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Nutritional strategies to support performance of commercial Pekin ducks exposed to a high-temperature thermal challenge over 29–41 days of age

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ABSTRACT

Context. Commercial ducks often experience high temperature in summer and nutritional strategies could help them cope under these conditions. **Aims.** To assess the effects of water and feed supplements on the growth performance of Pekin ducks exposed to high ambient temperature. **Methods.** Commercial Pekin ducks were supplemented with betaine in feed, betaine or vitamin C in water or had feed withdrawn for 9 h/day or provided with water alone, during Weeks 5 and 6 of age. Water was supplemented with an 'in house' electrolyte formulation and betaine in Week 6, only. The treatments were applied to two strains, the Cherry Valley (CV) and a commercial line selected from the CV strain for higher breast muscle yield identified as CVP2. On Days 29–41 of age, shed temperature was increased to 30.5°C for 9 h (08:30–17:30) and then returned to 22.7°C for the remainder of the day. Individual liveweights of ducks were measured on Day 28, Day 35 and Day 41 of age. Feed intake and water consumption were measured over Days 14–28, Days 29–35, and Days 36–41. On Day 41, one male and one female from each pen, were weighed, euthanised and the total breast muscle was removed and weighed. **Key results.** In Week 5, all supplements supported a higher LWG, although this was limited to 4.3–6.3%, with no effects on feed intake or feed to gain ratio. In Week 6, these same supplements provided no benefit and, in fact, vitamin C had a negative effect (−4.7%) on LWG. In Week 6, the electrolyte + betaine improved LWG by 17.1%, with no effects on feed intake or feed to gain ratio. The supplements had no effects on breast muscle weight or yields. The CVP2 selected line had a substantially higher LWG, with nearly all this being due to the 15.8% higher gain seen in males, as LWG of females was similar for both strains. **Conclusions.** Using electrolytes as a nutritional intervention can help Pekin ducks cope with adverse high temperature and should be evaluated under more extreme high-temperature challenges. **Implications.** Water electrolyte supplementation can support Pekin duck performance under high-temperature challenge.

Keywords: adverse high temperature, breast weight, electrolytes, liveweight gain.

Introduction

The Pekin duck (*Anas platyrhynchos domesticus*) is commonly used in commercial production, with the Cherry Valley Farms Ltd (CV), Grimuad Frères Sélection (GF) and Orvia bred strains being the most prominent. Often commercial meat ducks are reared in open-sided housing facilities with minimal environmental control. The birds can experience a range of thermal challenges in summer, resulting in mild to severe thermal stress (Awad *et al.* 2014; Farghly *et al.* 2019). Extensive research efforts have attempted to find nutritional strategies to alleviate the problems associated with high-temperature thermal challenges in broiler chickens (Gous and Morris 2005; Lin *et al.* 2006; Wasti *et al.* 2020). Limited efforts have been directed to this problem in meat ducks. It's probable that some of the nutritional strategies used to alleviate the adverse consequences of severe thermal stress in broiler chickens would be suitable for use with commercial ducks.

Under normal conditions, broiler chickens can synthesise adequate supplies of vitamin C (Khan *et al.* 2012). However, it has been proposed that the rate of synthesis might not be sufficient to meet requirements during severe high-temperature stress (Gous and Morris 2005; Lin *et al.* 2006). Supplemental vitamin C can improve growth and immunity responses of thermally challenged broiler chickens (Attia *et al.* 2011). Feed of broiler chickens supplemented with vitamin C (Vit C) at 200–250 mg/kg has been shown to improve liveweight gain (LWG) and feed to gain ratio while birds are being exposed to high temperatures (Kutlu and Forbes 1993; Sahin *et al.* 2003; Elkheir *et al.* 2008; Kadim *et al.* 2008). Supplementation of water with 20–35 mg/L of Vit C has been shown to improve feed to gain ratio and LWG in broiler chickens exposed to high temperature (Blaha and Kroesna 1997).

Food digestion and the metabolic heat generated add significantly to the heat load of rapidly growing meat birds. Withdrawing feed (FW) during the hottest period of the day reduces metabolic rate, decreasing heat production, body temperature, mortality and abdominal fat in high-temperature challenged broiler chickens (Francis *et al.* 1991; Abhu-Dieyeh 2006; Mohamed *et al.* 2019). Removal of feed for a period of hours before or during a high-temperature challenge can improve performance of broiler chickens (Francis *et al.* 1991; Ait-Boulahsen *et al.* 1993; Hiramoto *et al.* 1995; Mohamed *et al.* 2019). Other studies have reported poorer performance using this strategy (Lozano *et al.* 2006; Abhu-Dieyeh 2006; Uzum and Toplu 2013).

Major functions of betaine are as a methyl group donor, organic osmolyte and natural antioxidant in broiler chickens. These properties support improved performance and carcass traits (Attia *et al.* 2009; Rama Rao *et al.* 2011; Shakeri *et al.* 2018). The improvements have been associated with regulation of osmotic pressure under high temperature by acting to prevent dehydration, helping to maintain water content in cells (Mahmoudnia and Madani 2012). Feed supplemented with betaine at 700–1300 mg/kg has been shown to improve performance of broiler chickens exposed to high temperature stress (Ratriyanto *et al.* 2009; Khattak *et al.* 2012; Park and Kim 2017). Ducks supplied with betaine at 400–1200 mg/L of drinking water and exposed to high temperature have been shown to improve growth performance and this was associated with improved biomarkers of homeostasis in blood (Shin *et al.* 2019).

A physiological consequence of high-temperature stress is a disruption in the birds' acid–base balance. Electrolyte supplementation of poultry feed and/or water is a strategy used to combat the effects of high-temperature stress. Salts of sodium and potassium (NaCl, Na_2CO_3, $NaHCO_3$, KCl, K_2CO_3 and $KHCO_3$) have commonly been used to improve performance of broilers during constant and cyclic high temperature (Smith and Teeter 1989; Lin *et al.* 2006; Mushtaq *et al.* 2013; Downing *et al.* 2017). Electrolyte treatment has been shown to increase fluid intake and body water retention in broiler chickens (Sayed and Downing 2011). While individual electrolyte salts have been used to help broiler chickens cope with high temperature, a combination of Na, K and Cl salts has also supported better performance in broiler chickens (Sayed and Downing 2011; Downing *et al.* 2017).

The research objective was to assess the effects of nutritional supplements on the growth performance of Pekin ducks exposed to high ambient temperature. It is hypothesised that the beneficial effects of some nutritional strategies reported in broiler chickens could be duplicated to the benefit of commercial Pekin ducks during periods of high temperature.

Materials and methods

All experimental protocols were approved by the University of Sydney Animal Care and Ethics Committee and complied with the Australian Code of Practice for the use of Animals for Scientific Purposes (National Health and Medical Research Council (NHMRC) 2013; Protocol: 1-2011/1/5454).

Birds and husbandry

The treatments were applied to Pekin ducks reared as mixed-sex groups, consisting of equal numbers of males and females. A parent Cherry Valley (CV) strain and a commercial line selected for higher breast yield from the parent CV strain, identified here as CVP2, were used. The birds were produced, by the appropriate mating's performed at a commercial breeding farm (Pepe's Ducks Pty Ltd, Sydney, NSW, Australia), with the eggs being incubated at their commercial hatchery. At hatch, the ducklings were vent sexed and transported as 1-day olds to the experimental facility at The University of Sydney, Camden, NSW, Australia.

The experimental housing was a tunnel-ventilated shed, with 48 individual pens, 24 running down each side of the building. The shed was divided into four blocks of 12 pens, with treatments being allocated randomly within these blocks. Ducks were raised on deep litter, consisting of wood shavings that were turned regularly and replaced with new material when excreta contamination became unacceptable. The shed was lit with fluorescent lighting and light was maintained for the full 24 h of each day.

On arrival, 36 ducklings were placed randomly in each pen. Supplementary heat was provided with overhead lamps with a temperature on Day 1 of 35°C, as measured directly beneath the brooder lamps. The temperature was gradually reduced to 28°C by Day 7, to 26°C by Day 14 and then 24°C by Day 21. Birds were identified individually with numbered wing tags fitted on Day 7 of age. In Week 6 of age the number of birds in each pen was 24 with a floor space of 1875 cm^2/bird (13.9 kg/m^2).

Treatments

Six treatments were applied, as follows:

1. Control diet with tap water only.
2. Vitamin C (Vit C): control diet with tap water supplemented with vitamin C at 125 mg/L.
3. Betaine in water (BW): control diet with tap water supplemented with betaine (Betafin®) at 380 mg/L of betaine.
4. Betaine in feed (BF): control diet with betaine (Betafin®) supplemented in the diet at 950 mg/kg of betaine.
5. Feed withdrawal (FW): control diet with daily feed withdrawn during the period of high temperature (08:30–17:30).
6. Electrolytes + betaine (Elec + Bet): control diet with water supplemented with electrolyte salts (sodium chloride 2.0 g/L, sodium bicarbonate 2.175 g/L and potassium chloride 1.125 g/L) and betaine (Betafin®) at 380 mg/L of betaine.

Each treatment was randomly allocated to one pen in each block of 12 pens. This gave the CV and CVP2 lines and six treatments with four replicate pens for each treatment. Treatments 1–5 were applied on Days 29–41 of age, while Treatment 6 was applied on Days 36–41 only. On Days 29–41, the shed temperature was increased to 30–32°C for 9 h/day (08:30–17:30) and then reduced to 24°C for the remainder of the day (17:30–08:30). Temperature and relative humidity were recoded every 15 min with digital monitors placed throughout the shed. A thermal humidity index (THI) was determined using the formula reported by de Moraes *et al.* (2008), where THI (%) = 0.8Tdb + RH (Tdb –14.3)/100 + 46.3. Values were categorised for birds as being 'absolute comfort' (≤72%), as 'light discomfort' (72–76%), as 'discomfort' (77–80%), as 'severe discomfort' (81–84%), and when ≥85%, as creating 'life-threatening conditions' (de Moraes *et al.* 2008).

Diets and feeding

Diets were formulated and supplied by a commercial mill (Inghams Feed Mill, Berrima, NSW, Australia). For the first 2 weeks, ducks were fed a crumble starter diet and the remaining 4 weeks a pelleted grower diet. For reasons of 'commercial-in-confidence' details of the ingredient amounts used in the formulation of the diets are not being made available. The calculated nutrient compositions are given in Table 1. Pens had individual water supply with a row of four nipple drinkers situated along one side of each pen. The drinkers were raised in accordance with duck growth.

Table 1. The nutritional composition of starter and grower diets.

Nutrient	Starter (0–14 days)	Grower (14–41 days)
Protein (%)	22.20	18.80
ME (MJ/kg)	12.45	12.54
Methionine (%)	0.50	0.40
Methionine + cystine (%)	0.85	0.70
Lysine (%)	1.00	0.80
Threonine (%)	0.75	0.60
Tryptophan (%)	0.23	0.16
Cellulose (%)	4.00	5.00
Fat (%)	5.00	7.00
Minerals (%)	6.50	6.00
Calcium (%)	1.00	0.90
Available phosphorus (%)	0.40	0.40
Vitamins:		
A (UI/kg)	13 500	12 000
D (UI/kg)	3000	2000
E (UI/kg)	20	20

Performance and carcass measures

Individual liveweights (LW) were recorded on Day 14 (Week 2), Day 28 (Week 4), Day 35 (Week 5) and Day 41 (Week 6) of age using Wedderburn WS209B digital platform scales. At these same times, feed intake was determined as the difference between weights of feed provided and the weights of feed refused. Water consumption was recorded daily. On Day 41 of age, one male and one female duck were removed from each pen. The total of eight birds (four males and four females) per supplementary treatment were individually weighed, euthanised and the total breast muscle was removed and weighed.

Statistical analyses

Statistical analysis was conducted using the REML linear mixed model function of Genstat® 18th edition (Genstat for Windows 18th edition, version 18.1; VSN International, Hemel Hempstead, UK). Equality of variance was tested using residual plots. When the equality of variance could be improved using a $\log_e$ transformation, data were transformed or values with extreme outlier residuals were removed from the analysis. The fixed model included the effects of treatment, strain, sex and week and the random model included the effects of block, pen and wing tag. Initially, two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests, with a significance threshold of $P < 0.05$. Any non-significant interactions were removed from the model. The least significant difference (l.s.d.), equal to two times the standard error of differences (s.e.d.) was used to make pairwise comparisons of means when significance was recorded.

Results

Temperature and humidity

The average daily shed temperature and relative humidity (RH) over Days 29–41 are shown in Fig. 1. The average temperature over the high-temperature period was 30.5 ± 0.2°C (range: 27.5–32.2°C) and RH was 80.1 ± 3.0%. During the reminder of the day, the average temperature was 22.7 ± 0.1°C (range: 21.8–24.1°C) and RH was 92.2 ± 0.2%. The average THI during the high-temperature challenge was 83.7% and on the basis of the categories nominated by de Moraes *et al.* (2008), this would potentially cause 'severe discomfort' for the birds.

Liveweight (LW)

The performance measures are given in Table 2. For LW, the treatment × week interaction was significant ($P < 0.001$). At the end of Weeks 2 and 4 of age, there was no differences in LW for all allocated groups. In Week 5, the LW of the control and Elec + Bet groups were lower than for birds supplemented with betaine in water ($P < 0.05$). In Week 6, birds receiving the Elec + Bet treatment had higher LW than those in other treatments, except birds supplied with BF (all, $P < 0.05$). Birds supplied with BF had higher LW than those experiencing FW ($P < 0.05$).

The CVP2 birds had significantly ($P = 0.009$) higher LW than did the CV birds at all weeks (CV and CVP2; Week 2, 721 ± 4 and 751 ± 4 g; Week 4, 1792 ± 11 and 1876 ± 11 g; Week 5, 2156 ± 13 and 2278 ± 13 g; Week 6, 2535 ± 16 and 2660 ± 16 g). Throughout the 6-week production, males were heavier than females ($P < 0.001$; males and females; Week 2, 742 ± 4 and 729 ± 4 g; Week 4, 1863 ± 9 and 1804 ± 9 g; Week 5, 2273 ± 11 and 2160 ± 10 g; Week 6, 2700 ± 13 and 2497 ± 12 g).

Liveweight gain (LWG)

Treatment affected the LWG (Table 2), but this depended on week as the interaction between these was significant ($P < 0.001$). There was no treatment × strain interaction ($P = 0.844$). In Week 5, birds allocated to the control and Elec + Bet groups had lower LWG than those in the other treatments ($P < 0.05$). In Week 6, LWG was higher for birds receiving Elec + Bet than for those in all other treatments ($P < 0.05$). The control birds had higher LWG than did those receiving Vit C ($P < 0.05$), while those receiving BF had higher LWG than those receiving Vit C and on FW ($P < 0.05$). The LWG of birds on Elec + Bet was higher in Week 6 than Week 5 when on water only ($P < 0.05$), while for the birds on Vit C, the LWG was higher in Week 5 than Week 6 ($P < 0.05$). For other treatments, LWG was similar in Weeks 5 and 6.

The strain × sex interaction for LWG was significant ($P < 0.001$). Females from both CV (49.1 ± 1.2 g/day) and CVP2 (49.5 ± 1.2 g/day) had similar LWG. Males from CVP2 (67.2 ± 1.2 g/day) had higher LWG ($P < 0.05$) than did males of the CV strain (56.6 ± 1.2 g/day). There was a strain × week interaction ($P < 0.001$). The CV birds had similar LWG in Week 5 (52.5 ± 1.2 g/day) and Week 6 (53.2 ± 1.2 g/day), while for the CVP2 birds, the LWG was higher ($P < 0.05$) in Week 5 (58.1 ± 1.2 g/day) than in Week 6 (54.1 ± 1.2 g/day). There was a week × sex interaction ($P < 0.001$). In both Week 5 and Week 6, males had higher LWG than did females ($P < 0.05$). The LWG of males in Week 5 (59.2 ± 0.9 g/day) and Week 6 (60.1 ± 0.9 g/day) were similar, while for the females, the LWG in Week 5 (51.4 ± 0.9 g/day) was higher than it was in Week 6 (47.2 ± 0.9 g/day; $P < 0.05$).

A difference in LWG between the strains was observed by the Week 2 of age. In Weeks 2 and 4, the CVP2 birds had LWG

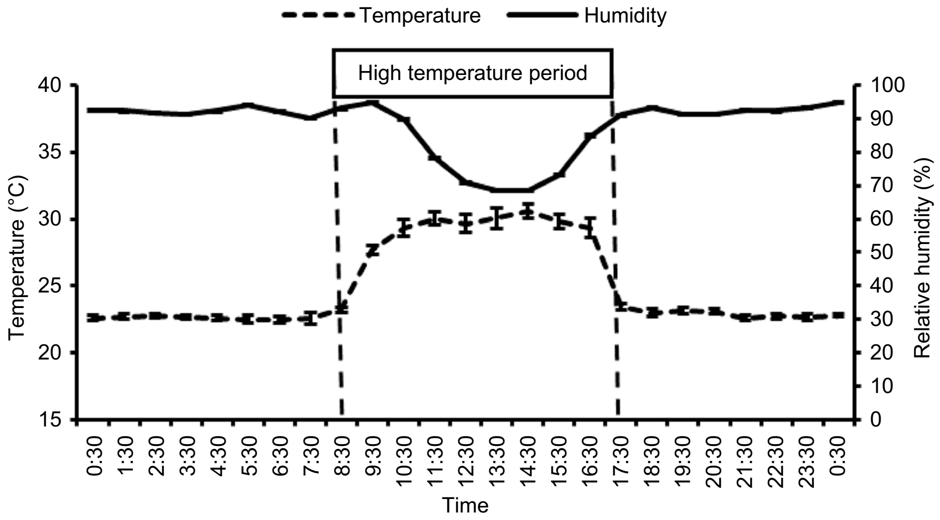

Fig. 1. The average (±s.e.m.) daily shed temperature and relative humidity over Days 29–41.

Table 2. The performance of ducks provided feed or water supplements while exposed to high temperature for 9 h daily during Weeks 5 and 6 of age.

Parameter	Week	Control	BF	BW	Elec + Bet	Vit C	FW	s.e.m.	*P*-value
	2	735	730	739	735	731	743	7	
Liveweight (g)	4	1828	1822	1850	1833	1832	1823	18	T = 0.973 W < 0.001 TW < 0.001
	5	2197b	2222ab	2239a	2204b	2224ab	2213ab	22	
	6	2579bc	2612ab	2599bc	2644a	2581bc	2571c	26	
LWG (g/day)	5	53.3b	56.5a	55.7a	53.3bB	56.9aA	55.9a	2.1	T = 0.762 W < 0.001 TW < 0.001
	6	52.8bc	54.1b	51.8bcd	61.8aA	50.3dB	51.2cd	2.1	
Feed intake (g/day)	5	167	166	174	165	177	168	4.8	T = 0.707 W < 0.001 TW = 0.091
	6	160	161	159	163	161	151	4.8	
Feed to gain ratio	5	3.21	3.02	3.17	3.16	3.18	3.18	0.07	T = 0.128 W = 0.075 TW = 0.682
	6	3.04	2.95	3.14	2.71	3.14	3.14	0.07	
Water intake (mL/day)	5	696	644	689	681	682	698	33	T = 0.677 W < 0.001 TW 0.440
	6	913	858	885	935	857	917	33	
Water to feed ratio	5	4.18	3.89	3.98	4.15	3.89	4.17	0.26	T = 0.622 W < 0.001 TW = 0.853
	6	5.76	5.41	5.60	5.77	5.40	6.10		

Data represent the means and s.e.m. of four replicate pens for each treatment, with 24 birds per pen (12 males and 12 females).
Within a row, the values without common small-case letters are significantly different at $P = 0.05$.
For individual performance measures, values within a column without common upper-case letters are significantly different at $P = 0.05$.
LWG, liveweight gain. Treatments: BF, betaine in feed; BW, betaine in water; Elec + Bet, electrolytes + betaine in water; Vit C, vitamin C; FW, feed withdrawal; T, treatment; W, week; TW, treatment × week.

of 53.9 ± 0.7 g/day and 80.7 ± 0.8 g/day respectively, compared with the CV birds, which had LWG of 51.7 ± 0.7 g/day and 76.9 ± 0.7 g/day respectively ($P < 0.05$).

Feed intake and feed to gain ratio

Treatment ($P = 0.707$) had no effect on feed intake (Table 2). Age had an effect ($P < 0.001$) with a higher feed intake in Week 5 (170 ± 2 g/day) than in Week 6 (159 ± 2 g/day). The CVP2 birds (171 ± 2 g/day) had a higher feed intake than did the CV birds (158 ± 2 g/day; $P < 0.001$).

Treatment ($P = 0.128$) had no effect on feed to gain ratio (Table 2). Feed to gain ratio was similar ($P = 0.075$) for both the CV (3.04 ± 0.04) and CVP2 birds (3.09 ± 0.04). The Week 5 feed to gain ratio (3.14 ± 0.05) was similar ($P = 0.434$) to that for Week 6 (2.99 ± 0.05).

Water intake and water to feed ratio

Treatment ($P = 0.677$) had no effect on water intake (Table 2). Water intake was similar ($P = 0.658$) for both the CV (782 ± 17 mL/day) and CVP2 birds (793 ± 17 mL/day). The Week 6 water intake (894 ± 13 mL/day) was higher ($P < 0.001$) than the intake in Week 5 (682 ± 13 mL/day).

Treatment ($P = 0.622$) had no effect on water to feed ratio (Table 2). Water to feed ratio was similar ($P = 0.116$) for both the CV (5.01 ± 0.13) and CVP2 birds (4.71 ± 0.13). The Week 6 water to feed ratio (5.67 ± 0.11) was higher ($P < 0.001$) than the water to feed ratio in Week 5 (4.04 ± 0.11).

Breast muscle yield

The effects of treatment, strain and sex on breast weight, breast weight expressed as a percentage of final LW and the ratio of feed weight to breast weight are given in Table 3. Treatment had no effect on breast weight ($P = 0.630$), percentage breast yield ($P = 0.497$) or ratio of feed weight to breast weight ($P = 0.630$). Breast weights of males (253 ± 6 g) and females (255 ± 6 g) were similar ($P = 0.865$). Males (22.2 ± 0.6) and females (22.1 ± 0.6) had similar feed weight to breast weight ratios ($P = 0.865$). Females (9.92 ± 0.16%) had greater percentage breast weight to LW ($P < 0.001$) than did males (8.97 ± 0.16%).

Breast weight was higher ($P < 0.001$) for the CVP2 birds (301 ± 6 g) than the CV birds (208 ± 7 g). The CVP2 birds (10.81 ± 0.17%) had higher percentage breast weight to LW ($P < 0.001$) than did the CV birds (8.08 ± 0.17%). The ratio of feed weight to breast weight of the CVP2 birds (18.4 ± 0.6) was lower ($P < 0.001$) than that of the CV birds (25.9 ± 0.7).

Table 3. The breast weight, breast as a percentage of liveweight and the feed to breast weight ratio for Pekin ducks at Day 41 of age and provided with feed and water supplements on Days 29–41 of age while exposed daily to a 9-h period of high temperature.

Treatment	Preslaughter weight (g)[A]	Breast weight (g)	Breast as % of liveweight	Ratio of feed to breast weight
Control	2679 ± 66	246 ± 12	9.18 ± 0.32	22.3 ± 1.2
Vitamin C	2723 ± 65	253 ± 11	9.29 ± 0.29	22.7 ± 1.1
Betaine in water	2702 ± 71	264 ± 11	9.77 ± 0.29	21.8 ± 1.1
Betaine in feed	2656 ± 65	254 ± 11	9.56 ± 0.30	23.4 ± 1.1
Feed withdrawal	2658 ± 65	243 ± 11	9.14 ± 0.29	23.1 ± 1.1
Electrolytes + betaine in water	2733 ± 65	266 ± 11	9.73 ± 0.30	20.6 ± 1.1
P-value	0.970	0.630	0.497	0.630

Data represent the means and s.e.m. of eight males and eight females (one of either sex from each pen) for each treatment.

[A] Day 41 liveweight of birds selected for the breast muscle measurement.

Discussion

On the basis of LWG and THI, the high-temperature thermal challenge resulted in disturbance severe enough to impinge on bird performance. Under thermoneutral conditions, the average LWG of the CV ducks reared as mixed sexes over Days 28–42 was 72 g/day (Downing 2010). On the basis of these observations, the average LWG of CV birds in the current study was about 75% of what could be expected under suitable shed temperatures.

Using the formulae of de Moraes *et al.* (2008), the average daily THI during the thermal challenge was 83.7% and proposed to cause 'severe discomfort' in broiler chickens. This categorisation needs be accepted with some scepticism as ducks may be more heat tolerant than are broiler chickens. The upper critical temperature during the growing period for LW, LWG and feed to gain ratio for ducks were reported to be 27.4°C, 27.4°C and 26.0°C respectively (Sun *et al.* 2019). For growing broilers (3–7 weeks) at 25°C, there was no effect on LWG or feed to gain ratio compared with growing at 20°C, but at 30°C all performance measures were depressed (Donkoh 1989). On the basis of these research outcomes, there is likely a 2–3°C difference in the critical upper temperature before there is an effect on LWG when comparing broilers and ducks. At 80% RH and the critical temperature difference affecting LWG in broiler chickens and ducks of 3°C (25.0 vs 27.4°C), the critical THI at which LWG would be affected is 74.9% for broiler chickens and 75.2% for ducks. This suggests that the 'severity' categories identified by de Moraes *et al.* (2008) for broiler chickens are likely to be adequately stating the potential risk to ducks. The THI of 83.7% determined in the current study is likely to be exposing the ducks to 'severe discomfort'.

In the present study, Vit C supplementation increased LWG by 6.7% in Week 5 but the extended use into Week 6 reduced LWG by 4.7%. Shin *et al.* (2019) provided CV ducks with 100–300 mg/L vitamin C in the water and exposed them to 6 h/day of severe high temperature (33–43°C) from Day 22 to Day 42 of age. At 100 mg/L, the LWG was improved by 9.2% and at 300 mg/L it was 17.1% higher. Kumar *et al.* (2017) exposed ducks to a similar temperature challenge and supplemented water with 300 mg/L vitamin C and included 800 mg/L betaine, and this improved LWG by 52.7% and feed to gain ratio by 18.5%. The explanation for the poor response in Week 6 is difficult to interpret; however, water supplementation at 200 mg/L was found to improve performance in broiler chickens exposed to 32°C in the first week but not in the second week of treatment (Abudabos *et al.* 2018). The thermal challenge used in the present study with the average temperature at ~30.5°C would have resulted is less severe stress than the much higher temperatures used by the others discussed above and could account for the lower responses observed here.

The FW during the period of high temperature improved LWG by 4.9% in Week 5, while again in Week 6 there was no benefit compared with the control birds. Heat load is largely a consequence of feed digestion and the greatest heat production is seen in the morning (Yahav *et al.* 2004), and so early feed consumption generates the highest heat load at potentially the hottest part of the day (Wilson *et al.* 1989). This association can be disrupted by FW in the morning so that heat load is minimised during the hottest period of the day. In Muscovy ducks experiencing summer thermal discomfort, FW daily (08:00–14:00 hours) over Weeks 4–12 of age resulted in a 2.6–3.7% improved LWG without effects on feed to gain ratio (Farghly *et al.* 2019). Other nutrient strategies in combination with FW could support meat ducks more adequately during high-temperature stress. Park and Zammit (2019) exposed ducks of 22–42 days of age to 34°C and implemented FW in combination with betaine supplementation (800 mg/L). The high temperature reduced LWG by 28.6%, while the FW in combination with betaine limited the reduction to 10.2%; however, FW in combination with betaine (800 mg/L) and Vit C (300 mg/L) supported the same LWG as the control treatment exposed to 24°C. Other reports have identified FW as having a negative effect on performance

(Wiernusz and Teeter 1996; Özban *et al.* 2003; Lozano *et al.* 2006; Uzum and Toplu 2013). A concern with FW as a strategy to combat high-temperature stress is whether the birds can compensate when feed is available. This probably depends on the temperature and duration when daily feed is made available.

In Week 5, BF and BW improved LWG by 6.0% and 4.5% respectively, with no benefit in Week 6 compared with water alone. Under longer periods of supplementation and more extreme thermal challenges, betaine use in ducks has been beneficial. When ducks at 21–42 days of age were supplemented with 800 mg/kg betaine and exposed to 33–40°C for 6 h/day, the LWG was 39.2% higher and feed to gain ratio 17.3% better (Kumar *et al.* 2017). A more extensive evaluation of betaine inclusion in feed also gave benefits. Meat ducks exposed to the same thermal challenge (33–43°C for 6 h/day) on Days 22–42 of age and fed a control diet supplemented with 700, 1000 or 1300 mg/kg betaine, had LWG higher by 46–49% and feed to gain ratio better by 12.1%, independent of the inclusion rate (Park and Kim 2017). Park and Park (2017) fed CV ducks feed supplemented with betaine at 1200 mg/kg twice daily (05:00–10:00 hours and 17:00–20:00 hours). Betaine supplementation improved LWG (65.6%) and feed intake (7.9%). Ducks were provided with water supplemented with 400, 800 or 1200 mg/L while exposed to 33–43°C for 6 h/day over Days 22–42 of age (Shin *et al.* 2019). The LWG was increased by 9.8%, 10.4% and 15.7% as the betaine inclusion rate increased, without any effect on feed to gain ratio. Betaine inclusion rates used in the current study were similar to those used in other studies, but the performance improvements were much smaller. These discrepancies are probably due to the severity of the thermal challenges used in the different experiments.

Water supplementation with the electrolytes and betaine improved LWG in Week 6 by 17.1%, with no effects on feed intake or feed to gain ratio. The benefit of betaine is questionable as the water supplementation with betaine alone had no effect on performance in Week 6. A consequence of betaine supplementation in some studies is an increase in blood concentrations of Na^+, K^+ and Cl^- (Park and Kim 2017; Park and Park 2017; Shin *et al.* 2019). This likely improvement to the electrolyte balance of the birds provides a possible reason for the betaine benefits. This potential action of betaine may limit any additional benefit to using betaine in combination with electrolytes.

The Elec + Bet supplement was not included as a treatment in Week 5. This was based on the view that excessive intake of the electrolyte salts could result in acidosis (Hayat *et al.* 1999; Molero 2007). Also, that the electrolytes would increase water consumption as observed in broilers (Smith and Teeter 1989; Smith 1994; Downing *et al.* 2017) and this potentially would result in wetter litter. This later consideration was not supported by the data as there was no effect of any supplement on water consumption.

To compensate for the loss of electrolytes during high temperature, NaCl, KCl, $NaHCO_3$ and NH_4Cl have been used in varying amounts either alone or in combination to support meat chicken performance and survivability during high-temperature challenges (Mushtaq *et al.* 2013). The effect of electrolytes at different inclusion rates has proved beneficial under different challenging temperature regimes. Supplying water supplement with 0.4% KCl or NaCl to broiler chickens (28–49 days of age) with shed temperature ranging 28–36.6°C has been shown to improve LW by 5.8% and 23.3%, and feed to gain ratio by 9.5% and 18.1% respectively (Dai *et al.* 2009). Under high ambient temperatures, providing $NaHCO_3$ in feed or drinking water is reported to improve broiler performance and survivability (Hayat *et al.* 1999; Ahmad *et al.* 2005; Mushtaq *et al.* 2005). Supplementing water with a combination of $NaHCO_3$, NaCl and KCl has been shown to improve the performance of broiler chickens exposed to high temperature (Sayed and Downing 2011; Downing *et al.* 2017; Elshafaei *et al.* 2020). While there is little information as to the role of electrolytes to help ducks with high temperature, the current results indicated that the benefits appear to be the same to those observed in broiler chickens.

The treatments had no effect on the breast weight or percentage breast yield or feed consumed to breast weight. Differences in the severity of the thermal challenge (temperature and duration), bird strain and age are key factors affecting the performance and breast yield in broiler chickens (Rosa *et al.* 2007; Lu *et al.* 2007; Zhang *et al.* 2012). In broiler chickens, exposure to higher temperatures and similar or longer periods than experienced in the current study has been shown to have negative effects on breast weight and yields (Smith 1993; Ain Baziz *et al.* 1996; Rosa *et al.* 2007). In some instances, these effects have been severe. Zhang *et al.* (2012) exposed broiler chickens to a constant 34°C or 23°C on Days 29–42 of age and found that the high temperature depressed breast weight by 31.5%. The negative effects of high temperatures on breast weight and yields in broiler chickens have occurred along with reduced feed intakes. In the present study, there were no effects on feed intake and it is probable that the ducks coped with the environmental conditions to limit any effect on breast weight or yield.

The selection resulting in development of the CVP2 line had substantial effect on bird performance. The LWG was higher in the CVP2 but nearly all of this was due to the 15.8% higher gain seen in males as the LWG of females was similar for both strains. The improved performance of the CVP2 strain was also related to higher feed intake but no benefit to feed to gain ratio. A production advantage of the CVP2 strain is the much higher breast weight and the better efficiency of feed consumed to breast weight.

Conclusions

Nutritional supplements of betaine in feed, betaine and vitamin C in water and limited daily feed withdrawal improved LWG in Week 5 of the high temperature, but this was limited to 4.3–6.3% with no effects on feed intake or feed to gain ratio. Electrolytes + betaine improved LWG but not feed intake or feed to gain ratio in Week 6 of the thermal challenge, while other supplements continued from Week 5 had no beneficial effects. The supplements had no benefit to breast muscle yield. Further studies in use of electrolytes under conditions causing more severe thermal stress in ducks is worthy of consideration.

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