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Divergent Selection for Water Conversion Ratio in Broiler Populations

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Poultry Science

by

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University of Arkansas
Bachelor of Science in Poultry Science, 2016
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This dissertation is approved for recommendation to the Graduate Council.

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Abstract

Water scarcity is a global reality and with the anticipated population growth, freshwater resources will be further strained to meet both human needs and agriculture applications. To ensure a water sustainable and food secure future, all aspects of agriculture must become more efficient. Two strategies were explored. The potential of improving water efficiency in broilers was examined. The first strategy was to develop a more efficient and accurate method for measuring water consumption/inputs in agriculture. To date, water measuring technology has lacked the necessary sophistication to assure accuracy and repeatability of low flow water usage.

After establishing a low flow water monitoring system, it was used to divergently select for water efficiency in broilers. This was done too not only to help determine heritability of water efficiency but to assess the direct response to selection and impact on correlated traits. From a modern random bred population, lines were selected based on water conversion ratio (WCR = water consumed/body weight gain) to create the low WCR (LWCR) and high WCR (HWCR) lines. After generation 2, the LWCR line had an overall WCR of 3.28 while the HWCR had a WCR of 3.46. Body weights appeared to remain similar between the lines with a slight improvement in feed conversion ratio observed in the LWCR line. Continued selection for WCR will provide further understanding of the heritability of WCR and the correlated response to selection on growth and efficiency related traits.

A subsequent study utilized the low flow water monitoring system to evaluate the WCR of four contemporary broiler strains. In addition to live performance measurements, carcass traits at two market ages (day 43 and 56) were evaluated. Differences in WI and WCR were observed. WCR ranged from 2.813 to 2.887 at 42 days and 3.230 to 3.379 at a market age of 56 days, respectively. Per bird WI ranged from 8.563 to 9.892 at day 42 and 13.903 to 15.668 at day 56.

The final section of this dissertation addresses steps that can be taken to assist in broiler breeder egg management to improve hatchability of eggs in tropical climates. Over the past 60 years, poultry has proven to be the most efficient and popular protein available, emerging as a food staple in less developed areas of the world. As a result, integrated poultry operations continue to push production in suboptimal environments lacking modern infrastructure and technology. Although the genetics/efficiencies of the modern-day broiler mask many of these shortcomings, the harsh environmental/climatic influences are less forgiving. The extreme temperatures of these climates pose new challenges within the poultry biological supply chain, that of which are overlooked by producers. Results show that implementation of data loggers can successfully track and identify temperature abuses of eggs from the nest through incubation and out in the field after chick placement. This technology can aid in the troubleshooting of temperature related challenges contributing to embryo and early chick loss.

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INTRODUCTION

Global Water Consumption

It is estimated that nearly 5 billion people or two-thirds of the global population lives under conditions of severe water scarcity (volumetric availability) for at least one month a year and 2.3 billion live in water-stressed (ability to meet human and ecological demand),countries, of which 733 million live in high and critically stressed countries (Mekonnen and Hoekstra, 2016; UN-water, 2021). Furthermore, the United Nations Department of Economic and Social Affairs and FAO estimate that the global population will grow to 8.6 billion by 2030 and 10 billion by 2050 (FAO, 2017; United Nations Department of Economic and Social Affairs Population Division, 2017). To support this future population growth, it is projected that the current food supply must increase by 60% (Alexandratos and Bruinsma, 2012). This increase in food supply will ultimately result in concurrent increases in freshwater demand. Total water consumption will increase 20 to 30% by 2050 (Boretti and Rosa, 2019).

Agriculture accounts for 72% of all water demand, followed by 16% for municipalities' households and services, and 12% by industries (UN-water, 2021). Cereal grains and other input grains for animal feed/production account for most of the water use in agriculture followed by the consumption by livestock. Of the livestock species characterized by Mekonnen and Hoekstra (2016) poultry is the most efficient followed by pork then beef.

Over the past 60 years, poultry has proven to be one the most efficient and popular edible protein sources available, emerging as a food staple in both water secure and stressed environments. Broilers have the lowest water footprint of any animal meat protein and eggs are one of the most nutritious and efficient animal products available (Mekonnen and Hoekstra, 2012). Currently poultry is raised by 80% of households in developing countries (FAO, 2020) and considering the efficiencies of both the broiler and table egg industries this number

expected to grow. In fact, since 1960 the global per capita consumption of eggs has doubled, while poultry meat consumption has increased fivefold (FAO, 2020). With the anticipated population growth consumption of poultry products is expected to increase especially in developing countries, most of which are completely or partly water stressed. As a result, poultry products will be a substantial part of the global protein supply for decades to come.

Water Consumption in Broilers

Water Metabolism

Water is the single most important nutrient in biology. Unlike food, life cannot sustain itself without water for an extended period. Like many animals, water constitutes about 70% of body weight in chickens (Leeson et al., 1976). Bird composition as it relates to water percentage fluctuates as the bird ages with water content being higher in younger birds due to the demanding growth requirements post hatch (Leeson et al., 1976). Water serves as the single most important regulator with respect to cellular homeostasis. Seventy percent of this water is contained intracellular and the remaining 30% is extracellular (Leeson et al., 1976). Within the extracellular makeup, 75% is found in the interstitial space and the remaining 25% in the plasma (Leeson et al., 1976). Water plays crucial roles in many metabolic and physiological processes including transportation of nutrients and hormones, conducting gases, nutrient homeostasis, and facilitation of transport and elimination of waste and by-products. Water also plays in integral role in thermoregulation of the bird.

Chickens obtain and maintain water from three sources; drinking, dietary and metabolism (Dirk et al., 2013; Leeson et al., 1976). Drinking water accounts for 70-75% of the bird's water balance while dietary water accounts for 12-15% of the balance. The remaining water is obtained from metabolic processes, more specifically the oxidation of nutrients (Dirk et al., 2013; Karamas, 1973; Leeson et al., 1976). Drinking behavior and water balance is in large

part controlled by hypothalamic control centers via neruo-hormonal feedback systems (Bailey, 1990; Larbier and Leclercq, 1994; Wayner and Sporn, 1963). Extracellular hyperosmolarity is facilitated by receptors for osmotic pressure and or ions like Na^+ (Larbier and Leclercq, 1994) when birds experience dehydration. Other organs responsible for water balance/reabsorption such as the kidney, are much less effective in avian species when compared to mammals. The avian kidney can only concentrate urine up to a maximum of 2-3 times the osmolality of plasma, compared to the mammalian kidney which can concentrate urine up to 5 times the osmolality of plasma (Collett, 2012). To compensate for kidney function, a large proportion of ureteral urine is absorbed in the coprodeum and caeca as a means to regulate water balance and maximize water retention (Bindslev and Skadhauge, 1971).

Most water absorption takes place in the intestinal tract of the bird. This occurs against an osmotic gradient that is solute-linked and dependent on sodium absorption (Van Der Klis et al., 1993a,b). The efficiency of water absorption is dependent on gastrointestinal health and function (Dirk et al., 2013). High intestinal viscosity within the small intestine has shown to reduce sodium and water absorption and increase water consumption. As a result, the coprodeum and caeca were responsible for higher water and sodium absorption and played a larger role in water balance regulation (Dirk et al., 2013). Increasing intestinal viscosity also facilitates a more active microbiota which can potentially initiate inflammation of the intestinal epithelial. As a result, paracellular permeability increases and causes a surge of water into the intestinal lumen and increased excreta moisture content (Collier et al., 2003; Van Der Klis and Versantvoort, 1999).

Physiological water loss or output primarily occurs in two ways, excreta and hot birds. Excreta is constructed of urine and feces. Original estimates have fecal matter composed of 60-70% water (Kerstens, 1964) while more recent data suggest feces suggest 75 to 80% water (Dirk et al., 2013). The second component of excreta is urine and urine is estimated to be 50%

water. Considering the compositions of both feces and urine most of the water output is generated through excreta. Broilers also lose moisture via respiration, more specifically evaporative loss (Kerstens, 1964). Evaporative loss primarily occurs within the moist surface layers of the respiratory tract. The inhaled air within the tract is saturated with water vapor at body temperature. Consequently, evaporative rate is proportional to respiratory rate (Kerstens, 1964). When birds are exposed to high environmental temperatures, birds will pant to help regulate body temperature i.e., evaporative loss. When birds pant, warm moist air is exhaled resulting in water loss and body temperature is cooled slightly. The efficiency/efficacy of evaporative loss depends heavily on environmental humidity. High humidity results in poor evaporative loss and thermoregulation as the moist air inhaled is already saturated with water and does not allow for proper/efficient evaporative loss.

Measuring Water Intake

Water intake (WI) has been measured in many ways over the last 40 years. Most WI measures have been on the flock level while only a few were attempted on the individual bird level. Marks (1980; 1981) utilized mason jar waterers and modified soft drink bottles to measure WI of selected and nonelected broiler lines. In these studies, water to feed ratios ranged from 1.3 to 2.6 with birds having a higher ratio in the first two weeks of production (Marks,1980; 1981). Although WI values varied between the experiments water to feed ratios were consistent with other literature. Gardiner and Hunt (1984) measured WI of 800 broilers using 200L graduated cylinders which suppled 2 36cm circular waterers. Gardner and Hunt found weekly broiler water consumption to be 226.4 L/ 1000 birds in week 1 and 2353.7L/ 1000 birds for week 9. Water to feed ratios varied from 1.34 to 2.06 and water to gain was 2.60 to 3.60. Gardiner and Hunt (1984) recorded some of the earliest broiler water to gain or water conversion ratio (WCR) measurements, in the literature. Over a 3-year period Pesti (1985) measured the consumption of 24 flocks reared between two broiler houses. Water was

delivered through 200 mini drinkers and then birds were transitioned to 100 2.44m water troughs. Pesti observed water to feed ratios of 1.77 and around 2.0 during the summer months (Pesti, 1984). Pesti also developed a prediction equation (Water consumption = 5.28g X bird age (days)) to determine water consumption at any age. Williams and colleagues (2013) characterized water consumption of flocks grown in 1991, 2000-2001, and 2010-2011. Williams utilized large scale inline flow meters to measure WI in commercial style housing. Williams observed differences between all grow periods with respect to WI (liter) per 1000 birds. During the 1991, 2000-2001, and 2010-2011-time frames water per 1000 birds were as followed: 140.33 liters/1000 birds, 160.54 liters/1000 birds, and 190.48 liters/1000 birds respectively. Water to feed ratios were calculated as 1.90, 1.98, and 2.02 respectively (Williams et al., 2013). McCreery (2015) measured water to feed ratios utilizing the same methods as Williams and coworkers (2013). Average water to feed ratio for the study was 1.77. Perhaps the most recent study measured WI of a 2015 randombred broiler strain at the individual level as well as pen level (Hiltz et al., 2021 (Chapter 1); Orlowski et al., 2020). Hiltz and colleagues developed a system and process for measuring low flow water in a floor pen and individual cage setting. Hiltz et al. (2021 (Chapter 1) observed more variation with respect to water to feed ratios and WCR when measuring water at the individual bird level. The technology can be used as a selection tool to select a broiler population for water efficiency (Hiltz et al., 2021 (Chapter 1)).

Factors Affecting Water Intake

Management

Management can influence WI in a multitude of ways. The most notable include environmental temperature, photoperiod and light intensity (drinking behavior), stocking density, and waterline height. Environmental temperature and its association with heat stress effects on WI are well documented in the literature. Wilson (1948) was one of the first to demonstrate the adverse effects that heat stress has on poultry. Wilson (1948) observed increased body

temperatures and respiration rate in addition to reduced water and feed intake when birds were exposed to temperatures exceeding 35°C (95°F). Wilson noted WI at 35°C (95°F) was doubled that of consumption at 21°C (70°F) (Wilson, 1948). Donkoh (1989) also demonstrated the effects of heat stress on WI. Donkoh reared broilers under four different ambient temperatures, 20, 25, 30, and 35C° (68, 77, 86 and 95°F). The birds raised at 30 and 35°C (86 and 95°F) consumed more water than the two lower temperature treatments. Lott (1991) observed that metabolic heat generated from feed digestion contributed to an increase of WI during heat stress. May and Lott (1992) demonstrated increase WI and decreased feed intake (FI) due to cyclic heat stress treatments. Belay and Teeter (1993) showed increased temperatures of 35°C versus 24°C (95°F versus 75°F) increased overall WI and excreta output. Increased air velocity utilizing tunnel fans also has been shown to impact WI (Lott et al., 1998; May et al., 2000).

Although the effects of both light intensity and duration have been well documented (Buyse et al., 1996) a direct effect or correlation with respect to WI is still unknown. Drinking behavior has been observed but only regarding when birds consume the most water during lights on. Broilers consume the most water immediately after lights come on and before lights go out in anticipation of the dark period (Fairchild and Ritz, 2009; McCreery, 2015). More research is needed to determine the effects of light intensity, duration, and wavelengths on WI in broilers.

Evaluations of stocking density has been characterized for a plethora of reasons including economics, welfare, meat quality, performance, and mortality (Abudabos et al., 2013; Cravener et al., 1992; Deaton et al., 1968; Dozier et al., 2005; Feddes et al., 2002). Feddes and colleagues (2002) raised birds at four different stocking densities and recorded performance and carcass traits. Differences between WI were observed only within the highest and lowest density treatments. However, differences were found for water to feed ratio between the two highest and the two lowest densities (Feddes et al., 2002).

Differences between watering systems have been observed by May and colleagues (1997), but since most of the industry utilizes nipple drinking systems, WI utilizing bell watering systems will not be reported in this review. Open/bell type waterers are not utilized in commercial settings because of challenges associated with maintenance and litter issues sand were phased out by the industry due to the aforementioned reasons. While implementing nipple drinker systems two factors (nipple line height and flow rate) are important when considering broiler performance and WI. Lott and colleagues (2001) raised birds at three different nipple drinker heights low, medium, and high. They observed that as drinker height increased BW decreased and FCR increased. Both very high and lowly placed nipple drinking lines can lead to water waste and poor litter quality. As noted by Lott, drinking from a nipple system is an unnatural drinking motion for broilers and the birds that consumed water from open water sources performed better (Lott et al., 2001).

Another factor to consider while using nipple drinker systems is the flow rate of water out of the nipple. Carpenter and colleagues (1992) conducted two trials to evaluate bird performance and mortality rate between two different flow rates. The first was a low flow nipple 0.4mL/s and the second was a high flow nipple 2.3mL/s. The first trial had an acute heat stress treatment during a normal grow out period and the other trial occurred in the summer. Overall differences in BW and mortality rate were observed in both experiments with high flow nipple performing better than the low flow nipple (Carpenter et al., 1992).

Diet + Nutrients

Diet and dietary factors affecting WI in broilers have been well documented over the last 70 years. Most notably excess nutrients within the diet and factors such as feed particle size can influence water consumption. Fiber inclusion in diets has been shown to affect WI in broilers. Van Der Klis et al (1999) studied the impact of dietary fiber on broiler performance. In this study they added 3% citrus pectin (a soluble viscosity increasing fiber) a 5% inert fiber, oat

hulls and finally a corn/soy control diet. Adding the citrus pectin increased WI and water to feed ratios whereas adding oat hulls as inert fiber had the opposite effect (Van Der Klis et al.,1999). The adverse effects of non-starch polysaccharides (NSP) are well known and have been characterized (Van Der Klis et al., 1993; Garcia et al., 2008). The addition of NSP's in the diet have been shown to increase WI and water excretion in broilers. NSP enzymes are used to remedy the adverse effects of NSPs (Van Der Klis et al., 1993; Garcia et al., 2008).

Early studies by James and Wheeler (1949) explored the relationship of dietary protein on WI in Rhode Island Red chickens. Birds were fed three diets containing different levels of protein 15, 20, and 25%. The birds fed the 15% protein diet consumed the least amount of water while the birds on the 25% protein diet consumed the most. Marks and Pesti (1984) also compared broiler performance utilizing high crude protein diets of 17% and 26% via high levels of soybean meal. The higher level of dietary protein yields higher WI. More recently researchers have used high and low crude protein diets to demonstrate changes in broiler performance and WI (Alleman and Leclercq, 1997; Mushtaq et al., 2013; van Emous et al., 2019).

Sodium and chloride also influence water consumption in poultry. Darden and Marks (1985) showed that increased levels of dietary salt increased water consumption and higher water to feed ratios in quail populations. Interactions of sodium and chloride levels in drinking water and the diet have been explored by Watkins and colleagues (2005). Levels of sodium and chloride exceeding acceptable requirement levels (50 mg/L for sodium and 250 mg/L chloride) had an adverse effect on broiler performance. Depending on the levels of sodium and chloride found in the drinking water adjustments in the diet should be made to ensure optimal levels are not exceeded (Watkins et al., 2005).

Feed form and particle size affecting broiler performance and more specifically WI has been characterized for some time. Preliminary studies evaluated the effect of different feed forms of fine, medium, coarse, and pellets (Eley and Hoffmann, 1949). No significant differences regarding WI and respective feed form were found. A more recent study by Serrano and

colleagues (2013) observed that broilers fed a mash diet between 19 to 25 days of age consumed less water than broilers fed a crumble or pellet feed form.

Genetics and Sex

Genetics also plays a role in water consumption of broilers. Marks (1980) measured water and feed intake of selected and non-selected broilers lines. Marks demonstrated that selected lines consume more water and feed than non-selected broilers, but the selected broilers had higher water to feed ratios. Williams and colleagues (2013) characterized water consumption of flocks grown in 1991, 2000-2001, and 2010-2011. Although genetics were not discussed broilers grown in each decade represent snapshot of the different genetic packages within the industry. As previously mentioned during the 1991, 2000-2001, and 2010-2011time frames water per 1000 birds consumed increased: 140.33 L/ 1000 birds, 160.54 L/ 1000 birds, and 190.48 L/ 1000 birds, respectively. Water to feed ratios were calculated as well: 1.90, 1.98, and 2.02, respectively (Williams et al., 2013). In an unpublished study, Hiltz and colleagues (Chapter 3) measured water consumption of four contemporary broiler packages. Strain and sex effects for WI were observed throughout the 56-day trial. Sex differences regarding WI were also characterized by Marks (1985). Marks observed that males consumed 4 to 9% more water for the duration of the trial.

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CHAPTER 1: DEVELOPMENT OF A NOVEL LOW FLOW WATER MONITORING SYSTEM IN AGRICULTURE/POULTRY SYSTEMS

Abstract

Water scarcity is a global reality and with the anticipated population growth, freshwater resources will be further strained to meet both human and agriculture applications. To ensure a water sustainable and food secure future, all aspects of agriculture must become more efficient. Two strategies were explored. The first strategy was to develop more efficient and accurate method for measuring water consumption/inputs in agriculture. To date, water measuring technology has lacked the necessary sophistication to assure accuracy and repeatability of low flow water usage. The second strategy utilized the improved water measuring technology, to develop water efficient genetics in agricultural populations (i.e., row crops, avian and mammalian species) and evaluate nutrition related associations. Although this low flow water monitoring system has applications in many agriculture/research fields the current research focuses on measuring water consumption in the commercial broiler.

[1]Introduction

It is estimated that nearly 5 billion people or two-thirds of the global population lives under conditions of severe water scarcity for at least one month a year and half a billion people live under severe water scarcity year-round (Mekonnen and Hoekstra, 2016). Furthermore, the United Nations Department of Economic and Social Affairs estimates the global population will grow to 8.6 billion in 2030 and 9.8 billion in 2050 (United Nations Department of Economic and Social Affairs Population Division, 2017). To support this future population growth, it is projected that the current food supply must increase by 60% (Alexandratos and Bruinsma, 2012). This increase in food supply will ultimately result in concomitant increases in freshwater demand. To

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meet the projected demand, all aspects of agriculture must continue to improve efficiency in production and processing. Ongoing improvements in nutrient utilization is also key.
Water is the most important nutrient in agriculture, but it is often overlooked because it is difficult to measure. For broilers, the expectation is that the flock will maintain normal hydration, therefore, water intake (WI) is considered a constant relative to feed intake unless influenced by environmental factors. Limitations in the ability to accurately measure water consumption in broilers has hindered the understanding of its heritability and potential correlations with economically important traits.

Characterization of water consumption for broilers on a flock level has been informative (Marks, 1980, 1981; McCreery,2015; May and Lott, 1992; Pesti et al., 1985) but is of little use in determining bird to bird variation. Previous studies measuring WI of broiler flocks utilized large scale flow meters on commercial style houses (McCreery, 2015). This technology successfully monitored WI over the life of the flock but failed to provide bird to bird variation in water consumption required for intense genetic selection on a pedigree level. Gardiner and Hunt (1984) attempted to measure water consumption in a floor pen setting using 200 L graduated container. Marks (1980) utilized modified soft drink bottle waterers in addition to conventional mason jar bell waterers, to measure WI of weight selected and non-selected lines of broiler chickens. The water measure methods employed by Gardiner and Hunt (1984) as well as Marks (1980) were much different than a conventional vertical drinking action nipple watering system and are not representative of current industry water systems. It would be ideal to identify a low flow water meter capable of measuring intermittent quantities of water characteristic of a single bird. Unfortunately, candidate meters that could be adapted are cost prohibitive. The objective of this research note was to introduce a novel industry relevant technology with the capability of measuring intermittent low flow water usage in poultry floor pen and individual cage systems. Water consumption technology will be extended to investigate the genetic parameters associated with WI and explore the possibility of developing water efficient poultry.

Materials and Methods

The University of Arkansas Institutional Animal Care and Use Committee approved the experimental procedures involving live birds under protocol #18083. Preliminary research measuring water consumption in broilers was conducted using traditional methods of measure. Watering nipples were fitted on the bottom of plastic 5-gallon containers and were suspended over each pen. This method was discontinued after a single trial because of repeated water leaks. Two additional variations of individual gravity fed prototypes were studied but abandoned because of problems with airlocks and inconsistent pressure regulation leading to leakage and waste.

Experiment 1: Floor Pen Water System

The next generation water monitoring system was designed for measuring water consumption for birds reared in an individual floor pen or for a single bird cage application (Image 1). Briefly, the floor pen application utilized Lubing waterlines and nipples to deliver the water from a pen dedicated, sealed, pressurized water reservoir. A controller housed in the regulation box was used to sustain a constant pressure of 6 psi on the water to the nipple drinker water line (Image 1). This pressure was determined based on achieving a nipple flow rate of 45 ml/min and assuring no system leakage. This solved the need for reservoir suspension as would be necessary for gravity fed systems. An internal microprocessor maintained real-time pressure regulation (Image 1). To measure water consumption, each water reservoir was filled, weighed, and connected to the pressure regulator box. After the sampling period, the reservoir was disconnected from the drip free connector and weighed. Water intake (WI) was calculated as the weight change (1 g water = 1 mL water) from start to finish of the trial period. This version of the floor pen application simultaneously supported water distribution to four different floor pens. Each floor pen had the water reservoir capacity of 7.6 L.

To test the floor pen system, a pilot trial was conducted with six regulation devices servicing 24 floor pens (1.32 m x 3.66 m). Each floor pen was equipped with two commercial

hanging feeders and a nipple drinker line (2 nipple drinkers/pen). In addition to the conventional nipple drinker line, each floor pen had one supplemental one-gallon waterer during the first week of the trial period. The supplemental waterer was included to guarantee adequate welfare by ensuring birds had access to water given the unproven performance of the novel water monitoring system.

A total of 650 fully pedigreed broiler chicks were generated from a 2 week egg collection from the 2015 Modern Randombred line (Orlowski et al., 2020) housed at the University of Arkansas poultry research farm. Chicks were hatched, wing banded, vaccinated for Marek's disease and randomly assigned to floor pens based on sire family. Each sire family consisted of all offspring generated from 3 dams mated to a single sire. Broilers were fed a commercial starter diet (Day 0 to 28) formulated to meet or exceed NRC requirements. Weekly WI, feed intake (FI) and individual BW was recorded for each floor pen. Each water line and regulation device were monitored for leaks to ensure accurate WI data.

Experiment 2: Individual Cage Water System

The individual bird low flow monitoring system was designed to be utilized in a feed conversion cage system where an individual bird's FI and WI could be monitored. The individual system closely resembled the floor pen system but on a smaller scale with water reservoir capacities of 4 L. Each regulation device housed four cage dedicated reservoirs constantly delivering a desired water pressure of 0.5 PSI to each individual nipple waterer cage setup. An initial pilot study utilizing the individual low flow monitoring system was conducted on 74 male broilers from the 2015 Modern Randombred line (Orlowski et al., 2020). The male broilers were taken directly from experiment 1 and represent the top 6 and bottom 6 sire families based on water conversion measured in experiment 1 from 1 to 4 wk of age. Water conversion ratio (WCR) was calculated as WI (g) / BWG (g) over the same time period. The selected broilers were housed in individual cages (0.46 m x 0.31 m x 0.41 m) fitted with feed conversion bunkers and a nipple waterer leading to the pressure monitoring device. The male broilers were

individually caged at 5 wk and allowed 2 wk to acclimate. Weekly WI, FI and BW was monitored during the acclimation period and used to identify birds that did not transition well to the cage system. The data presented represents individual bird WI, FI and BW data collected from 7 to 8 wk. A commercial finisher feed and water were provided *ad libitum*.

To demonstrate the efficacy of the novel technology Pearson correlations were calculated by wk for WI per floor pen and average WI per bird by sire family. For the individual cage water consumption analysis, data were presented as a scatter plot of individual bird WI verses other traits of economic importance. Best fit regression line was provided. All statistics were analyzed utilizing JMP Pro 15.4.

Results and Discussion

Experiment 1: Floor Pen Water System

In general, the novel low flow water system was able to characterize WI in a floor pen setting. Average WI $\pm$ SD per bird was 344 $\pm$ 46 wk 0 to 1, 797 $\pm$ 57 wk 1 to 2, 1245 $\pm$ 66 wk 2 to 3 and 1789 $\pm$ 103 for wk 3 to 4. These WI measures were some the first recorded values for modern-day broiler water consumption. In general, these WI values were consistently higher than found by Pesti et al., 1985. This is likely associated with BW since the 1985 broiler was substantially lighter, having half the weight of the modern broiler tested in this study. Pesti et al., (1985) estimated a daily water consumption standard of 5.284 g x age (day). For this study, a similar predictor would be 10.26 g x age (day). Considering WI in relation to gain allowed for the calculation of average WCR $\pm$ SD; 3.40 $\pm$ 0.58 wk 0 to 1, 2.88 $\pm$ 0.26 wk 1 to 2, 3.02 $\pm$ 0.28 wk 2 to 3 and 3.23 $\pm$ 0.21 for wk 3 to 4. The higher WCR for wk 0 to 1 is due to the inclusion of the supplemental waterers. The general increase in WCR from wk 1 to 4 reflects the greater maintenance cost as the bird ages.

Water measurement using the novel system described in this article allowed for the accurate and repeatable measure of WI in a floor pen and individual cage system. Since chicks were placed by sire family there were different stocking densities across floor pens. However,

crowding in this trial was never an issue regardless of the density as the lowest floor space per chick was 0.13m^2 (1.4 ft^2) to 4 weeks. The ability of the water system to distinguish between high density verses low density floor pens was the first comparison. All correlations between WI measures by wk were high and significant (Table 1). In fact, the only correlation below 0.9 was between wk 0 to 1 and 3 to 4 as expected. The strong WI relationship for pens with different stocking densities was not surprising but it does support the ability of the system to deliver water without disruptive water loss or limiting intake.

When expressing WI on a per bird, per pen or per wk basis, significant correlations were found (Table 1). Although not as strong as whole pen comparisons, significant correlations were strongest between single wk intervals (wk 0 to 1 and 1 to 2, 1 to 2 and 2 to 3 and wk 2 to 3 and 3 to 4). When extended to a 2-wk interval (wk 0 to 1 and 2 to 3 and 1 to 2 and 3 to 4) correlations were still significant but lower. No correlation was found for individual per bird WI between wk 0 to 1 and 3 to 4. Supplemental waterers were used for the first week of production and as a result water usage lost to evaporation or spillage inflated wk 0 to1 WI. Regardless, these results are encouraging since they support the expectation that high-water consumption birds maintain high consumption over time while low consumption birds continue to be low.

Experiment 2: Individual Cage Water System

Chicks were housed in floor pens by sire family to use results from the floor pen low flow water system to preselect birds from high and low water conversion families. At 5 weeks, a total of 96 males from the high and low groupings were moved to individual cages fitted with nipple waterers driven by a low flow cage system. Birds were allowed 2 weeks to acclimate. After elimination of birds that did not have complete data or failed to acclimate to the individual cage environment, 74 males remained.

WI from 7 to 8 wk was compared with traits of economic importance in Figure 1. In general, there was a slight positive relationship between WI and 8 wk BW (Figure 1a). The heaviest birds consumed the most water as expected but there was a large proportion of the

population that had relatively high 8 wk BW and average WI. Figure 1b displayed a positive linear relationship between WI and 7 to 8 wk BWG. Although there appeared to be a positive relationship, many of the birds showed variation in how they utilize/convert water into live weight. A slight negative relationship was observed for WI and FCR (Figure 1c). This plot exhibited the most variation within the flock and showed that feed utilization is not an obvious function of WI. The most conclusive linear relationship was between FI and WI (Figure 1d). Although the literature has often deemed W: F ratios to be 2.0 (Gardiner and Hunt, 1984; Marks, 1980, 1981); there is more variation than expected. Variation of water conversion ratio among the selected males was much larger. The most efficient individual had a WCR of 2.96, conversely the most inefficient individual yielded a WCR of 7.40. The average WCR of the population was 4.89 ± 1.02 for 7 to 8 wk of age.

Conclusion

Given the results of this preliminary trial using the novel water consumption technology data, new relationships between production traits as influenced by WI can be explored. Water to gain relationships have been previously described by Gardiner and Hunt (1984). Given the water measuring methods and the genetic lines utilized in their experiment, it would be interesting to reevaluate water utilization with the new system and today's commercial broiler. Furthermore, this system can be easily adapted to a real time WCR by committing a load cell to each reservoir. WCR could be added as a selection parameter for geneticists, as undeniably water will become a variable input cost. The performance and efficacy of the novel low flow water monitoring system was validated as an effective and sustainable way to measure individual bird water consumption. The low flow watering system will continue to be developed into a comprehensive industry application. Other versions of the low flow monitoring system are being developed for a lab animal, livestock, and horticulture application. This novel technology provides geneticists and researchers across all species an effective selection tool vital to the development of water efficient genetic lines.

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Figures and Tables

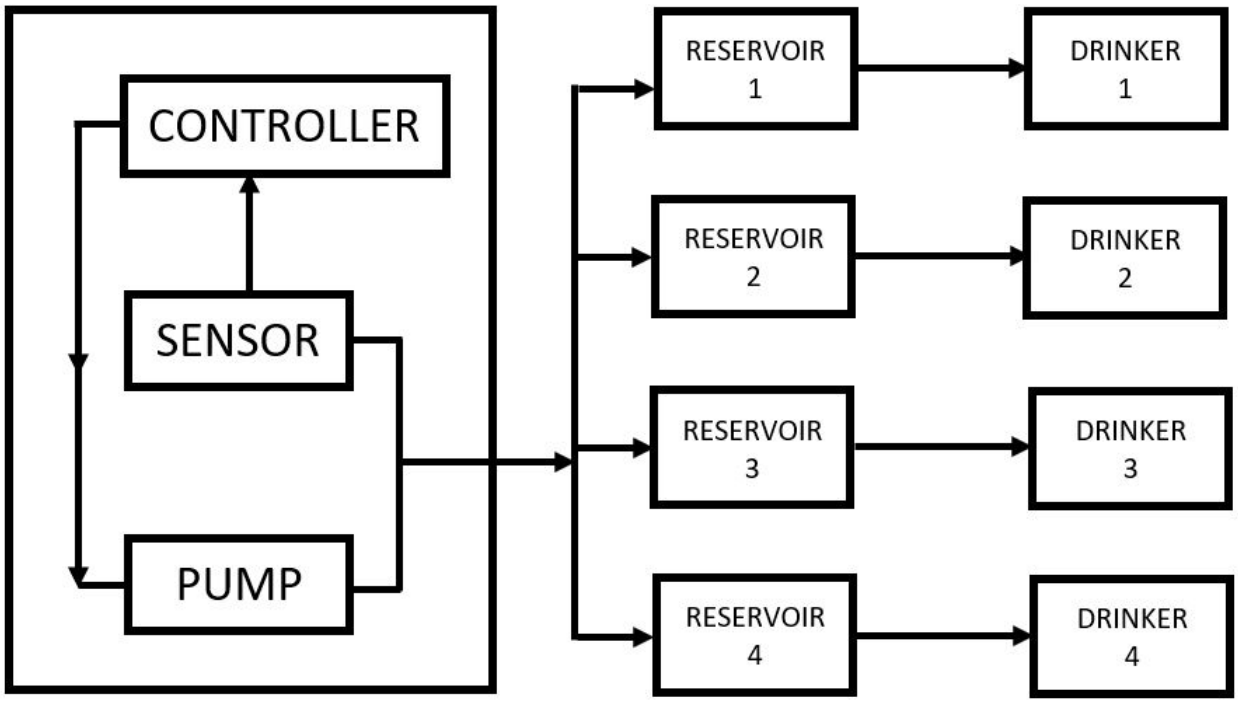

Image 1. Flow chart diagram of low flow water monitoring system

Table 1. Pearson correlations[1] of weekly water intake (WI) from hatch (0) to 4 weeks by sire family pen[2] (above diagonal) and by average per chick water consumption within sire family pen[3] (below diagonal)

Water consumption period (wk)	0 to 1	1 to 2	2 to 3	3 to 4
0 to 1	1.000	0.938***	0.895***	0.845***
1 to 2	0.651***	1.000	0.976***	0.934***
2 to 3	0.427*	0.635***	1.000	0.990***
3 to 4	0.093	0.435*	0.861***	1.000

[1]Significant correlation indicated by *p ≤ .05; **p ≤ .01; ***p ≤ .001

[2]Correlations were based on total g WI/ wk for all birds in floor pen.

[3]Correlations were based on weighted WI/ bird/ wk by floor pen

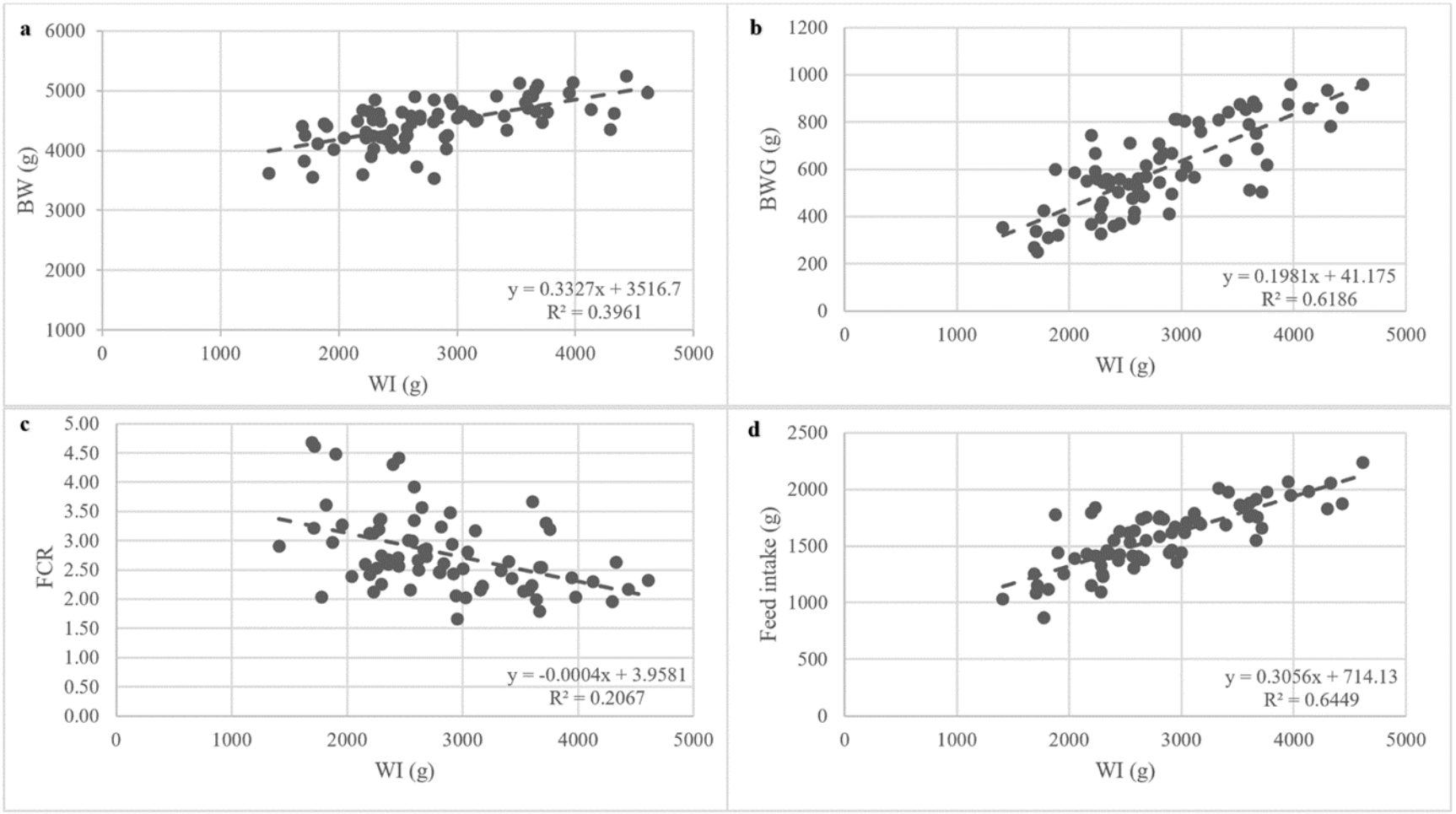

Figure 1. Water Intake (WI) as compared to traits of economic importance (7 to 8 wk)
1a, wk 8 BW vs WI; 1b, 7 to 8 wk BWG vs WI; 1c, 7 to 8 wk FCR vs WI; 1d, 7 to 8 wk FI vs WI

CHAPTER 2: DIVERGENT SELECTION FOR WATER CONVERSION RATIO IN BROILER POPULATIONS

Abstract

The current study evaluated the potential of improving water efficiency in broilers. To date, water measuring technology has lacked the necessary sophistication to ensure accuracy and repeatability of low flow water usage. After the establishment of a low flow water monitoring system (Chapter 1), it was used to develop water efficient and inefficient broiler lines. The selection program was implemented to determine heritability of water efficiency and to assess the response to selection and impact on correlated traits after several generations of selection. From a modern random bred population, lines were divergently selected based on water conversion ratio (WCR = water consumed/body weight gain) to create the low WCR (LWCR) and high WCR (HWCR) lines. After generation 2, the LWCR line had an overall WCR of 3.28 while the HWCR had a WCR of 3.46. Body weights appeared unchanged between the lines with a slight improvement in feed conversion ratio observed in the LWCR line. Continued selection for WCR will provide further understanding into the heritability of the trait and the response to selection of growth and efficiency related traits.

Introduction

Water is the essential nutrient in food animal production but is often overlooked due to the inability to accurately measure it. Hiltz et al. (2021; Chapter 1) developed a low flow water monitoring system that has yielded accurate water consumption data in broiler populations. Before this development there has been limited data with respect to water consumption on an individual bird level. Most of the available information regarding water consumption are based on whole flock measurements (Marks, 1980, 1981; McCreery, 2015; May and Lott, 1992; Pesti et al., 1985). The development of this technology has allowed researchers to quantify water consumption at the individual bird allowing for sensitive genetic selection (Hiltz et al.,2021; Chapter 1). The opportunity to understand the heritability of water consumption/efficiency and

potential correlations with economically important traits has become possible utilizing the methods developed by Hiltz et al. (2021; Chapter 1). Prior to this study minimal research has conducted on selecting food animal populations for water efficiency. Water consumption studies in other farm animals such as swine and beef have been done but none of which explore the genetic basis for water consumption (Thacker, 2000). Although plant geneticists have explored water efficiency traits, many of these scientists employ much different selection methods to develop drought resistant varieties. Traditional selective breeding is utilized in plant breeding but is often accompanied with biotechnical methods such as mutagenesis and tissue graphing (Martignago et al., 2020).

The inability to accurately measure water at small incremental levels has been the primary reason for not developing water efficient animal agriculture populations. Water consumption has always been monitored at the flock level, as it can indicate overall flock performance and detect abnormalities within production (e.g., disease). Utilizing the methods employed by Hiltz et al. (2021; Chapter 1), a 2015 modern random bred broiler population (Orlowski et al.,2020) was divergently selected for water conversion ratio (WCR) as calculated by WI (g) / BWG (g).

Materials and Methods

The University of Arkansas Institutional Animal Care and Use Committee approved the experimental procedures involving live birds under protocol #19086.

Selection Procedure

Initial breeders were selected from the Modern Randombred Line (Orlowski et al., 2020) maintained at the University of Arkansas. The Modern Randombred line is made up of 24 sire families. Each sire family consisted of 1 sire and 3 dams. From the 24 sire families, the top 6 performing sire families with respect to high and low water conversion ratio, from an initial characterization study (Hiltz et al.,2021; Chapter 1). From these selected birds, two genetic lines (High Water Conversion Ratio (HWCR) and Low Water Conversion Ratio (LWCR)) were

formed, he breeding structure established, and the lines were closed. Each line consisted of 12 sire families; each sire was mated to 3 dams. Full and half sib matings were avoided to limit the accumulation of inbreeding.

Selection pressure was employed at two levels. The first was done at a sire family level in a floor pen setting from day 0 to 28 days. The top 6 sire families for each line were selected based on their respective phenotype for WCR. Males from the selected families were placed in individual cages (0.46 m x 0.31 m x 0.41 m). WCR was based on individual bird performance from 28 to 42 days of age. Only male chicks were phenotyped during the individual bird phase.

Phenotyping Phase 1: Floor Pen Water System

Phenotyping was conducted with six regulation devices servicing 24 floor pens (1.52 m x 3.05 m). Each floor pen was prepared with pine shavings for litter and equipped with two commercial hanging feeders and a lubing nipple drinker line (2 nipple drinkers/pen). A total of 298 fully pedigreed broiler chicks were generated from a 14-day egg collection from the HWCR and LWCR broiler lines housed at the University of Arkansas poultry research farm. Chicks were pedigree hatched, wing banded, vaccinated for Marek's disease and randomly assigned to floor pens based on sire family. Each sire family consisted of all offspring generated from 3 dams mated to a single sire. All birds were reared to normal broiler production specifications. Broilers were fed a commercial starter diet (Day 0 to 28) formulated to meet or exceed NRC (1994) requirements. Weekly WI, feed intake (FI) and individual BW was recorded for each floor pen. Each water line and regulation device were monitored for leaks to ensure accurate WI data.

Methodologies for measuring WI were the same as employed by Hiltz et al. (2021; Chapter 1). This study utilized Lubing waterlines and nipples to deliver the water from a pen dedicated, sealed, pressurized water reservoir. A controller housed in the regulation box was used to sustain a constant pressure of 6 psi on the water to the nipple drinker water line. To measure water consumption, each water reservoir was filled, weighed, and connected to the

pressure regulator box. After the sampling period, the reservoir was disconnected from the drip free connector and weighed. Water intake (WI) was calculated as the weight change (1 g water = 1 mL water) from start to finish of the trial period. This version of the floor pen application simultaneously supported water distribution to four different floor pens. Each floor pen had the water reservoir capacity of 15 L.

Phenotyping Phase 2: Individual Cage Water System

The individual bird low flow monitoring system was designed to be utilized in a feed conversion cage system where an individual bird's FI and WI would be monitored. The individual system closely resembled the floor pen system but on a smaller scale with water reservoir capacities of 4 L. Each regulation device housed four cage dedicated reservoirs constantly delivering a desired water pressure of 0.5 PSI to each individual nipple waterer cage setup.

After 28 days of production in phase one, truncation selection was utilized, and sire family offspring were selected from the top 6 and bottom 6 sire families with respect to high and low WCR within each line. The respective sire families contributed males for phase two of selection. Due to a lower number of chicks 74 Male chicks from the top 9 families were randomly selected and placed into individual feed conversion cages (0.46 m x 0.31 m x 0.41 m). Weekly WI, FI and BW was recorded from 28 to 42 days. A commercial finisher feed and water were provided *ad libitum*. Feed was weighed into bunker style feeders at the start of each week and weighed out at the end of each week to calculate weekly FI. WI and WCR was calculated using methods described by Hiltz et al. (2021; Chapter 1). All statistics were analyzed utilizing JMP Pro 16. ANOVA tests were conducted with line as the main effect. Means were separated utilizing student's t test.

Results and Discussion

Phenotyping Phase 1: Floor Pen Water System

Performance measurements for HWCR and LWCR were presented by week and cumulative (Table 1). The LWCR line had heavier weights on day 7 and day 14. It also outperformed the HWCR line in FCR at day 14, bettering its counterpart by 12 points. No other measurements taken during this period were different but there were a few cumulative measurements that approached significance and were noteworthy. Although cumulative FI was similar between both lines the LWCR line had a lower FCR by 9 points. The LWCR also had a WCR of 3.28 while the HWCR recorded a WCR of 3.46. This is encouraging considering the smaller hatch numbers and one generation of selection. Day 28 BW for the LWCR line was 1387.9g and 1329.3g for the HWCR line respectively. After one generation of a single trait selection for WCR, it does not appear to negatively affect day 28 BW.

When evaluating each line based on the top 6 performing sire families, measurements between the two lines showed preliminary signs of divergence. No differences were found during the first week of production, but when comparing the second week of production differences were observed. The LWCR line had a lower FCR and WCR of 1.90 and 2.59 respectively. Compared to the HWCR line which recorded a FCR of 2.15 and a WCR of 2.96. The LWCR also had a higher BW at day 14 of 449.17g while the HWCR recorded a BW of 409.54g. No differences were observed in the third week of production. The LWCR line had a higher BW at day 28, more than 89 grams higher when compared to the HWCR line. WCR differences between the lines were observed both in the fourth week of the trial and cumulatively from weeks one through four. The LWCR line had a WCR of 3.13 compared to 3.81 for the HWCR line, a 68-point difference in week four. When evaluating the whole period, the LWCR line recorded a 3.07 WCR while the HWCR line recorded a 3.60 WCR, respectively. Although no differences were observed when comparing whole lines in phase one, differences were observed in the comparison between the top six sire families. BW and FCR in the LWCR

does not seem to be affected in a negative way either, in fact it seems to have a positive impact as the LWCR line performed better than the HWCR line in all of these performance parameters.

Phenotyping Phase 2: Individual Cage Water System

Performance measurements between both lines started to diverge in phase 2 of the experiment. WI was the only measurement differing between the two lines in week 5. The HWCR line consumed 2546.93g of water on average versus 2251.41g of water consumed by the LWCR line. In week 6 differences were observed in almost all performance measurements recorded. The HWCR line consumed 100g more feed than the LWCR and also had an FCR of 1.75, 11 points better than the LWCR. The HWCR line consumed 3186.10g of water during this time period while the LWCR consumed 2611.63g. On average the LWCR line consumed 574.47g less water but no differences were observed with respect to WCR. When comparing water to feed ratio the LWCR line had a lower W:F of 1.91, versus 2.16 for the HWCR line. Differences were found between the two lines while evaluating BWG, but not for BW. Unlike week 6, differences were not observed with respect to FCR for the entirety of phase 2. Similar to week 6, the LWCR line consumed 125g feed less than the HWCR line. WI differences were observed and continued to diverge between the two lines. The HWCR consumed 5717.38g of water compared to the LWCR's 4863.04g, over 850g less water during the two-week period. The LWCR line also had lower WCR and W:F during the two-week period with a WCR of 3.50 and W:F of 1.92, compared to the HWCR having a WCR of 3.78 and a 2.15 W:F.

Table 4 displays performance measurements of the top 18 male chicks from each line during phase two of the experiment. These chicks represent top candidates for the next generation of breeding sires. Performance measurements for these birds were even more exaggerated than the whole line comparison for phase two. Unlike the whole line comparison, the top LWCR chicks had a FCR of 1.75, 10 points better than the HWCR chicks for week 5 data. The LWCR recorded differences between WI, WCR, and W: F. Most notably were the differences of WCR and W:F. The LWCR had a WCR of 3.15 and a W:F of 1.80 while the

HWCR had a WCR of 4.26 and a W:F of 2.3, respectively. Much like the whole line comparison BW did not differ statistically in week 5. Unlike week 5, in week 6 of production FCR differences were not detected. Differences within the LWCR line with respect to WI, WCR, and W:F were significant. The LWCR line consumed over 900g less about water, in addition to bettering the HWCR line in WCR by 40 points. Again, BW differences were not found in week 6 of production. Cumulative measurements for phase 2 are indicative of the two-week period. However, differences were found with respect to FI and not FCR. Both lines recorded very similar FCR while the LWCR had a lower FI. Differences were observed for the two-week period in WI, WCR, and W:F. The LWCR line on average consumed 1554g less with respect to WI. The LWCR line also had a WCR of 3.25, 86 points better than the HWCR and a more efficient W:F ratio of 1.83 compared to 2.32.

Figure 5 displays whole line comparison WCR against traits of economic importance. Chicks with lower WCR values tended to perform well in all other measurements. For one generation of selection with the implemented selection intensity the results are encouraging. Although there appears to be some chicks within each line that don't perform as expected, the majority perform well with respect to line designation. Figure 6 displays the top 18 chicks within each line. These male chicks are breeding sire candidates for the next generation and contribute to the idea that a single trait selection for WCR does not appear to negatively impact of traits of economic importance.

After one generation of selection the lines appear to sow promise of divergence. Differences were observed with a lower selection intensity than typical intensities employed at an economic breeding program. Economically important traits such as FCR nor BW do not appear to be negatively affected by a single trait selection for WCR. The populations selected from were smaller than normal typical pedigree hatches meaning subsequent generations should yield a greater selection pressure and more divergence within the lines. The development of a more accurate selection tool in addition to an increase in the number of

records for both sexes will also help move the trait and increase heritability. Water efficiency related traits are not well documented in the literature and these lines could provide a foundation for similar traits and related morphology changes in farm animal populations. Water is absorbed in the lower part of the GI tract and ceca (Van Der Klis et al., 1993a, b; Dirk et al., 2013). Selection for WCR and similar water efficiency traits will have the most impact on the function and morphology of these respective organs. Water absorption and utilization occurs mostly in the small intestine and birds that are highly efficient with regards to water will most likely be highly efficient with feed as well. After a single generation of selection, the LWCR birds consumed on average 1554g less of water than the HWCR. This implies that even after a few generations of selections water use savings could be substantial. Economic breeding programs utilizing complex selection indices will be able to implement WCR and select birds for both water and feed efficiency in addition to the traditional traits found on commercial selection indices.

Conclusion

Given the preliminary results from both phases of the experiment, single trait selection for WCR does not appear to negatively impact traits of economic importance. Two important traits in commercial production, FCR and BW, did not differ in both phases of the experiment. A single trait selection of WCR showed promising indications of lowered WI and, as a result, a lower W:F ratio. Given the lower selection intensity and small hatch numbers, even more genetic progress is attainable for WCR. Furthermore, as the selection tool is developed, accuracies should improve as will selection intensities. Ideally both male and female chicks from candidate families will be identified and placed into individual cages at 14 days of age, allowing for a selection pressure for most of the bird's life and a comprehensive characterization for both sexes. This may confirm preliminary results suggesting that WCR/ water efficiency traits are highly correlated with FCR. Selection for WCR in economic breeding programs will undeniably be on selection indices for years to come.

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Figures and Tables

Table 1. Phase 1: Whole line comparison of performance measurements on an average per bird basis wk 1-4

		Weeks				
Line[1]	Trait[2]	0-1	1-2	2-3	3-4	0-4
HWCR	BW (kg)	0.137[B] ± 0.005	0.396[B] ± 0.001	0.752 ± 0.016	1.329 ± 0.026	
	FI (kg)	0.149 ± 0.013	0.537 ± 0.036	0.564 ± 0.012	0.891 ± 0.063	2.143 ± 0.088
	FCR (g:g)	1.63 ± 0.16	2.08[A] ± 0.07	1.85 ± 0.19	1.57 ± 0.11	1.72 ± 0.06
	WI (kg)	0.263 ± 0.008	0.739 ± 0.024	1.191 ± 0.032	2.036 ± 0.095	4.296 ± 0.156
	WCR (g:g)	2.83 ± 0.09	2.86 ± 0.08	3.82 ± 0.32	3.55 ± 0.14	3.46 ± 0.10
	W:F (g:g)	1.91 ± 0.17	2.11 ± 0.04	2.11 ± 0.04	2.04 ± 0.13	2.04 ± 0.06
LWCR	BW	0.153[A] ± 0.004	0.436[A] ± 0.010	0.797 ± 0.016	1.387 ± 0.022	
	FI	0.140 ± 0.012	0.512 ± 0.035	0.554 ± 0.011	0.880 ± 0.060	2.086 ± 0.076
	FCR	1.44 ± 0.14	1.96[B] ± 0.07	1.54 ± 0.18	1.52 ± 0.11	1.63 ± 0.07
	WI	0.272 ± 0.007	0.769 ± 0.023	1.137 ± 0.031	1.998 ± 0.091	4.187 ± 0.135
	WCR	2.82 ± 0.08	2.73 ± 0.08	3.18 ± 0.31	3.46 ± 0.14	3.28 ± 0.09
	W:F	2.07 ± 0.15	2.05 ± 0.04	2.07 ± 0.04	2.33 ± 0.13	2.02 ± 0.06

[A-B] Line means for a specific trait within a week without a common superscript are different (P > 0.05).

[1]HWCR = high water conversion ratio line; LWCR = low water conversion ratio line

[2]BW = body weight; FI = feed intake; FCR = feed conversion ratio= feed consumed/body weight gain; WI = water intake; WCR = water conversion ratio = water consumed/body weight gain; W:F = water to feed ratio= water consumed/feed consumed.

Table 2. Phase 1: Top 6 sire family line comparison of performance measurements on an average per bird basis wk 1-4

		Weeks				
Line[1]	**Trait[2]**	**0-1**	**1-2**	**2-3**	**3-4**	**1-4**
HWCR	BW (kg)	0.144 ± 0.005	0.409^{B} ± 0.009	0.762 ± 0.024	1.326 ± 0.032	
	FI (kg)	0.166 ± 0.017	0.518 ± 0.055	0.569 ± 0.018	0.873 ± 0.064	2.127 ± 0.097
	FCR (g:g)	1.83 ± 0.21	2.15^{A} ± 0.06	1.63 ± 0.06	1.55 ± 0.12	1.73 ± 0.08
	WI (kg)	0.265 ± 0.010	0.785 ± 0.033	1.238 ± 0.058	2.162 ± 0.131	4.451 ± 0.211
	WCR (g:g)	2.86 ± 0.12	2.96^{A} ± 0.10	3.54 ± 0.17	3.81^{A} ± 0.15	3.60^{A} ± 0.12
	W:F (g:g)	1.71 ± 0.20	2.17 ± 0.05	2.17 ± 0.05	2.54 ± 0.21	2.11 ± 0.08
LWCR	BW	0.154 ± 0.005	0.449^{A} ± 0.009	0.816 ± 0.024	1.416 ± 0.032	
	FI	0.142 ± 0.017	0.517 ± 0.055	0.558 ± 0.018	0.787± 0.064	2.006 ± 0.097
	FCR	1.45 ± 0.21	1.90^{B} ± 0.06	1.53 ± 0.06	1.32 ± 0.12	1.52 ± 0.08
	WI	0.270 ± 0.010	0.762 ± 0.033	1.148 ± 0.058	1.875 ± 0.131	4.056 ± 0.211
	WCR	2.76 ± 0.12	2.59^{B} ± 0.10	3.14 ± 0.17	3.13^{B} ± 0.15	3.07^{B} ± 0.12
	W:F	1.98 ± 0.20	2.06 ± 0.05	2.06 ± 0.05	2.44 ± 0.21	2.03 ± 0.08

A-B Line means for a specific trait within a week without a common superscript are different (P > 0.05).

[1]HWCR = high water conversion ratio line; LWCR = low water conversion ratio line

[2]BW = body weight; FI = feed intake; FCR = feed conversion ratio= feed consumed/body weight gain; WI = water intake; WCR = water conversion ratio = water consumed/body weight gain; W:F = water to feed ratio= water consumed/feed consumed.

Table 3. Phase 2: Whole line comparison of performance measurements on an average per bird basis wk 5-6

		Week		
Line[1]	**Trait**[2]	**5**	**6**	**5-6**
HWCR	BW (kg)	2.109 ± 0.028	2.956 ± 0.042	
	BWG (kg)	0.663 ± 0.016	0.847^{A} ± 0.021	1.511^{A} ± 0.030
	FI (kg)	1.190 ± 0.016	1.470^{A} ± 0.027	2.655^{A} ± 0.034
	FCR (g:g)	1.80 ± 0.03	1.75^{B} ± 0.03	1.76 ± 0.03
	WI (kg)	2.546^{A} ± 0.091	3.186^{A} ± 0.108	5.717^{A} ± 0.138
	WCR (g:g)	3.86 ± 0.16	3.75 ± 0.10	3.78^{A} ± 0.09
	W:F (g:g)	2.14 ± 0.07	2.16^{A} ± 0.06	2.15^{A} ± 0.04
LWCR	BW	2.153 ± 0.028	2.904 ± 0.042	
	BWG	0.654 ± 0.016	0.747^{B} ± 0.021	1.401^{B} ± 0.030
	FI	1.159 ± 0.016	1.371^{B} ± 0.027	2.530^{B} ± 0.034
	FCR	1.80 ± 0.03	1.86^{A} ± 0.03	1.82 ± 0.03
	WI	2.251^{B} ± 0.091	2.611^{B} ± 0.108	4.863^{B} ± 0.138
	WCR	3.59 ± 0.16	3.53 ± 0.10	3.50^{B} ± 0.10
	W:F	1.95 ± 0.07	1.91^{B} ± 0.06	1.92^{B} ± 0.04

A-B Line means for a specific trait within a week without a common superscript are different (P > 0.05).

[1]HWCR = high water conversion ratio line; LWCR = low water conversion ratio line

[2]BW = body weight; BWG= body weight gain; FI = feed intake; FCR = feed conversion ratio= feed consumed/body weight gain; WI = water intake; WCR = water conversion ratio = water consumed/body weight gain; W:F = water to feed ratio= water consumed/feed consumed

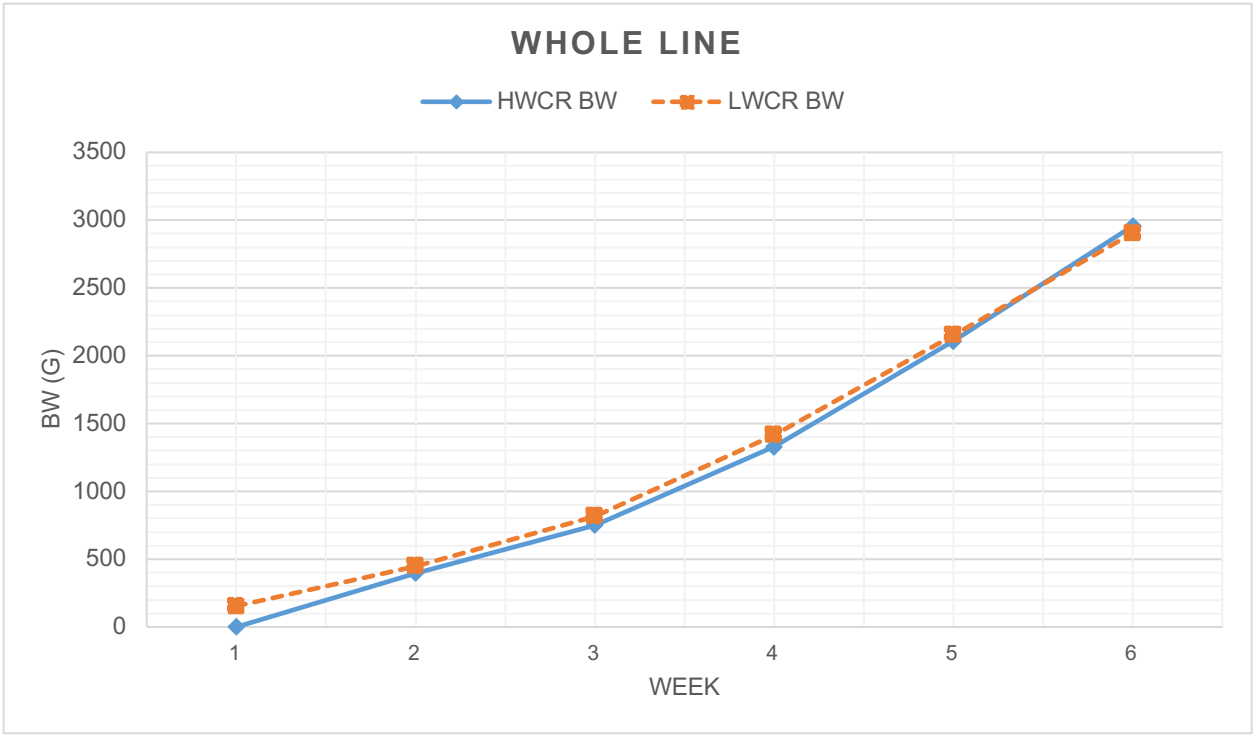
Table 4. Phase 2: Top 18 male chicks line comparison of performance measurements on an average per bird basis wk 5 to 6

		Week		
Line[1]	**Trait**[2]	**5**	**6**	**5-6**
HWCR	BW (kg)	2.115 ± 0.031	2.972 ± 0.055	
	BWG (kg)	0.640 ± 0.017	0.856^{A} ± 0.029	1.496 ± 0.038
	FI (kg)	1.185 ± 0.019	1.466 ± 0.037	2.659^{A} ± 0.046
	FCR (g:g)	1.85^{A} ± 0.03	1.73 ± 0.04	1.78 ± 0.03
	WI (kg)	2.732^{A} ± 0.106	3.441^{A} ± 0.139	6.192^{A} ± 0.168
	WCR (g:g)	4.26^{A} ± 0.15	4.01^{A} ± 0.09	4.11^{A} ± 0.08
	W:F (g:g)	2.30^{A} ± 0.08	2.33^{A} ± 0.06	2.32^{A} ± 0.05
LWCR	BW	2.140 ± 0.031	2.906 ± 0.055	
	BWG	0.668 ± 0.017	0.766^{B} ± 0.029	1.435 ± 0.038
	FI	1.157 ± 0.019	1.385 ± 0.037	2.534^{B} ± 0.046
	FCR	1.75^{B} ± 0.03	1.82 ± 0.04	1.77 ± 0.03
	WI	2.080^{B} ±0.106	2.552^{B} ± 0.139	4.638^{B} ± 0.168
	WCR	3.15^{B} ± 0.15	3.39^{B} ± 0.09	3.25^{B} ± 0.08
	W:F	1.80^{B} ± 0.08	1.85^{B} ± 0.06	1.83^{B} ± 0.05

A-B Line means for a specific trait within a week without a common superscript are different (P > 0.05).

[1]HWCR = high water conversion ratio line; LWCR = low water conversion ratio line

[2]BW = body weight; BWG= body weight gain; FI = feed intake; FCR = feed conversion ratio= feed consumed/body weight gain; WI = water intake; WCR = water conversion ratio = water consumed/body weight gain; W:F = water to feed ratio= water consumed/feed consumed



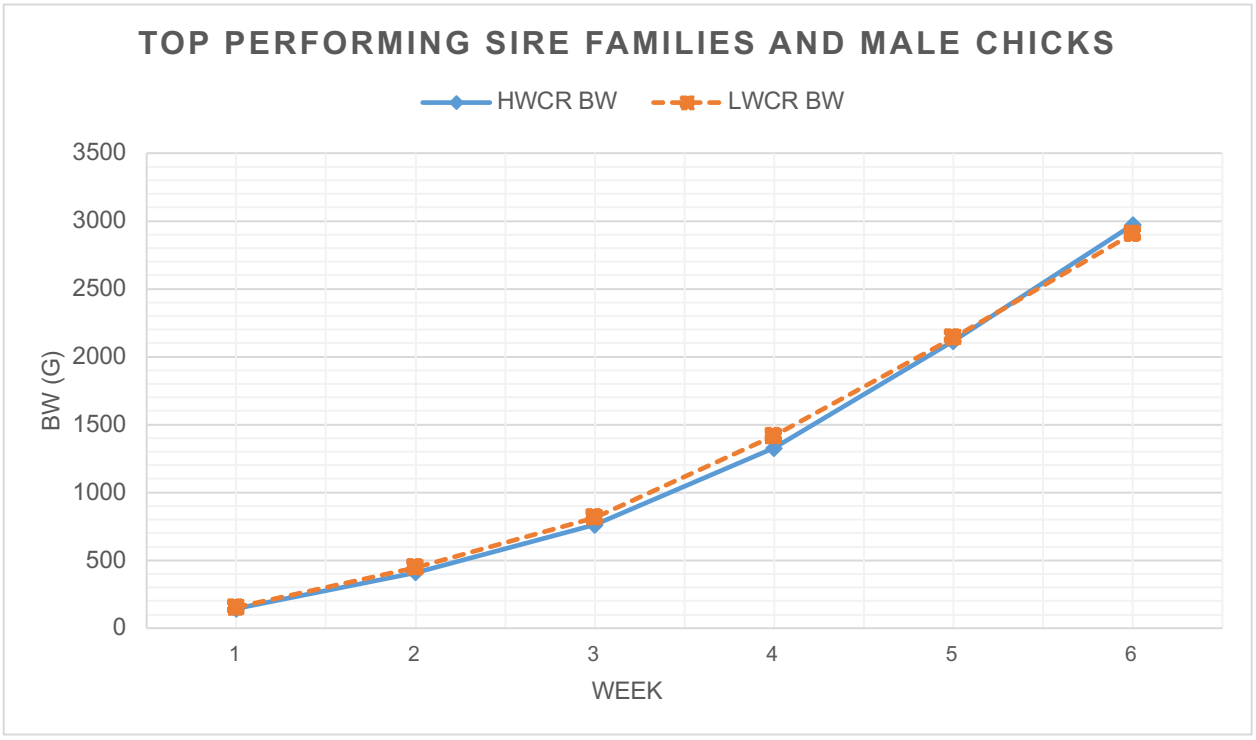
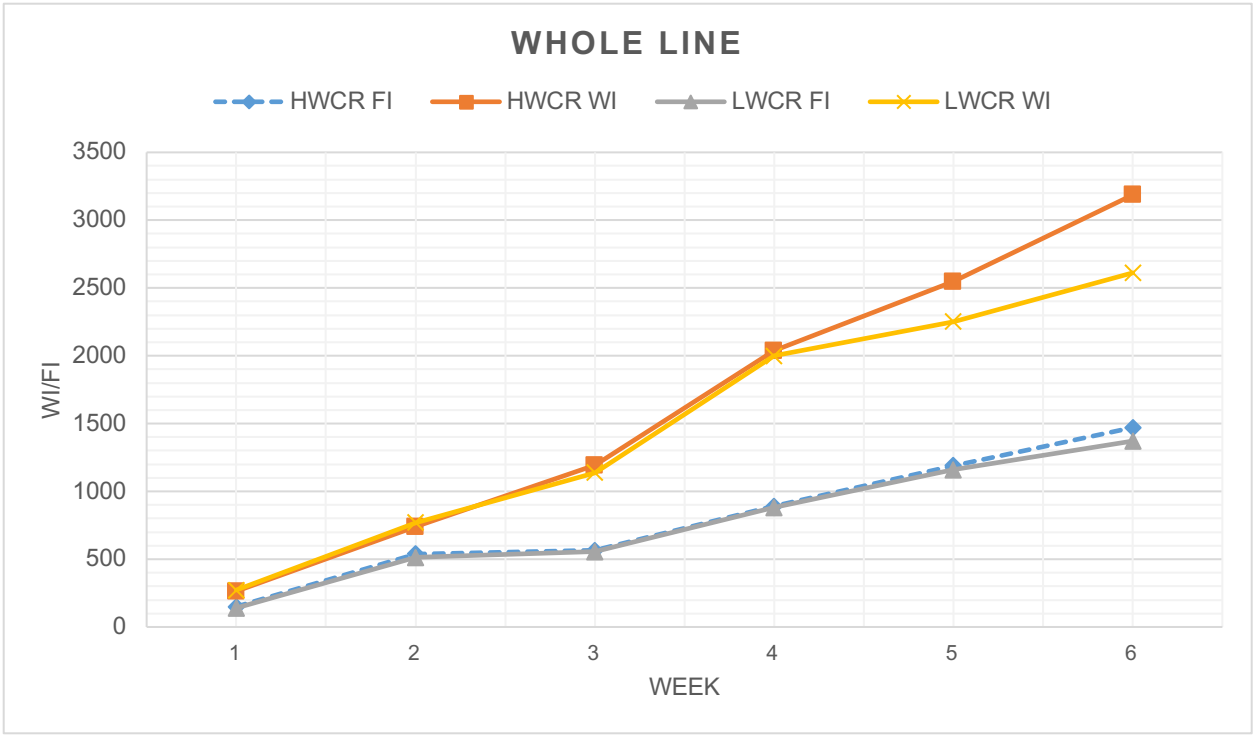


Figure 1. Phase 1 and 2: HWCR[1] and LWCR[2] BW[3] comparison wk 1-6
[1]HWCR = high water conversion ratio line; [2]LWCR = low water conversion ratio line
[3]BW = bodyweight (g)



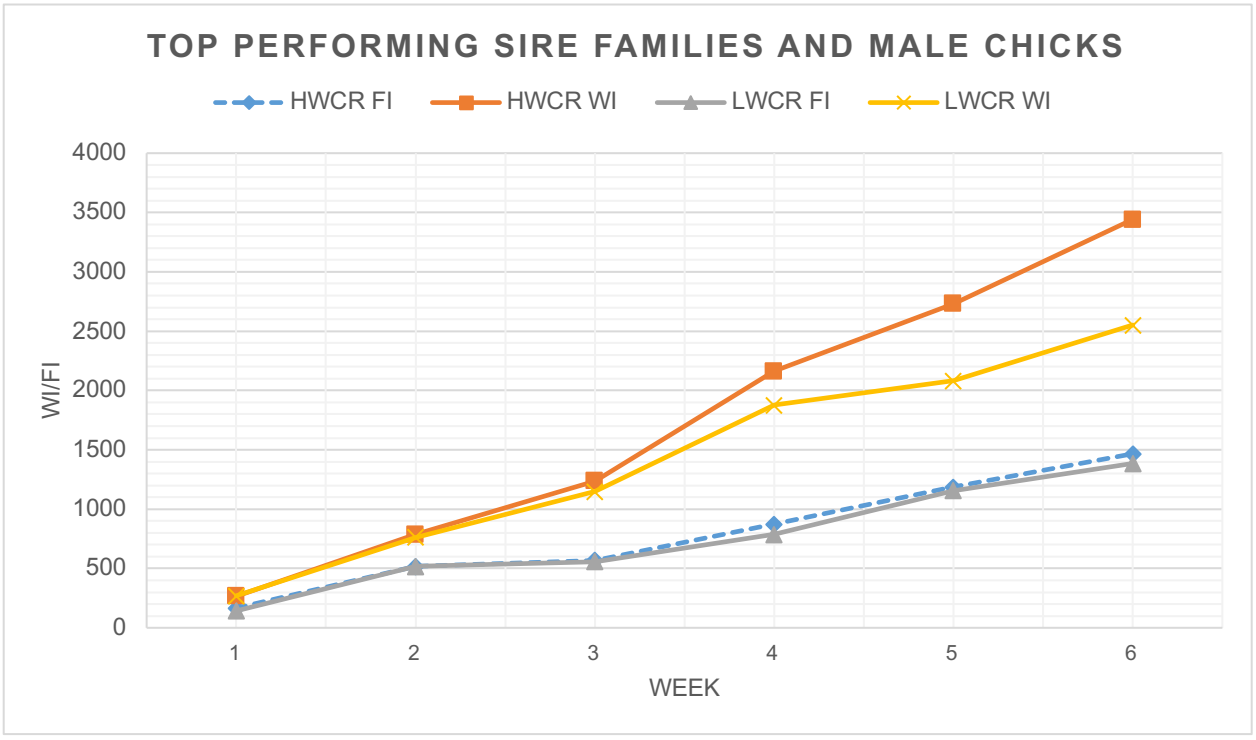


Figure 2. Phase 1 and 2: HWCR[1] and LWCR[2] WI[3]/FI[4] comparison wk 1-6
[1]HWCR = high water conversion ratio line; [2]LWCR = low water conversion ratio line
[3]WI = water intake; [4]FI= feed intake

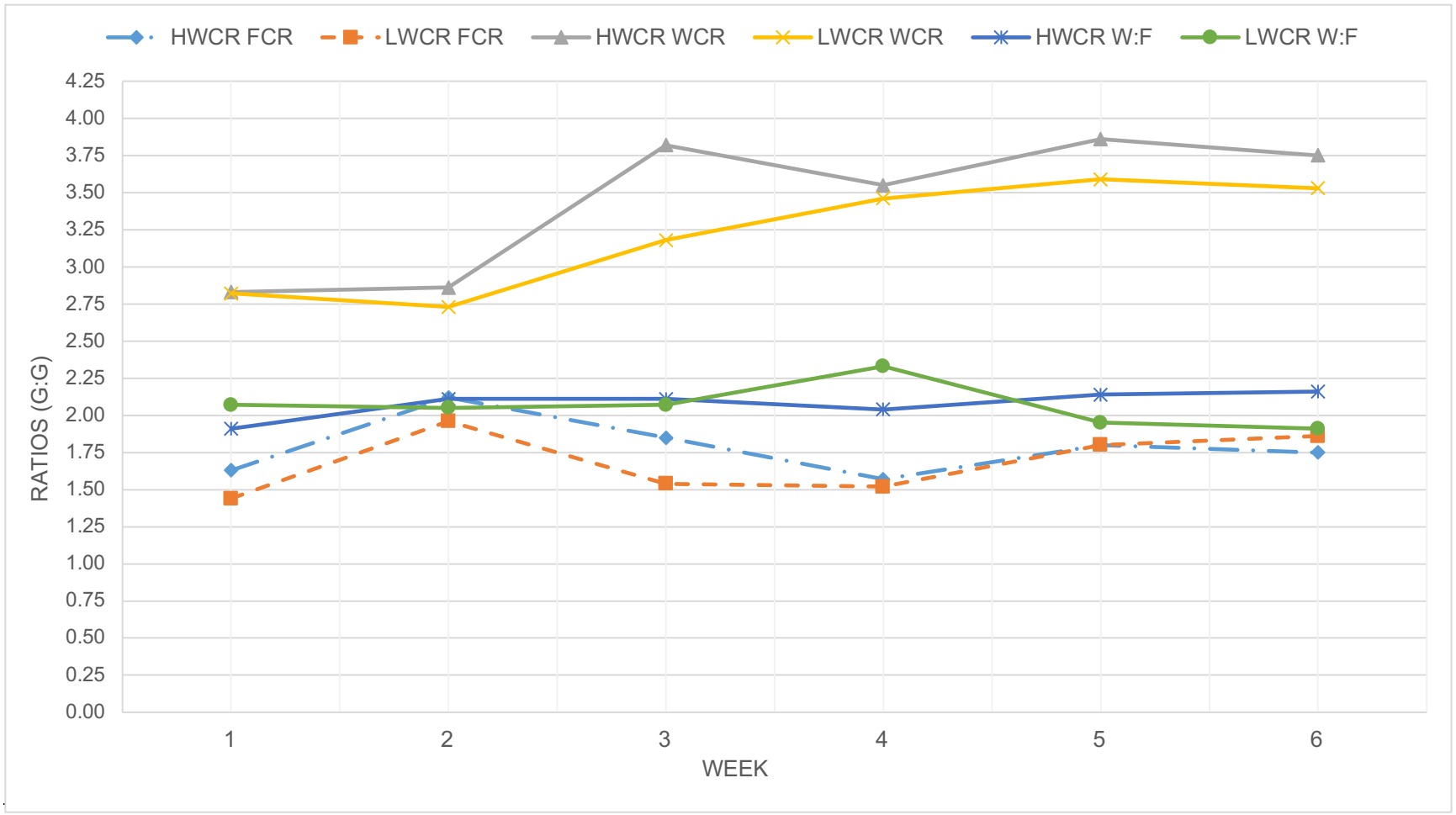


Figure 3. Phase 1 and 2: HWCR[1] and LWCR[2] line comparison of FCA, WCR[4], and W:F[5]
[1]HWCR = high water conversion ratio line; [2]LWCR = low water conversion ratio line;[3]FCR= feed conversion ratio= feed consumed/body weight gain; [4]WCR= water conversion ratio= water consumed/body weight gain; [5] W:F = water; feed ratio = water consumed/feed consumed

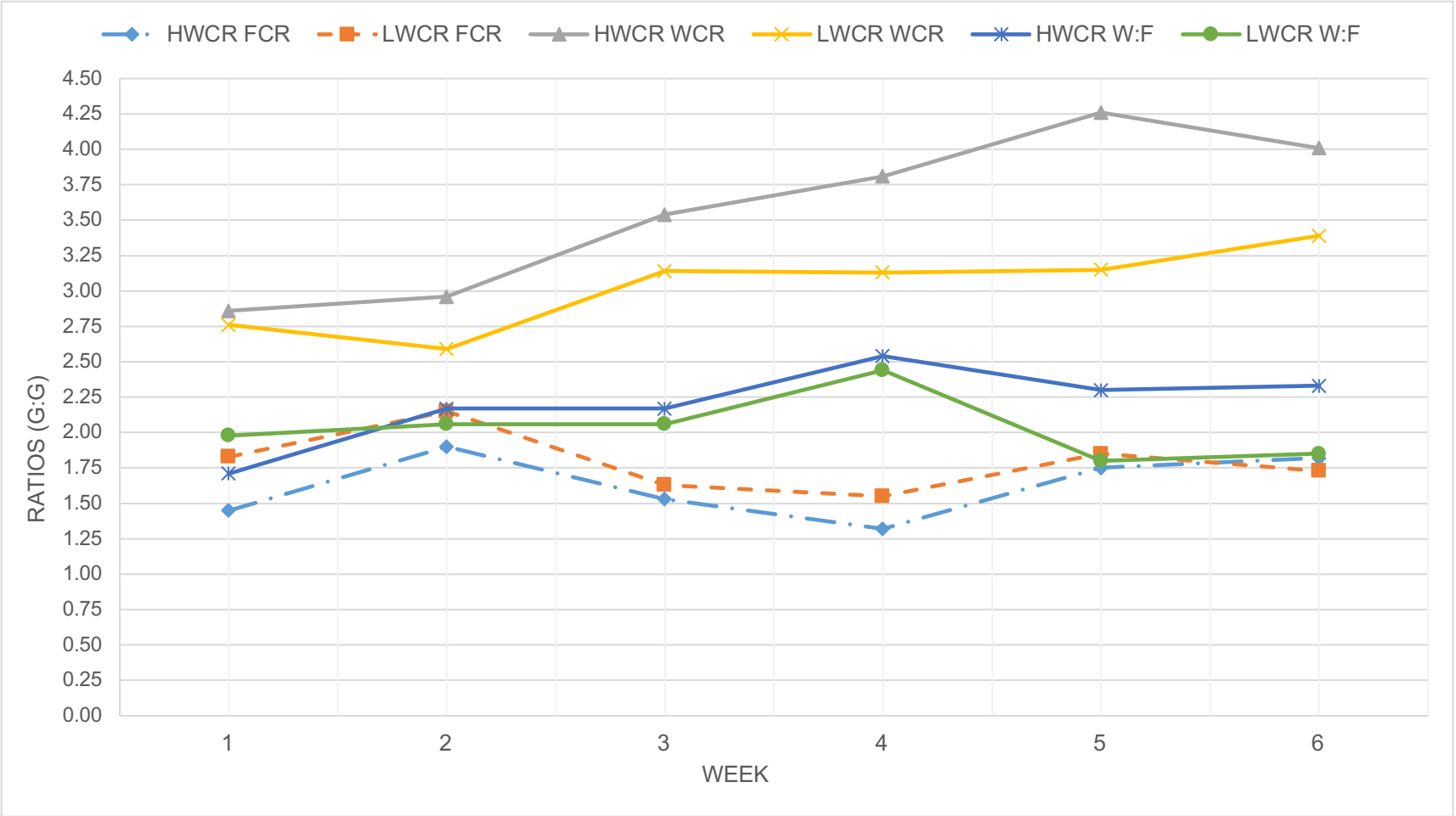


Figure 4. HWCR[1] and LWCR[2:] Top performing sire families: FCA, WCR[4], and W:F[5]
[1]HWCR = high water conversion ratio line; [2]LWCR = low water conversion ratio line;[3]FCR= feed conversion ratio= feed consumed/body weight gain; [4]WCR= water conversion ratio= water consumed/body weight gain; [5] W:F = water; feed ratio= water consumed/feed consumed

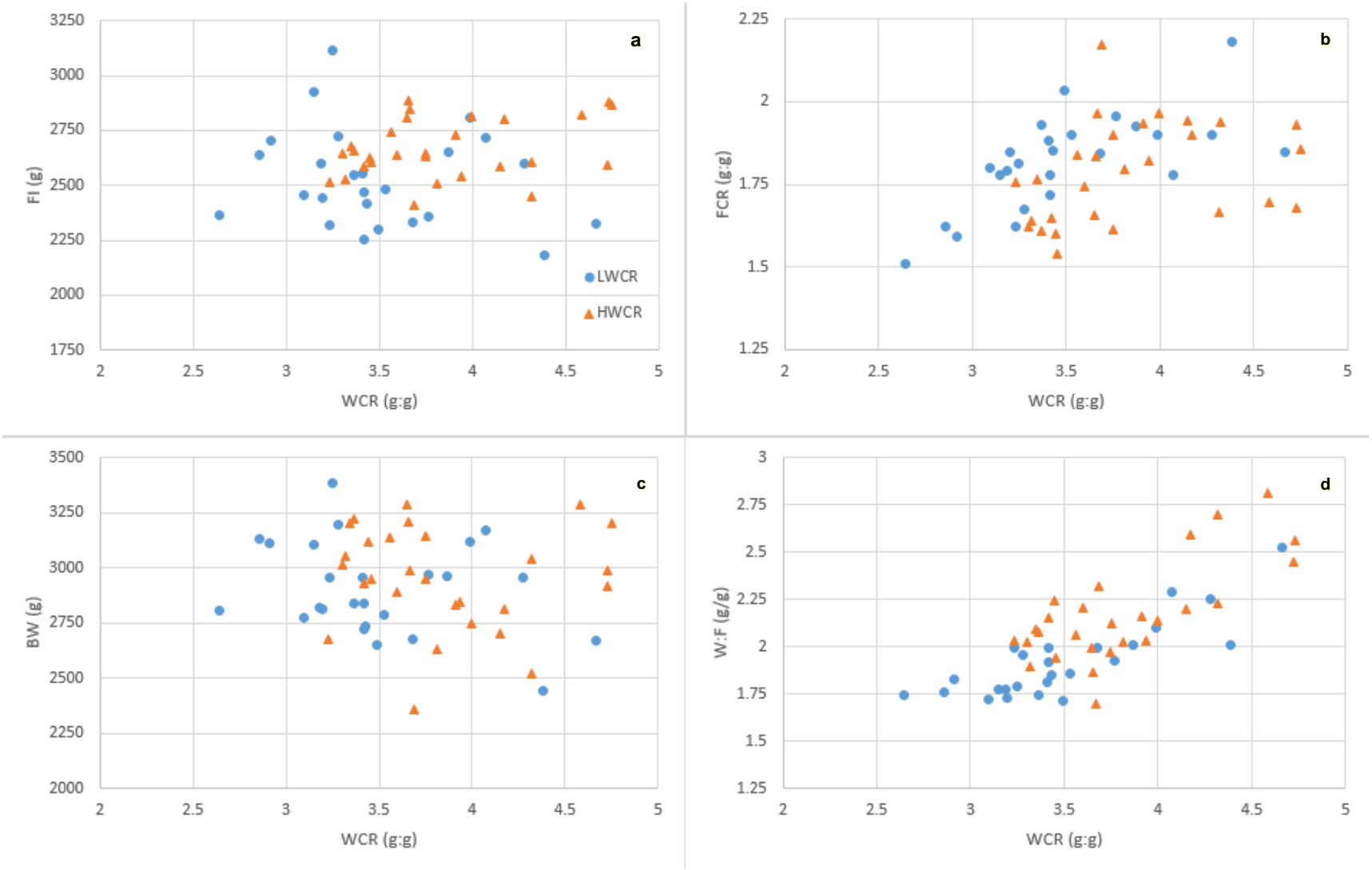


Figure 5. Phase 2 whole line comparison of WCR vs traits of economic importance
1a, d28-42 FI vs WCR; 1b, d28-42 FCR vs WCR; 1c, d42 BW vs d28-42 WCR; 1d d28-42 W:F vs WCR

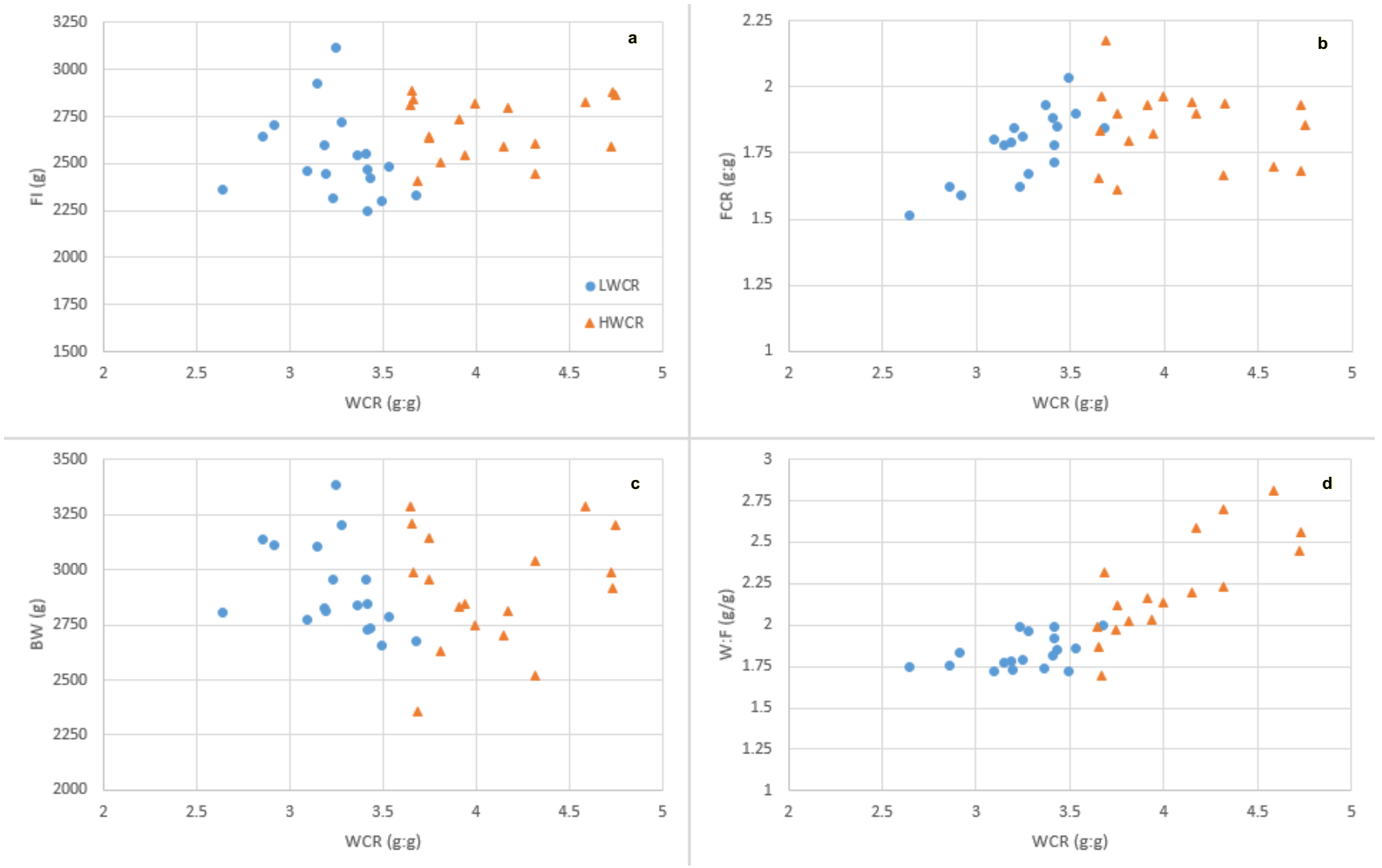


Figure 6. Phase 2 top 18 male chicks line comparison of WCR versus traits of economic importance
1a, d28-42 FI vs WCR; 1b, d28-42 FCR vs WCR; 1c, d42 BW vs d28-42 WCR; 1d d28-42 W:F vs WCR

CHAPTER 3: WATER, FEED INTAKE, AND PROCESSING EVALUATIONS OF FOUR CONTEMPORARY BROILER STRAINS

Introduction

Water consumption for broilers on a flock level has been characterized in previous literature (Marks, 1980, 1981; May and Lott, 1992; Pesti et al., 1985) but has not compared modern broiler strains nor have historic strains been compared within the same study. Marks (1980,1981) conducted two studies comparing water intake of selected and non-selected broiler lines and documented some of the first known water consumption data. Marks utilized the thens Canadian randombred line and an industry selected Cobb line for comparison. At the time of the study, the selected Cobb line represented 20+ years of selection for economic important traits such as BW and feed efficiency traits. Marks successfully demonstrated the progress of genetic selection and the difference between water and feed intake between the two lines. Gardiner and Hunt (1984) conducted an experiment using a commercially relevant cross of 100 male Ross x Arbor Acre chicks. Daily water intake was recorded until a processing age of 63 days. Marks (1985) also recorded sexual dimorphism between selected and non-selected lines in early feed and water intake. Marks utilized the Athens Canadian Randombred line for the unselected line and an undisclosed line for the selected broiler line. Again, Marks observed differences both between lines and sexes during the early stages of production. Little research has explored table egg layer water consumption. Howard (1975) measured water consumption of layers and characterized water intake during the process of egg formation. The breed used for the study was not disclosed.

Detailed water consumption data for commercial broilers and layer chickens has been somewhat ignored because of the difficulty in achieving accurate consumption records. In fact, most of the current water consumption data is based on flock water consumption trends using large scale flow meters on commercial style houses (McCreery, 2015). Field data, such as this, is often difficult to interpret because of environmental variation from house to house, farm to

farm. The current study measures water consumption in four broiler strains utilizing a refined method of quantitating consumption in a floor pen setting or on an individual bird basis (Hiltz et al., 2021; Chapter 1).

Materials and Methods

The University of Arkansas Institutional Animal Care and Use Committee approved the experimental procedures involving live birds under protocol #19086.

Live Bird Management

A total of 600 chicks from four contemporary broiler strains were obtained from a local hatchery. Two of the strains were appropriate for the general broiler whole bird/ parts/ tray pack market while the other two strains were selected to serve the high breast yield/ debone sector. An effort was made to source chicks from same age breeder flocks. All chicks, by commercial source and strain were vent sexed and wing banded. Three replicates of 25 chicks of each strain/sex combination were then randomly assigned to 3 of the available 24 floor pens (1.52 m x 3.05 m). Each floor pen was equipped with two commercial hanging feeders and a nipple drinker line (2 nipple drinkers/pen). Birds were fed a starter diet from d0-14, a grower diet from d14-28, a finisher diet from d28-42, and a withdrawal diet from d42-56 (Table 1). All diets were formulated as to not advantage any of the commercial broiler strains used in this study. Methods for measuring water intake were the same employed by Hiltz and colleagues (2021; Chapter 1) however modifications were made to the existing equipment to increase the size of each water reservoir capacity to 7.6 L. The water system was set to maintain a water pressure to deliver from each nipple 35 ml water per minute from 0 to 35 days and 70 ml per minute from 35 to 56 days.

Live Bird Performance Measurements

For the duration of the 8-week trial, data was collected that would yield specific growth and feed and water intake parameters. To accomplish this, all feed and water intake was recorded on a weekly basis. To capture broiler growth parameters, pen weights and bird counts

were recorded at weeks 1, 2, 3, 5, and 7. In order to monitor bird within pen variation, individual bird weights were collected at weeks 4, 6, and 8. These data were used to calculate feed conversion ratio (FCR), water conversion ratio (WCR) and W:F as described (Hiltz et al., 2021; Chapter 1).

Processing Evaluations

Two processing dates (43 and 57 days) were set to evaluate strain performance at realistic processing ages for parts and yield products. Prior to each processing, feed was withdrawn for a 10-hour period, but water remained available until harvest. On processing day, 12 birds per pen were randomly collected, humanely placed in plastic coops, and transported 300 meters from the research farm to the University of Arkansas pilot processing plant. All birds were identified by wing band, weighed on the back dock, and hung on an inline shackle system. Broilers were electrically stunned (11 V, and 11 mA for 11 s), exsanguinated by cutting the left carotid artery and allowed to bleed out for 3 minutes prior to entering the scald tank (53.8°C, 2 min). After scalding the carcass entered the mechanical picker where the feathers were removed. Prior to evisceration, necks and hocks were manually excised Eviscerated carcasses were then subjected to a chilling system consisting of a 3 h immersion chilling tank held at 0°C with manual agitation.

Processed Bird Measures

At 3 h postmortem, chilling tanks were drained of water, and carcasses were manually deboned to determine gram weights of *Pectoralis major* (breast) and *minor* (tender), wing, and whole leg. Part weights were then used to calculate yields relative to final back dock live weight. In addition, parts weights were evaluated in terms of WI (g) to weight (g) or part water conversion ratio (PWCR).

Statistical Analysis

All statistics were analyzed using two- way ANOVAs in JMP 16.4 (JMP 2021). The main effects analyzed were strain and sex in addition to the interaction between strain and sex.

Means were considered statistically different at a P value < 0.05 with means being separated using a student's t test.

Results and Discussion

Live Performance Measurements

Performance measurements were analyzed on a weekly basis and cumulatively at market ages (Tables 2-6). Strain differences in BW were observed every week of production. Each strain evaluated maintained a linear growth pattern. The two high yield strains (C and D) generally lagged the parts lines in BW until 56 days where C was not different from the A and B strains (Figure 1). B was consistently higher than the other 3 strains throughout the trial except at the previously mentioned 56-day weight. In general, C was the next heaviest then A and D respectively.

FI recorded by strain had weekly differences for the duration of the trial. Much like BW each strain maintained a similar trajectory for the entire testing period. At d35 FI for strain B started to slow and C surpassed it for the duration of the period. Strain D had lower FI for the for the entire production cycle and consumed on average 500g less than any other strain (Figure 2). Differences were also observed for A, which on average consumed 300g less than both B and C (Figure 2). WI also exhibits a linear relationship much like FI and BW (Figure 3). Differences were observed in every week of production. Much like FI, B had the highest WI until d35 when C consumption reached similar levels and surpassed B with respect to weekly WI. Strain A consumed less water than C from d28 until the end of the period. Strain D consumed less water than all the strains from d14 on and had lower WI at each market age. Strain D also consumed almost 700g less than A and 1500g less than both B and C, during the production period (Figure 3).

FCR for all four strains exhibited a linear relationship for the duration of the period with differences observed in 4 of the 7 weeks (Figure 4). Differences were not observed on day 21, 28, and day 49. FCR on day 21 and 28 appear similar and FCR for all the strains slightly

increased from day 21 to day 28 (Figure 4). Differences for cumulative FCR for the entire period were observed. Both B and A had FCRs of 1.71 and C had an overall FCR of 1.73 (Figure 4). Strain D outperformed its counterparts by 4 and 6 points respectively, recording an FCR of 1.66 (Figure 4). WCR measurements demonstrated a different trend. The first week all four strains had WCR observations around 2.5 but at d14 all four lines WCR values decreased. Inflated WCR values during the first week of production can be attributed to chicks adjusting to nipple drinkers and subsequent waste. Although differences were observed at d7 none were observed at d14. Differences were observed at d21 but not at d28. It is worth noting that WCR follows a similar trend line to FCR, that is a plateau of values before both respective performance measurements start to increase. Differences were observed at d35 and 42 but not d49. Cumulative WCR values at market ages favored A and D over B and C. At each age A and D outperformed B and C by around 10 points.

Both processing ages yielded different WCR measurements for each line. The parts lines did not perform better than D which is a yield package. In fact, D performed better than all the packages at both processing ages but also was the smallest package at each age. Strain B and C both had the highest processing weights but also had the most inefficient WCR measurements. High BWs are slightly correlated with high WI values, but more research is needed to characterize the heritability and correlated response of water efficiency traits. Even though differences were observed for WCR measurements it appears that neither program is implementing WCR on selection indices. It also is worth noting that all packages utilized in the study outperformed all performance objectives provided by each respective primary genetics company. This is not particularly abnormal for a research setting given the above average environments birds are grown in. Preliminary results from chapter 2 show a noteworthy reduction in WI while not adversely affecting BW in a single trait selection. Altered breeding objectives/ selection indices could shift water efficiency traits in broiler packages. Ideally strains

will be developed specifically for water stressed environments in order to help feed the global population.

Processing Evaluations

Carcass traits evaluated by PWCR are not documented in the available literature. The novel approach presents a unique way of analyzing the recent findings presented in the study. The relationship was presented by WI (g) / part weight (g), also referred to as PWCR. The amount of water (g) “needed” to produce part weight (g) is presented at two different processing ages, day 43 and 56 (Table 7, 10). Differences were only observed within strain with respect to PWCR at 43 days. The exaggerated PWCR observations of fat likely reflects the observed differences in the percentages of fat yield (Table 8). The lower fat yield in the A and D strains would suggest higher PWCRs with respect to fat. WOG PWCR also exhibits a similar relationship. Considering the WCR efficiencies of the A and D strains and particularly strain D, the differences were expected and offer less insight than the other relationships presented. Strain D recorded the lowest PWCR total breast value within the study. The PWCR value observed required 0.79-1.07g less water to produce a g of total breast. The lower water requirements needed to produce total breast tissue presents a new perspective into meat quality. Table 9 displays distribution of wooden breast myopathies within strain x sex, strain, and sex. Differences were observed within strain and strain D recorded the highest incidence and score. Wooden breast is a myopathy characterized the by replacement of muscle fibers with collagen and fat. The water content of muscle is around 77% (Özcan and Bozkurt, 2015). Although more research is needed to determine an accurate water content of wooden breast collagen (insoluble), typical water content of insoluble collagen and fat is much lower than lean muscle tissue. Given strain D required the least water and had the highest total breast yield, higher wooden breast incidence and severity could be related to lower water requirments. More

research is requied to help determine relationship between wooden breast and water requirments/content.

Wing yield and PWCR followed a similar trend to total breat yield/PWCR. Yield differneces between strain approached signifcance with strain D having the highest yield%. Differences were observed with respect to PWCR of wings, as D had the lowest observation, requiring 0.96-2.14g of water less than any other strain. This also could suggest lower muslce content on the wing with other componets (fat,skin,bone) making up a larger proportion of the observed weight. Differences in leg yield were observed in strain A which had 0.55-1.02% more yield than all of the other strains tested. Similar to strain D with respect to water requirments of leg and total breast, water requirments of leg were signifcant requiring 0.60 -1.13g less water than the other strains. This illicts questions about leg composition and structure and its potential relationship to leg functionality (ie welfare) between strains. It is noteworthy that PWCR sex differences were only observed in fat. This can be expected due to biological fat requirments of females for reproduction purposes.

Table 10 displays PWCR at a processing age of 57 days. Differences were observed in in fat PWCR, and more variation was noted compared to the earlier processing age. Strain B recorded the largest delta amongst all the strains, increasing by almost 75g. The fat metabolism of B could have increased substantially during the extra grow period. When observing sex x strain, it appears that the males across all the strains became much leaner, losing fat and allocating nutrients to muscle or skeletal structure. Differences were in all tested effects in WOG PWCR. The sexual dimorphism regarding WOG, wing, and leg PWCR efficiencies are notable. Males are more efficient in the later growth period and exhibit many similar relationships observed at the earlier processing age. Differences between strain for wing PWCR were not detected. Leg PWCR differences between strain was distinguished by breeding company products rather than product type. Strain A and D both require less water than both A and C

strains at the current processing age. Perhaps different breeding objectives steer different growth profiles yielding different nutrient requirements at the later processing age. Wing PWCR differences were only observed in the strain x sex interaction and between the sexes. Again, each package's male performed more efficiently than its female counterpart. Total breast PWCR within strain changed slightly from the earlier processing age. The yield packages had the lowest water requirements at this age which is expected. Strain D maintained is position as the most efficient but it along with C recorded equally high wooden scores and incidence. Possibly suggesting lower water requirements result in more breast myopathies. New relationships and correlations can be explored to further efficiencies and genetic selection within the poultry industry.

Carcass traits presented as percentages of BW at two processing ages are displayed in Tables 8 and 11. Strain C had the largest percentage of fat within the four strains measured at 1.39%. Strain B had the next highest percentage of 1.20% followed by lower percentages for A 1.01%, and D, 0.96%. Differences were observed in WOG percentages as well. Strain D was higher at 78.01% followed C at 77.37%, and A at 77.07%. The lowest observation recorded was for B at 76.49%. Differences were observed in the total breast trait as well with strain D having the larger percentage at 29.20%. Followed by C at 27.96% and A at 27.06, and B at 26.99%. No differences were found in wing percentages. Only one strain recorded higher leg percentages which was strain A. When evaluating wooden breast differences were observed when evaluating strain's average score. The high yield strains had the highest average scores with only strain D having a higher score of 0.833. Distributions of scores as a percentage only displayed differences in the 2 category. Strain D had 28.33% score 2 with all other strains recording 11.67%.

Conclusion

The methods utilized by Hiltz and colleagues (2021) were successful in characterizing water consumption of four contemporary broiler strains. WI and WCR values for each respective

strain have been recorded with differences observed between respective strains. Findings serve as baseline performance standards and indicate that little selection pressure has been employed on water efficiency traits in broiler populations.

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Figures and Tables

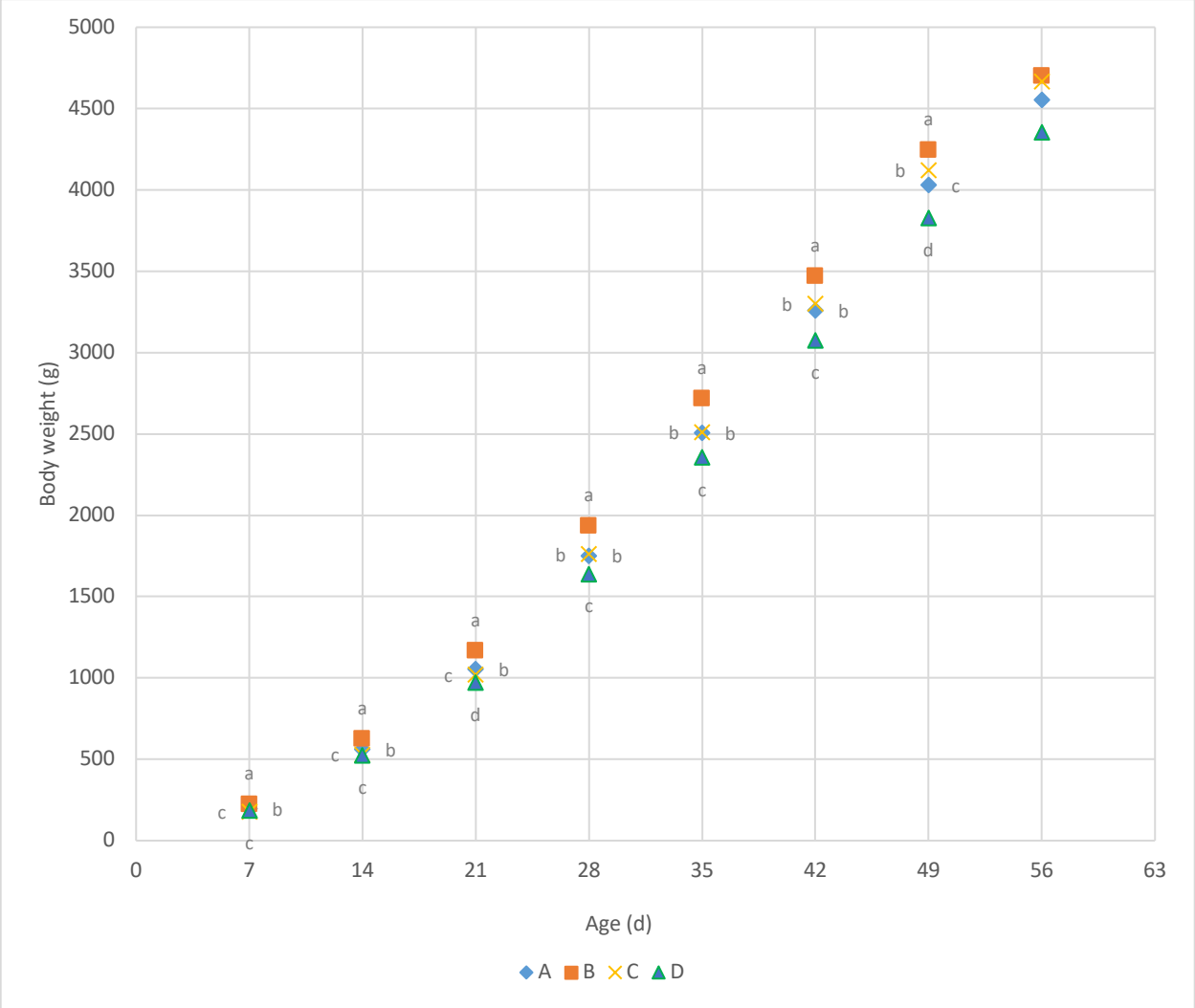


Figure 1. Strain[1] Comparison of body weight from 7 to 56 days of age
[a-d]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

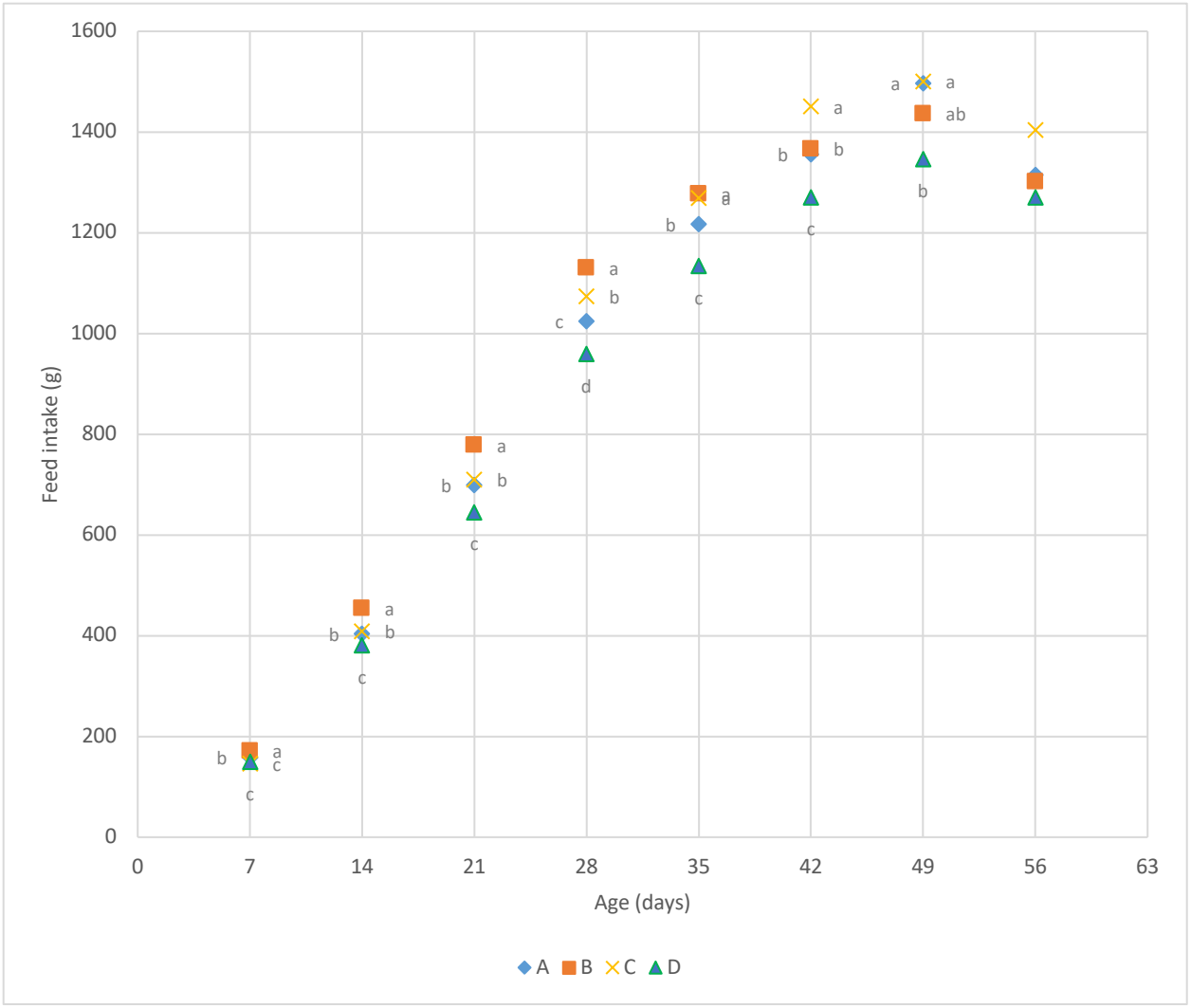


Figure 2. Strain[1] Comparison of feed intake from 7 to 56 days of age
[a-c]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler; whole bird/parts/tray pack market. Strain C and D serve the high breast yield/debone sector.

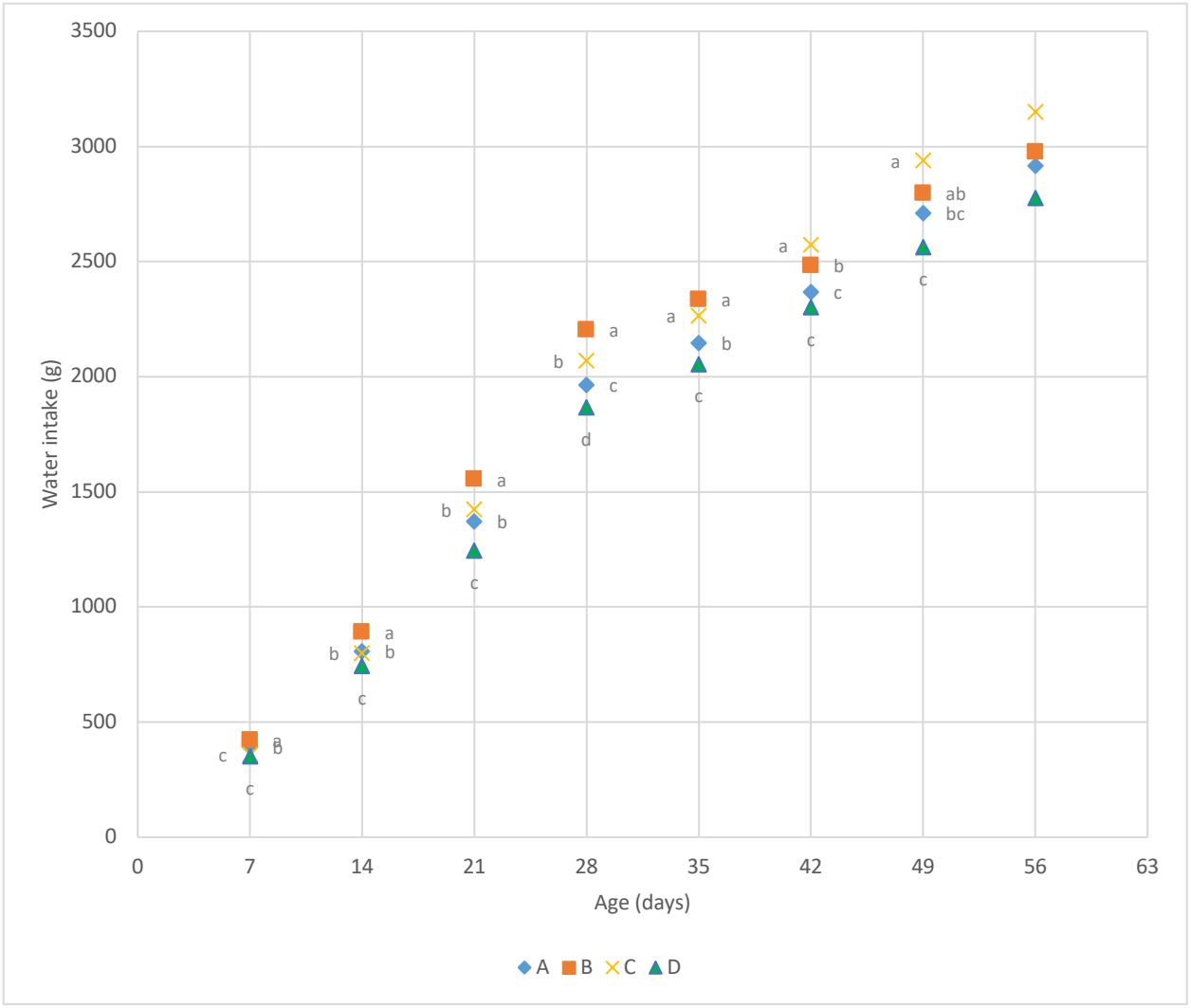


Figure 3. Strain[1] Comparison of water intake from 7 to 56 days of age
[a-d]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

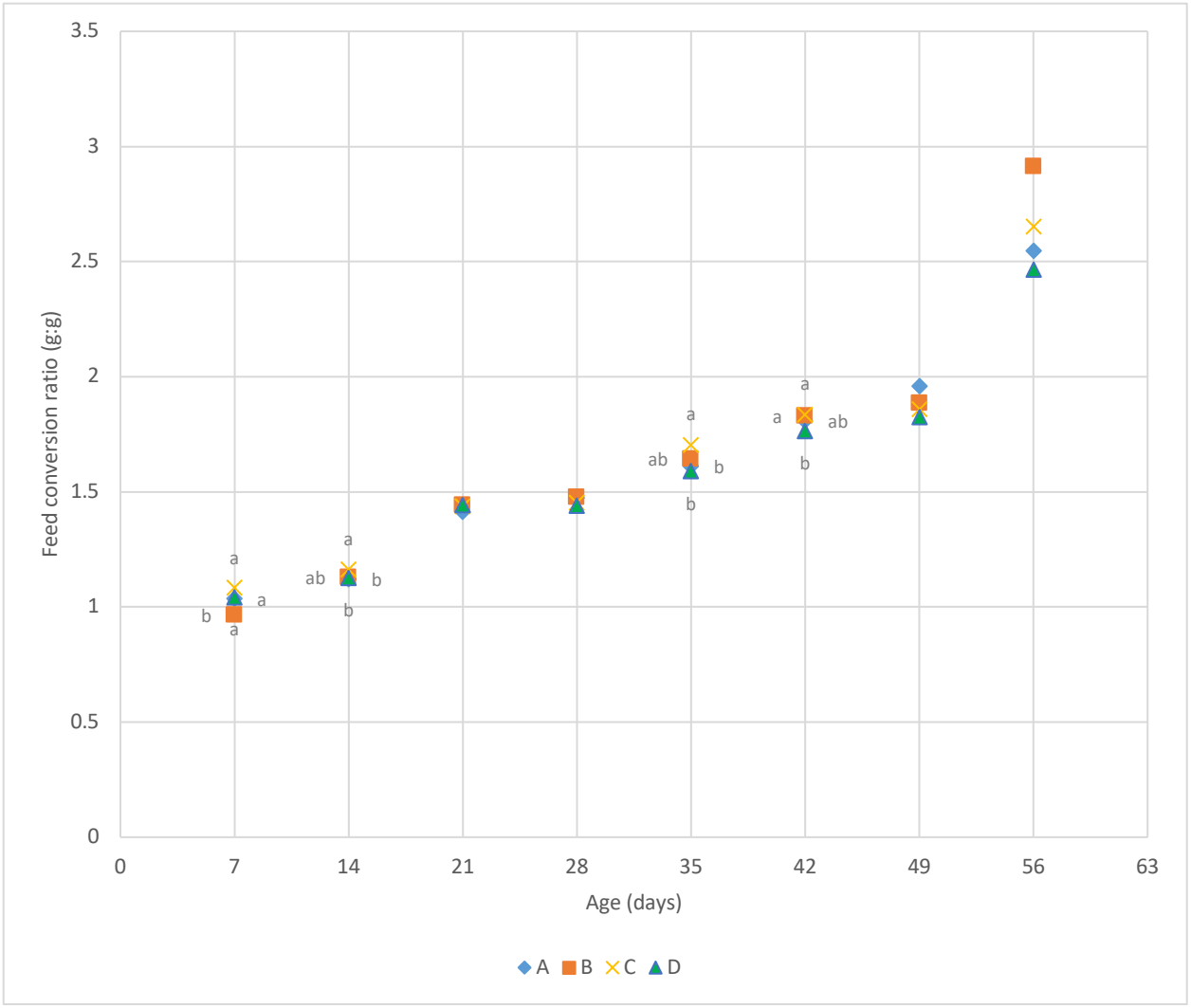


Figure 4. Strain[1] Comparison of feed conversion ratio from 7 to 56 days of age
[a-b]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

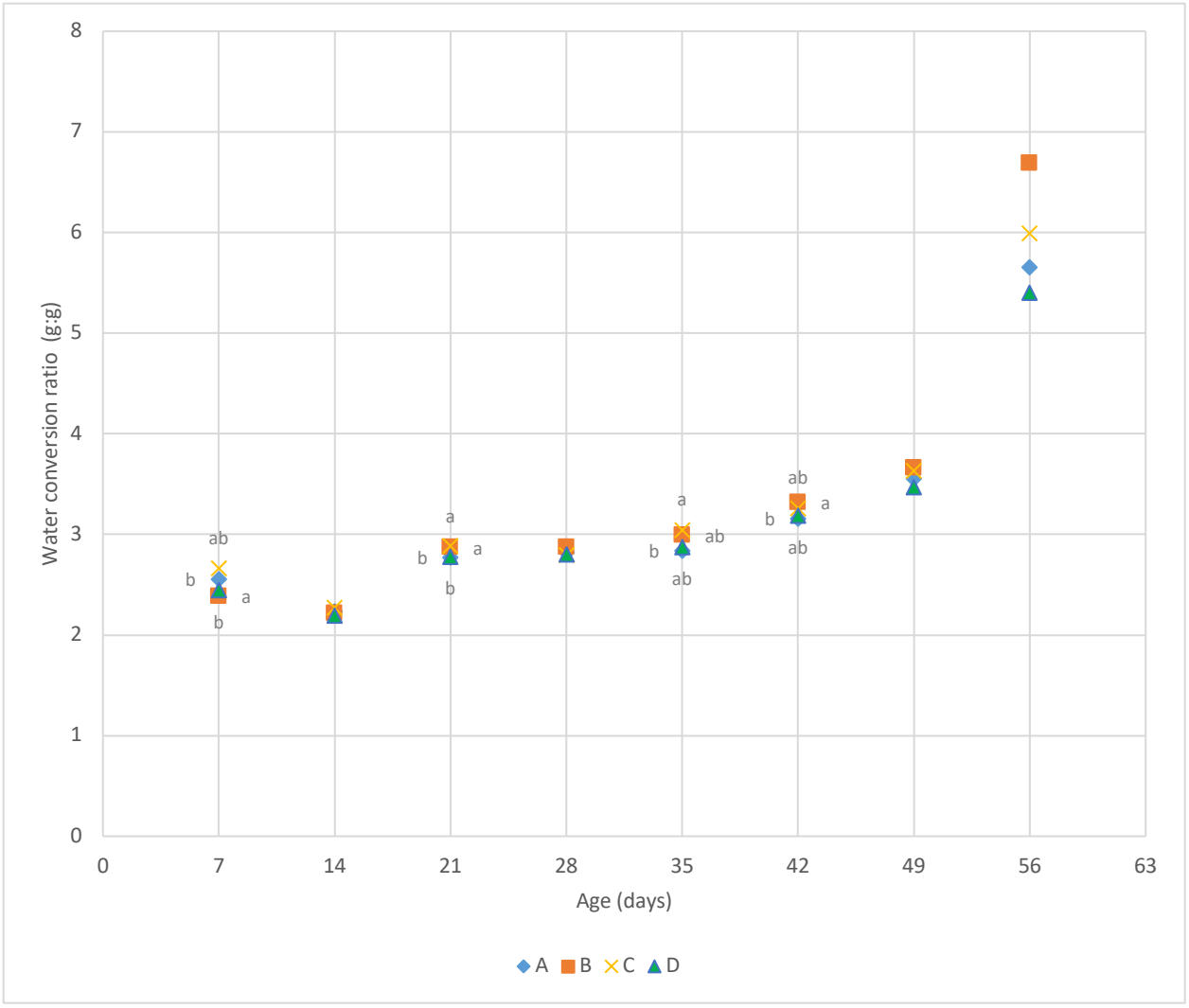


Figure 5. Strain[1] Comparison of water conversion ratio from 7 to 56 days
[a-b]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

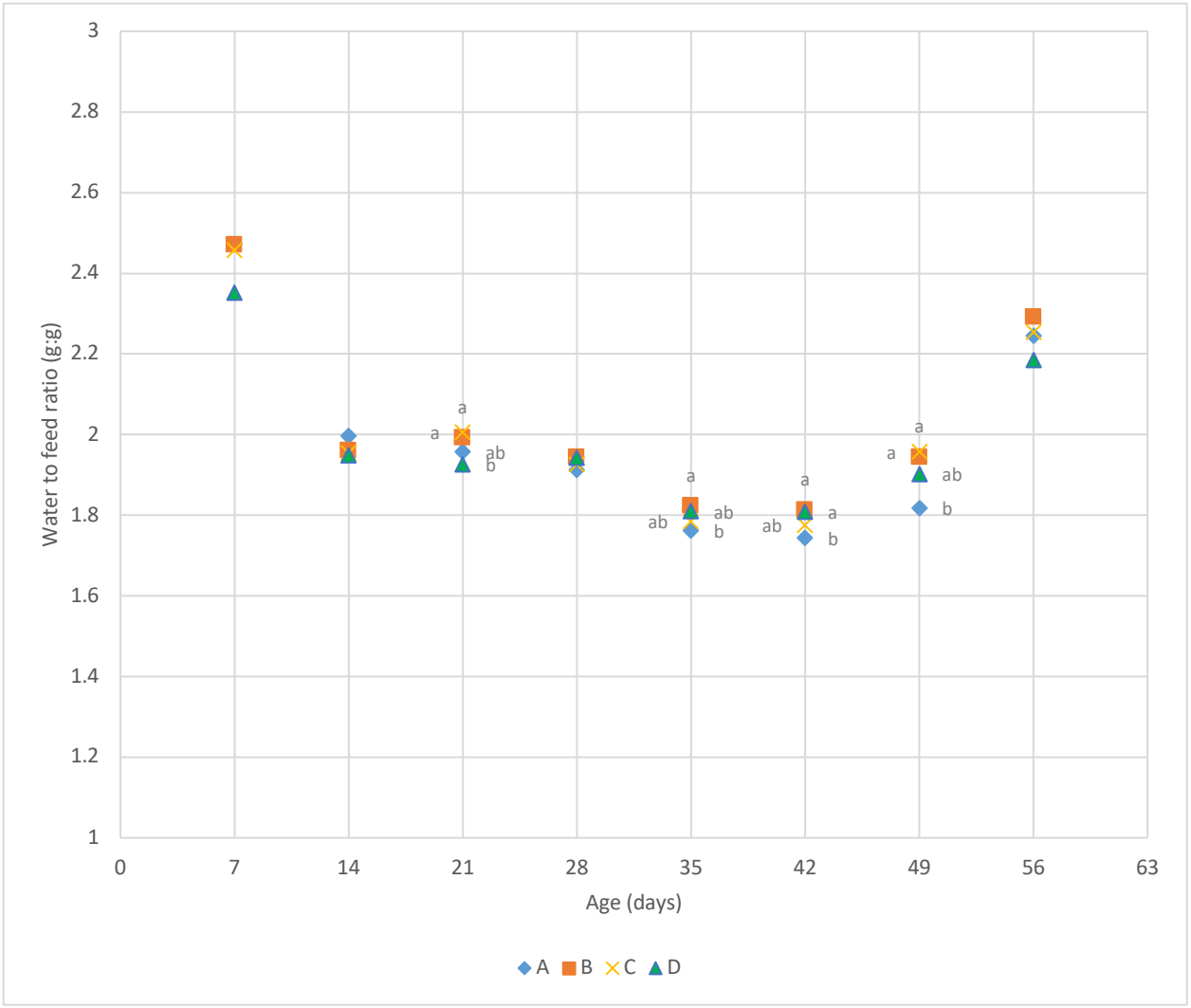
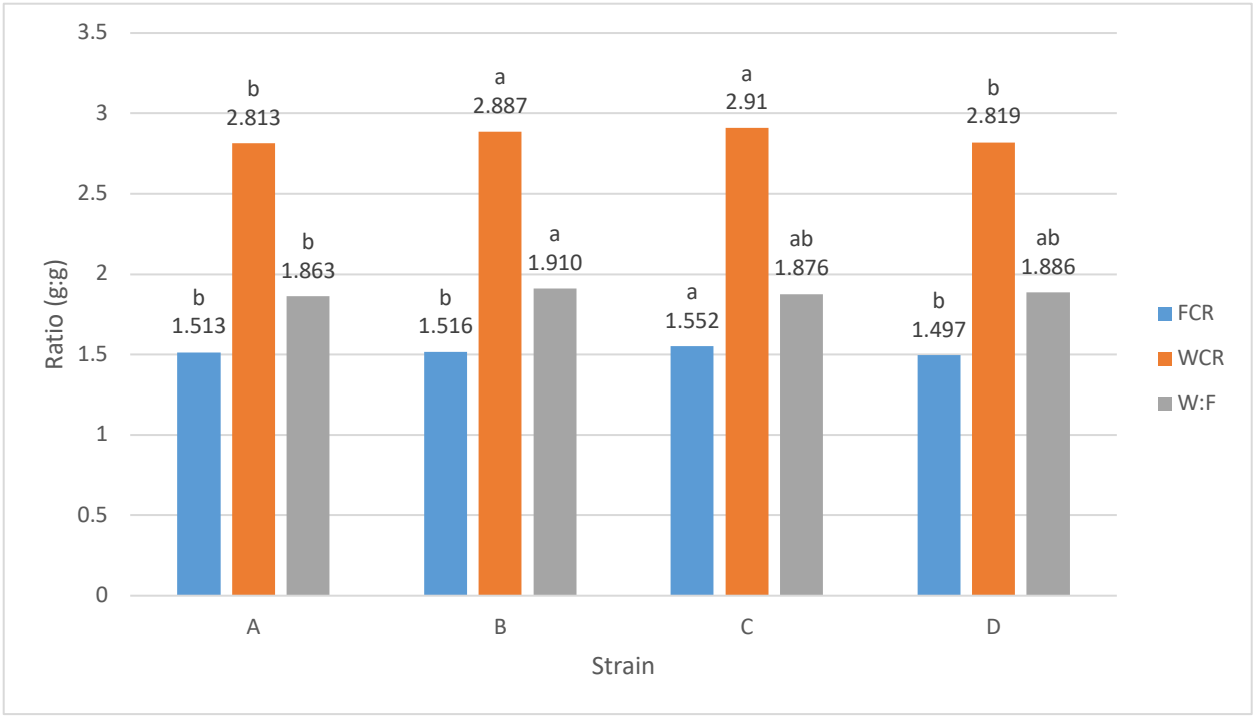


Figure 6. Strain[1] Comparison of water to feed ratio from 7 to 56 days
[a-b]Means within an age without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.



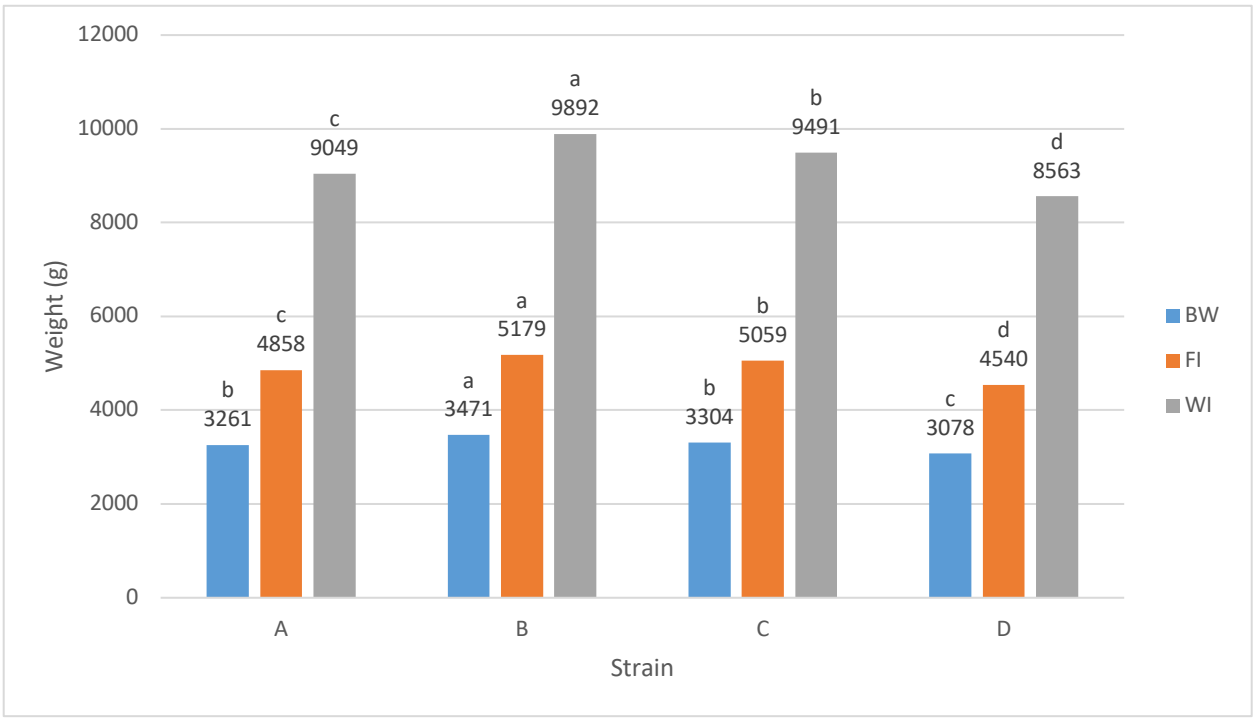
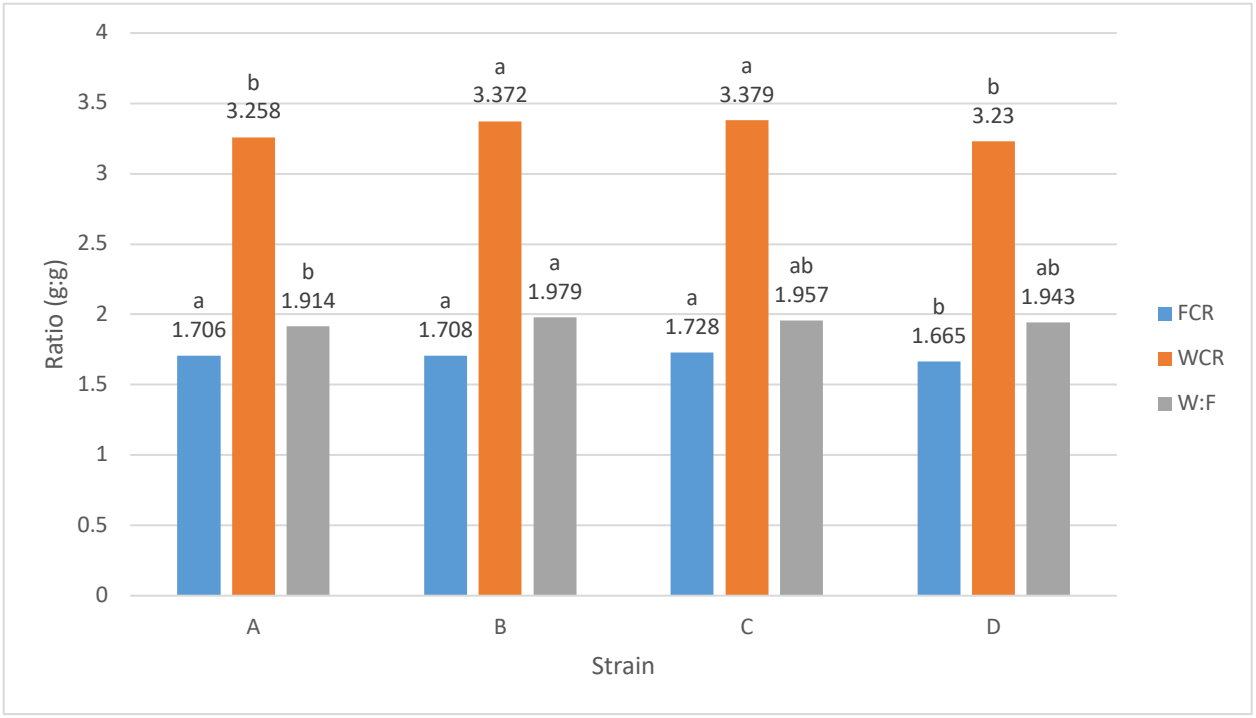


Figure 7. Strain comparison of performance measures from hatch to 42 days.
[a-c]Means without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.
[2]FCR= feed conversion ratio; WCR=water conversion ratio; W:F= water: feed ratio; BW= body weight; FI= feed intake; WI= water intake



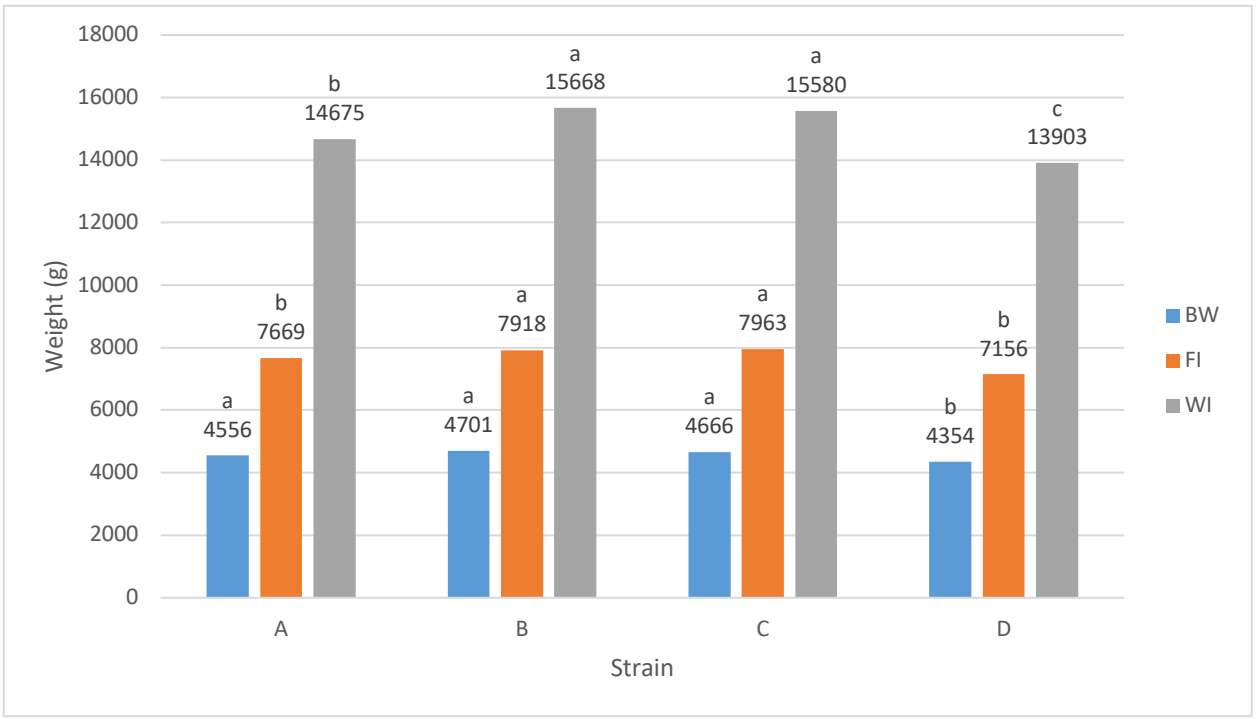


Figure 8. Strain comparison of performance measures from hatch to 56 days.
[a-c]Means without a common superscript determined to be different (P > 0.05)
[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.
[2]FCR= feed conversion ratio; WCR=water conversion ratio; W:F= water: feed ratio; BW= body weight; FI= feed intake; WI= water intake

Table 1. Composition of starter, grower, finisher, and withdrawal diets

Ingredient, % as-is	Starter	Grower	Finisher	Withdrawal
Corn	57.32	59.70	62.10	64.43
Soybean meal	34.35	31.86	29.36	26.87
DDGS[1]	2.00	2.00	2.00	2.00
Poultry fat	2.88	3.25	3.63	4.03
Limestone	1.07	1.02	0.96	0.91
Dicalcium phosphate	0.82	0.73	0.64	0.56
Salt	0.21	0.21	0.22	0.22
Sodium bicarbonate	0.29	0.28	0.27	0.27
L-Lysine HCl	0.29	0.28	0.27	0.25
DL-Methionine	0.35	0.32	0.29	0.26
L-Threonine	0.13	0.12	0.11	0.11
L-Valine	0.00	0.02	0.01	0.00
Vitamins[2]	0.10	0.08	0.05	0.03
Minerals[3]	0.10	0.08	0.05	0.03
Phytase	0.05	0.05	0.05	0.05
Choline chloride, 60%	0.05	0.03	0.00	0.00
Calculated content, % unless noted otherwise				
CP	21.65	20.60	19.53	18.47
Energy	3,050	3,100	3,150	3,200
Ca	0.90	0.85	0.80	0.75
Available P	0.45	0.43	0.41	0.39
Sodium	0.18	0.18	0.18	0.18
Chloride	0.24	0.24	0.24	0.24
Potassium	0.94	0.89	0.85	0.80
Digestible Lys	1.25	1.18	1.11	1.04
Digestible Met	0.65	0.61	0.57	0.53
Digestible TSAA	0.94	0.89	0.83	0.78
Digestible Thr	0.84	0.79	0.74	0.71

[1]Dried distiller's grains with solubles

[2]The mineral premix contributed (per kg of diet): zinc, 100 mg; magnesium, 100 mg; calcium, 69 mg; iron, 15mg; copper, 15 mg; iodide, 1.20; selenium, 0.25 mg.

[3]The vitamin premix contributed (per kg of diet): vitamin A, 30,864 IU; vitamin D_3, 22,046 ICU; vitamin E, 220 IU; niacin, 154 mg; d-pantothenic acid, 40 mg; riboflavin, 26 mg; pyridoxine, 6 mg; thiamine, 6 mg; menadione, 6 mg; folic acid, 4 mg; biotin, 0.3 mg; vitamin B_{12}, 0.05 mg.

Table 2. Influence of broiler strain[1] and sex on live performance measurements from 0 to 35 d

Treatment		BW gain	Feed intake	Water intake	FCR[2]	WCR[3]
Strain	Sex	(kg)	(kg)	(L)	(kg:kg)	(L:kg)
Interactive effects of Strain and Sex (n=3)						
A	M	2.658	3.753	7.309^{b}	1.412	2.750
A	F	2.266	3.252	6.051^{e}	1.436	2.671
B	M	2.910	4.097	8.211^{a}	1.409	2.823
B	F	2.436	3.526	6.609^{cd}	1.448	2.712
C	M	2.662	3.835	7.399^{b}	1.441	2.780
C	F	2.283	3.381	6.435^{d}	1.481	2.819
D	M	2.531	3.524	6.860^{c}	1.393	2.711
D	F	2.098	3.013	5.663^{f}	1.436	2.699
SEM		0.0247	0.0299	0.0892	0.0084	0.0285
Main effect of Strain (n=6)						
A		2.462^{b}	3.503^{c}	6.680^{c}	1.424^{b}	2.711^{bc}
B		2.673^{a}	3.812^{a}	7.410^{a}	1.428^{b}	2.768^{ab}
C		2.472^{b}	3.608^{b}	6.917^{b}	1.461^{a}	2.800^{a}
D		2.314^{c}	3.269^{d}	6.262^{d}	1.415^{b}	2.705^{c}
SEM		0.0175	0.0211	0.0631	0.0059	0.0202
Main effect of Sex (n=12)						
	M	2.690	3.802	7.445	1.414	2.766
	F	2.271	3.293	6.190	1.450	2.725
SEM		0.0124	0.0150	0.0446	0.0042	0.0143
P-value						
Strain		<0.001	<0.001	<0.001	<0.001	0.011
Sex		<0.001	<0.001	<0.001	<0.001	0.061
Strain × Sex		0.252	0.310	0.020	0.647	0.075

[a-f]Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]FCR = feed conversion ratio = Feed intake / Body weight gain

[3]WCR = water conversion ratio = Water intake / Body weight gain

Table 3. Influence of broiler strain[1] and sex on live performance measurements from 0 to 42 d

Treatment		BW gain	Feed intake	Water intake	FCR[2]	WCR[3]
Strain	Sex	(kg)	(kg)	(L)	(kg:kg)	(L:kg)
Interactive effects of Strain and Sex (n=3)						
A	M	3.501	5.231	9.939[b]	1.494	2.839
A	F	2.927	4.485	8.158[e]	1.532	2.787
B	M	3.745	5.591	10.961[a]	1.423	2.926
B	F	3.099	4.768	8.824[d]	1.539	2.847
C	M	3.537	5.397	10.158[b]	1.526	2.872
C	F	2.993	4.721	8.825[d]	1.577	2.948
D	M	3.326	4.921	9.427[c]	1.480	2.835
D	F	2.746	4.158	7.700[f]	1.514	2.803
SEM		0.0298	0.0407	0.1006	0.0094	0.0276
Main effect of Strain (n=6)						
A		3.214[b]	4.858[c]	9.049[c]	1.513[b]	2.813[b]
B		3.422[a]	5.179[a]	9.892[a]	1.516[b]	2.887[a]
C		3.265[b]	5.059[b]	9.491[b]	1.552[a]	2.910[a]
D		3.036[c]	4.540[d]	8.563[d]	1.497[b]	2.819[b]
SEM		0.0210	0.0288	0.0711	0.0066	0.0195
Main effect of Sex (n=12)						
	M	3.528	5.285	10.121	1.498	2.868
	F	2.942	4.533	8.377	1.541	2.847
SEM		0.0149	0.0204	0.0503	0.0047	0.0138
P-value						
Strain		<0.001	<0.001	<0.001	<0.001	0.006
Sex		<0.001	<0.001	<0.001	<0.001	0.284
Strain × Sex		0.397	0.372	0.010	0.788	0.058

[a-f]Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]FCR = feed conversion ratio = Feed intake / Body weight gain

[3]WCR = water conversion ratio = Water intake / Body weight gain

Table 4. Influence of broiler strain[1] and sex on live performance measurements from 0 to 49 d

Treatment		BW gain	Feed intake	Water intake	FCR[2]	WCR[3]
Strain	Sex	(kg)	(kg)	(L)	(kg:kg)	(L:kg)
Interactive effects of Strain and Sex (n=3)						
A	M	4.375	6.873	12.854^{c}	1.572	2.939^{c}
A	F	3.594	5.836	10.665^{f}	1.624	2.968^{bc}
B	M	4.638	7.142	14.038^{a}	1.540	3.027^{b}
B	F	3.755	6.090	11.344^{e}	1.623	3.022^{b}
C	M	4.477	7.023	13.364^{b}	1.569	2.985^{bc}
C	F	3.689	6.096	11.497^{e}	1.652	3.116^{a}
D	M	4.208	6.389	12.231^{b}	1.519	2.907^{c}
D	F	3.370	5.383	10.021^{g}	1.598	2.974^{bc}
SEM		0.0410	0.0461	0.1300	0.0148	0.0271
Main effect of Strain (n=6)						
A		3.984^{c}	6.355^{b}	11.760^{b}	1.598^{a}	2.954^{b}
B		4.197^{a}	6.616^{a}	12.691^{a}	1.581^{ab}	3.024^{a}
C		4.083^{a}	6.560^{a}	12.431^{a}	1.611^{a}	3.051^{a}
D		3.789^{d}	5.886^{c}	11.126^{c}	1.558^{b}	2.941^{b}
SEM		0.0290	0.0326	0.0920	0.0105	0.0192
Main effect of Sex (n=12)						
	M	4.424	6.857	13.122	1.550	2.964
	F	3.602	5.851	10.882	1.624	3.020
SEM		0.0205	0.0230	0.0650	0.0074	0.0135
P-value						
Strain		<.0001	<.0001	<.0001	0.016	0.002
Sex		<.0001	<.0001	<.0001	<.0001	0.010
Strain × Sex		0.581	0.549	0.042	0.684	0.115

[a-g]Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]FCR = feed conversion ratio = Feed intake / Body weight gain

[3]WCR = water conversion ratio = Water intake / Body weight gain

Table 5. Influence of broiler strain[1] and sex on live performance measurements from 0 to 56 d

Treatment		BW gain	Feed intake	Water intake	FCR[2]	WCR[3]
Strain	Sex	(kg)	(kg)	(L)	(kg:kg)	(L:kg)
Interactive effects of Strain and Sex (n=3)						
A	M	4.959	8.226	16.040	1.659	3.235
A	F	4.060	7.112	13.309	1.753	3.281
B	M	5.177	8.565	17.274	1.655	3.337
B	F	4.130	7.270	14.063	1.761	3.407
C	M	5.097	8.539	16.764	1.676	3.290
C	F	4.152	7.387	14.397	1.779	3.467
D	M	4.797	7.756	15.286	1.617	3.187
D	F	3.827	6.555	12.519	1.713	3.272
SEM		0.0731	0.0994	0.2060	0.0171	0.0514
Main effect of Strain (n=6)						
A		4.510[a]	7.669[b]	14.675[b]	1.706[a]	3.258[b]
B		4.654[a]	7.918[a]	15.668[a]	1.708[a]	3.372[a]
C		4.624[a]	7.963[a]	15.580[a]	1.728[a]	3.379[a]
D		4.312[b]	7.156[c]	13.903[c]	1.665[b]	3.230[b]
SEM		0.0517	0.0703	0.1457	0.0121	0.0364
Main effect of Sex (n=12)						
	M	5.008	8.272	16.341	1.652	3.262
	F	4.042	7.081	13.572	1.752	3.357
SEM		0.0365	0.0497	0.1030	0.0086	0.0257
P-value						
Strain		0.001	<.0001	<.0001	0.016	0.018
Sex		<.0001	<.0001	<.0001	<.0001	0.019
Strain × Sex		0.787	0.815	0.277	0.982	0.611

[a-c]Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]FCR = feed conversion ratio = Feed intake / Body weight gain

[3]WCR = water conversion ratio = Water intake / Body weight gain

Table 6. Influence of broiler strain[1] and sex on flock uniformity[2] assessed at four, six, and eight weeks

Treatment		Four weeks	Six weeks	Eight weeks
Strain	Sex	(%)	(%)	(%)
Interactive effects of Strain and Sex (n=3)				
A	M	9.263[ab]	7.923[ab]	5.683
A	F	8.320[ab]	6.387[ab]	6.040
B	M	7.067[ab]	6.850[ab]	7.183
B	F	6.723[b]	7.817[ab]	6.193
C	M	7.313[ab]	6.650[ab]	8.370
C	F	8.777[ab]	6.500[ab]	5.553
D	M	9.493[a]	8.343[a]	5.967
D	F	9.253[ab]	6.120[b]	6.197
SEM		0.9004	0.7332	1.2977
Main effect of Strain (n=6)				
A		8.792[ab]	7.155	5.862
B		6.895[b]	7.333	6.688
C		8.045[ab]	6.575	6.962
D		9.373[a]	7.232	6.082
SEM		0.6367	0.5185	0.9176
Main effect of Sex (n=12)				
	M	8.284	7.442	6.801
	F	8.268	6.706	5.996
SEM		0.4502	0.3666	0.6488
P-value				
Strain		0.072	0.734	0.816
Sex		0.981	0.175	0.393
Strain × Sex		0.589	0.172	0.598

[a-b] Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]Uniformity= Coefficient of variation within flock = population standard deviation/population mean

Table 7. Part water conversion ratio[1] of male and female broilers from four commercial strains[2] processed at 43 d

Treatment		Live BW	Fat	WOG[3]	Total breast[4]	Wing	Leg[5]
Strain	Sex	(g:g)	(g:g)	(g:g)	(g:g)	(g:g)	(g:g)
Interactive effects of Strain and Sex (n=3)							
A	M	2.907	359.150	3.779	10.713	39.735	12.840
A	F	2.863	243.036	3.707	10.603	38.594	12.869
B	M	2.987	305.009	3.901	11.056	40.382	13.475
B	F	2.922	207.306	3.825	10.831	39.281	13.506
C	M	2.967	248.395	3.819	10.547	40.347	13.599
C	F	3.028	190.988	3.928	10.865	40.358	14.355
D	M	2.926	313.095	3.766	10.173	38.781	13.446
D	F	2.843	287.260	3.630	9.581	37.646	13.451
SEM		0.0445	20.950	0.0435	0.2049	0.6515	0.2477
Main effect of Strain (n=6)							
A		2.885	301.093^{a}	3.743^{ab}	10.658^{a}	39.165^{ab}	12.854^{c}
B		2.955	256.157^{bc}	3.863^{a}	10.943^{a}	39.832^{a}	13.491^{ab}
C		2.998	219.619^{c}	3.874^{a}	10.706^{a}	40.353^{a}	13.977^{a}
D		2.884	300.177^{ab}	3.698^{b}	9.87^{b}	38.214^{b}	13.449^{b}
SEM		0.0315	14.812	0.044	0.1449	0.4607	0.1751
Main effect of Sex (n=12)							
	M	2.947	306.412	3.817	10.622	39.811	13.340
	F	2.914	232.148	3.773	10.470	38.970	13.545
SEM		0.0222	10.475	0.031	0.1024	0.3257	0.1283
P-value							
Strain		0.055	0.003	0.027	<0.001	<0.001	0.003
Sex		0.316	<0.001	0.330	0.310	0.087	0.259
Strain × Sex		0.404	0.175	0.262	0.213	0.768	0.378

[a-c] Means without a common superscript determined to be different (P > 0.05)

[1]Part water conversion ratio = water intake/part weight

[2]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[3]Chilled carcass without giblets

[4]Total breast sum of *Pectoralis major* and *P. minor*

[5]Leg sum of bone-in, skin-on thigh and drumstick

Table 8. Carcass traits of male and female broilers from four commercial strains[1] processed at 43 d

Treatment		Live BW	Fat	WOG[2]	Total breast[3]	Wing	Leg[4]
Strain	Sex	(kg)	(%)	(%)	(%)	(%)	(%)
Interactive effects of Strain and Sex (n=3)							
A	M	3.42	0.83	76.89^{cd}	27.11	7.32	22.64
A	F	2.85	1.19	77.24^{bc}	27.00	7.43	22.26
B	M	3.67	0.99	76.55^{d}	26.97	7.40	22.18
B	F	3.02	1.41	76.43^{d}	27.01	7.46	21.61
C	M	3.42	1.19	77.71^{ab}	28.10	7.37	21.85
C	F	2.92	1.59	77.03^{cd}	27.81	7.50	21.10
D	M	3.23	0.93	77.69^{ab}	28.72	7.54	21.78
D	F	2.71	0.99	78.32^{a}	29.67	7.55	21.15
SEM		0.0523	0.066	0.211	0.317	0.064	0.207
Main effect of Strain (n=6)							
A		3.14^{b}	1.01^{c}	77.07^{b}	27.06^{c}	7.38	22.45^{a}
B		3.35^{a}	1.20^{b}	76.49^{c}	26.99^{c}	7.43	21.90^{b}
C		3.17^{b}	1.39^{a}	77.37^{b}	27.96^{b}	7.44	21.48^{b}
D		2.97^{c}	0.96^{c}	78.01^{a}	29.20^{a}	7.55	21.47^{b}
SEM		0.0370	0.046	0.149	0.224	0.045	0.146
Main effect of Sex (n=12)							
	M	3.44	0.99	77.21	27.73	7.41	22.11
	F	2.87	1.30	77.26	27.87	7.49	21.53
SEM		0.0261	0.033	0.105	0.159	0.032	0.103
P-value							
Strain		<0.001	<0.001	<0.001	<0.001	0.093	0.001
Sex		<0.001	<0.001	0.771	0.516	0.106	0.001
Strain × Sex		0.503	0.051	0.034	0.248	0.763	0.848

[a-e] Means without a common superscript determined to be different (P > 0.05)

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]Chilled carcass without giblets

[3]Total breast sum of *Pectoralis major* and *P. minor*

[4]Leg sum of bone-in, skin-on thigh and drumstick

Table 9. Wooden breast scores[1] for male and female broilers from four commercial strains[2] processed at 43 d

Treatment		Average	Distribution (%)		
Strain	Sex	Score	Score 0	Score 1	Score 2
Interactive effects of Strain and Sex (n=3)					
A	M	0.833	40.00	36.67	23.33
A	F	0.233	76.67	23.33	0.00
B	M	0.667	53.33	26.67	20.00
B	F	0.200	83.33	13.33	3.33
C	M	0.600	50.00	40.00	10.00
C	F	0.533	60.00	26.67	13.33
D	M	0.933	43.33	20.00	36.67
D	F	0.733	46.67	33.33	20.00
SEM		0.1323	10.541	10.801	5.893
Main effect of Strain (n=6)					
A		0.533[b]	58.33	30.00	11.67[b]
B		0.433[b]	68.33	20.00	11.67[b]
C		0.567[ab]	55.00	33.33	11.67[b]
D		0.833[a]	45.00	26.67	28.33[a]
SEM		0.0935	7.454	7.638	4.167
Main effect of Sex (n=12)					
	M	0.758	46.67	30.83	22.50
	F	0.425	66.67	24.17	9.17
SEM		0.0661	5.270	5.401	2.946
P-value					
Strain		0.046	0.214	0.652	0.027
Sex		0.003	0.016	0.396	0.006
Strain × Sex		0.209	0.365	0.532	0.167

[a-b] Means without a common superscript determined to be different (P > 0.05)

[1]Score = 0 = none, 1 = moderate, 2 = severe wooden breast

[2]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

Table 10. Part water conversion ratio[1] of male and female broilers from four commercial strains[2] processed at 57 d

Treatment		Live BW	Fat	WOG[3]	Total breast[4]	Wing	Leg[5]
Strain	Sex	(g:g)	(g:g)	(g:g)	(g:g)	(g:g)	(g:g)
Interactive effects of Strain and Sex (n=3)							
A	M	3.24	384.37	4.09^{cd}	11.58	43.02^{c}	13.74^{e}
A	F	3.34	228.38	4.20^{bc}	11.53	45.08^{b}	14.73^{cd}
B	M	3.30	410.35	4.18^{bc}	11.73	42.34^{c}	14.80^{cd}
B	F	3.41	238.43	4.30^{ab}	11.60	45.38^{ab}	15.68^{b}
C	M	3.20	277.06	3.99^{d}	10.77	42.10^{c}	14.43^{de}
C	F	3.50	191.58	4.39^{a}	11.48	47.14^{a}	16.95^{a}
D	M	3.20	402.41	3.98^{d}	10.41	42.72^{c}	14.33^{de}
D	F	3.26	236.73	4.06^{cd}	10.29	43.89^{bc}	15.37^{bc}
SEM		0.0513	21.3095	0.0583	0.250	0.648	0.241
Main effect of Strain (n=6)							
A		3.29	306.37^{a}	4.15^{ab}	11.55^{ab}	44.05	14.24^{c}
B		3.36	324.39^{a}	4.24^{a}	11.67^{a}	43.86	15.24^{ab}
C		3.35	234.32^{b}	4.19^{a}	11.12^{b}	44.62	15.69^{a}
D		3.23	319.57^{a}	4.02^{b}	10.53^{c}	43.30	14.85^{b}
SEM		0.036	15.068	0.0412	0.1767	0.4580	0.171
Main effect of Sex (n=12)							
	M	3.24	368.55	4.06	10.62	42.54	14.33
	F	3.78	223.78	4.24	10.47	45.37	15.68
SEM		0.0256	10.655	0.0291	0.125	0.032	0.121
P-value							
Strain		0.077	0.002	0.012	<0.001	0.280	<0.001
Sex		0.001	<.0001	0.001	0.570	<0.001	<0.001
Strain × Sex		0.134	0.194	0.048	0.314	0.047	0.011

[a-e] Means without a common superscript determined to be different (P > 0.05)

[1]Part water conversion ratio = water intake/part weight

[2]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[3]Chilled carcass without giblets

[4]Total breast sum of *Pectoralis major* and *P. minor*

[5]Leg sum of bone-in, skin-on thigh and drumstick

Table 11. Carcass traits of male and female broilers from four commercial strains[1] processed at 57 d

Treatment		Live BW	Fat	WOG[2]	Total breast[3]	Wing	Leg[4]
Strain	Sex	(kg)	(%)	(%)	(%)	(%)	(%)
Interactive effects of Strain and Sex (n=3)							
A	M	4.95	0.85	79.25	27.96	7.53	23.59
A	F	3.99	1.48	79.52	28.99	7.41	22.71
B	M	5.23	0.81	79.11	28.22	7.83	22.34
B	F	4.13	1.43	79.30	29.38	7.52	21.74
C	M	5.24	1.15	80.13	29.71	7.61	22.17
C	F	4.11	1.85	79.60	30.48	7.42	20.63
D	M	4.78	0.81	80.27	30.77	7.48	22.32
D	F	3.84	1.38	80.23	31.74	7.43	21.23
SEM		0.067	0.079	0.288	0.466	0.085	0.279
Main effect of Strain (n=6)							
A		4.47^{b}	1.17^{b}	79.39^{bc}	28.47^{c}	7.47	23.15^{a}
B		4.68^{a}	1.12^{b}	79.20^{c}	28.80^{c}	7.67	22.04^{b}
C		4.68^{a}	1.50^{a}	79.86^{ab}	30.09^{b}	7.52	21.40^{c}
D		4.31^{c}	1.10^{b}	80.25^{a}	31.25^{a}	7.46	21.78^{bc}
SEM		0.047	0.056	0.204	0.329	0.060	0.197
Main effect of Sex (n=12)							
	M	5.05	0.91	79.69	29.16	7.61	22.61
	F	4.02	1.54	79.66	30.14	7.45	21.58
SEM		0.033	0.040	0.144	0.233	0.043	0.140
P-value							
Strain		<.0001	0.000	0.009	<.0001	0.080	<.0001
Sex		<.0001	<.0001	0.894	0.009	0.014	<.0001
Strain × Sex		0.440	0.875	0.529	0.980	0.491	0.419

[a-c] Means without a common superscript determined to be different (P > 0.05) by a repeated t test

[1]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

[2]Chilled carcass without giblets

[3] Total breast sum of *Pectoralis major* and *P. minor*

[4]Leg sum of bone-in, skin-on thigh and drumstick

Table 12. Wooden breast scores[1] for male and female broilers from four commercial strains[2] processed at 57 d

Treatment		Average	Distribution (%)		
Strain	Sex	Score	Score 0	Score 1	Score 2
Interactive effects of Strain and Sex (n=3)					
A	M	0.967	23.33	50.00	20.00
A	F	0.433	63.33	30.00	6.67
B	M	1.133	30.00	26.67	43.33
B	F	0.608	50.00	46.67	3.33
C	M	1.267	16.67	40.00	43.33
C	F	0.933	33.33	40.00	26.67
D	M	1.133	30.00	26.67	43.33
D	F	1.000	26.67	46.67	26.67
SEM		0.161	10.737	8.250	6.562
Main effect of Strain (n=6)					
A		0.700	43.33	40.00	13.33[b]
B		0.871	40.00	36.67	23.33[ab]
C		1.100	25.00	40.00	35.00[a]
D		1.067	28.33	36.67	35.00[a]
SEM		0.114	7.592	5.833	4.640
Main effect of Sex (n=12)					
	M	1.125	25.00	35.83	37.50
	F	0.744	43.33	40.83	15.83
SEM		0.081	5.368	4.125	3.281
P-value					
Strain		0.083	0.289	0.954	0.012
Sex		0.004	0.028	0.404	0.000
Strain × Sex		0.572	0.289	0.081	0.195

[a-b] Means without a common superscript determined to be different (P > 0.05) by a repeated t test

[1]Score = 0 = none, 1 = moderate, 2 = severe wooden breast

[2]Strain A and B are designed to serve the general broiler whole bird/parts/tray pack market, while C and D serve the high breast yield/debone sector.

CHAPTER 4: CHARACTERIZATION OF ENVIRONMENTAL/CLIMATIC INFLUENCES ON BROILER EMBRYOS AND CHICKS IN A RURAL SUB-SAHARAN ENVIRONMENT

Abstract

Over the past 60 years, poultry has proved to be the most efficient and popular protein available, emerging as a food staple in less developed areas of the world. As a result, integrated poultry operations continue to push production in suboptimal environments lacking modern infrastructure and technology. Although the genetics/efficiencies of the modern-day broiler mask many of these shortcomings, the harsh environmental/climatic influences are less forgiving. The extreme temperatures of these climates pose new challenges within the poultry biological supply chain, that of which are overlooked by producers. This research note will investigate three time periods within early production where environmental/climatic influences can have adverse effects on embryonic development/chick quality.

Introduction

The United Nations Department of Economic and Social Affairs estimates the global population will grow to 8.6 billion in 2030 and 9.8 billion in 2050 (United Nations Department of Economic and Social Affairs Population Division, 2017). To support this future population growth, it is projected that the current food supply must increase by 60% (Alexandratos and Bruinsma, 2012). It is well documented that poultry will be a substantial part of the future global food supply. Since 1960 the global per capita of eggs consumed has doubled, while poultry meat consumption has increased fivefold (FAO, 2020). Currently poultry is raised by 80% of households in developing countries (FAO, 2020). Most of this subsequent growth is taking place in regions of the world such as Africa and Asia. Such regions give way to documented challenges of extreme temperatures and poor infrastructure. Identifying and characterizing the environmental/climatic influences is an integral part of a profitable and sustainable business approach. The lack of modern technology and infrastructure experienced in these regions gives way to obvious problems remedied through intuitive practical methods.

Most of the world's integrated poultry operations are present in developed countries where on site facilities are sufficient in providing adequate embryonic/chick environments. As more integrated poultry operations expand into developing countries, subtle areas of improvement within the biological supply chain will become obvious. The lack of environment-controlled facilities and transportation methods can yield early embryonic mortality in addition to poor broiler performance. This is a greater problem in emerging countries where extreme temperatures complicate keeping eggs/chicks at recommended temperatures. Although there has been ample research concerning maximizing embryonic storage conditions (Decuypere and Michels, 1992; Dymond et al., 2013; Fasenko, 2007; Goliomytis et al., 2015; Reijrink et al., 2008, 2009), little research has been done characterizing the unpredictable conditions experienced in the developing world. The objective of this study was to demonstrate the value of data loggers to characterize the environmental/climatic challenges experienced by integrated poultry operations in developing countries.

Materials and Methods

Mozambique is a developing country on the southeastern coast of Africa. There are numerous established integrated poultry operations spread throughout the country. This study took place in the northern portion of the country during the winter season where average temperatures range from 61°F to 79°F. Though temperatures appear lower, most facilities housing poultry/eggs operate at higher ambient temperatures. MadgeTech EGGTEMP data loggers were used as the mechanism for data collection. These data loggers are egg shaped and collect temperature and humidity readings in 60 second intervals. This note examines three periods of time where embryos/chicks can experience temperature stress: 1. After oviposition, data will begin recording in the nest box. This simulates the experience after oviposition that is egg collection, storage on the farm, and transportation to the hatchery. 2. The loggers were then placed in the setter for the last 3 days of incubation, to examine conditions in the setter,

vaccine/holding rooms, and transportation to the farm for placement. 3 Chick placement through the first 2 days of production.

The data loggers used in the experiment collected over 32,000 temperature and relative humidity readings during the 11-day period. To simulate the experience of an embryo the 6 data loggers were activated inside the breeder house and randomly placed into nest boxes. At all phases of the egg or chick processing the data loggers moved independent of each other and randomly through the process. For example, during a scheduled egg collection, the loggers were handled like every other egg. They were collected and placed into an egg flat. Once in the egg flat, the flats of eggs were sorted in the on-farm sort/storage room. After sorting the eggs, the flats were loaded on a truck and transported to the hatchery. Upon arrival at the hatchery, the loggers were unloaded and placed in the hatchery cold room. The loggers were chilled with the other eggs until they were placed in the egg warming room until incubation. After the preincubation warming room, the loggers skipped the 18-day incubation phase and were transferred into hatching baskets in the hatcher. Chicks and loggers were pulled after the chicks were dry. The chicks and loggers underwent the typical grading and sorting process. Upon the completion of the sort, the chicks and loggers were placed in the vaccination holding rooms to simulate the vaccination process. Once vaccinated the chicks and loggers moved to the loading dock to await the transport vehicle. The chicks and loggers were then loaded on delivery vehicles and taken to the broiler complex across town. Upon arrival the chicks and loggers were scattered throughout the broiler house to get a comprehensive house temperature and relative humidity profile. The loggers remained in the broiler house for a duration of 3 days.

Upon completion of the egg/chick journey the data loggers were gathered and data downloaded for review. The data generated from the data loggers was used to identify areas of concern where temperature and humidity deviated from industry standards. Recommendations for stabilizing egg and chick environments were presented to industry representatives.

Results and Discussion

Once the data loggers were powered on, temperature and humidity readings started to log. Figures 1 and 2 illustrate two MadgeTech EGGTEMP data loggers throughout a 14-day period. Breeder farm nest boxes and house temperatures reached 84°F at its highest point and humidity started to show an inverse relationship with respect to temperature. After collection, the eggs were sorted and transferred to an onsite cool room where temperature dropped to 70°F. At this point humidity started to increase steadily. After 2-4 hours of onsite storage, eggs were loaded onto an open truck for transport to the hatchery. Temperatures rose to a high of 97°F and declined to 90°F for a short period before settling at 83°F for the duration of transportation. When the logger reached 97°F, relative humidity hit 88%. This short period of time poses a great risk to embryo health and sustainability given the radical changes in temperature and pre incubation embryonic development. Ozlu and coworkers (2018) describe the negative impact that temperature cycling has on eggs particularly from older breeder flocks. The extreme humidity fluctuations were of great concern because it represented egg sweat which is known to support the growth of bacteria on the surface of the shell as well as the movement of spoilage organisms through the pores of the shell (Fromm and Margolf, 1958).

After transport, eggs were transferred to the hatchery cool room for short term storage. Temperatures bottomed out at 62°F and humidity hovered around 72%. In the pre-incubation warming room, temperatures rose to 77°F and humidity topped out at 94% in this room before settling back down to 66%. Again, the high humidity is less than ideal for hatching eggs, as this can create opportunistic environments for bacterial/fungal growth. This warming room had temperature and humidity controls and provided some stability with respect to environmental conditions. After 4-6 hours of warming, eggs were set in the hatcher to simulate hatching conditions. The incubation step of the hatching egg journey was bypassed because of the limited time parameters and the fact that the incubators in use were tightly controlled and continuously monitored in multiple locations for temperature and humidity. Keeping the data

loggers in the incubator would not have contributed new information. As expected, the hatcher maintained a controlled environment with temperatures holding steady at 99.5°F and setpoint humidity at 65%. At time of hatch both temperature and humidity rose slightly, as expected.

Chicks were pulled from the hatcher and went through a sorting process. It appears that densities within sorting boxes and facilities were acceptable with temperatures ranging from 90°F to 99°F. After the sorting process birds and loggers were moved into a separate area for vaccination. Bird densities and conditions in the respective vaccination boxes/rooms were less than ideal and likely created acute heat stress conditions as described by Ernst and coworkers (1984). For example, temperatures in the vaccination environment exceeded 104°F before the vaccination process was completed and the chicks moved to a pre-transport holding bay.

In Mozambique the chick holding bay is typically a covered area where chicks wait in boxes until trucks are available for transport. This allows outdoor conditions to influence the environment the chicks are waiting. This trial was conducted in the middle of winter and only reflects the cooler months of a place like northern Mozambique. Temperatures exceeded 94°F during the 4-8 hour holding period but were relatively satisfactory. Although short holding times are desirable many integrated poultry operations in developing areas must wait until trucks are available or for the workday to begin. After some time in the holding bay chicks were loaded on to open trucks and transported to their respective grow out facilities. Since the trucks were open and not climate controlled, direct sunlight was a factor in addition to outdoor ambient temperatures. Temperatures again exceeded 104°F for some of the data loggers but depending on the location within the stacks, chicks experienced temperatures up to 110°F. Upon arrival at the farm chicks showed signs of acute heat stress and in some cases hypoxic conditions as described by Ernst et al., 1984. Humidity conditions post hatch were acceptable and remained low throughout the vaccination and transport process. Therefore, the stress condition observed upon arrival was associated with temperature and not confounded with humidity.

After the chicks were unloaded and placed, the loggers were spread out within the house away from any direct heat source. In Figure 1 shortly after placement, temperatures plummeted into 75-83°F range. Unfortunately, ambient temperatures struggled to exceed 84°F for the next 60 hours of production. All the while humidity levels settled at 75% for most of this respective time. It wasn't until the third day of production where temperatures were at a satisfactory level optimal for production. Chicks experienced poor temperature conditions for one of the most important periods of production. Early cold stress is known to stunt performance and, in some cases, predispose chicks to ascites. Figure 2 illustrates the environment for another area of the same house. This logger seems to be in a better managed area within the house. Although temperature fluctuations are like the ones recorded in figure 1, it appears that this part of the house was managed significantly better. Through the first 60 hours of production most of the time was within the 84-90°F temperature range. These differences within the house are known but little is done to remedy the hot and cold zones.

Conclusion

Given the climate of Mozambique and much of the developing world, maintaining consistent environments is puzzling and poses many challenges. The ability to maintain egg storage environments below the physiological zero temperature threshold is near impossible but with minor adjustments substantial improvement can be made. Integrating dehumidifiers within on-site facilities is a simple and cost-effective way to control humidity. Utilizing climate-controlled trucks/vans for egg and chick transport can reduce temperature cycling and improve hatchability and chick performance. Improving and tightening hatch windows allows for precise and efficient chick transport and delivery, which ultimately decreases mortality and increases performance. Once the chicks are housed decreasing the size of charcoal heaters while increasing the number will allow for a more uniform environment for the chicks rather than numerous hot and cold spots. Although this note only examines one 14-day period during the Mozambique winter it does show that this data logging tool can help identify areas of

temperature and humidity extremes that will negatively impact flock performance. One can only imagine how temperature extremes are experienced during the summer months. It would be revealing to conduct further trials to fully characterize and quantify the seasonal temperature and humidity impact on hatchability and live broiler performance.

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Figures and Tables

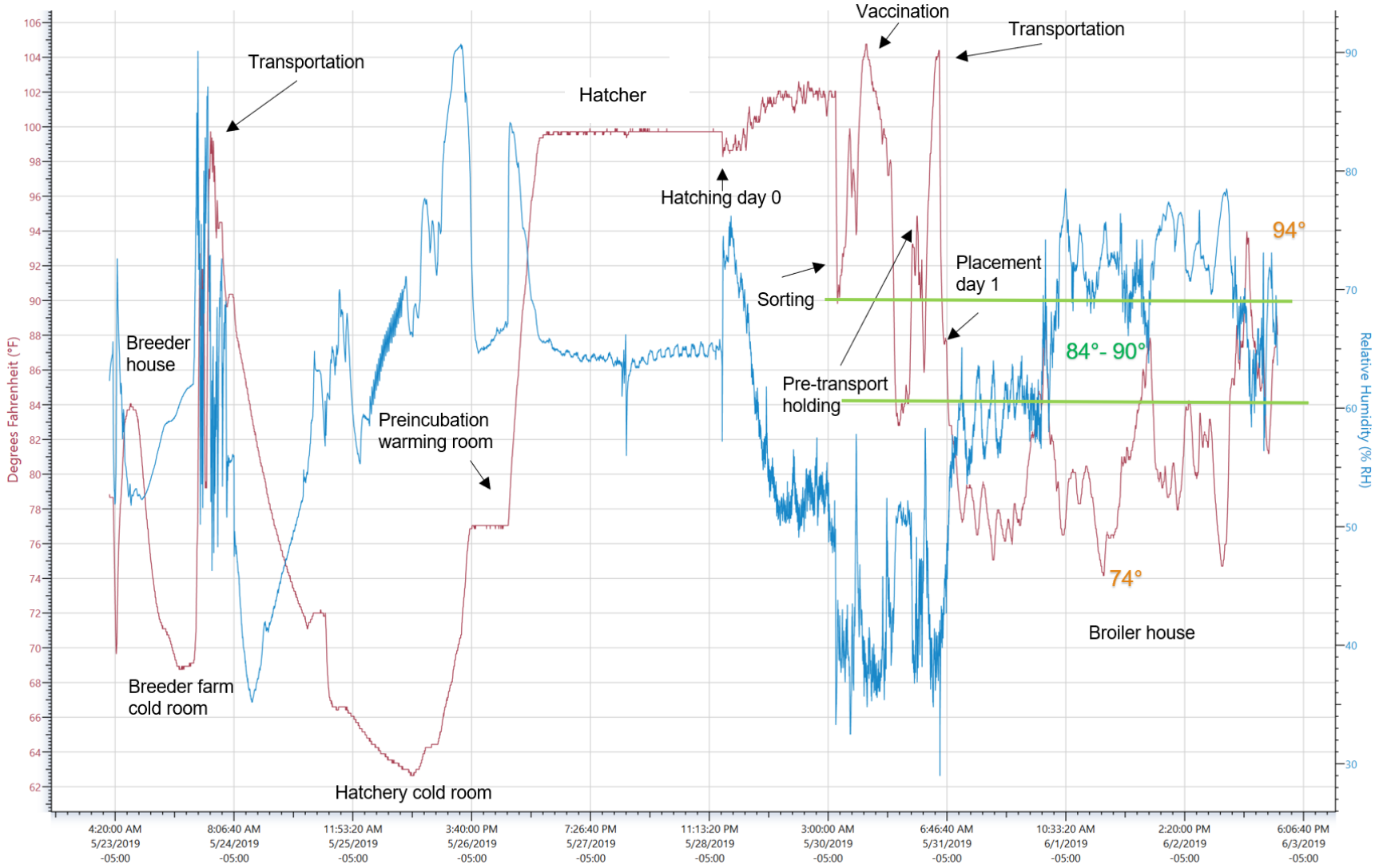

Figure 1. MadgeTech EGGTEMP data logger #1

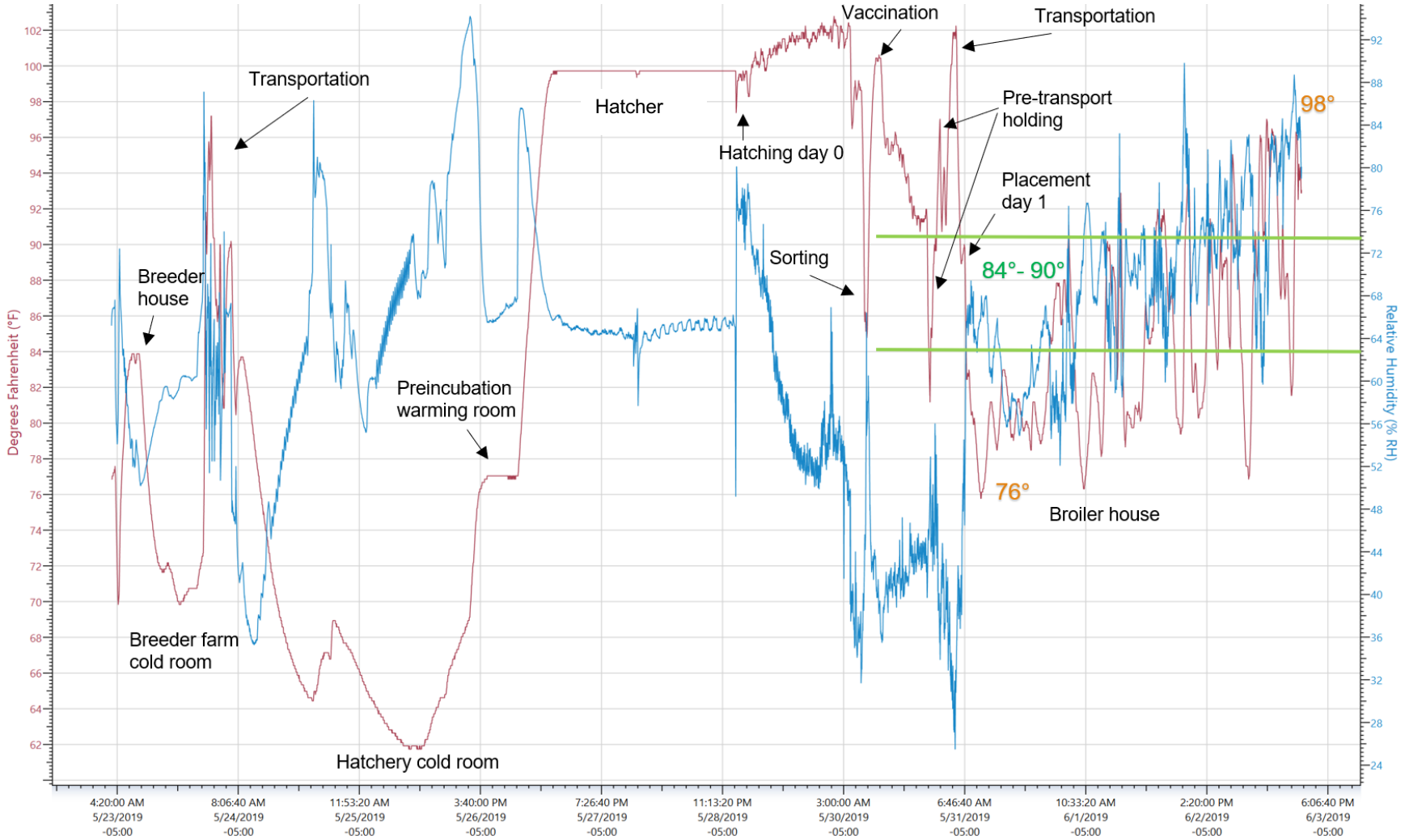

Figure 2. MadgeTech EGGTEMP data logger #2

CONCLUSION

The development and implementation of a low flow water monitoring system was successful in a poulty production research enviroment (Hiltz et al., 2021 (Chapter 1). The development of both a pen and individual cage setting was demonstrated. After the development and proof of concept, the low flow water monitoring system was utilized to select a broiler population for high and low water conversion ratio (WCR)(Chapter2). The technology developed has showed promise, delivering accurate and precise water intake data and was further validated in Chapter 3 where water intake data was collected on 4 commercial broiler strains.

References

Hiltz, J. Z., Orlowski, S. K., Harrington, L. N., Maynard, C. W., Tabler, T. W., and Anthony, N. B. 2021. Applied Research Note: Development of a novel low flow water monitoring system in poultry/agriculture systems. Journal of Applied Poultry Research, 30(2), 100151. https://doi.org/https://doi.org/10.1016/j.japr.2021.100151

APPENDIX

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Nicholas Anthony
Fr:	Craig Coon
Date:	February 9th, 2018
Subject:	IACUC Approval
Expiration Date:	February 1st, 2021

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **18083:** *General Rearing of Selected chicken and Quail Populations*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond February 1st, 2021 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Nicholas Anthony, Sara Orlowski, and Joseph Hiltz. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/tmp

18083

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Walter Bottje
Fr:	Craig Coon
Date:	June 12th, 2019
Subject:	IACUC Approval
Expiration Date:	June 6th, 2022

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **19086:** *Empowering US Broiler Production for Transformation and Sustainability : Aim 1.2 Divergently select broilers for high and low water efficiency*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond June 6th, 2022 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Walter Bottje, Sara Orlowski, Joseph Hiltz, Travis Tabler, and William Dougherty. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/tmp

19086