



Review: Key tweaks to the chicken's beak: the versatile use of the beak by avian species and potential approaches for improvements in poultry production



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ABSTRACT

The avian beak is a multipurpose organ playing a vital role in a variety of functions, including feeding, drinking, playing, grasping objects, mating, nesting, preening and defence against predators and parasites. With regards to poultry production, the beak is the first point of contact between the bird and feed. The beak is also manipulated to prevent unwanted behaviour such as feather pecking, toe pecking and cannibalism in poultry as well as head/neck injuries to breeder hens during mating. Thus, investigating the beak morphometry of poultry in relation to feeding and other behaviours may lead to novel insights for poultry breeding, management and feeding strategies. Beak morphometry data may be captured by advanced imaging techniques coupled with the use of geometric morphometric techniques. This emerging technology may be utilized to study the effects of beak shape on many critical management issues including heat stress, parasite management, pecking and feeding behaviour. In addition, existing literature identifies several genes related to beak development in chickens and other avian species. Use of morphometric assessments to develop phenotypic data on beak shape and detailed studies on beak-related behaviours in chickens may help in improving management and welfare of commercial poultry.

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Implications

The beak plays a vital role in many daily functions of avian species. However, information is presently lacking on the impact of beak morphometry on the functionality of the beak in poultry. This review highlights the importance of beak morphometry with respect to key challenges faced by the poultry industry, i.e. feeding efficiency, feather pecking, sexing of day-old chicks and heat stress. Based on the information available on other avian species relevant to these areas, the recommendations of this review warrant further research in beak morphometry of poultry. Thus, the conclusions of this review have implications for future research directions in the field of poultry science.

Introduction

The beak is a versatile organ as it is not only used to probe for and ingest feed but is also used for grasping and manipulating objects (Matsui et al., 2016), defending against ectoparasites (Clayton et al., 2005), nest building, mating, fighting and communicating. There is extensive literature on the evolution of the beak with respect to the ecological niches of various avian species. For example, the beak morphology of various

finch species have been studied to determine the relationship between beak shape and feeding methods in Charles Darwin's famous works. Moreover, attempts have been made to explain the biomechanical aspects of beak shape in relation to feeding (Genbrugge et al., 2011) and the influence of feeding method on beak shape and sexual dimorphism in finches (Herrel et al., 2010). The domestic chicken is the most common bird species on earth with an estimated population of 23 billion birds alive at any one time (Qualman, 2018). Despite their prevalence and economic significance, detailed morphometric studies do not exist in domestic chickens. Nevertheless, the beak is an important structure used in many of the natural behaviours of the chicken such as preening and mating. The beak may also be used in unwanted behaviours such as feather pecking, which is a great economical and welfare concern of the poultry industry (Icken et al., 2017). Thus, to minimize the impact of this unwanted behaviour, present industry practice involves beak trimming as a preventive measure against injurious pecking. While IR treatment has less potential to cause chronic pain (Struthers et al., 2019a, 2019b), manipulation of the beak may impact many aspects of production. For example, beak conformation may have consequences for feeding behaviour as the ability of poultry to select larger or smaller particle sizes due to their beak morphometry may be related to dietary particle size preferences and thereby influence performance (Iqbal, 2019). Therefore, studying the morphometry of beaks in detail may help address issues of commercial relevance, such as feather pecking and eating

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in laying hens, optimization of dietary particle and pellet size of poultry feeds, the capacity of selection within layer and broiler flocks and a more comprehensive understanding of feeding behaviour. Therefore, the aim of this review is to outline the association of beak morphometry and its versatile functions by describing the selected key functions of the beak in avian species with a focus on the domestic chicken and implications for key issues in poultry production.

Beak specialization in accordance with function

Feeding

The beak is the first point of contact between the bird and feed but is often neglected in behavioural studies. The tip of the beak has a rich supply of nerves and sensory receptors (Fahey et al., 2007) providing the bird with the ability to examine the physical attributes of the feed. Also, the presence of taste buds inside the beak provides a mechanism to assess the nutritional value of feed through the sense of taste (Roura et al., 2013). Beaks allow avian species to select their feed in a way that minimizes the time taken to consume feed and thereby permit maximal nutrient intake (Soobramoney and Perrin, 2016). Beak size and shape determine avian feeding ecology (Marquiss and Rae, 2002; Lu et al., 2010) and correspond to grain/seed selection (Marquiss and Rae, 2002; Titulaer et al., 2018), eating method (Herrel et al., 2010) and foraging habits (Marquiss and Rae, 2002). Generally, larger beaks are suitable for handling large grains (Soobramoney and Perrin, 2016; Titulaer et al., 2018) or other food items (Lu et al., 2010). Besides beak size, the difference in the upper and lower beak length (top beak overhanging the lower beak) may have implications for feeding as long overhangs beyond a certain length may interfere with feeding (Clayton et al., 2005). Beak shape and size are also associated with changes in bite force (Genbrugge et al., 2011), and it is presumed that narrow beaks (when viewed laterally, have a smaller distance from top to bottom of the beak) are associated with better manipulation of seeds, whereas deeper beaks (when viewed laterally, having a relatively greater distance between top and bottom of the beak) are associated with better seed crushing ability (Herrel et al., 2005). The beaks of finches are well studied in this regard and provide a good example of how beak size and shape corresponds to feeding methods and dietary choices (Supplementary Table S1). Unfortunately, such data are scarce for other avian species especially for commercially relevant species such as poultry.

Variation in the beak shape of turkeys (Dalton et al., 2017), ISA Brown hens and Cobb 500 broilers (Karima, 2019) have been reported in recent years. However, these studies provide no association between beak shape and feeding behaviour. Nevertheless, if the feeding behaviour of commercial poultry is determined by beak shape as is the case within finches, variation in beak shape among significant commercial poultry breeds could impact feeding behaviour and thereby influence poultry management practices and nutrition. Previously, poultry have shown the ability to select feed of various particle sizes (Gous and Swatson, 2000; Moss et al., 2017). Furthermore, preliminary data (Akter et al., 2019) have shown that diet selection and feeding behaviour impact feed efficiency in layer hens, as individual birds select different dietary components from layer mash. This behaviour may in part be due to the ease of which feed particles may be prehended by individuals with various beak shapes (potentially caused by beak treatment). It also appears that the impact of beak shape on feeding depends upon the severity of hen beak trimming and the resulting difference in the upper and lower beak lengths (Prescott and Bonser, 2004).

Preening and ectoparasite control

Beaks are a useful tool for preening and pest control and have adaptations for this purpose. For example, the maxillary overhang is a feature that plays a role in preening (Moyer et al., 2002) by providing a

template for the lower beak to rub against and crush feather parasites (Clayton et al., 2005). The exact role of the overhang for ectoparasite control depends upon the species of the host and parasite. Clayton et al. (2005) reported that pigeons with intact beak overhangs are more effective at killing feather lice than those with the overhang removed. However, Waite et al. (2012) did not find a significant difference in the number of pigeon flies (*Pseudolynchia canariensis*) killed by preening between pigeons with or without an intact beak overhang. Nevertheless, flies may not be a key ectoparasite targeted during preening as compared to lice.

Beak shape may influence the efficiency of ectoparasite control. Moyer et al. (2002) reported that Scrub-Jays with hooked beaks are more effective at ectoparasite control as compared to the ones with straight and pointed bills. It is interesting to note that although there is a positive correlation in the overhang length and ectoparasite control (Clayton and Walther, 2001), hooked beaks of parrots and raptors with extremely large overhangs do not improve preening and most probably are adaptations related to feeding (Clayton et al., 2010). In owls, relatively shorter bill hooks (4.2–4.8 mm) were found to be free of lice infestations (Bush et al., 2012). However, studies in poultry have not been conducted but may be of interest particularly in regard to laying hens.

Effect of beak trimming

Beak trimming in poultry is another important aspect as the beak is manipulated to prevent feather pecking, but may also impact feeding. Beak-trimmed poultry may experience altered feeding behaviour, either due to the alteration of beak shape or the nature of this practice as an invasive and painful procedure (Cheng, 2006; Kuenzel, 2007; Gentle, 2011). Beak trimming causes an overall reduction of beak-centric behaviours including feeding times, pecking and beak wiping (Marchant-Forde et al., 2008). This phenomenon is observable within commercial poultry houses as beak-trimmed laying hens have a reduced feed intake compared to those which have not been beak-trimmed (Craig et al., 1992; Honaker and Ruzsler, 2004; Marchant-Forde et al., 2008). Furthermore, beak-trimmed turkeys had reduced feed wastage in two large-bodied turkey strains compared to those who were not beak-trimmed, which also indicates that feeding behaviour is changed by beak trimming (Noble and Nestor, 1997). Compared to the conventional hot-blade beak trimming, which results in acute and chronic pain, newer methods utilizing IR lasers for beak treatment are less painful and more precise (Dennis et al., 2009). Glatz (2003) found that severe beak trimming using hot-blade cauterization which results in a shorter upper beak (10–11 mm) reduced feed intake by 7.8 g/day in laying hens compared to a less severe beak trimming with longer upper beaks (13–15 mm). Prescott and Bonser (2004) demonstrated that if beak trimming (hot-blade treatment) resulted in a difference of the upper and lower beak lengths greater than the diameter of the feed pellets, the success of pecking and picking up food particles was low. There is a large potential for variability in nutrient intake and particle selection between individuals and at the flock level, which may also persist with beak trimming if it is not performed uniformly.

However, IR trimming had no impact on feed intake in Struthers et al., 2019a which reflects the reduced impacts of this less invasive beak trimming method.

In addition to altering feeding behaviour, beak trimming may have important consequence for ectoparasite control. The maxillary overhang has a key role in effective preening and ectoparasite control. Layer hens receive beak trimming in order to prevent feather pecking, (Glatz, 2005) which could make them susceptible to ectoparasites such as red mite (*Dermanyssus gallinae*), chicken body louse (*Menacanthus stramineus*) and northern fowl mite (*Ornithonyssus sylvianus*) (Jacobs et al., 2019). Beak trimming has been directly linked to increased numbers of northern fowl mites and chicken body lice (*M. stramineus*) in laying hens owing to reduced/ineffective preening (Vezzoli et al., 2015). Thus, as the ability to control ectoparasites is likely

compromised by the removal of the maxillary overhang, which is of significance for industry. Behaviours such as dust bathing to control ectoparasite burden are thereby likely of even greater importance for beak-trimmed poultry.

In addition to preening and ectoparasite control, beak shape is highly relevant to feather pecking which is an important welfare issue. The current practice of preventing feather pecking via beak trimming is effective, however has its own welfare implications in terms of acute or chronic pain (Gentle, 2011) regardless of the method used. Furthermore, due to welfare concerns, beak trimming is banned either through legislation or voluntarily by the industry in many countries. For instance, in Scandinavian countries, beak trimming is banned for several decades (Norway 1974, Finland 1986, Sweden 1988), and since 2013, it is also banned in Denmark and Austria (McDougal, 2020). In Denmark, the Danish egg association voluntarily stopped beak trimming in caged laying hens from July 2013 and in barn and free-range laying hens from July 2014 (Riber and Hinrichsen, 2017). Among the European Union (EU) countries, the German poultry industry voluntarily stopped beak trimming of layers since 1 August 2016 and stocking of beak trimmed pullets since January 2017. Similarly, the Dutch poultry industry voluntarily introduced a ban in September 2018. The UK, however, expects a ban to be introduced in the next 5 years (McDougal, 2020). Among the non-EU countries, Switzerland has banned beak trimming in 1992 (Farm Animal Welfare Committee [FAWC], 2007). It is likely that other countries may follow. Therefore, alternatives to beak trimming in poultry to prevent feather pecking such as selection for blunt beaks are being proposed (Preisinger, 2018). However, the effect of this selection on feeding behaviour and parasite control is yet to be determined.

Sexual dimorphism and mate selection

The beak is also involved in mating behaviours of avian species. Sexual behaviour of male chickens involves grasping the females comb with the beak, which may injure the comb or head (De Jong et al., 2009). In a range of avian species, sexual dimorphism between genders is observed either in their body mass, tarsus length or wing length and differences in beak size and shape due to differences in behaviour or resource use have also been reported (Casaux and Baroni, 2000; Temeles et al., 2010). For example, Herrel et al. (2010) found longer beaks in female finches than males relative to their body size. However, sexual dimorphism in beak shape and/or beak size is not widely studied. Nevertheless, if sexual dimorphism in beak size or shape is common amongst a variety of avian species, and this dimorphism is present in young chicks, this provides a potential opportunity for the poultry industry to explore the possibility of using beak size and shape (as well as other characteristics) to determine the gender of day-old chicks. Thus, further research regarding beak morphometry in commercial poultry is warranted.

Thermoregulation

Birds are endothermic animals which produce their own heat, and excess heat must be dissipated into the environment. This is particularly important in poultry production as high losses can occur during temperature extremes. Due to the effectiveness of feathers to insulate heat, featherless appendages like the beak and legs are vital to exchange heat with the environment (Fan et al., 2019). Although the surface area of the beak is small compared to that of the body, it does contribute significantly to the un-insulated area of the body in birds (Greenberg et al., 2012). For instance, the beak commonly accounts for around 2–5% of body surface area, and the heat exchange through the beak could be up to 20% of the total heat exchange from the body (see Supplementary Table S2), with the exception of toco-toucans (*Ramphastos toco*). Remarkably, in Toucans, heat exchange to the surrounding

environment through the beak can be as high as 400% of the basal heat production (Tattersall et al., 2009). While data are lacking for poultry, data from peafowl may give an approximation. Heat exchange through the beak occurs through direct contact with the surrounding environment or through other mechanisms, like yawning (Gallup et al., 2009), gular flutter (Talbot et al., 2018) and panting (van de Ven et al., 2019). Heat stress is detrimental for production, and as temperatures approach 37 °C, feed intake is reduced by 15.8% and average daily gain is reduced by 31.9% (He et al., 2019). Therefore, a good understanding of the mechanisms of combating heat stress in poultry is vital for the poultry industry.

In broiler chickens, it is reported that up to 80% of heat loss can occur through gular fluttering in conditions at 95 °F (35 °C) and 40% relative humidity (Saeed et al., 2019). It appears that the majority of heat exchange in chickens occurs through the head as this area demonstrates the highest temperature gradient with respect to the ambient temperature in 42-day-old broiler chickens (Tickle and Codd, 2019). In other thermographic studies in chickens, the head region (including comb, wattles, beak and surrounding soft tissues and feathers) also shows the highest temperature in comparison to other body parts (Andrade et al., 2017; Souza-Junior et al., 2019). Thermal images of broiler chickens by Gerken et al. (2006) indicated that beak temperature was lower than the wattles and the comb, so the beak's contribution towards heat exchange through direct contact with the environment is probably lower than that of the comb and the wattles. Nevertheless, the contribution of beak towards heat loss in chickens appears quite significant when other mechanisms of heat exchange such as gular flutter and panting are taken into account.

Therefore, various factors related to beak such as extent of vascularization (Tattersall et al., 2009) along with the size and shape of the beak may have an effect on thermoregulation in avian species. Although the authors are not aware of any studies on variations in beak vascularization, published information on beak surface area and heat exchange in various avian species that heat loss from beak is probably a function of beak size (or exposed surface area) is presented in Supplementary Table 2. Within species, variations in beak size may have its impact on thermoregulation abilities and larger beaks may be a useful feature to cope with heat stress. Between two sub-species of sparrows, one having 17% greater surface area of the beak than the other, Greenberg et al. (2012) found 33% greater heat dissipation through the beak surface in the sub-species having greater beak surface area. This amount of heat exchange through beak surface was estimated to have a potential of saving around 7.7% of water loss (about 9.7 mg/h) from evaporative cooling. This water-saving due to greater heat exchange through larger beaks may be a useful feature to avoid the risk of dehydration in avian species under high temperatures, such as poultry production throughout the summer months or young chicks during transport. Moreover, under humid conditions, evaporative cooling may not be very effective and loss of heat through the beak surface could be advantageous as Gardner et al. (2016) found a selection pressure for longer beaks in humid environments by examining 36 species of Australian passerine.

In commercial species, artificial selection for larger beaks may be a strategy to combat heat stress in poultry and other avian species of commercial relevance, but further research is required. In a study of 214 avian species among 8 taxonomic groups, Symonds and Tattersall (2010) found that most of the species tend to follow Allen's rule which proposed smaller appendage size in endothermic animals living in colder regions and observed and found significant positive relationships of beak size and temperature for parrots, penguins, Canadian galliformes (grouse, quail, ptarmigans and wild turkey) and gulls. Additionally, 64 out of a total of 110 species showed evidence of a relationship between beak size and temperature in Tattersall et al. (2017). Surprisingly, this list did not include jungle fowl (poultry's ancestor), and it seems that in general, chickens do not follow Allen's rule as their beaks are still quite small compared to the relatively hot climate

conditions of the tropical region. However, Burness et al. (2013) report that quails reared at 15 °C developed shorter beaks as compared to the quails reared at 30 °C. Nevertheless, there is a lack of information available for poultry, and further studies may help to quantify the contribution of the chicken beak in heat loss and thermoregulation.

Therefore, further investigation is required to determine if the rule applies within chicken species and if beak size is correlated with the ambient temperature, as it may have commercial significance. Possible implications for poultry management and rearing in industry are that broiler chickens grown in the peak summer heat might benefit from genetic selection for larger beak size or be able to be reared at slightly warmer temperatures during the early production period to promote beak development and improve evaporative cooling later in production.

Genetics of beak shapes

Due to the critical role of the beak in feeding and other functions described above, it is important to explore the possibilities of genetic selection for beak structure associated with useful feeding behaviours and thus improved feed efficiency. Selection for genes based on their specific roles in beak development could help in improving the feeding efficiency and reducing the capacity to cause injury from feather pecking in poultry species. However, it is important to note that such selection would need to be done without impacting feeding and grooming behaviours. Through gene expression comparisons, the influence of several genes on beak shape and size has been described in chickens and other avian species (Supplementary Table S3).

Despite the well-documented role of these genes in beak development, the authors could not find any literature regarding gene or any molecular marker-based selection for commercial applications in the poultry industry. However, phenotypic measurement of the length of sharp overhang (upper beak extension beyond the lower beak) has been examined in laying hens with a heritability of 0.10 to 0.25 and suggested to be feasible for selection to reduce the length of the sharp overhang. This has great potential to reduce injuries related to cannibalism and feather pecking within the poultry industry (Icken et al., 2017; Preisinger, 2018). Another approach assessing beak shape based on landmark morphometry has been used in turkeys (Dalton et al., 2017) and captures beak shape more accurately than measuring beak length alone, which may aid in the selection of beak phenotypes suitable for reduced feather pecking and cannibalism.

Advanced technologies to study beak size and shape

Unfortunately, data regarding beak size and shape of commercial poultry are lacking, despite the size of the global poultry industry. Advanced imaging technologies like 3D scanning, computed tomography (CT) scan and magnetic resonance imaging (MRI) may be used to collect detailed data on physical structures. These data may be coupled with behavioural data and geometric morphometric analysis to generate informative data on beak shape, size and mechanical functionality. Landmark-based geometric morphometrics visualizes subtle features and variation in shape of a structure and the placement of biological landmarks, allowing size and shape differentiation (Dalton et al., 2017). Thus, the entire structure may be measured and its form compared, rather than just comparing the length and width, for a greater level of detail. If coupled with emerging technologies like machine learning, which focuses on software capable of learning from data (which could be images, videos or recorded parameters), it may prove quite useful within research and industry applications. Such technology may allow us to determine if sexual dimorphism is present in young chicks, the role of beak shape in feeding behaviour and selection, and aid in developing new techniques for the management of heat-stress, ectoparasite control and feather pecking. Thus, this new technology and emerging field of research may provide positive bird welfare and economic outcomes for the poultry industry.

Concluding remarks

The beak is a versatile organ, and its structure and functionality may alter multiple behaviours such as preening, feather pecking, ectoparasite defence and feeding, in which all have significant implications for economic and welfare aspects of the poultry industry. Therefore, detailed studies on the relationship between beak morphology and behavioural functions should be a focus of investigation for future studies. There is a significant amount of knowledge available on beak development and the genes involved. Moreover, imaging techniques, behavioural video recording and geometric morphometric analysis can generate very accurate data on beak shape, size and mechanical functionality. Data from these techniques may provide a great deal of knowledge to understand the exact mechanisms of how birds use their beaks to explore the environment, obtain feed and interact with their conspecifics. This should help fine-tune management and breeding strategies for more efficient production and better welfare outcomes for the poultry industry.

Supplementary materials

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.animal.2020.100119>.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. This manuscript reviews findings from published literature which can be accessed from respective journal websites or databases for peer-reviewed literature.

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Declaration of interest

None.

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