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Water for Domestic Ducks: The Benefits and Challenges in Commercial Production

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Although we have been farming ducks for at least 4,000 years, with some accounts suggesting domestication having begun more than 38,000 years ago, there are still many unknowns for optimizing domestic duck welfare in a commercial setting. Ducks being waterfowl, are semi-aquatic and have unique behavioral needs when compared to other commonly farmed poultry species. Providing ducks with open water which allows for full body immersion so that they may perform their full repertoire of water-related behaviors is important for their health and welfare. However, in a commercial setting this remains challenging due to biosecurity, contamination, health, and management concerns. An important question is therefore how best to provide ducks with a commercially feasible and safe water source in which they can derive maximum welfare and health benefits with no adverse consequences to health or global water resources. This review considers the amount of water provision necessary to satisfy duck's water-related needs to enhance yet not compromise their welfare in a commercial setting based on current knowledge, as well as identifies the outstanding questions for future research to address.

Keywords: ducks, animal welfare, water provision, behavior, poultry

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INTRODUCTION

In 2019, approximately 5.7 billion domestic farmed ducks were slaughtered globally (FAO, 2021). As with other poultry species, this number is expected to increase in the coming years, with reports forecasting the industry to grow by USD$1.31 billion dollars by 2024 (TechNavio, 2021). Coupled with the global drive toward improved animal welfare for farm animals, there is a need for research to develop management strategies that optimize welfare as well as ensure system sustainability. For domestic ducks, one of the major points of contention for improved welfare is the provision of open water sources (Karcher and Mench, 2018). As waterfowl, ducks are semi-aquatic animals that under natural conditions will spend a large part of their life in or around water. Open water sources which allow head or body immersion allow ducks to perform their full repertoire of preening and bathing behaviors, which are important for their health and welfare. However, providing ducks with open water in commercial production is challenging due to biosecurity, contamination, health, and management concerns. Thus, there is a need to develop management strategies that may supply water to promote positive welfare outcomes for ducks while mitigating the potential negative consequences.

Domestic ducks are predominantly farmed for meat production, but are also used for foie gras, eggs, and feathers (Karcher and Mench, 2018). This review focuses on the three most common species of domestic ducks used for commercial meat production which are Pekin, Muscovy, and Mulard ducks, which is a hybrid crossbred of the Pekin and Muscovy, also called a Mule duck. Other domestic duck species used for meat or egg production include Aylesbury, Rouen, Indian Runner, or Khaki Campbell ducks. In commercial production systems domestic ducks have been further selected and bred specifically for meat production resulting in different strains of each breed over time. Traditionally, Pekin ducks and other less commonly used domestic ducks, are believed to have originated from the wild Mallard duck (*Anas platyrhynchos*) or a combination of the wild Mallard duck and Chinese spot-billed duck (*Anas zonorhyncha*). While Muscovy ducks are believed to have originated from the wild Muscovy duck (*Cairina moschata*) (Stahl, 2005; Qu et al., 2009; Hou et al., 2012). The origins and evolutionary history of the domestic duck may, however, be more complex than previously assumed (Guo et al., 2021).

Over 80% of global duck meat production occurs in Asia (including China, Myanmar, Vietnam, Bangladesh, Indonesia, and India), followed by Europe (including France, Germany, Hungary, and the UK) and North America (FAO, 2021). The market weight for domestic grower meat ducks typically ranges from 2.75 to 4 kg (Chen et al., 2021). Pekin ducks reach this market weight and are slaughtered around 4–5 weeks of age, while Muscovy and Mulard ducks (hybrid Pekin and Muscovy crossbreed) reach this weight around 10 weeks of age (Chen et al., 2021). Breeder flocks of ducks producing fertile eggs are kept for much longer and follow a production cycle similar to laying hens where they reach sexual maturity around 20 weeks of age and lay for many months (Chen et al., 2021).

Domestic ducks may be kept in various types of production systems including intensive indoor (fully enclosed or open-sided), semi-intensive, extensive (free-range), or integrated farming systems (e.g., with rice paddy or fish farming systems) (Jalaludeen and Churchil, 2020). They are typically housed on litter or raised plastic/wire floor-based systems with a combination of natural and artificial lighting and ventilation depending on how enclosed the systems are (Karcher et al., 2013; Karcher and Mench, 2018). Due to the biosecurity concerns associated with the provision of open water sources there has been a general move toward more intensive indoor housing systems where ducks typically only have water access via nipple or bell drinkers (Rodenburg et al., 2005; Chen et al., 2021). Where open water sources are provided this has been done using troughs, baths or showers in indoor systems, and small ponds or pools in systems with outdoor access (Rodenburg et al., 2005; Chen et al., 2021). In terms of housing regulations, globally, there are some recommendations for water provision for bathing or head dipping where it does not compromise duck health, but to date there is no regulation that requires open water provision in commercial housing (Poultry S&Gs Drafting Group, 2016). Some voluntary farm assurance schemes, such as RSPCA Assured in the UK, Humane Choice in Australia, and Animal Welfare Approved by AGM in the USA, require some form of water provision for ducks to perform water-related behaviors. However, currently there is no duck meat being produced to any of these voluntary farm scheme standards.

Although the demand for duck meat continues to grow, recent literature reviews of Pekin ducks in commercial systems have highlighted the overall lack of research relating to commercial duck production in general, particularly in comparison to other poultry species (Chen et al., 2021; Makagon and Riber, 2021). This lack of research has meant best practice for issues such as water provision to optimize domestic duck welfare remains unknown.

This non-systematic literature review focuses on the current available research relating to water provision for domestic ducks used for meat production in both experimental and commercial settings. The research examined and summarized in this review has been divided into sections however there is some overlap between them. The sections include duck water-related behaviors; thermoregulation; motivation to access water and effects of water deprivation; differences in duck breeds, age, and the time ducks dedicated to water-related behaviors; water provision considerations such as water depth and temperature, space and location; the effect of water on duck health and performance; and management considerations for litter, and water usage and hygiene. This review aims to consider the amount of water provision necessary to satisfy ducks' water-related needs to enhance while not compromising their welfare in a commercial setting based on current knowledge, as well as identify areas for future research.

DUCKS AND WATER-RELATED BEHAVIORS

Bathing and Preening Behaviors

Similar to the wild Mallard duck, domestic ducks exhibit preening and bathing behaviors important for maintaining eye, nostril and feather condition (Jones et al., 2009; Jones and Dawkins, 2010a; O'Driscoll and Broom, 2011; Nicol et al., 2017). Being semi-aquatic, ducks' feather condition is particularly critical for maintaining water repellence which ensures protection and buoyancy when in the water. When provided the opportunity, domestic ducks will utilize water for swimming, ducking and diving, head dipping and tossing, dabbling, wing rubbing, resting in or near water, and wet preening (Miller, 1977; Rodenburg et al., 2005; Jones et al., 2009; Waitt et al., 2009; Liste et al., 2012a; Mi et al., 2020). Wet preening is a maintenance behavior that relies on water access. The bathing behavioral sequence involves ducks immersing their head and wings in water to then toss and shake the water over their body. This is followed by a series of head shaking, wing rubbing, and preening movements (Rowe, 1983). Preening specifically involves oiling and nibbling. Oiling is when a duck mechanically squeezes their uropygial (preen) gland to secrete and distribute the oil-like secretion through their feathers using bill movements. Nibbling is the rapid movement of a duck's bill in a chewing-like motion over their body (Rowe, 1983). The preen gland is a pear-shaped bilobed holocrine gland located near the base of a duck's tail, which secretes glycolipids (ALjalaud, 2013; Mohamed, 2019). The gland is thought to contribute to maintaining the flexibility and water-repellent nature of a duck's feathers due to the gland's hydrophobic secretions (Mi et al., 2020). It may also play a role in protecting against bacterial and fungal infections, as well as contributing to thermoregulation, pheromone production, and hormone (e.g., prostaglandin and growth) production (Hassanin et al., 2021).

Access to water appears to play a significant role in the development of the preen gland. Mi et al. (2020) compared preen gland development in 120 Sanshui white ducks (from 1 until 42 days of age) with or without access to a water pool (5 × 6 m and 60 cm depth) in an experimental setting. A lack of water access significantly inhibited the growth of the preen glands based on gland weight, size, and quality of oil secretion. They also found ducks with water access spent more time preening in comparison to ducks without water access (Mi et al., 2020). In addition to self-preening, ducks may also engage in allopreening but the evidence in ducks is currently limited. Allopreening is thought to function as both a social and comfort behavior between birds which have a social bond (Spruijt et al., 1992). While allopreening has been reported in some wild duck species including Whistling, Carolina, and Manderin ducks (Harrison, 1964), others have suggested that it is almost entirely absent (Kenny et al., 2017). Delogu et al. (2012) exploring the transmission routes of Avian Influenza in experimental housing conditions reported that both self and allopreening activities were observed in eight commercially-bred Mallard ducks. However, no details were provided on the behavioral sequence involved. Dong et al. (2021) explored self and conspecific-directed pecking behaviors in commercial Pekin ducks and observed both severe and gentle conspecific-directed pecking. They suggested that allopreening may play a role in gentle feather pecking behavior in domestic ducks, but further research is required to confirm this given the current lack of information available.

Preening and bathing are important for duck comfort and maintenance and can also have a social function. Liste et al. (2012a) assessed the effect of water depth (shallow, intermediate, and deep) on bathing behaviors in a commercial setting and found on average 2.8 (±1.2) Pekin ducks involved in each bathing bout regardless of water depth. Ducks also engaged in behaviors at the water's edge like resting, standing, and foraging simultaneously with other ducks. These findings were consistent with Waitt et al. (2009), who found Pekin ducks in an experimental setting spent more time using open water sources (troughs and baths) when two or more ducks were present, whereas the nipple drinkers were used more individually. Jones and Dawkins (2010a) also found that when comparing three water sources (troughs, turkey Plasson drinkers, and nipple drinkers) in a commercial setting, Pekin ducks used troughs simultaneously the most, potentially because it was the only water source provided that allowed head dipping. However, Rice et al. (2014) observed Pekin ducks drinking in groups more often than individually when only nipple drinkers were available on commercial farms. In a choice experiment, Liste et al. (2014) observed ducks to exhibit following behavior when approaching bathing areas highlighting the impacts of group social cohesion on choice. These findings all found that when open water sources were provided, ducks preferred to spend time simultaneously bathing, indicating that bathing may also facilitate positive social experiences, although this would need to be further confirmed. More details on variables related to the extent and frequency of water-related behaviors are discussed in the section Variables Affecting Water-Related Behaviors.

Thermoregulation

During high temperatures and humidity, ducks are at a high risk of experiencing heat stress. Unlike many mammals, avian skin does not contain sweat or sebaceous glands so they are unable to dissipate excess heat through sweating when hot (King and Farner, 1961). Ducks instead rely on mechanisms such as evaporative cooling, where heat is dissipated through the respiratory tract by panting and from unfeathered body surfaces, such as feet into the environment (Richards, 1970). Thus, water may play a critical role in ducks' thermoregulation processes.

A duck's thermoneutral zone ranges from 7 to 23°C (Huang et al., 2008; El-Badry et al., 2009), with the optimal ambient temperature in a commercial housing system suggested to be from 10 to 15°C (El-Shafaei et al., 2016; Farghly et al., 2017; Sun et al., 2019). Ducks may display signs of heat stress at temperatures as low as 15°C, through increased panting. Jones and Dawkins (2010a) observed 46 commercial duck flocks (448,011 ducks) and found panting to occur in younger ducks (23 days of age) at room temperatures of 17.7°C and in older ducks (43 days of age) at 14.8°C. Increased panting was also associated with an increased proportion of ducks performing wet preening behavior, either by taking water into their bills from troughs and drinkers or by ducking their heads and tossing water over their bodies from troughs (Jones and Dawkins, 2010a). Temperatures above 29°C have been shown to decrease ducks' body weight and weight gain, mainly due to a negative effect on appetite and feed consumption (Huang et al., 2008; Farghly and Mahmoud, 2018). These findings were repeated by House et al. (2021), where decreased body weight and weight gain in Pekin ducks were positively correlated with decreased feed intake, but negatively correlated with increasing ambient temperatures from 20 to 30°C. Thermoregulation may also differ among breeds, with Muscovy ducks having better thermal tolerance than Pekin ducks. Zeng et al. (2014) exposed both Pekin and Muscovy ducks to 39 ± 0.5°C for 1 h, before returning to 20°C. Although, heat stress negatively affected all ducks based on expression of heat shock proteins, inflammatory factors, and total antioxidant capacity in ducks' livers, the Muscovy ducks had fewer negative effects suggesting better thermal tolerance.

The role open water plays in ducks' ability to thermoregulate body temperature and avoid heat stress, can be seen in how ducks increase the amount of heat they lose by immersing their feet in water in response to environmental temperatures (Kilgore and Schmidt-Nielsen, 1975). Open water which allows for swimming has been demonstrated in both experimental and commercial settings to improve body care behaviors and the thermoregulatory ability of ducks (Suswoyo and Sulistyawan, 2014; El-Shafaei et al., 2016; Farghly et al., 2017; Farghly and Mahmoud, 2018). El-Shafaei et al. (2016) found in an experimental setting that 48 Muscovy ducks (10 weeks of age) with open water access (pool 2 × 0.5 m) had lower average body temperatures, and lower blood stress indicators of plasma corticosterone concentrations and heterophil to lymphocyte (H/L) ratios than the heat stressed control group without open water. Farghly et al. (2017) in an experimental setting assessed the effect time of day (10:00–12:00, 12:00–14:00, and 14:00–16:00) and outdoor open water access for 2 h had on 180 Muscovy ducks (from 4 until 16 weeks of age). They also found ducks with water access had lower body temperatures than control groups, particularly when provided water access from 12:00 to 14:00. In another experiment Farghly and Mahmoud (2018), provided 180 Muscovy ducks (from 4 until 16 weeks of age) with an outdoor open water source for 2 h (10:00–12:00), 4 h (10:00–14:00), or 6 h (10:00–16:00) a day. Here they found water access for at least 4 h reduced ducks' average body temperature. Total time and time of day for open water access could therefore be important factors to consider for the potential thermoregulatory benefits.

For intensive indoor systems without open water sources, alternative methods of cooling via water have been tested. Farghly et al. (2018) explored wet feed and cold drinking water as methods to mitigate heat stress in domestic ducks in an experimental setting. They assessed three types of feeding systems (*ad libitum* dry feed, diurnal wet feed, or *ad libitum* wet feed) and two drinking water systems (tap water or cold water) in 180 Muscovy ducks. The combination of wet feed and cold water resulted in lower body temperatures as well as improved body weight, meat quality, and blood parameters, suggesting it could be an effective method of mitigating heat stress during hot weather. There is also evidence from other intensive poultry systems (laying hens and broiler meat chickens) utilizing sprinkler systems for surface wetting of birds to alleviate symptoms of heat stress (Liang et al., 2020). In commercial open-sided sheds in Australia, fogging systems generate fine water mist to reduce temperatures as needed across hotter months but the application of these systems to also surface wet the birds and enable wet preening or other health benefits are unknown. Whilst the behavioral and health impacts of similar systems, such as showers, have been explored in indoor-housed domestic ducks, the potential of misting systems as an alternative water source for both reducing heat stress and enabling wet preening also require testing. Any negative impacts of cold stress in relation to water provision for ducks housed in open-sided sheds (or outdoor systems) where ambient temperatures drop in the winter should also be considered. However, further research is required to confirm this as currently there is a lack of literature available.

MOTIVATION TO ACCESS WATER

Assessing the value of open water to ducks through measuring their water-related motivation facilitates better understanding of whether it is a necessity for good welfare in commercial systems. Due to artificial selection pressure and housing environments of domestic farm animals it can be difficult to interpret the degree to which an animal's motivation for a specific resource or environment is influenced by the constraints of their current housing and management. The motivation or choice of an animal is influenced by their preferences, prior experiences, as well as internal and external circumstances (Nicol, 1997; Kirkden and Pajor, 2006). While preference and motivation are often used interchangeably, in this context preference relates to an animal's choice between resources or environments. Whereas motivation, relates to the strength of an animal's desire to obtain or avoid a resource or environment and does not necessarily require a choice to be made (Kirkden and Pajor, 2006). One method of determining strength of motivation is by requiring an animal to pay a cost, such as working to perform a task or losing one resource to gain another. The highest cost paid indicates the strength of motivation (Kirkden and Pajor, 2006). Motivation tests have been used to assess motivation to access resources in several domestic animals such as perch and nest access in laying hens (Olsson and Keeling, 2002; Kruschwitz et al., 2008), litter substrate in broiler meat chickens and laying hens (Widowski and Duncan, 2000; Monckton et al., 2020), and water provision in mink (Cooper and Mason, 2000; Mason et al., 2001; Warburton and Mason, 2002; Hansen and Jensen, 2006).

To date, there has been minimal research into ducks' level of motivation to access water and different types of water sources. Cooper et al. (2002) conducted an experiment observing 24 Pekin ducks (from 4 until 8 weeks of age) to determine their motivation to access nipple drinkers, Plasson bell drinkers, deeper turkey bell drinkers, or troughs. Motivation was assessed by providing barriers of different heights (0, 75, 155, 195, 255 mm) to access the different water sources. The ducks preferred and were willing to "work" harder to access troughs in comparison to other water sources. Although 8 weeks of age is older than most Pekin ducks raised for meat production, the findings are consistent with the suggestion that ducks are motivated to access open water sources [but see Jones et al. (2009) on preferences across different types of water sources in Section Water Depth and Temperature]. Comparisons with commercially farmed mink that are also semi-aquatic and typically raised without water access show some benefits of water provision such as increases in positive play behavior and reduced incidences of stereotypic behaviors (Mononen et al., 2008; Vinke et al., 2008; Kornum et al., 2017). Mink have also shown a high stress response when their water access is removed (Vinke et al., 2008) but it remains a challenge to provide them open water access in a commercial setting.

A motivation paradigm of pushing weighted doors was recently validated in Pekin ducks (Barrett and Blache, 2019). The ducks were willing to push a weighted door up to 80% of their body weight to access a nest box and showed stress-induced hyperthermia when access was thwarted (Barrett et al., 2021). This paradigm could be used to quantify the motivation of commercial ducks to access different types of open water sources. However, it may remain difficult to quantify the effect of water absence on ducks' mental state and hence welfare, when there is no previous exposure to open water sources. Water provision may alleviate negative states while also enabling the opportunity for positive experiences and mental states for domestic ducks, which is in accordance with current drives toward more positive experiences for farm animals (Mellor, 2015).

EFFECTS OF WATER DEPRIVATION

Although the best method of determining whether deprivation is resulting in poorer welfare is debated, it has previously been done through observing animals following a period of deprivation for abnormal behaviors (e.g., stereotypies) and redirected behaviors, or rebound activity (Nicol and Guilford, 1991). For deprivation to cause poorer welfare it must prevent an animal from performing a behavior it is highly motivated to perform to the extent that it causes the animal to experience negative mental states (Dawkins, 1988).

Abnormal or redirected behaviors can serve as coping mechanisms for sub-optimal environments (Mason and Latham, 2004). This coping strategy has been suggested to develop as the motivation to perform a thwarted behavior builds up from the time it was last performed until it can be performed again (Vestergaard et al., 1999). Where these behaviors are repeated and continue to be repeated without the environment changing or motivation being satisfied, they may develop into stereotypies (Wechsler, 1995).

Feather pecking has been observed in commercial ducks (Karcher and Mench, 2018; Dong et al., 2021), but evidence of abnormal behaviors specifically related to water deprivation are limited. Mohammed et al. (2015) in an experimental setting reported an increased amount of feather pecking and higher serum corticosterone concentrations in 24 Muscovy ducks (37 until 70 days of age) without open water access. However, no details were provided on the housing design, and the collection of data was limited. Similarly, El-Edel et al. (2015) in an experimental setting found Pekin ducks housed indoors without water access showed more exploratory and aggressive feather pecking behaviors than those outdoors with open water access.

Riber and Mench (2008) assessed the effect of feed and water-based enrichments on feather pecking and cannibalism in Muscovy ducks housed indoors (with natural light and ventilation provision) in an experimental setting. While feed and water-based enrichment allowed for foraging and preening, cannibalism and low levels of feather pecking were still observed in all groups and occurred most in ducks without enrichment. Causes of cannibalism and feather pecking behaviors in ducks are likely complex and multifactorial, similar to other poultry, and therefore require a combined and dynamic approach of good husbandry and management practices, which may include providing open water sources to satisfy ducks' behavioral needs (Nicol et al., 2017; Cronin and Glatz, 2021).

Temporary deprivation of a resource can also be applied to determine the resource's value. An animal may exhibit rebound activity following restriction of performing a certain behavior. During rebound, the behavior will be performed at an increased tendency, often higher than the original level prior to deprivation (Kennedy, 1985). This effect has been suggested to occur either due to an increased motivation to perform the behavior which accumulates during the time of restriction, or because of dishabituation (Nicol, 1987; McFarland, 1989). Dishabituation suggests increased activity levels are a response to renewed novelty rather than deprivation, however this explanation does not result in poorer welfare because it is not associated with increased motivation to perform the behavior (Nicol and Guilford, 1991).

Jones et al. (2009) conducted an experiment to assess rebound behavior involving 120 Pekin ducks (from 3 until 8 weeks of age) with different water sources: bath with full body access, trough with head-dipping, shower with full body access from above, nipple drinkers without open water access, or nipple drinkers where baths were provided at 5 weeks of age. The ducks provided bath access at 5 weeks spent similar time drinking, dabbling, and bathing in baths, but spent less time resting at or in the bath as ducks with access for the entire experiment. This difference in resting behavior suggests that previous experience may influence how ducks' use water sources. At 7 weeks of age another rebound test was conducted where all ducks without previous access to a bath were provided access. Ducks from the nipple drinker only group showed evidence of rebound activity, spending more than double the time bathing (7.6%) as ducks with previous access to a bath (3.4%) (Jones et al., 2009). This observation of rebound activity following deprivation may indicate a lack of open water access to prevent ducks from performing motivated behaviors, leading to frustration and poorer welfare or prevent positive experiences.

VARIABLES AFFECTING WATER-RELATED BEHAVIORS

Research to date shows that when domestic ducks are provided the opportunity to access open water, they choose to access it and use it to perform a variety of water-related behaviors, such as wet preening and bathing. However, many variables affect the extent and frequency to which these behaviors are displayed, including duck breed and strain, age, and the time needed to satisfy water-related behaviors.

Types of Commercial Domestic Ducks (Species, Breeds, and Strains)

The Pekin duck is the most common domestic duck used for commercial duck meat production, followed by the Muscovy duck and Mulard duck (hybrid Pekin and Muscovy crossbreed) (Chen et al., 2021). The Pekin duck is a dabbling duck which has originated from the domestication of the wild Mallard duck (*A. platyrhynchos*) native to Europe, Asia, and North America, or from a combination of the wild Mallard duck and Chinese spot-billed duck (*A. zonorhyncha*) which is phenotypically different but genetically similar to the Mallard (Guo et al., 2021). Under natural conditions these wild ducks are mainly aquatic (Cherry and Morris, 2008). The Muscovy duck originates from the wild Muscovy duck (*C. moschata*) from Central and South America and is also mainly aquatic but lives in tropical marshy forests (Cherry and Morris, 2008). Archaeological findings in southern China suggested that ducks were domesticated sometime during the New Stone Age more than 4,000 years ago (Cherry and Morris, 2008). However, a recent genome study by Guo et al. (2021) suggests that domestic duck species may not have originated from the present-day wild duck species and are instead from a currently unidentified ghost wild duck population. Observations of present-day wild ducks may therefore not provide as accurate a representation of domestic ducks' behavioral needs and use of water as previously assumed. Additionally, domestic duck breeds and strains are continuously evolving through artificial selection to achieve improved performance, meaning previous research may have limited applicability to present-day domestic ducks.

Research to date has observed behavioral differences between duck species, notably with fear and stress reactions being a particular issue in Pekin ducks and feather pecking and aggression being a higher risk in Muscovy ducks (Rodenburg et al., 2005; Nicol et al., 2017). While both display preening and bathing behaviors there are some minor differences which could have implications for use and preferences of open water source. Reiter et al. (1997) assessed the differences in body weight, behavior and feather development in Pekin, Muscovy, and Mulard ducks in indoor and free-range commercial housing systems with or without open water access. Ducks were observed three days a week from 1 to 10 weeks of age for feeding, drinking, preening, sieving (i.e., shoveling or sifting) in litter or grass, standing, sitting, and bathing behaviors. All ducks displayed similar behaviors, with some differences observed between species. Bathing behaviors for all ducks made up on average 2% of total time and most preening activities occurred while standing, with only the Pekin ducks preening while in the water. Knierim et al. (2004) also observed Muscovy ducks to use showers differently to Pekin ducks, with Muscovy ducks moving away from showers when they were switched on whereas Pekin ducks would rest under them. A more recent study by El-Edel et al. (2015), observed differences in behavior between two strains of Pekin ducks (French and Cherry Valley) and Mulard ducks in an experimental indoor housing system without open water and an outdoor housing system with open water access. Pekin ducks spent more time preening and performed more behaviors associated with body care than the Mulard ducks. Mulard ducks were more curious than Pekin ducks, spending more time overall performing exploratory behaviors. Another interesting observation was that Cherry Valley Pekin ducks panted more than the other ducks indicating that they may be more sensitive to heat stress (El-Edel et al., 2015). Open water sources may therefore be especially important for certain duck species, breeds, or strains to mitigate the risk of heat stress (see Section Thermoregulation).

Most of the literature has focused on Pekin and Muscovy duck species, with only Reiter et al. (1997) and El-Edel et al. (2015) including the hybrid Mulard duck and Mi et al. (2020) using Sanshui White ducks. No research was found relating to other domestic ducks used for meat or egg production such as Aylesbury, Rouen, Indian Runner, or Khaki Campbell ducks. There is also a lack of research on the different strains of each breed. For example, in Pekin ducks, where it was specified, most studies in this review used Cherry Valley (UK) strains, with only one study on the Maple Leaf Farms White (American) strain and one on the Grimaud Freres (French) strain.

When provided the opportunity all ducks studied do utilize open water sources to perform a variety of water-related behaviors. The general lack of research on comparing different duck types and how they use water sources is currently a major limitation, and more research is needed to understand potential differences across domestic ducks in commercial production and their use and behavioral need of open water sources.

Age

Age also impacts the amount of time domestic ducks spend performing bathing and other water-related behaviors. Liste et al. (2012a) observed Pekin ducks in a commercial setting spending more time as they aged using shallow pools in comparison to deep pools. However, as the ducks were provided access to shallow pools at 14 days of age but intermediate and deep pools at 21 days of age (due to the risk of ducklings drowning), the previous experience with shallow pools could have contributed to the higher use. Briese et al. (2009) (abstract in English) in an experimental setting compared showers and modified Plasson drinkers in Muscovy ducks from 5 to 10 weeks of age. They observed an increasing duration and number of ducks at water sources as they aged with the drinkers being used more often and for longer during preening. They also observed younger ducks to prefer the modified Plasson drinkers while older ducks preferred the showers more (Briese et al., 2009).

Jones and Dawkins (2010a,b) observed Pekin ducks spending an increasing amount of time dry and wet preening as they aged (from 23 to 43 days of age) and that older ducks displayed heat stress induced panting at lower temperatures than younger ducks. These findings suggest increased time performing water-related activities as ducks age may relate to thermoregulation requirements. This also means that season and external environmental temperatures will likely influence domestic ducks' use of water sources, particularly in open-air systems. Studies assessing the effects of heat stress on ducks showed Pekin and Muscovy ducks with water access during hot weather had higher weight gain and lower body temperature, H/L ratio, and corticosterone concentrations than ducks without water access (Farghly et al., 2017; Farghly and Mahmoud, 2018; Abdo-Ghanima et al., 2020). This suggests the provision of open water sources may be particularly important for older ducks during hotter seasons to facilitate thermoregulation and mitigate the risk of heat stress.

The age in which domestic ducks are provided access to water sources in commercial settings is critical to consider given that meat production ducks may be slaughtered as early as 4 weeks of age (Chen et al., 2021). In most commercial settings, domestic ducks may not be given access to open water until they are at least 14 days of age, to reduce the risk of drowning or thermal stress and may therefore only be receiving open water benefits for a very short period. Whereas, domestic ducks kept for longer periods, such as egg laying or breeder ducks (e.g., approximately 60–70 weeks), open water sources will likely have sustained impact across their longer lifespans (Cherry and Morris, 2008).

Time

Observations of wild Mallard ducks show that wet preening bouts range from a few minutes to more than 2 h (Rowe, 1983). Another observational study during summer showed wild black ducks on average spent 26% of time preening, 2% swimming, and

<1% bathing each day (Wooley and Owen, 1978). Paulus (1988) studied mottled ducks in winter and found them to spend on average 9% of time preening in water and an additional 36% of their time resting within 2 m from the water. Findings on the time domestic ducks spend engaging in water-related behaviors vary, but when open water is available, ducks use it. Liste et al. (2012a) found Pekin ducks in a commercial setting between 29 and 48 days of age performed 6.8 bathing bouts a day on average with each bout lasting approximately 28 ± 24 min. Waitt et al. (2009) recorded the behavior of 94 Pekin ducks at 47 days of age with four different water sources (baths, troughs, showers, or nipple drinkers). Within a 12-h period and of the 10 bathing bouts analyzed, ducks spent on average 9.3 min (563.3 ± 79.7 s) at baths, 9.25 min (555.4 ± 54.7 s) at troughs, 13.6 min (817.7 ± 71.8 s) at showers, and 4 min (243.0 ± 67.9 s) at nipple drinkers (Waitt et al., 2009).

Jones and Dawkins (2010a) observed 46 flocks of Pekin ducks (448,011 ducks) across five different commercial housing systems in the UK during both a cold and hot season. On average over a 3-h period, ducks spent 15.8% of their time dry preening and 1.8% of time wet preening, with the amount of time wet preening being significantly higher with access to open water sources (vs. wet preening via the nipple drinkers). Jones et al. (2009) provided 120 Pekin ducks (from 3 to 8 weeks of age) with five different water sources in an experimental setting: bath, trough, shower, nipple drinkers only, or nipple drinkers then a bath at 5 weeks of age. Ducks with bath or shower access spent on average 22% of their time engaging in water-related activities, while ducks with troughs spent 15%, nipple-bath spent 11.4%, and nipple-only spent 6.6% of their time. While the age of the ducks impacted the amount of time spent at each water source, by 6 weeks of age all the ducks with open water (baths, troughs, and showers) spent similar amounts of time bathing regardless of the water source. While ducks were observed to spend <5% of time actually bathing, they spent a total of 15–22% of time engaging in water-related behaviors when also including resting on water, dabbling, and drinking (Jones et al., 2009). Liste et al. (2012a) demonstrated ducks to spend even more time performing water-related behaviors. They observed 64 Pekin ducks (from 3 to 7 weeks of age) in an experimental setting to spend on average 8.9% of time (2.1 h/day) in water and 36% of time (8.5 h/day) engaging in water-related behaviors (inside the pool, at the pool side, and at drinkers).

When extrapolating these findings to commercial settings it is worth considering the minimum time ducks were provided open water access in studies. Where information was provided most studies in this review, ducks were provided constant access to an open water source from a specific age (Jones et al., 2009; Waitt et al., 2009; O'Driscoll and Broom, 2011, 2012; Liste et al., 2012a,b, 2013; Mohammed et al., 2015; Schenk et al., 2016; Mi et al., 2020). This may differ from some commercial situations where ducks only have access to open water for set periods of time each day. Farghly et al. (2017, 2018) in experimental settings assessed the effects of providing Muscovy ducks with access to water in the form of a swimming pool for 2, 4, or 6 h a day. All ducks with open water access had improved mortality rates, weight gain, and feed conversion compared to ducks without access, with access for 4 h a day seeing the greatest improvements (see Section Effects of Water Provision on Health and Performance Parameters). Thus, while duration of water access is likely important, further research is required to determine whether there is a minimum time requirement for open water access to satisfy domestic ducks' water-related behavioral needs in current domestic duck types in commercial production systems.

TYPES OF WATER PROVISION

Both the practical and preferential needs of domestic ducks need to be considered when determining what type of water source will adequately satisfy their needs. For example, if the aim is to provide domestic ducks with an open water source in which they can swim, then practically speaking, the water must be of a suitable ambient temperature to avoid thermal stress (cold or heat) and of certain depth so that ducks can fully immerse themselves as well as float on the water surface. Once basic practical needs are met then whether ducks prefer swimming at certain temperatures or depths in comparison to others should also be considered. The following section addresses some of the key factors to consider when providing domestic ducks water in a commercial setting, including temperature, depth, total space per duck, and the location of water source.

Water Depth and Temperature

Whether a water source allows for partial or full body immersion is determined by the available volume of water, which is determined by its depth and dimension. For partial immersion, ducks should be able to fully dip their head under water to perform behaviors such as dabbling, sieving, and foraging, as well as toss water over their bodies for wet preening (McKinney, 1965). Under natural conditions, wild duck breeds have been observed to forage and dabble 95% of the time in water <15 cm deep (Paulus, 1988). Liste et al. (2012b) compared the impact of different trough sizes and depths (8 and 12 cm) on the health and performance of Pekin ducks in an experimental setting. Both depths allowed for partial immersion of ducks' heads and all ducks were found to have similar nostril, eye, and feather cleanliness, as well as performance measures. This is consistent with other studies in this review where depths of at least 8 cm were provided to allow for partial or head immersion (Cooper et al., 2002; Bakken et al., 2006; Jones et al., 2009; Waitt et al., 2009; Liste et al., 2012a,b).

In a commercial setting, Liste et al. (2012a) looked at the effect of water depth (10, 20, and 30 cm) on Pekin duck behavior. Ducks used all water depths but used shallow pools more for sitting and dabbling, and intermediate and deep pools more for sitting and floating with deep pools also being used for swimming. They noted that the water temperature differed depending on depth, with shallow pools having higher temperatures corresponding with the ambient temperature (∼19–22°C) compared to intermediate and deep pools (∼17–20°C) (Liste et al., 2012a). This difference in water temperature influenced ducks' use of water depths, with ducks using shallow pools the most, but spent less time in them when water temperatures were higher. Jones et al. (2009) and Waitt et al. (2009), conducted similar experiments comparing Pekin ducks' use of showers (overhead water), baths (25 cm deep), troughs (8 cm deep), and nipple drinkers. They both found ducks to use all water sources for bathing water-related behaviors, but used showers and baths in particular for socializing and resting in or under. Rather than indicating a preference for water depth, these results suggest domestic ducks use different water depths for different purposes.

When domestic ducks are only able to partially immerse themselves in water, it limits their ability to perform their full repertoire of bathing behaviors. A range of different water sources of varying depths would provide opportunities for performance of all water-related behaviors. Water temperature may affect ducks' behavior and use of water sources. Findings by Liste et al. (2012a) suggest that a minimum water depth could be one way of minimizing water temperature fluctuations so that ducks may choose to use open water sources regardless of ambient temperature changes. However, further research is needed to determine the impacts on behavior and whether there are critical temperature limits (both hot and cold), which prevent ducks from utilizing water sources to fulfill bathing and other water-related behaviors and how this may correspond with ambient temperatures across seasons.

Water Space Requirement

Water use has a social component with domestic ducks showing simultaneous bathing in water regardless of the type of open water source (Waitt et al., 2009; Jones and Dawkins, 2010a; Liste et al., 2012a) and drinking in groups under drinker lines (Rice et al., 2014) (see Section Bathing and Preening Behaviors). The Department for Environment, Food and Rural Affairs (1987) *Ducks: Code of Recommendations for the Welfare of Livestock* states at least 0.5 m of drinking space per 100 birds up to 8 weeks of age, equating to 5 mm per duck. However, there is very little research looking at the minimum water space ducks require for drinking or bathing purposes. Most available research on open water sources has not specified water space allowance for each duck and research with different space allowances has simultaneously compared different water sources making it difficult to conclude on effects of space alone.

In an experimental setting, O'Driscoll and Broom (2011) provided Pekin ducks with either chicken bell drinkers at 20 mm/duck, troughs at 34 mm/duck, or baths at 29 mm/duck. Although behavioral observations were not recorded, ducks with bell drinkers had the dirtiest nostrils, eyes, and feathers, and the worst gait scores. In another experiment, O'Driscoll and Broom (2012) provided Pekin ducks with either chicken bell drinkers at 20 mm/duck, turkey bell drinkers at 29 mm/duck, troughs at 34 mm/duck, or baths at 29 mm/duck. While the greatest proportion of ducks preening was observed at baths, the greatest number of individual ducks preening was observed at troughs. The troughs and baths both had a greater proportion of ducks spending their time preening when near the water, and head-dipping occurred the most with baths in comparison to the drinkers (O'Driscoll and Broom, 2012). Across UK commercial production systems with troughs (4.1–5.9 mm/duck, average 5.3 mm/duck), turkey Plasson drinkers (6.1 mm/duck), and nipple drinkers (2.5–10 mm/duck, average 5.8 mm/duck), the maximum number of ducks using a water source at one time was highest with troughs, then Plasson drinkers, and lowest with nipple drinkers (Jones and Dawkins, 2010a). Conclusions directly on the effect of space alone are difficult, although analyses suggest preening rates were highest when ducks were provided at least 6 mm/duck of water space allowance.

The limited number of studies available highlights the need for further research to determine the minimum space requirements for domestic ducks to both individually and socially engage in water-related behaviors in a commercial setting and how minimum space is likely dependent on the type of water source provided.

Water Location (Indoor vs. Outdoor)

The location of water sources and whether domestic ducks are provided outdoor access may also have an impact on duck behavior and welfare. There is currently little research examining the effect of water source location, with available results on health and performance parameters contradictory (El-Edel et al., 2015; Abdo-Ghanima et al., 2020) (see Section Effects of Water Provision on Health and Performance Parameters).

El-Edel et al. (2015) conducted an experiment comparing an open-sided indoor system without open water and an outdoor system with open water in Pekin and Mulard ducks. Ducks housed indoors performed more body and feather maintenance behaviors and showed more exploratory and aggressive feather pecking behaviors. These findings may have related to the lack of open water access whereby ducks without open water access had to perform more maintenance behaviors and for longer to maintain themselves. It may also suggest ducks without open water access had higher levels of stress in comparison to ducks with open water (see Section Effects of Water Deprivation). It is difficult to draw conclusions around water source location due to the many confounding variables involved when considering outdoor access. However, when comparing indoor and outdoor water sources, open water provision itself does appear to provide benefits independent of those associated with outdoor access. Further research is needed to explore not only the impact of water source location but also variations in factors such as natural light, ventilation, and environment provided by different indoor and outdoor commercial housing systems.

EFFECTS OF WATER PROVISION ON HEALTH AND PERFORMANCE PARAMETERS

Open water sources are important for allowing ducks to perform comfort and maintenance behaviors, which are beneficial for maintaining ducks' eye, nostril, and feather cleanliness and condition (see Section Bathing and Preening Behaviors). However, the potential risks to duck health and hygiene from poor litter and water hygiene management associated with open water sources in a commercial setting is a central motivation for restricting water access for domestic ducks (Erisir et al., 2009;

Jones and Dawkins, 2010b; Liste et al., 2012b, 2013; Klambeck et al., 2017). The appropriate management of both litter and water are therefore crucial for mitigating the risks of any negative consequences and remains an ongoing challenge when providing open water sources to domestic ducks in a commercial setting (see Section Management and Environmental Considerations for Water Provision).

When well-managed, in addition to satisfying domestic ducks' water-related needs, access to open water may also provide health and performance benefits based on studies conducted in predominantly experimental settings. Farghly and Mahmoud (2018) in an experimental setting, compared Muscovy ducks housed indoors without open water to those with outdoor open water access for either 2, 4, or 6 h a day. Ducks with open water access had better mortality rates, body weights, and feed conversion at 12 weeks of age, with water access for 6 h a day resulting in the best performance. Abdo-Ghanima et al. (2020) assessed the impact of open water sources on Pekin ducks in indoor and outdoor experimental housing settings. They found similar results, with ducks with open water access having higher body weights, as well as better feed conversion, immune response, and oxidative stress parameters at 8 weeks of age than those without (Abdo-Ghanima et al., 2020). In contrast, El-Edel et al. (2015) found Pekin and Mulard ducks housed in an open-sided indoor experimental system without open water access had better immunity than ducks in an outdoor system with access to open water. In these three studies, however, it is unclear the influence outdoor access may have had and what results can be contributed to open water access itself [see Section Water Location (Indoor Vs. Outdoor)].

Farghly and Mahmoud (2018) also found Muscovy ducks with open water access to have improved feather condition, less hock discoloration and fewer breast blisters. All ducks had some signs of superficial footpad lesions, with ducks given access to open water for 4 and 6 h a day having the worst. Klambeck et al. (2017) (abstract in English) found Pekin ducks with troughs to have the best footpad condition and ducks with nipple drinkers to have the worst. However, in this experiment, ducks with nipple drinkers were housed on partly slatted floors compared to those with troughs on straw bedding, which likely influenced the results.

Liste et al. (2012b) in an experimental setting showed narrow, intermediate and wide troughs to all be effective at maintaining Pekin ducks' feather, eye, and nostril condition, which was likely because all water sources allowed for partial immersion for preening and bathing behaviors. Low levels of footpad lesions were found in all groups but ducks with access to intermediate troughs had the best foot pad condition (Liste et al., 2012b). O'Driscoll and Broom (2011), compared wide-lip bell drinkers and nipple drinkers in 1,000 Pekin ducks. They found ducks with nipple drinkers to have worse gait scores and to be more likely to have dirty and blocked nostrils. They then conducted a second experiment comparing a chicken bell drinker, a trough, and a bath water source. Ducks with the chicken bell drinker had the worst gait scores and dirtiest nostrils, as well as dirtier feathers and lower body weight at 43 days of age compared to ducks with a trough or bath (O'Driscoll and Broom, 2011). The worse gait scores observed with bell drinkers in both experiments was not related to footpad dermatitis scores, which did not differ between water sources. Heyn et al. (2009) (abstract in English) reported similar findings comparing open water drinkers and nipple drinkers, with open water drinkers positively impacting plumage condition and nostril cleanliness in Pekin ducks.

Findings on feather, eye, and nostril condition suggest that when well-managed, increasing access to open water sources are beneficial for duck hygiene. In addition to this, open water sources may provide performance benefits such as lower mortality rates and higher body weights. Conclusions on health and open water sources, however, should be made cautiously due to most studies being conducted in experimental settings and on a small number of ducks making them difficult to apply to commercial settings. Litter and water hygiene management are critical in the commercial setting and will have effects on bird health as evidenced in the following sections (see Section Management and Environmental Considerations for Water Provision). It is also unclear the impact that other confounding factors such as outdoor access may have on results.

MANAGEMENT AND ENVIRONMENTAL CONSIDERATIONS FOR WATER PROVISION

Litter Management

Litter is important for domestic ducks for thermoregulation, providing comfortable rest areas, and opportunities to perform behaviors such as foraging and rooting (Reiter et al., 1997; Rodenburg et al., 2005; Nicol et al., 2017). For litter to fulfill these purposes it should be dry, friable, and composed of a suitable substrate. Several duck housing systems will provide raised plastic or wire flooring (Karcher et al., 2013; Karcher and Mench, 2018) but for those that provide litter, straw has been the most common type of litter used in research on open water sources, with only two studies using wood shavings (Riber and Mench, 2008; Schenk et al., 2016). This has implications when applying findings to commercial setting where litter types other than straw are used, such as pine or wood shavings, rice hulls, or sawdust. For example, in Australia, wood shavings are predominantly used with daily litter management to ensure litter quality across the growth cycle.

Providing domestic ducks both litter and open water sources in a commercial setting poses management and hygiene challenges due to moist litter and an increased risk of bacterial contamination of water sources (Erisir et al., 2009; Jones and Dawkins, 2010b; Liste et al., 2012a; Klambeck et al., 2017). Increased litter moisture has been consistently demonstrated to increase the risk of foot and leg health issues in ducks (Jones and Dawkins, 2010a,b; Schenk et al., 2016; Klambeck et al., 2017). Schenk et al. (2016) found at 9 days of age Pekin ducks in commercial research settings with troughs to have poorer footpad health and higher mortality than those with pin-metered water lines. However, by 33 days of age, ducks with pin-metered water lines had worse footpad lesions than those with troughs. Pine litter was managed daily to maintain dryness. This result is consistent with other research finding the provision of open water sources in commercial settings to improve footpad condition in Pekin ducks compared to where only nipple drinkers were provided (Jones and Dawkins, 2010b; O'Driscoll and Broom, 2011). These studies used straw (chopped or long) litter that was topped up daily. Ducks' foot and leg health has also been closely linked to ambient temperatures, humidity, and ammonia levels (Jones and Dawkins, 2010b; Liste et al., 2012b). Jones and Dawkins (2010b) suggest that litter moisture levels of <40%, average temperatures <16°C, and ammonia concentrations <11 ppm are best for managing the foot and leg health of Pekin ducks.

Placing open water sources in inappropriate locations such as over, or too close to littered areas can increase the likelihood of moist litter occurring (Erisir et al., 2009; Jones et al., 2009; O'Driscoll and Broom, 2011; Liste et al., 2012b). To avoid this, water sources should be located in areas with adequate drainage and away from littered areas (Liste et al., 2012b; RSPCA UK, 2013; Nicol et al., 2017). This has been demonstrated in several studies conducted in experimental (O'Driscoll and Broom, 2011, 2012; Liste et al., 2012b) or commercial settings (Liste et al., 2012a, 2013). In these studies, litter was provided on a central concreted floor area with grooved concrete ramps along each side leading up to the open water sources on raised drainage areas and perforated plastic floors. Waitt et al. (2009) suggested a similar idea for drainage where showers are used by providing a separate, well-drained area away from littered areas for Pekin ducks to enter when they choose. The use of misting systems directly over litter has also been explored commercially in Australia (Poultry S&Gs Drafting Group, 2016) where the litter is managed because misters are used intermittently during the day for set time periods. For water that may be provided directly over litter, further research is needed to determine if these misting systems adequately satisfy ducks' water-related needs and whether there are any implications when only provided intermittently (see Section Time).

Appropriate management and housing system redesign could provide domestic ducks the opportunity to engage in water-related behaviors while mitigating the potential negative consequences associated with open water provision but needs verifying in a commercial setting. Open water sources may require more frequent litter management to ensure the litter remains dry and the logistics of commercial management would need to be balanced between water output and litter top-ups to ensure ducks do not remain with wet litter for extended periods.

Water Usage and Wastage

Providing open water sources in commercial duck production will increase water usage and wastage (Rodenburg et al., 2005; Damme et al., 2010 as cited in Liste et al., 2013; Schenk et al., 2016), similar to water usage for cooling purposes in other poultry systems (Liang et al., 2020). An unpublished report from a commercial farm in Australia reported a 63% increase in water usage with troughs and nipple drinker provision in comparison to drinkers alone (Poultry S&Gs Drafting Group, 2016). Several factors can influence water usage, including whether the system is self or manual filling, uses a ballcock, and the distance and depth from the water surface to the trough lip.

Liste et al. (2013) and Schenk et al. (2016) in commercial research settings used self-filling, ballcock water trough systems with all troughs emptied, cleaned, and refilled twice per day. Liste et al. (2013) observed narrow troughs with an exposed ballcock encouraged Pekin ducks to peck at it or attempt to perch on it, which caused the troughs to repeatedly overflow. Consequently, intermediate sized troughs used more water than narrow and wide troughs with an average of 3.3 L of water per duck daily compared with 1.5 or 1.7 L of water per duck (Liste et al., 2013). They suggested that using ballcocks that are submerged or inaccessible may avoid this water wastage issue. Schenk et al. (2016) also found water troughs to increase the water usage in the barn relative to sheds with pin-metered lines only for drinking.

Limiting time access to open water sources has been suggested as one way of managing water usage and additional labor requirements (Rodenburg et al., 2005; Liste et al., 2013). However, research is still needed to determine the minimum time requirement and optimal time of day for water access to ensure ducks' water-related needs are being adequately met. Misting systems have also been suggested as a potential solution, where refinements in poultry water sprinkler technology can minimize water usage and wastage (Liang et al., 2020). Ducks use different water sources such as troughs and showers, for different water-related behaviors (see Section Water Depth and Dimension). So while showers or misters may address some of the water wastage concerns in commercial settings more research is needed to determine whether they appropriately satisfy ducks' water-related needs.

Water Hygiene Management

The main factors impacting water hygiene and quality include high numbers of microbiological organisms, contamination level of water, whether the system is self or manual filling, and the volume of water per duck (Liste et al., 2012b, 2013; Schenk et al., 2016). It is difficult to define the limit in which water hygiene for bathing water begins to negatively affect duck health and welfare and many factors could affect the susceptibility of different flocks or individual birds to infections. Currently, most available limits are based on defining palatable drinking water requirements for farm animals with a lack of research on whether there is flexibility in this definition for duck bathing water. Recommendations for the water quality parameters for farm animal drinking water can be found in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC ARMCANZ, 2000), and standards for poultry drinking water in the National Farm Biosecurity Manual Poultry Production (DAFF, Biosecurity Consultative Group 2009).

Liste et al. (2012a) looked at the impact of water cleanliness on Pekin ducks' bathing behavior in a commercial setting. When the water was dirty, ducks spent less time overall in the water with less time sitting during bathing and more time drinking from drinkers. Details as to what constituted dirty water in comparison to clean were not provided but they did note that ducks continued to bath in pools that were very dirty with green algae growing in the corners (Liste et al., 2012a). This finding demonstrates that bathing water may not necessarily need to meet drinking water quality standards where suitable drinking water is also provided.

Open water sources such as troughs have been shown to contain higher numbers of microbiological organisms than nipple drinkers [Knierim et al., 2004; van Krimpen and Ruis, 2011; Liste et al., 2013; Schenk et al., 2016; Klambeck et al., 2017 (abstract in English)]. In all cases the numbers of *Escherichia coli* and total coliforms were unacceptable for drinking quality [*E. coli* >NIL organisms/100 ml and coliforms >100 organisms/100 ml (Biosecurity Consultative Group, 2009)]. Liste et al. (2013) did not find these levels to negatively affect Pekin ducks' health when using the water for bathing and having turkey bell drinkers for drinking water. In contrast, Schenk et al. (2016) observed higher mortality at all ages of Pekin ducks with troughs in comparison to pin-metered water lines, however, troughs were being provided as both drinking and bathing water. This suggests that providing open water sources in addition to drinking water may help mitigate some of the water hygiene challenges in a commercial setting.

While open sources such as troughs can be self-filling, they still require daily cleaning to manage water hygiene, which is an increased labor requirement commercially (Knierim et al., 2004 as cited in Liste et al., 2013; Schenk et al., 2016). Furthermore, adequate drainage such as slatted flooring around the water source is likely needed to prevent the build-up of stagnant water (Liste et al., 2012b; RSPCA UK, 2013; Nicol et al., 2017).

The total depth, volume, turnover rate, and temperature of water provided to ducks are also considerations for water hygiene management (Nicol et al., 2017). Liste et al. (2013) comparing three different open water troughs in Pekin ducks found the deeper intermediate troughs (80.3 ml/duck, 12 cm deep) with the highest water turnover rate to have the lowest microbiological organisms count. While shallower wide troughs (112.9 ml/duck, 8 cm deep) with the most volume of water per duck had the highest microbiological organism count followed by narrow (42.4 ml/duck, 8 cm deep) troughs. They also found Eenterococci and *E. coli* levels to positively correlate with water temperature, which was suggested to contribute to the higher microbiological organism counts in the shallower troughs (Liste et al., 2013).

The management of water hygiene is complex and requires numerous factors to be considered. While there are several suggestions for managing the hygiene of open water sources, to be commercially feasible they need to consider all factors, including the overall water usage and its impact on the future sustainability of the production system.

CONCLUSION

Where provided the opportunity, ducks use open water sources to perform a variety of motivated bathing and preening behaviors, which are important for body maintenance, thermoregulation, and for facilitating social opportunities with other ducks. The opportunity to perform these behaviors also likely benefits domestic ducks' welfare through promoting positive experiences and mental states. Further research is needed still to better understand the complexities of domestic ducks' water-related behavioral needs, as well as what and how certain factors influence their use of water.

To date, there has been limited research on the provision of open water which is applicable to commercial settings and concerns on management, biosecurity, health, and system sustainability are yet to be addressed. Appropriate management of litter and water hygiene are two of the main challenges that require addressing when attempting to provide open water sources to ducks in commercial settings.

From this review the main research gaps remaining include identifying differences in behavior based on domestic duck breed, strain, and age; the minimum time required for meaningful water access; the water space, depth, and volume requirements to satisfy water-related needs; the impact of both ambient and water temperature on water source use; and the suitability of water sources depending on the overall production system. Addressing these research gaps and commercial management concerns in the future will be essential if we are to provide ducks with a water source in which they can derive maximum welfare and health benefits with no adverse health or global water resources consequences.

AUTHOR CONTRIBUTIONS

SB conceptualized and prepared the original draft version of the review and DC provided substantial consultation and edits to the original draft version. Both authors contributed to the reviewing and editing of the final version, and approved the final version of the manuscript.

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Conflict of Interest: SB contributed to this review independently from her work with RSPCA Australia. However, SB has represented RSPCA Australia when providing feedback during the development process of the Australian Animal Welfare Standards and Guidelines for Poultry, which contains ducks within the scope. DC is currently conducting water-related research supported in part by the Australian Duck Meat Association but they did not play a role in the preparation of this review.

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