski A., Engberg R.M., Højberg O. (2014). *Clostridium perfringens* challenge and dietary fat type affect broiler chicken performance and fermentation in the gastrointestinal tract. Animal., 8: 1–11.

Karasow W.H., Phan D., Diamond J.M., Carpenter F.L. (1986). Food passage and intestinal nutrient absorption in hummingbirds. Auk, 103: 453–464.

Kimura N., Mimura F., Nishida S., Kobayashi A., Mitsuoka T. (1976). Studies on the relationship between intestinal flora and cecal coccidiosis in chicken. Poultry Sci., 55: 1375–1383.

King A.S., McLelland J. (1984). Birds. Their Structure and Function. London, Baillière-Tindall, pp. 84–109.

Kirk Baer C. (1999). Comparative nutrition and feeding considerations of young Columbidae. In: Zoo and wild animal medicine – Current therapy 4, Fowler M.E., Miller R.E. (eds). W.S. Saunders, Philadelphia, USA, pp. 269–277.

Klasing K.C. (1999). Avian gastrointestinal anatomy and physiology. Semin. Avian Exotic Pet Med., 8: 42–50.

Knarreborg A., Simon M.A., Engberg R.M., Jensen B.B., Tannock G.W. (2002). Effects of dietary fat source and subtherapeutic levels of antibiotic on the bacterial community in the ileum of broiler chickens at various ages. Appl. Environ. Microb., 68: 5918–5924.

Kobryń H., Kobryńczuk F. (2004). Apparatus digestorius. In: Animal anatomy, vol. 3. (in Polish). Scientific Publishing Company PWN, Warsaw, pp. 367–380.

Kotarski S.F., Waniska R.D., Thurn K.K. (1992). Starch hydrolysis by the ruminal microflora. J. Nutr., 122: 178–190.

Kubena L., Byrd J., Moore R., Ricke S., Nisbet D. (2005). Effects of drinking water treatment on susceptibility of laying hens to *Salmonella enteritidis* during forced molt. Poultry Sci., 84: 204–211.

Lan G.Q., Abdullah N., Jalaludin S., Ho Y.W. (2010). *In vitro* and *in vivo* enzymatic dephosphorylation of phytate in maize–soya bean meal diets for broiler chickens by phytase of *Mitsuokella jalaludinii*. Anim. Feed Sci. Tech., 158: 155–164.

Lang E.M. (1963). Flamingoes raise their young on a liquid containing blood. Experientia, 19: 532–533.

Langenfeld M.S. (1992). Systema digestorium, *s. apparatus digestorius.* In: Chicken anatomy (in Polish). Scientific Publishing Company PWN, pp. 91–117.

Lauer E., Helming C., Kandler O. (1980). Heterogeneity of the species *Lactobacillus acidophilus* (Moro) Hansen and Moquot as revealed by biochemical characteristics and DNA-DNA hybridisation. Zbl. Bakt. Mik. Hyg. I. C., 1: 150–168.

Lauková A., Mareková M., Javorský P. (1993). Detection and antimicrobial spectrum of a bacteriocin-like substance produced by *Enterococcus faecium* CCM4231. Lett. Appl. Microbiol., 16: 257–260.

Leasure E., Foltz V. (1940). Experiments on absorption in the crop of chickens. J. Am. Vet. Med. Assoc., 96: 236.

Leger J.S., Vince M., Jennings J., McKerney E., Nilson E. (2012). Toucan hand feeding and nestling growth. Vet. Clin. N. Am-Exotic., 15: 183–193.

Liebert F., Wecke C., Schoner F. (1993). Phytase activities in different gut contents of chickens as dependent on levels of phosphorus and phytase supplementations. Proc. 1st European Symposium Enzymes in Animal Nutrition, pp. 202–205.

López-Calleja M.V., Bozinovic F. (2000). Energetics and nutritional ecology of small herbivorous birds. Rev. Chil. Hist. Nat., 73: 411–420.

Lumeij J.T. (1994). Gastroenterology. In: Avian medicine principles and application, Ritchie B.W., Harrison G.J., Harrison L.R. (eds). Wingers, Lake Worth, FL, pp. 482–521.

Mabelebele M., Alabi O., Ngambi J., Norris D., Ginindza M. (2014). Comparison of gastrointestinal tracts and pH values of digestive organs of Ross 308 broiler and indigenous venda chickens fed the same diet. Asian J. Anim. Vet. Adv., 9: 71–76.

Mackie R., White B., Isaacson R. (1997). Gastrointestinal microbes and host interactions. In: Gastrointestinal microbiology, vol. 2. Chapman & Hall, New York, USA.
Madsen V., Valkiūnas G., Iezhova T.A., Mercade C., Sanchez M., Osorno J.L. (2007). Testosterone levels and gular pouch coloration in courting magnificent frigatebird (*Fregata magnificens*): variation with age-class, visited status and blood parasite infection. Horm. Behav., 51: 156–163.
Matsumoto R., Hashimoto Y. (2000). Distribution and developmental change of lymphoid tissues in the chicken proventriculus. J. Vet. Med. Sci., 62: 161–167.
May J., Deaton J. (1989). Digestive tract clearance of broilers cooped or deprived of water. Poultry Sci., 68: 627–630.
Mayr G. (2010). Phylogenetic relationships of the paraphyletic 'caprimulgiform' birds (nightjars and allies). J. Zool. Syst. Evol. Res., 48: 126–137.
McCain S. (2015). Charadriiformes. In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 112–115.
McLelland J. (1979). Digestive system. In: Form and function in birds, vol. 1, King A.S., McLelland J. (eds). Academic Press, London, pp. 69–181.
McLelland J. (1990). Digestive system. In: A colour atlas of avian anatomy. Wolfe Medical Publications Ltd., London, pp. 47–65.
McLelland J. (1993). Apparatus digestorius [systema alimentarium]. In: Handbook of avian anatomy: nomina anatomica avium, Baumel J., King A.S., Breazile J.E., Evans H.E., Berge J.C.V. (eds.). Cambrigde, MA: Publications of the Nuttall Ornithological Club, USA, no. 23, pp. 301–328.
Mekonnen H., Mulatu D., Kelay B., Berhan T. (2010). Assessment of the nutritional status of indigenous scavenging chickens in Ada'a district, Ethiopia. Trop. Anim. Health Pro., 42: 123–130.
Michetti P., Mahan M., Slauch J., Mekalanos J., Neutra M. (1992). Monoclonal secretory immunoglobulin A protects mice against oral challenge with the invasive pathogen *Salmonella typhimurium*. Infect. Immun., 60: 1786–1792.
Michetti P., Porta N., Mahan M.J., Slauch J.M., Mekalanos J.J., Blum A., Kraehenbuhl J.-P., Neutra M.R. (1994). Monoclonal immunoglobulin A prevents adherence and invasion of polarized epithelial cell monolayers by *Salmonella typhimurium*. Gastroenterology, 107: 915–923.
Miskelly C.M., Taylor G.A., Gummer H., Williams R. (2009). Translocations of eight species of burrow-nesting seabirds (genera *Pterodroma*, *Pelecanoides*, *Pachyptila* and *Puffinus*: Family Procellariidae). Biol. Conserv., 142: 1965–1980.
Mongin P. (1976). Composition of crop and gizzard contents in the laying hen. Brit. Poultry Sci., 17: 499–507.
Montaner A.D., Beltzer A., Carlo E.D., Mosso E. (1997). Anatomía macroscópica e histológica de esófago, estómago, intestino y recto de la garcita azulada, Buturoides striatus (Aves: Ardeidae). Rev. Ceres., 44: 83–93.
Montville T., Winkowski K., Ludescher R. (1995). Models and mechanisms for bacteriocin action and application. Int. Dairy J., 5: 797–814.
Moore R., Park S., Kubena L., Byrd J., McReynolds J., Burnham M., Hume M., Birkhold S., Nisbet D., Ricke S. (2004). Comparison of zinc acetate and propionate addition on gastrointestinal tract fermentation and susceptibility of laying hens to *Salmonella enteritidis* during forced molt. Poultry Sci., 83: 1276–1286.
Mwalusanya N., Katule A., Mutayoba S., Minga U., Mtambo M., Olsen J. (2002). Nutrient status of crop contents of rural scavenging local chickens in Tanzania. Brit. Poultry Sci., 43: 64–69.
Nielsen B.L. (2004). Behavioural aspects of feeding constraints: do broilers follow their gut feelings? App. Anim. Behav. Sci., 86: 251–260.
Niethammer G. (1933). Anatomisch-histologische und physiologische Untersuchungen über die Kropfbildung der Vögel. Z. Wiss. Zool. Abt., 144: 12–101.
Oakley B.B., Lillehoj H.S., Kogut M.H., Kim W.K., Maurer J.J., Pedroso A., Lee M.D., Collett S.R., Johnson T.J., Cox N.A. (2014). The chicken gastrointestinal microbiome. FEMS Microbiol. Lett., 360: 100–112.

Olah I., Glick B. (1979). Structure of the germinal centers in the chicken caecal tonsil: light and electron microscopic and autoradiographic studies. Poultry Sci., 58: 195–210.
Olah I., Glick B., Taylor R. (1984). Meckel's diverticulum. II. A novel lymphoepithelial organ in the chicken. Anat. Rec., 208: 253–263.
Olah I., Kupper A., Kittner Z. (1996). The lymphoid substance of the chicken's Harderian gland is organized in two histologically distinct compartments. Microsc. Res. Techniq., 34: 166–176.
Onyango E., Bedford M., Adeola O. (2005). Phytase activity along the digestive tract of the broiler chick: A comparative study of an *Escherichia coli*-derived and *Peniophora lycii* phytase. Can. J. Anim. Sci., 85: 61–68.
Pace D., Landolt P., Mussehl F. (1952). The effect of pigeon crop-milk on growth in chickens. Growth, 16: 279–285.
Pacheco M.A., García-Amado M.A., Bosque C., Domínguez-Bello M.G. (2004). Bacteria in the crop of the seed-eating green-rumped parrotlet. Condor, 106: 139–143.
Padilla L.R. (2015). Gaviiformes, Podicipediformes, and Procellariformes (Loons, Grebes, Petrels, and Albatrosses) In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 89–96.
Ponte P., Lordelo M., Guerreiro C., Soares M., Mourao J., Crespo J., Crespo D., Prates J., Ferreira L., Fontes C. (2008). Crop *β*-glucanase activity limits the effectiveness of a recombinant cellulase used to supplement a barley-based feed for free-range broilers. Brit. Poultry Sci., 49: 347–359.
Prévost J., Vilter V., Françaises E.P. (1963). Histologie de la secretion oesophagienne du manchot empereur. Proc. XIIIth International Ornithological Congress, pp. 1085–1094.
Pritchard P.J. (1972). Digestion of sugars in the crop. Comp. Biochem. Physiol. A., 43: 195–205.
Ptak A., Bedford M.R., Świątkiewicz S., Żyła K., Józefiak D. (2015). Phytase modulates ileal microbiota and enhances growth performance of the broiler chickens. PloS one, 10: e0119770.
Pye G. (2003). Apodiformes and coliiformes (Swifts, Swiftlets, Mousebirds). In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 239–245.
Quesenberry K.E., Hillyer E.V. (1994). Supportive care and emergency therapy. In: Avian medicine: principles and application. Ritchie B.W., Harrison G.J., Harrison L.R. (eds). Lake Worth, FL: Wingers, pp. 382, 416.
Ramirez G., Sarlin L., Caldwell D., Yezak C., Hume M., Corrier D., Hargis B. (1997). Effect of feed withdrawal on the incidence of *Salmonella* in the crops and ceca of market age broiler chickens. Poultry Sci., 76: 654–656.
Redrobe S. (2015). Pelecaniformes (Pelicans, Tropicbirds, Cormorants, Frigatebirds, Anhingas, Gannets). In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 96–99.
Richards M., Proszkowiec-Weglarz M. (2007). Mechanisms regulating feed intake, energy expenditure, and body weight in poultry. Poultry Sci., 86: 1478–1490.
Richardson A. (1970). The role of the crop in the feeding behaviour of the domestic chicken. Anim. Behav., 18: 633–639.
Riddle O., Bates R.W., Dykshorn S.W. (1933). The preparation, identification and assay of prolactin – a hormone of the anterior pituitary. Am. J. Physiol., 105: 191–216.
Rubio-García M., Rubio-Lozano M., Ponce-Alquicira E., Rosario-Cortes C., Nava G., Castañeda-Serrano M. (2015). Improving appearance and microbiologic quality of broiler carcasses with an allostatic modulator. Poultry Sci., 94: 1957–1963.
Sacranie A., Svihus B., Denstadli V., Moen B., Iji P., Choct M. (2012). The effect of insoluble fiber and intermittent feeding on gizzard development, gut motility, and performance of broiler chickens. Poultry Sci., 91: 693–700.
Salminen S., Deighton M., Gorbach S., Wright A.V. (1993). Lactic acid bacteria in health and disease. In: Lactic acid bacteria, Salminen S., Wright A.V. (eds). Mercel Dekker, Inc. New York, pp. 199–225.
Savory C.J. (1985). An investigation into the role of the crop in control of feeding in Japanese quail and domestic fowls. Physiol. Behav., 35: 917–928.
Schultz D.J. (2003). Columbiformes (pigeons, doves). In: Zoo and wild animal medicine, 5th ed., Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 180–187.

Seo K., Holt P., Vaughn L., Gast R., Stone H. (2003). Detection of *Salmonella enteritidis*-specific immunoglobulin A antibodies in crop samples from chickens infected with *Salmonella enteritidis*. Poultry Sci., 82: 67–70.

Shetty S., Hegde S. (1993). Pigeon milk: a new source of growth factor. Experientia, 49: 925–928.

Shetty S., Hegde S., Bharathi L. (1992). Purification of a growth factor from pigeon milk. Biochim. Biophys. Acta BBA-Gen. Subjects, 1117: 193–198.

Sibbald I., Hutcheson L.M. (1959). The inability of the crop to convert β-carotene to vitamin A within four hours. Poultry Sci., 38: 698–700.

Sibley C.G., Ahlquist J.E. (1990). Phylogeny and classification of birds: a study in molecular evolution. Yale University Press, New Haven, Connecticut.

Slater P. (1974). The temporal pattern of feeding in the zebra finch. Anim. Behav., 22: 506–515.

Smith J.A. (2015). Passeriformes (Songbirds, Perching Birds). In: Zoo and wild animal medicine, Fowler M.E., Miller R.E. (eds). Louis, MO, Saunders, pp. 236–246.

Soedarmo D., Kare M.R., Wasserman R. (1961). Observations on the removal of sugar from the mouth and the crop of the chicken. Poultry Sci., 40: 123–128.

Stelwagen K., Carpenter E., Haigh B., Hodgkinson A., Wheeler T. (2009). Immune components of bovine colostrum and milk. J. Anim. Sci., 87: 3–9.

Stern N., Svetoch E., Eruslanov B., Perelygin V., Mitsevich E., Mitsevich I., Pokhilenko V., Levchuk V., Svetoch O., Seal B. (2006). Isolation of a *Lactobacillus salivarius* strain and purification of its bacteriocin, which is inhibitory to *Campylobacter jejuni* in the chicken gastrointestinal system. Antimicrob. Agents Ch., 50: 3111–3116.

Stevens C.E., Hume I.D. (1998). Contributions of microbes in vertebrate gastrointestinal tract to production and conservation of nutrients. Physiol. Rev., 78: 393–427.

Stevens C.E., Hume I.D. (2004). Comparative physiology of the vertebrate digestive system. Cambridge University Press, New York.

Strompfova V., Laukova A. (2007). *In vitro* study on bacteriocin production of Enterococci associated with chickens. Anaerobe, 13: 228–237.

Studer-Thiersch A. (1967). Beiträge zur Brutbiologie der Flamingos (*Gattung phoenicopterus*). Zool. Gart., 34: 154–229.

Sturkie P. (1976 a). Alimentary canal: anatomy, prehension, deglutition, feeding, drinking, passage of ingesta, and motility. In: Avian physiology, Sturkie P.D. (ed.). Springer-Verlag, New York, NY, pp. 185–195.

Sturkie P. (1976 b). Secretion of gastric and pancreatic juice, pH of tract, digestion in alimentary canal, liver and bile, and absorption. In: Avian physiology, Sturkie P.D. (ed.). Springer-Verlag, New York, NY, pp. 196–209.

Svihus B. (2014). Function of the digestive system. J. Appl. Poultry Res., 23: 306–314.

Svihus B., Hetland H., Choct M., Sundby F. (2002). Passage rate through the anterior digestive tract of broiler chickens fed on diets with ground and whole wheat. Brit. Poultry Sci., 43: 662–668.

Svihus B., Sacranie A., Denstadli V., Choct M. (2010). Nutrient utilization and functionality of the anterior digestive tract caused by intermittent feeding and inclusion of whole wheat in diets for broiler chickens. Poultry Sci., 89: 2617–2625.

Svihus B., Lund V., Borjgen B., Bedford M., Bakken M. (2013). Effect of intermittent feeding, structural components and phytase on performance and behaviour of broiler chickens. Brit. Poultry Sci., 54: 222–230.

Szarski H., Grodziński Z. (1987). Digestive system. In: Comparative anatomy of vertebrates (in Polish). Scientific Publishing Company PWN, Warsaw, pp. 538–539.

Taylor M. (2000). Anatomy and physiology of the gastrointestinal tract for the avian practitioner. In: Birds, Post Grad Found in Vet. Sci. Univ. of Sydney, Aus. Proc., 334, pp. 107–113.

Taylor M., Murray M.J. (1999). Endoscopic examination and therapy of the avian gastrointestinal tract. Semin. Avian Exot. Pet Med., 8: 110–114.

Teekell R., Knox E., Watts A. (1967). Absorption and protein biosynthesis of threonine in the chick. Poultry Sci., 46: 1185–1189.

Thompson J.L., Hinton M. (1997). Antibacterial activity of formic and propionic acids in the diet of hens on Salmonellas in the crop. Brit. Poultry Sci., 38: 59–65.

Tully T.N. (2009). Ratites. In: Handbook of avian medicine, Tully T.N., Dorrestein G.M., Jones A.K. (eds). Elsevier/Saunders, pp. 228–233.
Van Dijk A., Veldhuizen E.J., Kalkhove S.I., Tjeerdsma-van Bokhoven J.L., Romijn R.A., Haagsman H.P. (2007). The β-defensin gallinacin-6 is expressed in the chicken digestive tract and has antimicrobial activity against food-borne pathogens. Antimicrob. Agents Ch., 51: 912–922.
Van Immerseel F., Rood J.I., Moore R.J., Titball R.W. (2009). Rethinking our understanding of the pathogenesis of necrotic enteritis in chickens. Trends Microbiol., 17: 32–36.
Wagstrom E.A., Yoon K.-J., Zimmerman J.J. (2000). Immune components in porcine mammary secretions. Viral Immunol., 13: 383–397.
Waite D.W., Deines P., Taylor M.W. (2012). Gut microbiome of the critically endangered New Zealand parrot, the kakapo (*Strigops habroptilus*). PloS one, 7: e35803-e35803.
Waite D.W., Taylor M.W. (2015). Exploring the avian gut microbiota: current trends and future directions. Front. Microbiol., 6: 673.
Wally J., Buchanan S.K. (2007). A structural comparison of human serum transferrin and human lactoferrin. Biometals, 20: 249–262.
Wehner G., Harrold R. (1982). Crop volume of chickens as affected by body size, sex, and breed. Poultry Sci., 61: 598–600.
Wheelwright N.T. (1983). Fruits and the ecology of Resplendent Quetzals. Auk, 100: 286–301.
Woodward C., Kwon Y., Kubena L., Byrd J., Moore R., Nisbet D., Ricke S. (2005). Reduction of *Salmonella enterica* serovar Enteritidis colonization and invasion by an alfalfa diet during molt in Leghorn hens. Poultry Sci., 84: 185–193.
Yeoman C.J., Chia N., Jeraldo P., Sipos M., Goldenfeld N.D., White B.A. (2012). The microbiome of the chicken gastrointestinal tract. Anim. Health Res. Rev., 13: 89–99.
Yildirim Z., Johnson M.G. (1998). Characterization and antimicrobial spectrum of bifidocin B, a bacteriocin produced by *Bifidobacterium bifidum* NCFB 1454. J. Food Protect., 61: 47–51.
Zheng X., Martin L.D., Zhou Z., Burnham D.A., Zhang F., Miao D. (2011). Fossil evidence of avian crops from the Early Cretaceous of China. P. Natl. Acad. Sci., 108: 15904–15907.
Ziswiler V., Farner D.S. (1972). Digestion and the digestive system. In: Avian biology, vol. II, Farner D., King J., Parkes K. (eds). Academic Press, New York, London, pp. 343–430.

Received: 13 II 2016
Accepted: 20 IV 2016