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Global Poultry Industry and Energy Evaluation – A Brief History

V. Ravindran

INTRODUCTION

The domesticated chicken has a highly complicated genealogy stretching back 8,000 years and involving Asian Red Jungle fowl as the main progenitor. Eggs and chicken meat have been an important part of the human diet ever since. This ancestor weighed around 500g when mature and laid 4-10 eggs per annum. The production levels have continually improved through selection over the centuries but the most dramatic changes occurred during the past 60 years. Today, contemporary meat chicken strains are capable of reaching a live weight of 2.5 kg at 33-35 d of age and laying hens that produce 330 eggs in 52 weeks of lay. Genetic selection brought about by commercial breeding companies is largely responsible for the bulk of these improvements. In a widely quoted study, Havenstein et al. (2003) concluded that genetic improvements in modern broilers account for 85% of the increase in broiler growth and advances in nutrition only provided the balance 15% of the changes. While this contention is factual, it is not as simple as this statement and is somewhat misleading. The growth potential of improved strains was achievable only through concurrent improvements in many other aspects, including remarkable advances in nutritional sciences and evaluation.

The original intent of this presentation was to outline and discuss only the progress in energy evaluation; however, given that the trends in feed evaluation paralleled and contributed to improved poultry performance, a dual approach will be employed – historical developments in the growth of poultry industry along with trends in feed evaluation.

Layer industry

For centuries, poultry production consisted of households having a few hens in the backyard to supply eggs for home consumption. The exact period of origin of ‘modern’ layer production remains a matter of conjecture. At the turn of the 20th century, governments, especially in the USA and Europe, began

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encouraging domestic egg production because of the ease of setting up coops in the backyards and the high nutritive value of eggs to enrich the nutrition of local population. There is evidence, at this time, that many keen individuals were applying scientific principles of selection, feeding and husbandry.

Then came the two World Wars and their conclusions, with the layer sector becaming something of a 'haven for ex-servicemen'. After the wars, many ex-servicemen had no jobs and encouraged to go into agriculture. They were offered special training courses and financial assistance, quite often in poultry production since the capital requirement was relatively small. A holding of 1,000 layers was deemed sufficient to provide a living for a man, wife and child. Cockerels were removed at 16 weeks and sold for table consumption – that was the common practice until the 1930s, when vent sexing was introduced from Japan, after which male chicks could be culled at day-old.

Chicken production's first step on the road to innovation and, the expansion that followed it, came in 1923 with the introduction of first electrically heated incubator. A new tier of the industry was established and thousands of hatcheries started shipping day-old chicks by trains and post. The laying breeds were selected for maximum egg production and there were so many. Farmers chose the breed based on what other farmers in their area preferred or because they were persuaded by boastful ads that talked up the egg production of breeds that won medals at poultry expositions. Choice of breeds laying higher number of eggs was a smart strategy following the privations of world wars and the Great Depression: It maximised the protein you could get without sacrificing the bird.

Purebreds served as the mainstay of the layer industry until mid-1940s. In 1945, Professor Lush and his team in Iowa State College started crossing chicken breeds along the lines of maize breeding; a 5-week conference on 'Heterosis' followed in 1950, which established the foundation for modern chicken breeding. The pioneering work was done in the USA, but import restrictions due to Newcastle disease meant many other countries was barred from accessing hybrid stock. In Europe, however, crossbreds were independently developed during this period. Newcastle vaccine was developed in 1948 and the ban was lifted in mid 1950s.

Greater employment, incomes and prosperity during the 1950s (after the end of Second World War) resulted in increased demand for eggs and meat. Intensification was just around the corner, triggered by the development of deep litter housing. The hens were moved indoors to barns enabling better control of husbandry and this resulted in marked increases in egg output, efficiency and profitability. But perhaps the greatest game changer was the very rapid development of battery cages for layers to meet the increasing demand for eggs in 1960s, resulting in further improvements in economic efficiency.

Looking back at the changes in the layer industry over the past 100 years, the public expectations have changed and we have travelled a full circle in terms of production systems. From free range rearing at the start to barns and cages and back to free range in the developed world, where enough animal proteins are consumed, the consumers have become discerning and are now concerned more of the quality of life of animals producing the eggs - their welfare. But the dichotomy that exists in global production, in terms of production systems, must also be acknowledged. In the developing world, protein malnutrition is rampant. The welfare of animals is not consequential, but rather the nutrition and health of the human population.

Meat Chicken Industry

Production of chickens for their meat has traditionally been a sideline to the egg-laying business, non-laying hens or roosters were slaughtered for family use. Chicken meat was a delicacy and luxury, eaten only once or twice a year on special occasions. In the United States in the 1800s, chicken was much more expensive than other meats and it was sought by the rich because it was an uncommon dish.

Chicken became a feature at the dinner table only after the birth of ‘modern’ broiler farming in the 1950s. Several forces contributed to this development (i) application of crossbreeding and fast growing meat birds; (ii) availability of antibiotics and their growth promoting effects (1949); (iii) development of vaccine to prevent the devastating effects of Newcastle disease; (iv) increasing family incomes and affluence, and demand for animal proteins. Contests organised by US Poultry Associations and USDA, from 1949 onwards, called ‘The chicken of tomorrow’ to select and crossbreed bigger and better chickens was another key event that promoted the popularity of broilers in the USA.

The commercial broiler industry took off in the 1960’s and, it has not slowed down since and the growth continues to this date at an average rate of 3% per annum. Broiler farming underwent major changes in structure and technological advances and evolved into the present sophisticated industry. Fast growing broiler strains were developed through intense selection and crossbreeding by breeding companies (in USA and Europe), and vertical integration became the norm, with a single company involved in every stage of production, processing and marketing.

Today, chicken meat is the most consumed and popular meat worldwide. 2018 was a watershed year to the industry, with the chicken meat overtaking pig meat as the number 1 animal protein globally. Its increased popularity is taking place at the expense of red meat industries and driven by health concerns. Chicken meat is the ubiquitous food of our era, crossing multiple cultural boundaries with ease. With its mild taste and uniform texture, the meat presents a blank canvas for the flavour palette of almost any cuisine.

The expansion of poultry farming is a success unparalleled in history by any animal industry. As noted above, most of the improvements in broiler performance is attributed to improved genetics. But, it must be recognised that, this remarkable growth was achieved and sustained only by concurrent changes in poultry science, especially the nutritional aspects. Compiling an overview of the advances in nutrition during the past 70 years is a daunting task and a list of select key advances is provided below. The key nutritional developments included *inter alia* (i) feed evaluation, in terms of energy and protein, (ii) concept of ideal protein, (iii) formulation on the basis of digestible nutrients, (iv) better understanding nutrient requirements, (v) more precise feed formulations, (vi) pelleting technology, and (vii) the advent of feed additives. Other driving forces included disease prevention, integration, husbandry, housing, equipment, further processing and fast food technologies.

Advances in Feed Evaluation

For number of obvious reasons, measurement of energy and protein availability are the first step in feed evaluation. Phosphorus and calcium are the latest additions to the feed evaluation package.

Advances in our understanding of protein nutrition have closely followed the genetic advances in both the layers and broilers. Starting from the use of just protein content in feed formulations, we have progressed through the application of total amino acids, total tract digestibility, ileal digestibility and standardised ileal digestibility. The superiority of standardised ileal digestible amino acids is now accepted unquestionably by the poultry industry.

In contrast, as we will see below, the methodology to determine available energy for poultry has remained at a standstill for the past 60 years. The reason being that the measurement of available energy is complicated; the difficulty relates to the fact that it is not a chemical entity, but a summation of energy available from energy-yielding nutrients (carbohydrates, lipids and protein).

Hundred years ago, the energy content of poultry feeds was not considered and the supply was ensured simply by the inclusion of high levels of cereals. Even by 1954, when the first Nutrient Requirements of Poultry (NRC) was published, no mention at all is made either of the energy content of feedstuffs or of energy in tables of nutrient requirements. It was thought that the consideration for energy supply does not arise in poultry because the birds were fed *ad libitum*. The practical emphasis was on describing feeds as energy sources rather than defining energy requirements for productive purposes.

The choice of appropriate energy system has been debated for over 70 years, starting from publications by Mitchell & Haynes (University of Illinois) in late 1920's and later by Fraps in 1940's. Based on work conducted with ruminants in the 1920's, Fraps and co-workers (1946), from Texas Agricultural Research Station, proposed a system based on net energy (NE). But there were inherent problems with the plethora of assumptions made in this approach and this was abandoned in the 1950's. This group also proposed and produced data for a system of Productive Energy (PE) for growing chicks using comparative slaughter techniques. The PE system was used in research but the level of practical application was limited.

Since mid-1950's, following landmark publications by Hill, Anderson and Renner of Cornell University, and Potter and Matterson of University of Connecticut, apparent metabolisable energy (AME) became the accepted system of describing the available energy in feed ingredients. The rapid rooster assay of true metabolisable energy (TME) became popular in the 1980's, but have slowly lost favour over the years due to welfare issues. Effective energy and ileal digestible energy are some of the other systems that have been tested. The net energy system has received attention periodically, but its value in poultry feed formulations is yet to be proven. However, in spite of these uncertainties, energy tables of feed composition started to appear based on AME in the 1960s. The AME is clearly a default system because it is simple and easily determined compared to other measures of available energy. Its use is universal and its limitations are overlooked.

Limitations of AME

A point of contention is the question of additivity when ingredients are mixed together in feed formulations. AME is assumed to be additive when ingredients are combined, which is not always true – especially when fibrous and poorly digestible ingredients are used.

AME is a reliable indicator of what is available for maintenance and production, but not a predictor of how efficiently then uses what is available. Thus diets with the same ME are not necessarily used with equal efficiency when fed to birds. This may be due to fermentation of the DM component, the extent of which depends on the chemical composition of the feed and the age of the birds.

NE overcomes the shortcomings of AME. In theory, it is the only energy system that closely describes the energy available in an ingredient for bird's metabolic functions (Swick et al., 2013). This system is widely used in ruminants and pigs – animals with significant fermentation capacities. In poultry, as per expert opinions, NE system provides no advantage over the ME system due to number of reasons (van der Klis and Jansman, 2019; Zuidhof, 2019). Importantly, the NE system is cumbersome, costly and time consuming, and has limited use in routine screening of ingredients.

AME versus AMEn

The use of a correction for differences in nitrogen retention during experiments was also widely debated. AME_n is an estimate of ME, which differs from AME in that a correction is made for nitrogen retention (NR), which may be either positive or negative. It is argued that body N, when catabolized, is excreted as energy-containing products, mainly uric acid. AME values are thus influenced by body N retained or lost. Because the assay diets are often imbalanced, NR differs for different diets. As a result, AME data are less likely to be additive.

Correction to zero N retention makes a simple assumption that the test ingredient is used entirely as an energy source. This correction is negative in many cases because of low N intake and AMEn is therefore higher than the uncorrected estimate. This approach therefore 'penalises' high-protein ingredients, which serve as sources of both energy and amino acids

Commercially both the AME and AME_n data are used by the nutritionists. The controversy over N correction will continue; however, its effect in most practical situations is minor and the additional work involved in its determination is difficult to justify. The most compelling argument for making no correction is that, since broilers and layers fed balanced practical diets are always in positive N balance, AME values must remain uncorrected to give a classical AME value. The ‘real’ value of N correction is when number of ingredients/ samples differing in protein content/quality are compared and the assay diets promote a negative N balance. The difficulty of precise measurement of NR is another issue as evidenced in published literature where reported values are often higher than those expected for modern broilers (55-65%). An elegant critical analysis of the usefulness of AME vs. AMEn can be found in Abdollahi et al. (2021).

Opportunities to improve the usefulness of AME

The need for consensus protocols

Metabolisable energy is determined in energy balance experiments with myriad of minor variations in procedures across research stations. Consequently, published ME values of ingredients are highly variable. There are two sides to this variability – the ‘real’ ingredient variation and methodological effects. The first source is the one of practical interest to develop the matrix values and the latter is an issue that should be minimized as much as possible. The implication is that the precision of AME measurement could be improved by standardising the methodology (in terms of assay duration, diet composition, age of birds etc.). Then the ‘real’ inherent variation can be determined enabling comparison across laboratories.

Broilers vs. laying hens

ME assays are seldom conducted with layers because of the confounding effects of egg production. The differences in the digestive physiology and nutrient utilisation between broilers and layers are predictable. Thus there are clear benefits in determining ME with layers, instead of applying broiler ME values.

Effect of feed form

Nutrient digestibility assays have almost always used mash diets largely because of its simplicity. On the other hand, commercially broilers are fed pelleted diets and the applicability of data generated using mash diets to pelleted diets is questionable

Recent results from Massey University suggest that the application of AMEn determined using mash diets may result in over- or under-estimation (Khalil et al., 2021a). These data indicate that assay diets for the evaluation for individual ingredients may need to consider the use of pelleted diets.

Influence of broiler age

The fact that young broilers do not efficiently digest nutrients has been known for many years. This is especially true during the first two weeks of life of broilers. The digestive tract of the newly hatched chick is immature and must undergo immense changes before it is fully capable of efficiently digesting the nutrients. Recent Massey data confirm the effect of age and highlight that the AME of an ingredient must be determined using birds of an age at which the value will be applied (Khalil et al., 2021b). Age effects as a variable in the matrix must be considered and the modern software should be able to capitalise on this stochastic nature.

Ileal digestible energy

By default, AME has become the common measure used to describe available energy in ingredients in poultry. As the term indicates, it refers to metabolisability rather than digestibility. It is measured at the excreta level and, contains urine that is voided along with faeces and also includes the energy loss/ gain due to microbial mass from the hindgut. The change of available energy measurement at the ileal level will overcome these limitations and align energy availability with the measurement of digestibility of other nutrients. The lack of relationship between AME and growth responses often seen in feed additive research lends further credence to look at ileal digestible energy as an alternative options. There is some recent work at Massey University on the measurement of ileal digestible energy (Khalil et al., 2021c), but further work is warranted before it could be considered for application in practical feed formulations.

Conclusions

The global commercial poultry industry has a colourful and extremely successful history. Over the past century, its growth has been without a rival among animal industries. Paralleling this growth, there had been continuing advances in all aspects of poultry nutrition with the exception of energy systems. The system of energy evaluation has not progressed since the 1960s, despite several possibilities other than the AME have been considered. None of other systems has proven to be advantageous over the AME. It is obvious that the AME will continue to be the system of choice to describe the available energy content of feeds and energy requirements of poultry in the foreseeable future. There are number of improvements outlined above, however, must be made to enhance the usefulness of AME in feed formulations.

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Rethinking Energy in Reduced-Crude Protein Broiler Diets

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INTRODUCTION

Dietary energy received considerable attention in the 1940's and 1950's in young growing meat-type chickens (Fraps, 1944; Mueller et al., 1956; Allison, 1958; Hill and Anderson, 1958) and the analytical method described by Hill and Anderson (1958) is still used widely today in young broiler chickens to determine dietary metabolizable energy (ME), defined as the heat of combustion of the diet minus the combined heats of the combustion of the excreta produced from that feed. Energy is widely recognised as the most expensive component of broiler feed and remains elusive to determine and quantify accurately (Kleyn and Chrystal, 2020). More recently, critical reviews by Mateos et al., (2019) and Wu et al., (2020) identified flaws in published ME values and methodologies to determine dietary energy. Furthermore, the assumption that the ME content of feed is equal to the additivity of the ingredients may not be correct, whilst genotype, environmental temperature and other nutrients such as dietary fibre influence the amount of net energy (NE) available for metabolism (Mateos et al., 2019; Wu et al., 2020). Accurately determining dietary ME is further complicated by dietary lipid content described as "extra caloric effect" at low inclusion levels but, declining as added lipid increases (Leeson and Summers, 2005). This is relevant in reduced crude protein (CP) diets formulated to be "iso-energetic", since the reduction in dietary CP is accompanied by increasing supplemental non-bound amino acids (AA) and a shift in the source of dietary energy, mainly from a combination of lipid and carbohydrate to carbohydrate and little or no added lipid (Fancher and

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Jensen, 1989a,b; Aftab et al., 2006; Siegert et al., 2016; Chrystal et al., 2020a,b,c; Chrystal et al., 2021). Relative fat pad weights and feed conversion ratios (FCR) increase in tandem with reductions in dietary CP implying that broilers offered reduced CP diets over-consume dietary energy relative to protein and deposit this excess as body lipid (Gous et al., 1990). NE represents the closest estimate of the "true" available energy content of feed and accounts for the heat increment (HI) of digestion (Noblet et al., 2010). Whilst efforts to develop a robust NE system for poultry are pursued (Swick et al., 2013; Carre et al., 2014; Wu et al., 2019), these typically apply a correction to ME values, based on dietary lipid and CP content, thus transferring any error in the ME value to NE.

N-corrected AME (AMEn MJ/kg DM) values are calculated by correcting N retention to zero using the factor of 36.54 kJ/g N retained in the body (Hill and Anderson, 1958). The efficiency of utilisation of amino acids for AMEn has been estimated to be 85% for lean gain deposition and 60% for deamination and catabolism. Additionally, the efficiency of utilization of amino acids for NE was considered to be 70% for protein deposition and 30% for deamination and catabolism, whilst reported NE values have been determined to be 77.5% of reported AMEn values (Rostagno et al., 2011; Tillman, 2019). Furthermore, CP is simply measured as the nitrogen content of the feed multiplied by 6.25 on the assumption that the average protein content of feed and feed ingredients is 160 g/kg yet, for decades, true protein conversion factors have been proposed (Jones, 1941). As a measure of nitrogen content, CP is acceptable, but the AA absorbed into the portal blood system from the gastrointestinal tract and utilised directly for lean protein deposition in the broiler would not undergo catabolism and would thus not produce associated HI of digestion. Thus, in theory, the reduction in HI should increase the NE of reduced CP diets and this might partly explain increased lipid deposition in broilers offered these diets (Chrystal et al., 2020d). Further research on energy metabolism in tangibly reduced CP is therefore warranted.

Tangibly reduced dietary crude protein

As non-bound AA become more economically feasible, a greater array of these AA will be included in commercial diets at increasing inclusion levels and dietary CP and soybean meal contents will continue to decline. The economic benefits of reducing dietary CP stem from reductions in energy expenditure on excreting excess nitrogen as uric acid and sparing of matrix space in feed formulation for inclusion of less energy dense ingredients, potentially reducing feed costs (Kidd and Choct, 2017).

Instructively, Kamran et al. (2008) offered broilers maize/soyabean-based diets from 1 to 35 days post-hatch with graded reductions in CP from 200 to 170 g/kg in which the energy-to protein ratio was maintained and observed depressed weight gains of 13.4% (610 vs. 704 g/bird) and compromised feed conversion efficiency by 29.2% (337 vs. 476 g/kg). More recently, a reduction in dietary AMEn from 12.85 to 12.01 MJ/kg in tangibly reduced CP (143 g/kg) maize/soyabean meal-based diets resulted in an 18.5% decrease ($P < 0.001$) in relative fat pad weights (10.1 vs. 12.4 g/kg) but weight gain and FCR were inferior (1760 vs. 1879 g/bird; $P = 0.024$ and 1.765 vs. 1.629 g/g; $P < 0.001$) in male Ross 308 broilers from 14 to 35 days post-hatch (Chrystal et al., 2020b).

The classical method of AME determination (Hill and Anderson, 1958) requires total excreta output and feed intake measurements over 3 days (33 to 35 days post-hatch in Chrystal et al., 2020a, for example) and gross energy (GE) is determined utilising an adiabatic bomb calorimeter. The dietary AME values are calculated from the following equation:

$$\mathrm{AME_{diet}}\ (\mathrm{MJ/kg\ DM}) = \frac{(\text{feed intake} \times \mathrm{GE_{diet}}) - (\text{excreta output} \times \mathrm{GE_{excreta}})}{(\text{feed intake})}$$

Reductions in dietary CP are accompanied by linear increases in observed AME and an average decrease in CP from 205.8 to 161.9 g/kg resulted in a 2.43% increase ($P < 0.001$) in AME from 12.75 to 13.06 MJ/kg (Chrystal et al., 2020a,b,c). Despite diets formulated to be iso-energetic, reductions in dietary CP significantly enhanced energy utilization, as measured by increased AME:GE ratios. This can be attributed at least in part to increases in starch digestibility and disappearance rates generated by dietary CP reductions. In addition, the energy density of a feedstuff may not remain constant and an AMEn value of 37.0 MJ/kg was ascribed for soybean oil in all the feeds formulated. However, increasing energy values of lipid as its dietary inclusion decreases have been reported. Leeson and Summers (2005) found that the energy value of lipid increased from to 34.56 to 41.42 MJ/kg AMEn when added dietary lipid was decreased from 40 to 5 g/kg. This is relevant in reduced CP broiler diets, since added vegetable oil declined on average by 72.3% (from 42.96 to 11.92 g/kg) whilst dietary starch increased by 35.4% (from 318.9 to 431.9 g/kg) over 4 studies (Chrystal et al., 2020a,b,c; Chrystal et al., 2021). A decrease in dietary CP increases non-bound amino acid inclusion rates at the expense of soyabean meal and non-bound amino acids are notionally 100% digestible whilst soyabean is in the order of 90% digestible (Chrystal et al., 2021). Additionally, reducing CP is accompanied by other benefits including improved N utilisation, decreased N excretion, drier litter, with reduced N-content and, a reduction in quantity of faecal matter produced (Lemme et al., 2019, Chrystal et al., 2021). In Chrystal et al., (2021) a reduction in CP from 222 to 165 g/kg linearly reduced ($r = 0.453$; $P < 0.001$) water intake by 15.0 % (521 versus 613 g/bird) over the total excreta collection period and numerically reduced water:feed intake ratios. A reduction in faecal output relative to feed intake increases calculated AME, utilising the classical Hill and Anderson (1958) equation. The reduction in faecal output is influenced by increased diet digestibility and the potential energy of a diet is yielded by the heat of combustion of the dietary organic matter whilst some of this energy is lost as organic matter in the excreta (Emmans, 1994). The coefficient for faecal organic matter has been estimated as 3.80 kJ/g (Emmans, 1994) implying that excreta from reduced CP diets has lower GE, and this may also partly explain increases in calculated AME. AMEn is widely used to compare the energy content of feed and feed ingredients (Mateos et al., 2019). However, the N correction for AME imposes a penalty of 3 to 5% for maize and 7 to 12% for high protein soyabean meal (Lopez and Leeson, 2008) suggesting that comparison of AMEn between normal and reduced CP diets might penalise the contribution of intact protein to dietary energy.

The HI of digestion describes the energy lost as heat during metabolism of nutrients and NE has been proposed by Wu et al., (2019) as a more accurate system for feed formulation to meet the energy requirements for maintenance and growth performance of meat-type chickens. These authors used a range of diets to quantify measurements of O_2 consumption and CO_2 expiration in closed-circuit calorimetry chambers and used multiple linear regression to compute the energy contribution of the dietary chemical components. The coefficients of CP for dietary energy were reduced by 0.239 for GE (SE = 0.003), 0.129 for AME (SE = 0.017) and 0.064 for NE (SE = 0.029), representing 46 and 50% reduction of CP contributions from GE to AME and AME to NE respectively. Prediction equations generated were then validated over an additional 16 diets and NE was proposed as an adjustment to AMEn (Wu et al., 2019) as follows:

$$\mathrm{NE}_{(\mathrm{MJ/kg})} = \mathrm{AMEn}_{(\mathrm{MJ/kg})} \times 0.808 - \mathrm{CP}_{(\%)} \times 0.017 + \text{ether extract}_{(\%)} \times 0.031$$

A dietary CP reduction of 10 g/kg was thus estimated to reduce the AMEn by a factor of 0.017. In addition to the errors that are inherent in AMEn being transferred to NE, the CP (N) in protein-bound compared with that in non-bound AA are likely to have vastly different HI of digestion. In theory, non-bound AA are rapidly absorbed by the broiler and directly transported to the sites of protein accretion whilst bound AA in feed ingredients require digestion and, by implication higher HI. However, net protein synthesis, or accretion, occurs as the difference between protein deposition and protein degradation, occurring mainly in skeletal muscles as a dynamic continuous process that further complicates energy metabolism (Swick, 1982). The rapid accumulation of breast-muscle protein in rapidly growing chicks is largely due to a marked decrease in the fractional rate of degradation (Maruyama et al., 1978; Tesseraud et al., 2000). Thus, whilst it is tempting to speculate that non-bound AA must have a lower HI of digestion compared with their protein-bound counterparts, adjusting AMEn based on a single factor for CP, may be too simplistic.

Conclusions

The relationship between GE, AME and NE in meat-type chickens is influenced by many factors including the chemical components of the diets and the levels of each ingredient in the diets. The chemical nature of dietary CP differs between feed ingredients and includes non-N compounds that will differ in HI of digestion. Additionally, digestibility coefficients are static measures usually determined at the distal ileum, whilst the rate at which nutrients are consumed, their transition across the gut mucosa, entry into the portal circulation and arrival at the sites of metabolism, defined as "digestive dynamics" will play an increasingly important role in nutrition. It is therefore suggested that HI of digestion should include data that makes allowance for digestive dynamics of feed and feed ingredients, to define the loss of energy more accurately in a NE system. Finally, although reductions in dietary CP have demonstrated flaws in AME and NE determination, it is likely that AME and AMEn will remain most widely used in broiler feed formulation for the foreseeable future.

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Energy Utilisation Response to Broiler Age Varies Depending on Cereal Grain

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INTRODUCTION

Available energy in feed or feed ingredients for poultry can be measured by different systems, with the apparent metabolisable energy (AME; Hill and Anderson, 1958), despite its limitations (Mateos et al., 2019; Wu et al., 2020), being the commonly accepted and extensively used system.

Three methods namely, direct, substitution (or difference) and regression, have been used to determine the AME of ingredients for poultry. In each method, the excreta can be collected by total collection, which is the preferred method, or partial collection (marker method) using the ratio of an indigestible marker present in diet and excreta. Each method has its own merits and drawbacks, and the main difference between these methods being how the test ingredients are included in the assay diets (Wu et al., 2020).

The substitution method is used to determine the AME of poorly palatable ingredients, or those containing high protein content or anti-nutrients. This method requires formulating two sets of diets, a basal (or reference diet) and a test diet, which is developed by replacing a portion of the basal diet with the test ingredient (Sibbald et al., 1960; Farrell, 1978). Because the reference diet is a nutritionally balanced diet, this method overcomes the main limitation of the direct method. However, the substitution method suffers from some disadvantages in that the AME of the test ingredient can be influenced by the composition of the basal diet, the assumption of additivity and the inclusion level of the test ingredient (Wu et al., 2020; Olukosi, 2021).

Bird age has been shown to have a substantial effect on the digestion and absorption of energy-yielding nutrients (Sibbald et al., 1981). Birds of different ages have variable ability to digest and

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metabolise feed ingredients especially those containing anti-nutritive substances such as soluble non-starch polysaccharides (Ravindran et al., 2004).

Moreover, the capacity of digestive tract to digest and absorb nutrients is limited during the early life of broilers and, there is consensus that the nutrient digestibility generally increases with advancing age (Brumano et al., 2006; Olukosi et al., 2007). The impact of age on AMEn of cereal grains (wheat, sorghum, barley and maize) using the substitution method was determined in the current study.

Results

The retention of both DM and N showed a linear response ($P < 0.001$) with advancing age, with the retentions decreasing as the birds grew older. The highest DM and N retentions were recorded in weeks 1 and 2. Although the bird age did not exhibit any linear or quadratic response ($P > 0.05$; Fig. 1A), the AMEn of wheat was observed to increase ($P < 0.001$) from 12.53 MJ/kg DM in week 1 to 14.55 MJ/kg DM in week 2, then declined in following weeks compared to week 2.

The influence of broiler age exhibited a linear decrease ($P < 0.001$) on the retention of DM and N retentions with advancing age of birds. The DM retention declined from 77.8% in week 1 to 74.7% in week 6 and the highest N retention of 70.9% was recorded in week 1, declining to 58.1% in week 6. The AMEn of sorghum increased quadratically ($P < 0.05$) with advancing age, from 12.84 MJ/kg DM in week 1 to 13.95 MJ/kg DM in week 2, then plateaued up to week 6 (Fig. 1B).

For barley, the retention of DM and N showed linear decreases ($P < 0.001$) with advancing age. The birds retained the highest DM and N in week 1 and the lowest in week 6. Broiler age had no influence ($P > 0.05$) on the AME or AMEn of barley (Fig. 1C).

The DM retention of maize declined linearly ($P < 0.001$) from 80.3% in week 1 to 76.9% in week 6. A similar trend was observed for N retention, wherein N retention decreased linearly ($P < 0.001$) as the birds grew older from 76.8% in week 1 to 63.1% in week 6. The AME and AMEn of maize were unaffected ($P > 0.05$) by the age of broilers (Fig. 1D).

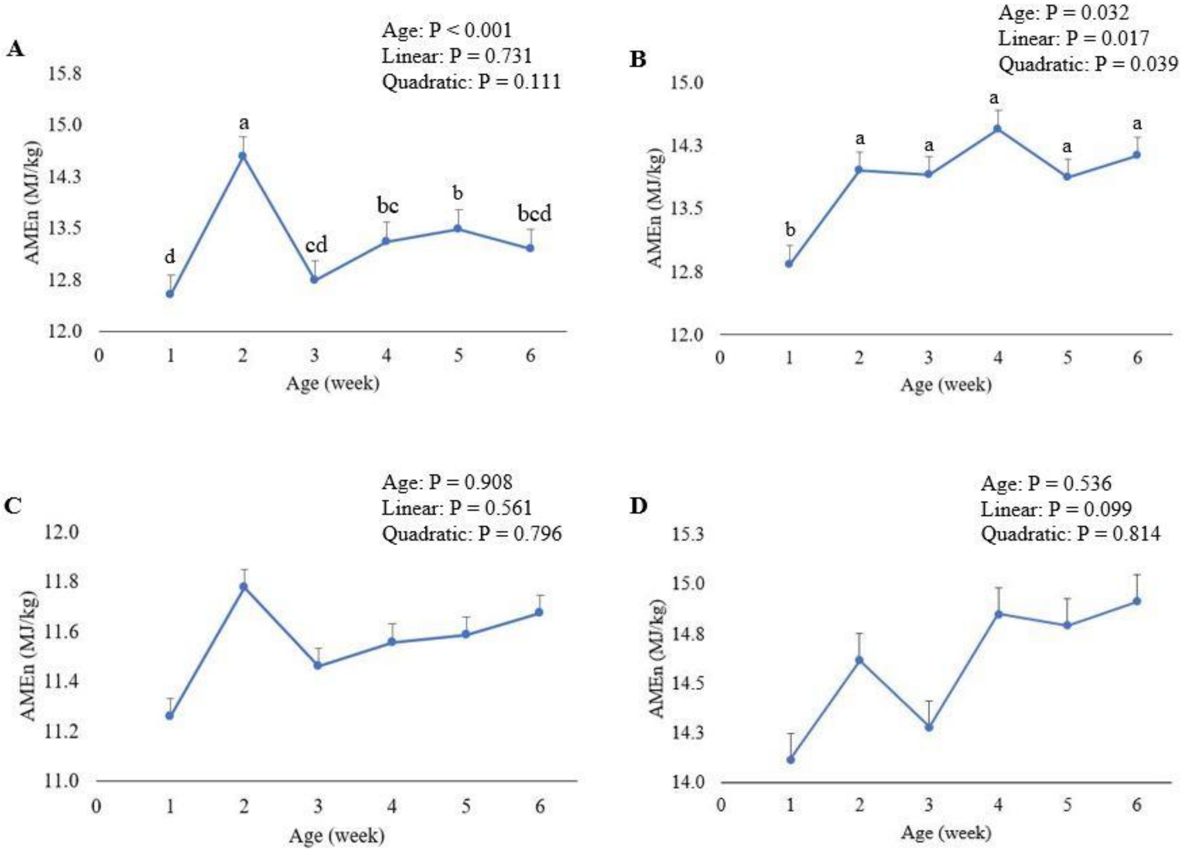

Figure 1. Effect of broiler age on the nitrogen-corrected apparent metabolisable energy (AMEn) for wheat (A), sorghum (B), barley (C) and maize (D); mean ± standard error. $^{a-d}$ Values with different superscripts differ significantly ($P < 0.05$).

Discussion

The highest retention of DM and N of all cereal grains were recorded in weeks 1 and 2, and declined thereafter as the birds grew older. These findings are similar to those of Lopez and Leeson (2007) who showed that the retention of N in a maize-soybean meal diet declined as broilers grew older, especially after 28 d of age. Aderibigbe et al. (2020) similarly reported significant reductions in the retention of DM and N in a maize-soybean meal diet from 1 to 42 d of age of broiler chickens. Yang et al. (2020) reported that the advancing age of broilers significantly decreased the N retention of cereal-based diets from 68.8% at 7 d of age to 60.9% at 35 d of age. The observed age-related reductions in the N retention in the current study are to be expected, reflecting surplus N from increasing feed consumption and decreasing needs of N for growth (Bartov, 1995).

In the current study, the lowest AMEn values were recorded in week 1 for all four cereal grains (statistically significant for wheat and sorghum, and numerically for barley and maize) and increased thereafter. Published data on the influence of broiler age on the AME of cereals are limited and all available data relate to complete diets. Current findings agree with previous studies in broilers fed complete practical diets, where the utilisation of energy-yielding nutrients improved with age (Zelenka, 1968; Batal and Parsons, 2002). Batal and Parsons (2002) showed that the AMEn of a maize-soybean meal diet increased with age (from 13.33 MJ/kg at 7 d to 14.35 MJ/kg at 14 d) and, then plateaued after 14 d of age. However, in a subsequent study by the same authors (Batal and Parsons, 2004), no differences were observed in the AMEn of a maize-soybean meal diet between 7 and 14 d of age. Thomas et al. (2008) showed that the AMEn of wheat- and maize-based diets increased between d 7 (11.06 and 12.28 MJ/kg, respectively) and d 14 (13.24 and 13.01 MJ/kg, respectively), with no further change between 14 and 21 d of age. Aderibigbe et al. (2020) observed that the AMEn of a maize-soybean meal diet increased from 13.6 to 13.8 MJ/kg between 11 to 21 d of age, then plateaued until 42 d of age.

In diets containing adequate levels of protein, AME is a function of utilisation of lipids and starch. Available data on fat and starch digestion patterns lend support to the increase in AME with age. Tancharoenrat et al. (2013), investigating several fat sources, found that the total tract fat digestibility was low in week 1 and increased with advancing age. Similar observation reported by Lessire et al. (1982) who examined the influence of age on the fat digestibility and AME of beef tallow. It was found that the apparent fat digestibility and AME of beef tallow increased by 8.5% and 4.3%, respectively, between weeks 2 and 6. Scheele et al. (1997) also revealed that the apparent digestibility of animal fat increased after the second week post-hatch and the AME increased by 1.0 MJ/kg between weeks 2 and 4. Batal and Parsons (2002) showed that the apparent digestibility of fat in a maize-soybean meal diet increased with advancing age from 59% at week 1 to 74% at week 2 post-hatch. These researchers attributed the increase in AMEn to the increase in fat digestibility with advancing age of broilers. Svihus (2011) indicated that there is a strong correlation (r = 0.984) between the AME and digestibility of starch, the main source of energy in cereal-based diets. Hatchlings can digest starch rapidly due to high activity levels and accumulation of starch-degrading endo-enzymes such as α-amylase and disaccharidase in the pancreas during the embryonic development (Sklan and Noy, 2000). Akiba and Murakami (1995) stated that the activity of amylase increased by 10% between 1 and 21 d post-hatch. Noy and Sklan (1995) also reported that the secretion of amylase was low at 4 d post-hatch and increased by 100 folds at 21 d post-hatch; however, there was no difference in starch digestibility between 4-21 d of age. Uni et al. (1995) found that starch digestibility of a maize-soybean meal diet increased from 90% at d 4 to 95% at d 14 of age. Similar increases in starch digestibility with advancing broiler age has been reported by Zelenka and Ceresnakova (2005) and Batal and Parsons (2002).

Conclusions

The current findings, along with those previous studies, demonstrate that the effect of age is relevant in the determination of AMEn of cereal grains. The influence of age of birds on the AMEn of cereal grains was grain-dependent. Whilst AMEn of wheat and sorghum were influenced by age, the AMEn of barley and maize were unaffected. The current findings question the validity of using single AME or AMEn values for feed ingredients in broiler diet formulations across different ages.

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A Reappraisal of Whole Grain Feeding for Chicken-Meat Production

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ABSTRACT

Whole grain feeding has been widely adopted in countries where wheat is the dominant feed grain. Whole grain feeding regimes reduce feed manufacturing costs and are believed to improve gut integrity, feed conversion, energy utilisation and litter quality. However, the adoption of whole grain feeding in practice is in advance of the corresponding research. Additionally, responses to whole grain feeding have been reported to be variable. Therefore, the purpose of this evaluation is to determine the effect of whole grain form (pre- or post-pellet) and inclusion (%) on relative gizzard weights, feed conversion ratio and apparent metabolisable energy while also identifying the amount and possible causes of variability in the literature. With improved understanding and definitions of whole grain feeding practices and advantages, we may further enhance the performance of poultry offered whole grain feeding regimes.

Keywords: Broiler chickens, gizzard, meta-analysis, whole grain feeding

INTRODUCTION

Whole grain feeding is an increasingly accepted practice in countries where wheat is the dominant feed grain for chicken-meat production. This includes Australia, New Zealand, Canada and Europe where an approximate post-pellet whole grain inclusion of 150-200 g/kg is offered in Australia and Canada and 600 g/kg is offered in Europe. In New Zealand, an

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approximate 50-100 g/kg whole grain is incorporated into the pelleted (pre-pellet whole grain) because of quarantine regulations for imported feed grains.

Despite the wide acceptance of whole grain feeding, the response of broilers to whole grain feeding regimes is highly variable due to differences in methodologies of the relevant studies as emphasized in previous reviews (Singh et al., 2014; Liu et al., 2015). For example, "whole grain feeding regimes" encompasses a broad range of methods including whole grain forms (pre- or post-pellet), whole grain type (wheat, barley, etc), inclusion levels, inclusion method (abrupt or gradual inclusion of whole grain) and basal diet types. Therefore, determining the effect of whole grain addition on gizzard functionality and broiler performance is problematic. Liu et al. (2015) reported wide variations in responses of broilers to whole grain inclusion. For example, whole grain inclusions ranging from 75 to 500 g/kg generated 0.7 to 100% improvements in relative gizzard weights over 14 reports (Liu et al., 2015). Additionally, whole grain feeding showed potential to enhance feed conversion by 1.34 to 12.90% over 15 selected reports and increase apparent metabolisable energy (AME) by -0.31 to 1.73 MJ/kg over 23 reports. But, there were no correlations between whole grain inclusion and the improvements in gizzard weights or feed conversion ratios (Figure 1). These observations illustrate the inherent variability of whole grain feeding regimes. However, this data was made up of 15 reports from 11 studies over 1995 to 2008, thus a more comprehensive review of published whole grain feeding studies may better elucidate the effect of whole grain inclusion. Furthermore, a systematic evaluation should be instructive to quantify the influence of various approaches on responses in broilers to whole grain feeding regimes.

Therefore, the objective of the current evaluation is to identify the possible causes for this variability of responses and determine the effects of whole grain form and percentage inclusion on gizzard functionality (relative gizzard weight and content), growth performance (weight gain, feed intake, FCR) and nutrient utilisation (AME) via systematic approach to provide a comprehensive reappraisal of whole grain feeding regimes.

Methodology

Singh et al. (2014) stated that "direct comparison of data from published studies is difficult because of differences in feeding systems and experimental methodology". Indeed, the variability across whole grain feeding studies makes comparisons between studies problematic; only more so within the context of a literature review. Therefore, a systematic evaluation was completed to quantify the effect of whole grain form (pre- vs post-pelleting) and inclusion (%) on the response of broilers to whole grain, and to explore the extent of experimental variation across studies. Additionally, data was collected on the type (wheat, barley, oats, rice, sorghum or triticale) of whole grain, inclusion method (abrupt versus gradual adaption), basal diet (ground grain) type (wheat, maize, sorghum, etc.), year of publication, length of the experimental period and age of the broilers at the trial start and end to determine if this information helps to describe the variability that exists in responses from whole grain feeding trials.

Database construction

There have been a total of 57 peer-reviewed papers published on the inclusion of whole grain in broiler diets between 1987 and 2019 to the best of the authors' knowledge. Papers were included in the analysis if they met the following criteria; included whole grain into the diet and reported the inclusion level, included a suitable control, reported the ground grain and protein meal used in the pelleted concentrate portion of the diet and tabulated at least one of the following: relative gizzard weight (g/kg), relative gizzard content (g/kg), FCR (g/g), AME (MJ/kg), or data which allows the calculation of the aforementioned parameters. After applying the selection criteria, the following 52 papers reporting 69 individual experiments and 287 treatments were accepted in the final database. The papers included: Mastika and Cumming (1987); Jensen (1994); Rose et al. (1995); Kiiskinen (1996); Uddin et al. (1996); Preston et al. (2000); Jones and Taylor (2001); Nahas and Lefrancois (2001); Rutkowski and Wiaz (2001); Bennett et al. (2002); Hetland et al. (2002); Plavnik et al. (2002); Hetland et. Al. 2003; Engberg et al. (2004); Svihus et al. (2004); Taylor and Jones (2004); Wu and Ravindran (2004); Wu et al. (2004); Dozier et al. (2006); Ravindran et al. (2006); Amerah and Ravindran (2008); Celik et al. (2008); Gabriel et al. (2008); Amerah et al. (2009); Biggs and Parsons (2009); Clark et al. (2009); Svihus et al. (2010); Amerah et al. (2011); Aghazadeh and TahaYazdi (2012); Anderson et al. (2012); Fernandes et al. (2013); Jacobs and Parsons (2013); Lv et al. (2013); Torres et al. (2013); Kliseviciute et al. (2014); Husvéth et al. (2015); Singh and Ravindran (2015); Singh et al. (2015); Abdollahi et al. (2016); Gracia et al. (2016); Nishii et al. (2016); Sittiya et al. (2016); Emadinia et al. (2017); Moss et al. (2017a); Moss et al. (2017b); Moss et al. (2017c); Truong et al. (2017); Mabelebele et al. (2018); Moss et al., (2018); Abdollahi et al. (2019); Singh and Ravindran 2019; Singh et al. (2019). A total of 5 papers were excluded as they did not meet the criteria (Nanto et al., 2012; Sittiya and Yamauchi, 2014; Nanto et al., 2015a,b; Nishii et al., 2015).

Meta-analysis

Within the database, 34% of the dataset was comprised of control treatments, 10% was pre-pellet whole grain treatments and 56% was post-pellet whole grain treatments. Thus, this needs to be taken into consideration in the interpretation of data on whole grain form, as experiments are lacking for pre-pellet whole grain feeding and data may not be as variable as it originates from only two research labs. The majority of grains examined as the whole grain component was wheat consisting 71% of the whole grain treatments, followed by barley (12%), rice (5%), sorghum (5%), triticale (3%), a 50-50 blend of wheat and barley (3%) and oats (1%). There was a wide range of whole grain inclusions used; 34% of the dataset had 0% whole grain, 35% of the dataset had 10-250 g/kg whole grain, 25% of the dataset had 260-500 g/kg whole grain, 5% of the dataset had 510-750 g/kg whole grain and 1% of the dataset had over 760 g/kg whole grain. Of the 189 whole grain treatments, it was specified that 49 implemented a gradual adaption of birds during the experiment from a lower whole grain inclusion level up to the specified treatment level, all of which comprised of post-pellet whole grain, which may add to the variability in responses between post-pellet whole grain feeding regimes. The majority (69%) of treatments had wheat as the dominant ground grain within the pelleted concentrate, followed by maize (24%), sorghum (6%) and rice (1%), which is sensible as whole grain feeding is a practice mainly employed in countries which feed wheat-based diets. Additionally, almost the entirety (96%) of the dataset had soybean meal as the dominant protein meal, with the remaining diets consisting of soy isolate (3%) or meat and bone meal (1%) as the dominant protein meal. On average, studies included in the analysis started at 8 days (median = 7) and finished at 35 days (median = 36).

Data were statistically analysed by a general linear model procedure and Pearson correlations using SPSS® IBM Statistics 25 program (IBM Corporation, Somers, NY, USA) software and model prediction using R Studio version 0.99.903. In order to generate these models, nonsignificant coefficients were excluded and the reduced equation recalculated for each response variable. Significance was accepted at the 5% level of probability via a student's t-test. Each experiment reported within a paper was given a unique experiment identifier which was included in the models as a random factor to account for experimental leverage.

Results and discussion

Upon analysis of the entire dataset, it was apparent that the response of broilers to whole grain inclusion (pre and post-pellet) was so varied that a general linear model may not be appropriate, as the "Experiment ID" random factor was in most cases, the most significant component of the model. This indicates there are differences in the birds, feeding systems and/or experimental methodology that were not addressed in the analysis. Perhaps one reason for this variation is the broad range of diets and methods that are classified under the category of 'whole grain feeding'. The database consisted of 69 individual experiments and 287 lines of data or 'treatments', of which 66% contained whole grain. Within these whole grain treatments, multiple combinations of methods are used, including the form of whole grain (pre-pellet, post-pellet), whole grain type (wheat, barley, etc.), inclusion level, gradual adaption to whole grain, the age whole grain treatments start and the study length.

To visualize the spread of data, the mean values and the percentage response from the control for relative gizzard weight (g/kg) in response to whole grain inclusion for each experiment have been graphed in Figures 2 and 3; and the mean values and the percentage response from the control for FCR (g/g) in response to whole grain inclusion for each experiment have been graphed in Figures 4 and 5. Relative gizzard weight and FCR were selected as they are the most commonly reported response variables in broilers to whole grain inclusion, and typically the area with which the greatest responses may be seen. Variability in gizzard and performance responses to whole grain feeding was observed in the current paper and confirms the findings of Singh et al. (2014) and Liu et al. (2015). Figure 2 illustrates the large experimental variation in gizzard weight which explains why past linear regressions of the response of multiple studies do not show significant relationships between whole grain and relative gizzard weight; because the absolute values vary greatly between different experiments. Nevertheless, it is evident that when comparing the slopes, the responses in relative gizzard weight to whole grain inclusion within individual studies are mostly positive. This is particularly evident in Figure 3, where the majority of whole grain inclusion treatments generate a positive % improvement in relative gizzard weight compared to the ground grain control. However, Figures 4 and 5 demonstrate the decisive split in the response of FCR to whole grain inclusion, where Figure 5 demonstrates an almost even division between positive and negative responses in FCR. In an attempt to reduce variability, pre-pellet whole grain treatments were temporarily removed from the dataset to explore if just the analysis of control and post-pellet treatments may give clearer responses. The variability was still consistent upon removal of the pre-pellet treatment, and demonstrates that whole grain form may not be the major contributor to the large variability seen within the literature; likely due to the small contribution of pre-pellet whole grain treatments to the overall database.

The entire database (including pre-pellet whole grain treatments) was further explored to determine how other reported experimental variables (other than the highly significant random effect of experimental ID) may individually contribute to this variation. Experimental period, age at the start of the experiment, age at the end of the experiment were significantly correlated to responses in relative gizzard weight and FCR. Pearson correlations between response parameters (relative gizzard weight (g/kg), response in gizzard weight (%), feed conversion ratio (FCR; g/g) and response in FCR (%)) and experimental variables (Year of publication, age of birds at the experiment start and end, and the number of days of the experimental period) are shown in Table 1. Sensibly, the year of publication is highly negatively correlated with FCR, reflecting the fact that the efficiency of broilers has improved substantially over the years due to genetic advances. Relative gizzard weight is also highly negatively correlated, which is sensible given that modern broilers are carrying more muscle on their skeletons and the relative weight between organs and whole body is decreasing; they will have relatively less gizzard in relation to their larger body mass compared to their lighter framed ancestors. However, what is interesting is that both the percentage response in FCR and relative gizzard weight to whole grain inclusion are tending to show the opposite effect; meaning that modern broilers may be starting to show diminished responses in FCR and gizzard weight and to whole grain inclusion. This could reflect that genetics have improved to such an extent that birds are approaching their biologically optimal performance and therefore nutritional interventions have less room for impact; 'once the cup is full, you cannot keep filling it'.

The overall length of the experimental period, age at the start and age at the end of the experimental period are all positively correlated with FCR. This is sensible as broilers have a more efficient FCR at a younger age. Interestingly, age at experiment start has a strong negative relationship with the percentage response in FCR. This indicates that the later whole grain is introduced, the better the FCR. It is possible that this correlation may be indicating that it is best not to start the whole grain feeding regime when the chick is too young to consume the whole grain. A regression of this relationship reveals that studies that started within 0-5 days of hatch may report an increased FCR to whole grain inclusion while studies that include whole grain after approximately 5 days post-hatch report a decreased, or more efficient, FCR (r2 = 0.105; $P < 0.001$). However, it has previously been suggested that a gradual inclusion of whole wheat, starting with small inclusion rates prior to 7 days post-hatch is advantageous to ensure acceptance of the grain (Singh et al., 2014). In the present analysis, only 25% of whole grain treatments employed gradual adaption. Thus, the poorer FCR in experiments that offered whole grain to chicks within the first 5 days post-hatch is likely due to the fact that the majority of treatments employed abrupt inclusion of whole grain.

There is clearly strong influence of experimental factors which make the interpretation of the response of broilers to whole grain difficult, which require further detail and information in order to elucidate. To explore if removing the effect of differing methodology aids interpretation of the data, the individual cage means from five whole grain feeding studies completed at the University of Sydney from 2016-2018 were compiled, as they all followed the same experimental methods (Moss et al., 2017a; Moss et al., 2017b; Moss et al., 2017c; Truong et al., 2017; Moss et al., 2018). Thus, we may explore if there are significant relationships when most experimental factors are kept consistent. Of course, in systematic analysis, there is always the possibility that perhaps the variability in the responses observed would have occurred anyway, and without further studies there is no way to precisely conclude if it is the differing methodology that has caused it. Within the selected subset of the database, there were a total of 246 observations. All experiments occurred over the same length of experimental period, within a year of each other, with the same strain of broilers, and occurred within the same experimental facility.

Within this dataset, there is a clear relationship between gizzard weight and the proportion of ground, pre-pellet and post-pellet whole grain ($r^2 = 0.529$; $P < 0.001$);

$$\text{Relative gizzard weight (g/kg)} = -0.017 \times \text{PercentGround} - 0.001 \times \text{PercentPre} + 0.165 \times \text{PercentPost} + 17.119$$

Where; PercentGround, PercentPre and PercentPost is the percentage of ground grain, pre and post-pellet whole grain, respectively, of the total diet. From this relationship, it is apparent that post-pellet whole grain feeding generated the largest improvements in relative gizzard weight, which is in agreement with many reports in the literature (Liu et al., 2015).

More factors may be included to the model which increases its complexity but also improves the amount of variability that may be explained for diets based on wheat or barley (r^2

= 0.724; $P < 0.001$). The prediction equation for birds fed wheat with pre-pelleting addition of whole grain is:

$$\text{Relative gizzard weight (g/kg)} = -16.326 + 0.046 \times \text{WG inclusion (\%)} + 0.063 \times \text{Total grain (\%)} + 0.104 \times \text{Diet protein (\%)} + 0.014 \times \text{Diet starch (\%)}.$$

Where; WG inclusion is the percentage of whole grain in the diet, total grain is the total percentage of ground and whole grain in the diet, diet protein is the percentage of crude protein within the diet, and diet starch is the percentage of starch within the diet. To predict relative gizzard weight for birds fed barley, add 2.273, for post-pelleting addition of whole grain, add 2.966; for ground grain addition add 0.101.

It is evident from the equation above that pre-pellet whole grain and wheat as the whole grain have little to no impact on gizzard weight but post-pellet whole grain and barley as the feed grain generate the largest gizzards. Additionally, it is important to note that other dietary factors such as the protein or starch content of the diet or the total proportion of grain will influence gizzard weight, but dietary factors are seldom examined in whole grain feeding studies.

The relationship between FCR and the proportion of ground, pre-pellet and post-pellet whole grain is not nearly as strong ($r^2 = 0.062$; $P = 0.001$);

$$\text{FCR (g/g)} = -0.0022 \times \text{PercentGround} - 0.0007 \times \text{PercentPre} - 0.0024 \times \text{PercentPost} + 1.5216$$

Where; PercentGround, PercentPre and PercentPost is the percentage of ground grain, pre and post-pellet whole grain, respectively, of the total diet.

Instead of splitting out the effect of different forms of whole grain, there is a more substantial quadratic relationship between whole grain inclusion (pre- or post-pellet) and FCR. This relationship is improved further when Gizzard pH is included ($r^2 = 0.235$; $P < 0.001$), and highlights the importance of improvements in ‘gut integrity’ generated with whole grain feeding regimes for translation to improvements in performance;

$$\text{FCR (g/g)} = 0.000079 \times \text{WG}^2 - 0.001539 \times \text{WG} + 0.06831 \times \text{GizzpH} + 1.208$$

Where; WG is the percentage inclusion of whole grain in the diet and GizzpH is the pH within the gizzard. A well-developed gizzard is proposed to promote secretion of gastric juices and reduce feed overconsumption in broilers (Svihus et al., 2011), and both of these mechanisms would contribute to an increased acidity within the gizzard and the improvement of nutrient digestion. Increasing the acidity of the gut may also reduce the bacterial load within the gut and reduce the risk of developing disease such as clinical or subclinical necrotic enteritis (Garrido et al., 2004). Thus, this anti-pathogenic effect may also be contributing to any improvements in FCR and growth performance.

Finally, within this dataset there is also a relationship between apparent metabolisable energy (AME) and the proportion of ground, pre-pellet and post-pellet whole grain ($r^2 = 0.387$; $P < 0.001$). The prediction equation for birds with pre-pelleting addition of whole grain is:

$$\text{AME (MJ/kg)} = 10.258 + 0.018 \times \text{WGinclusion} + 0.030 \times \text{Total grain}$$

Where; WG inclusion is the percentage of whole grain in the diet and total grain is the total percentage of ground and whole grain in the diet. To predict AME for birds fed diets with no whole grain, add 0.423, to predict AME for birds fed diets with post-pellet whole grain, add 0.018, to predict AME for birds fed diets with enzyme inclusion, add 0.329.

Thus, it is evident that within this database, post-pellet whole grain inclusion had the greatest influence on AME as far as grain form is concerned, and enzyme inclusion to the diet also advantaged AME. Whole grain feeding has been shown to improve nutrient utilization and a summary of these responses is reported in Singh et al. (2014). It is evident from the above model that post-pellet whole grain feeding has a larger impact on energy utilization than pre-pellet whole grain feeding. However, data within the literature is conflicting. Pre and post-pellet whole grain feeding were determined to be both as effective at improving AME in Wu et al. (2004), and pre-pellet whole grain feeding was shown to be the most effective at improving AME in Moss et al. (2017b). In the Liu et al. (2015) review, an average energy uplift of 0.51MJ to whole grain feeding (pre- and post-pellet) was reported but the variability in AME response was large with the range of responses spanning from −0.04 to 1.73MJ across 19 sets of observations. Pre-pellet whole grain feeding does not generate as great improvements in gizzard weight; nevertheless, has been shown to improve energy utilization in the above mentioned studies. Thus, this relationship may require further examination to determine the underlying mechanisms.

Comparing whole grain feeding studies with similar methodology has allowed us to draw meaningful relationships from the otherwise variable data. However, some variability remains unexplained. In addition to the broad range of methods and grain types classified under whole grain feeding, other dietary factors not included in the present evaluation may contribute to the significant level of variation. For example, this analysis did not contain enzyme inclusion as a variable. However, phytase has been shown to be more effective in diets with whole grain inclusion (Moss et al., 2017c). Treatment interactions were observed for FCR and AME where whole barley inclusion improved FCR by 3.20% and AME by 0.33 MJ/kg but in ground barley diets phytase compromised FCR by 3.11% and AME by 0.12 MJ/kg in Moss et al. (2017c). Therefore, other dietary factors such an enzyme inclusion are likely contributing to the observed variability of performance responses to whole grain feeding regimes.

Another consideration of whole grain feeding not examined in the present evaluation was the incidence of dilated proventriculi. Dilated proventriculi is primarily caused by viral infection but appears to have dietary predisposing factors, and involves an enlargement and thinning of the proventriculus which may worsen digestive functionality and performance (Taylor and Jones, 2004). Whole barley inclusion was reported to reduce the incidence of dilated proventriculi from an average of 4.76% in treatments with ground grain to zero reported cases in diets with whole grain inclusion in Moss et al. (2017c). Similarly, the incidence of dilated proventriculi was reduced from 8.35 to 1.05% in (Truong et al., 2017). The reduction of dilated proventriculi likely reflects a more robust gizzard and may serve as a useful indicator of 'gut integrity'; however, it is not commonly reported.

Variability may also be expected due to the inherent challenges that can arise in whole grain feeding regimes, including; feed-flicking, select feeding and the dietary separation of marker when nutrient digestibility is measured. Feed-flicking is an undesirable behavior where selected particles are thrown or 'raked' from the feeder resulting in feed wastage. This poses problems in an experimental setting as the wasted feed cannot be quantified and thus exaggerates feed intakes and compromises FCR. Feed-flicking has been reported to occur in post-pellet whole grain treatments (Moss et al., 2017b); however, it is not confined to whole grain feeding. For example, feed-flicking has also been reported in Fanatico et al. (2013) where birds were observed to feed-flick when offered crumbled diets which contained a range of large and small particles.

Perhaps the reason feed-flicking appears to occur in post-pellet whole grain feeding treatments is it permits 'select-feeding' as the diet is offered as two components; the low protein whole grain and the high protein pelleted concentrate. Birds are capable of enhancing their growth performance by selecting the best combination of protein sources for their individual needs (Gous and Swatson, 2000). Select-feeding contributes to the responses observed in broiler chickens under whole grain feeding regimes (Forbes and Shariatmadari, 1994; Forbes and Covasa, 1995). Nevertheless, the effect of select-feeding on performance is debatable as some studies have not reported an advantaged performance of select-feeding under whole grain feeding regimes (Olver and Jonker, 1997; Delezie et al., 2009; Moss et al., 2018). Additionally, feed-flicking and select-feeding may be one cause of the variation and discrepancies present between whole grain feeding experiments as the reported formulated amount of whole grain included in the diet may not be representative of what the birds consumed. In fact, Moss et al. (2018) offered whole grain and pelleted concentrate separately to encourage select feeding and allow the recording of each dietary component. The pelleted concentrate was formulated to represent diets containing 75, 150 and 300 g/kg whole wheat but whole wheat was then provided ad lib. It was found that as the notional whole grain inclusion increased birds ate proportionally less whole grain when given the unhindered opportunity to select.

Finally, another challenge of whole grain feeding experiments, which has not been analysed here, is the determination of nutrient digestibility via a dietary marker. Calculation of starch and protein (N) digestibility coefficients along the small intestine is problematic as the quantity of dietary marker consumed is confined to the pelleted concentrate and thus relative proportions of dietary marker to nutrient may not be accurate. This issue also applies to pre-pellet whole grain to some extent as the whole grain component will be separated from the rest of the pellet within the gizzard and thus the accuracy of the marker is affected. Therefore, the effects of whole grain inclusion on the digestibility of starch and protein (N) in the small intestine is yet to be determined accurately and this aspect certainly merits further investigation.

Conclusion

It is evident from the current evaluation that whole grain feeding studies are not straight forward as the term ‘whole grain feeding’ encompasses a range of feeding strategies and methods which influences the response of broilers to whole grain. Importantly, this review has shown whole grain feeding is more complicated than just the inclusion level and form of whole grain added, as these factors do not explain the variation in the responses of broilers to whole grain feeding alone. Likely, other factors such as the way whole grain is incorporated into diets for poultry as well as the formulation of the diet they are added to are of importance. However, there are few studies examining the influence of other dietary factors on the response of broilers to whole grain feeding regimes. It is remarkable that whole grain feeding is used so broadly in Europe, Canada and Australasia and yet there is only a total of 57 published studies (up to

2019), of which 52 were appropriate to include in this systematic evaluation, and of these. However, the vast majority have occurred in the past 10 years and thus it is evident that whole grain feeding is gaining rising attention. As whole grain feeding is extensively used in poultry diets based on wheat, there is vast opportunity for further study to characterise the influence of inclusion methods on whole grain feeding and reduce the variability that exists between studies by more accurately defining whole grain feeding methodology. With this improved understanding and definitions of whole grain feeding practices and advantages, we may further enhance the performance of poultry offered whole grain feeding regimes.

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Table 1 Pearson correlations between response parameters (relative gizzard weight (g/kg), response in gizzard weight (%), feed conversion ratio (FCR; g/g) and response in FCR (%)) and experimental variables (Year of publication, Age of birds et experiment start and end, and the number of days of the experimental period).

	Relative gizzard weight (g/kg)	Response in gizzard weight (%)	FCR (g/g)	Response in FCR (%)
Year of publication	r = -0.320	r = -0.113	r = -0.541	r = 0.097
	P = <0.001	P = 0.087	P = <0.001	P =0.104
Age experiment start	r = -0.163	r = 0.054	r = 0.379	r = -0.324
	P = 0.013	P = 0.415	P = <0.001	P = <0.001
Age experiment end	r = 0.081	r = 0.064	r = 0.689	r = -0.152
	P = 0.219	P = 0.333	P = < 0.001	P = 0.010
Experimental period	r = 0.184	r = 0.022	r = 0.304	r = 0.136
	P = 0.005	P = 0.738	P = <0.001	P = 0.022

Figure 1 The lack of relationship between the percentage of whole grain inclusion and (I.) the percentage increase in relative gizzard weight (g/kg) and (II.) the percentage improvement in feed conversion ratio (FCR; g/g) demonstrates the variability between eleven whole grain feeding studies (adapted from Liu et al. (2015)).

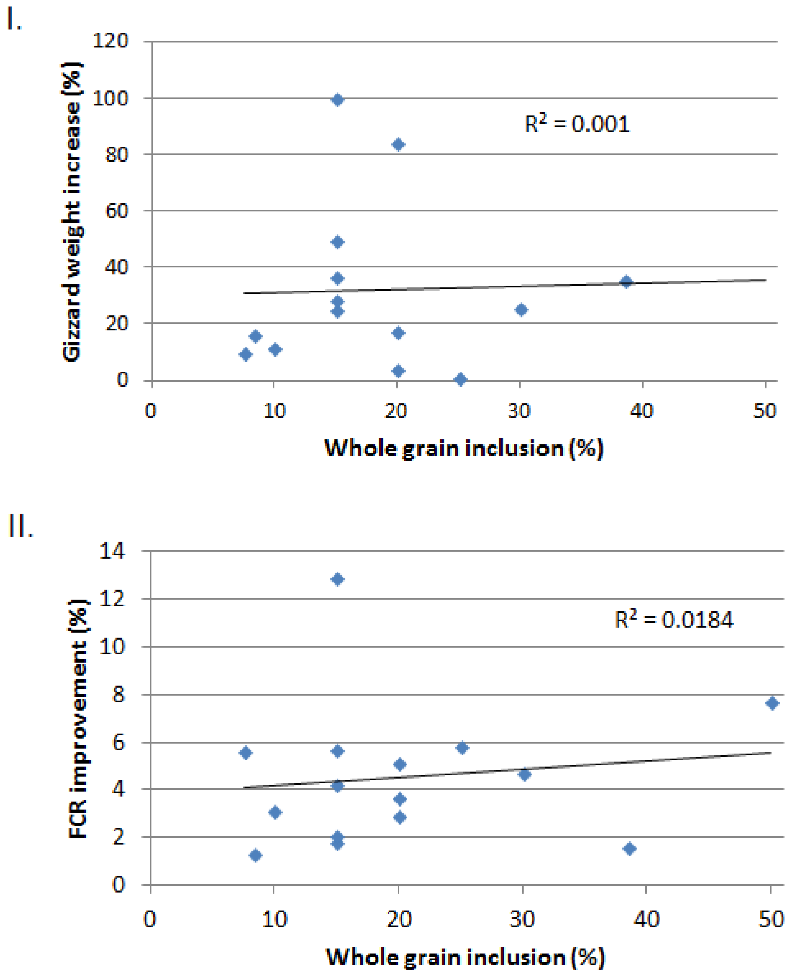


Figure 2 The individual relationships (estimated marginal means) between relative gizzard weight (g/kg) and pre- and post-pellet whole grain inclusion (%) from the dataset of 52 papers (ExpID).

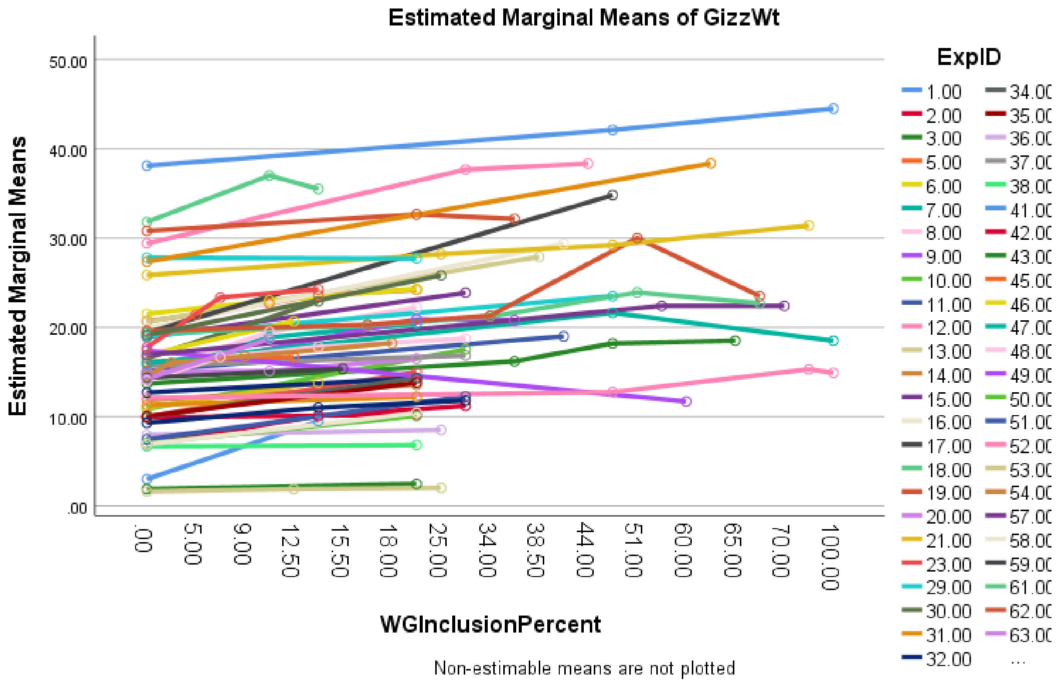


Figure 3 The individual percentage responses (estimated marginal means) in comparison to the control between relative gizzard weight (g/kg) and pre- and post-pellet whole grain inclusion (%) from the dataset of 52 papers (ExpID).

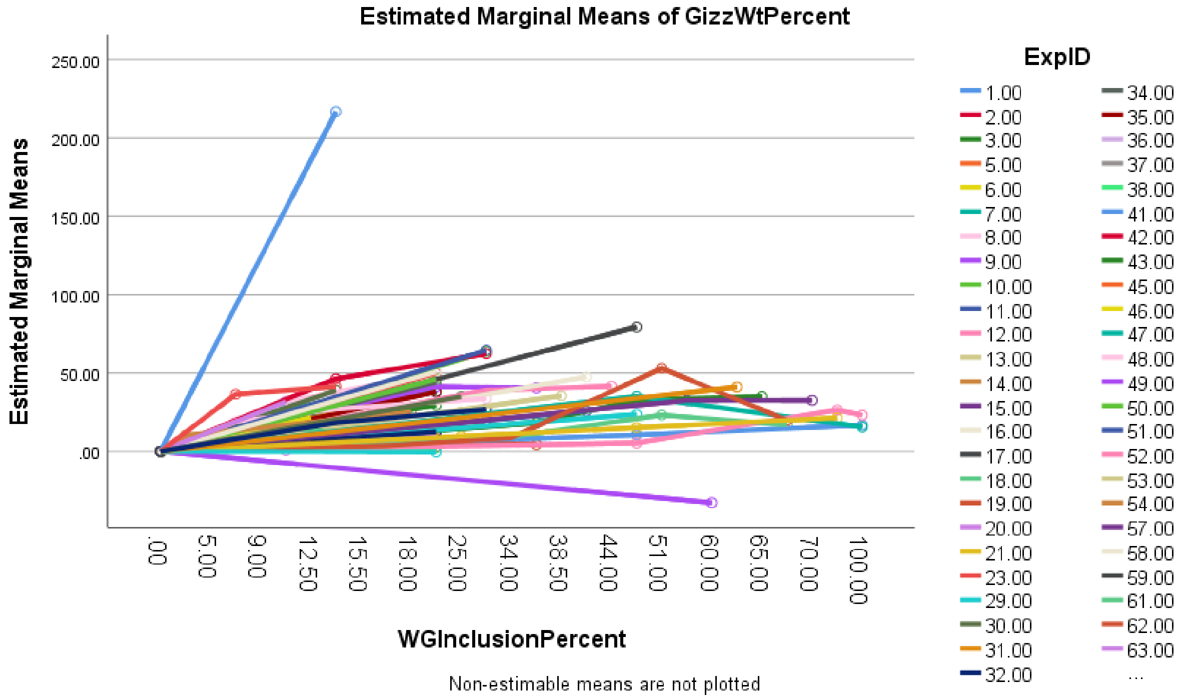


Figure 4 The individual relationships (estimated marginal means) between feed conversion ratio (FCR; g/g) and pre- and post-pellet whole grain inclusion (%) from the dataset of 52 papers (ExpID).

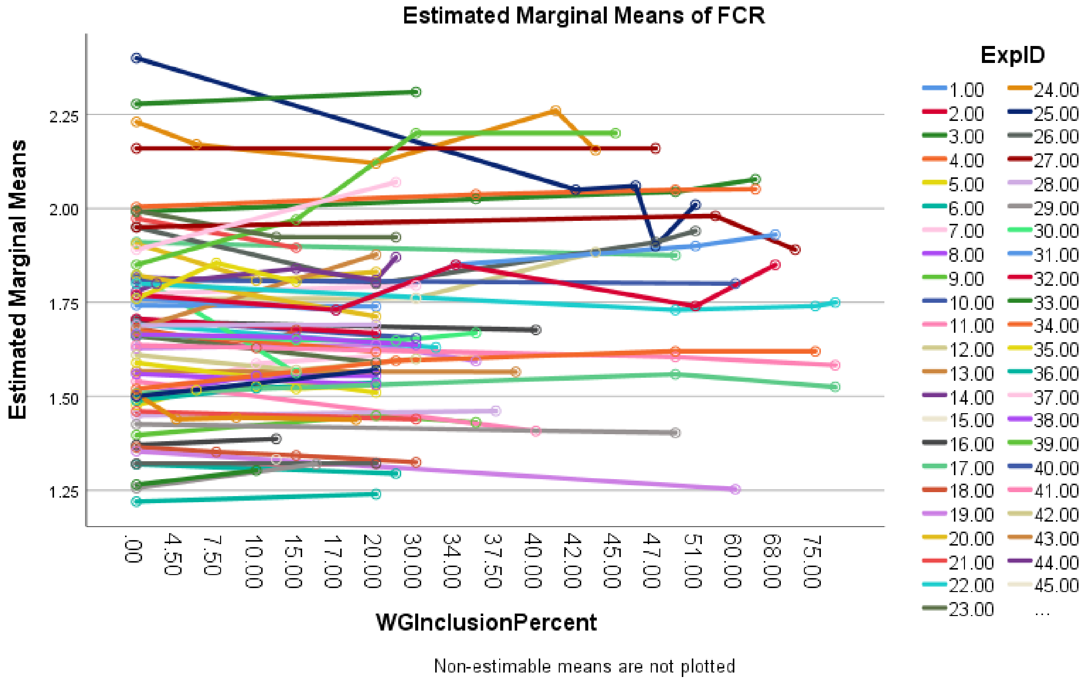
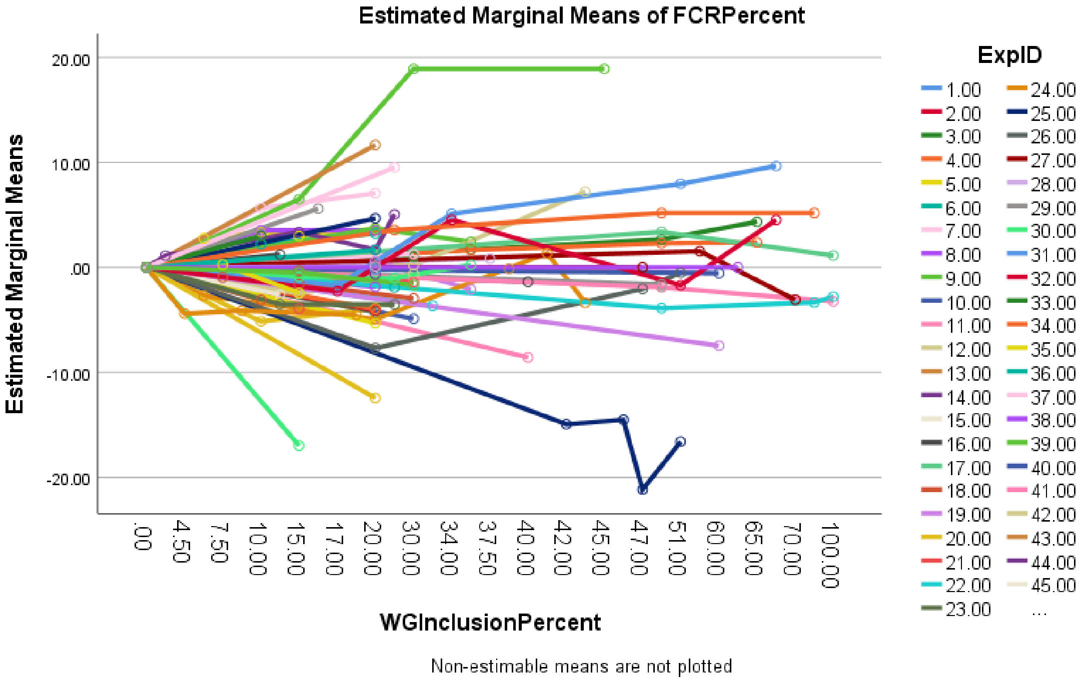


Figure 5 The individual percentage responses (estimated marginal means) in comparison to the control between feed conversion ratio (FCR; g/g) and pre- and post-pellet whole grain inclusion (%) from the dataset of 52 papers (ExpID).



Update on Digestible Calcium Research in Broilers

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INTRODUCTION

The measurement of digestible nutrients in feed ingredients has now become the cornerstone of contemporary poultry nutrition to formulate diets that closely match the nutrient requirements for optimal and sustainable production. Historically, digestibility in poultry has been determined over the total digestive tract but this approach suffers from several limitations. Today, the superiority of nutrient digestibility measured at the terminal ileum is accepted unquestionably by the poultry industry (Lemme et al., 2004). The classic example is the move in the industry from using total amino acids and total tract digestible amino acids to ileal digestible amino acids in feed formulations and this shift had been an immense success. However, the requirement of phosphorous (P) is still being considered on available P basis and that of calcium (Ca) on total Ca basis. Due to the ever-increasing price of inorganic phosphates and the growing concern over environmental P pollution, the measurement of ileal P digestibility in feed ingredients has received attention in the recent past and currently considered as the preferable method to measure P availability for poultry (WPSA, 2013). Concurrent measurement of Ca digestibility in feed ingredients is also necessary because of the close relationship between Ca and P in the absorption and post-absorptive utilisation of these minerals. Applying the digestible nutrient principle to P and Ca will be a natural extension of the use of digestible amino acids and aligns these two minerals with routine feed evaluation.

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During the past 7 years, a series of studies have been conducted at Massey to measure the ileal Ca digestibility in feed ingredients, to explore the factors affecting Ca digestibility and to determine the requirement of digestible Ca in poultry (Anwar et al., 2015; 2016a,b,c; 2017; 2018; David et al., 2019, 2020a,b; 2021). Some of the key factors affecting Ca digestibility were examined and included broiler age, supplemental phytase and bird-type (broilers vs. layers). The Ca digestibility values determined in these studies and published data were used to develop dietary treatments to determine the digestible Ca requirement for broiler starters from day 1 to 10 post-hatch.

Digestible Ca as affected by the age of broilers

Age of birds is one of the key factors that influences the nutrient digestibility (Batal and Parsons, 2002). However, there are limited reports on the effect of broiler age on ileal Ca digestibility (Shastak et al., 2012; Angel et al., 2013; Morgan et al., 2015). Among these, only one has reported the age effect on ingredient Ca digestibility (Angel et al., 2013). Furthermore, the Ca digestibility estimates reported in most of these studies are confined to the first three weeks and none has covered the entire growth period of broilers. Therefore, a study was conducted to measure the effect of age (7, 14, 21, 28, 35 and 42 days, post-hatch) on the Ca digestibility of limestone. The findings revealed that the apparent ileal Ca digestibility coefficients were linearly decreased from day 7 (0.51) to day 42 (0.27) in broilers (Figure 1). It is clear that the use of digestible Ca values of ingredients is not interchangeable among different age groups and age-dependant values need be considered when formulating diets for different age groups of broilers.

Digestible Ca as affected by phytase

It is well established that supplemental microbial phytase improves P absorption in poultry by increasing the bioavailability of phytate-P (Selle and Ravindran, 2007), but the effects on Ca digestibility remain contradictory. Some reports indicate that phytase addition improves Ca digestibility of diets (Ravindran et al., 2006; Walk et al., 2012b), whereas others have found little or no benefit (Walk et al., 2012a). On the other hand, phytase doses higher than the widely recommended dose of 500 FTU/kg (referred to as superdoses) are known to hydrolyse the phytate (IP6) as well as the lower phytate esters (IP5 to IP1). Superdosing is currently used by the industry and, reported to improve the growth performance and nutrient utilisation over the normal dose by removing the anti-nutritive effects of lower phytate esters (Cowieson et al., 2011). However, the influence of microbial phytase (including the superdose) on the Ca digestibility of feed ingredients has not been previously reported.

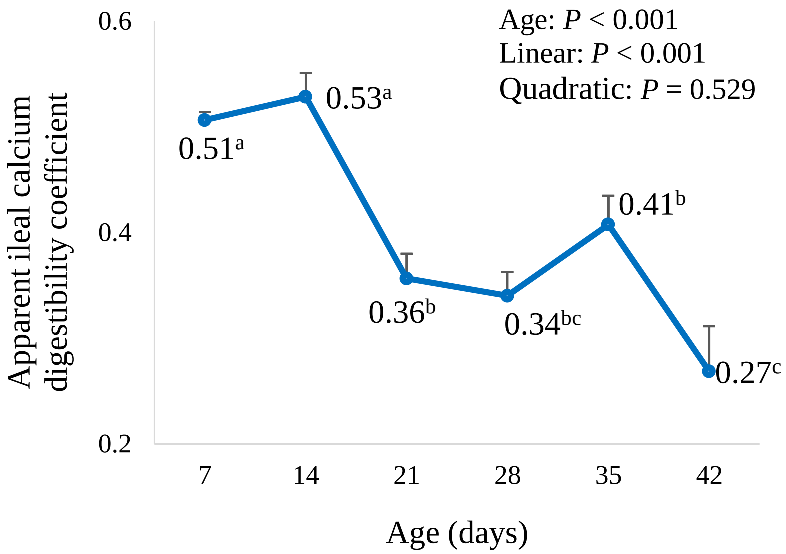

Figure 1. Effect of broiler age on the apparent ileal calcium digestibility coefficient (mean ± SD). $^{a,b,\ c}$ Values with different superscripts differ significantly ($P < 0.05$).

Therefore, two experiments were conducted to measure the influence of phytase doses (0, 500 and 2000 FTU/kg) on the true ileal Ca digestibility of soybean meal (SBM) and canola meal (CM) in broiler starters and finishers (Figure 2). True ileal Ca digestibility coefficients of SBM and CM, with no phytase, were determined to be 0.51 and 0.53, respectively, for broiler starters and 0.33 and 0.22, respectively, for broiler finishers. These results also confirm (not statistically compared) the finding that the Ca digestibility decreases with advancing age of broilers. Microbial phytase increased the true ileal digestibility coefficients of Ca in SBM and CM, but the effect was more pronounced for the CM. This finding indicates that comparatively more phytate-bound Ca was released by phytase in the CM, which may be due to the relatively high phytate concentration of CM. The superdosing of phytase (2000 FTU/kg) increased the Ca digestibility in both CM and SBM by two-fold. These findings support the conventional wisdom that the use of phytase superdose will be more beneficial in diets based on high-phytate ingredients.

Digestible Ca as affected by the bird-type

Bird type is another factor that may affect the Ca digestibility. Ileal Ca digestibility studies comparing the digestibility between broilers and layers are scant. In addition, no studies have been reported the ingredient Ca digestibility in laying hens.

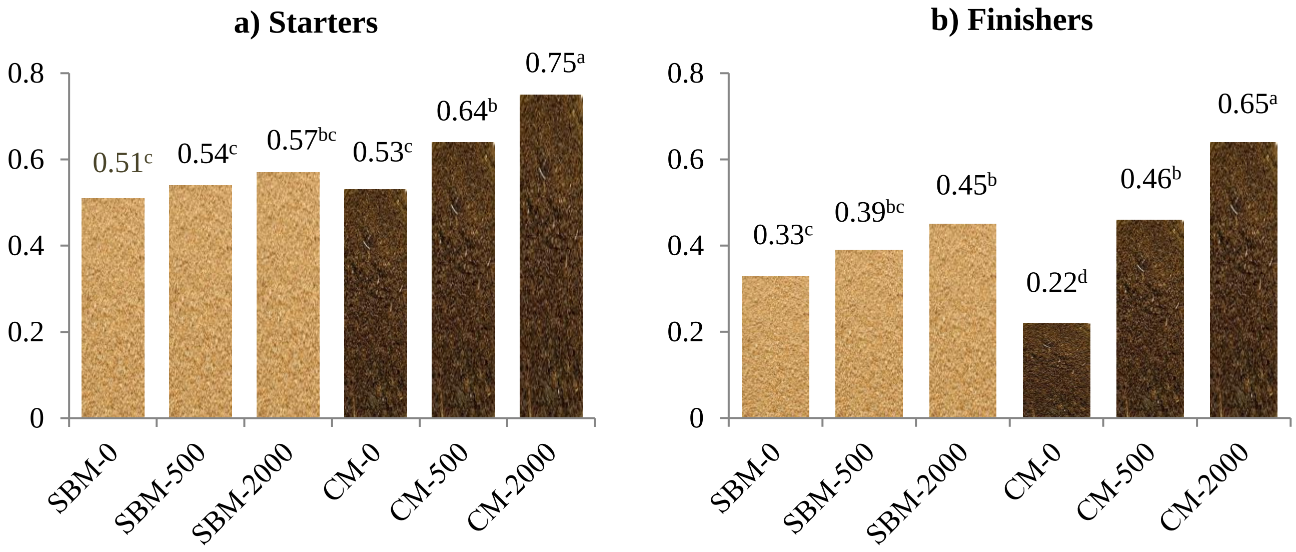

Figure 2. Effect of phytase doses (0, 500 and 2000 FTU/kg) on the true ileal calcium digestibility coefficient of soybean meal (SBM) and canola meal (CM) in broilers starters (a) and finishers (b).

Therefore, studies were conducted to determine the apparent ileal Ca digestibility coefficients of two limestone sources (A and B) in broilers and layers. Apparent ileal Ca digestibility of both limestones was found to be higher in laying hens compared to broilers. The apparent ileal Ca digestibility coefficient of limestone A for broilers and layers were 0.50 and 0.62, respectively. The corresponding values for limestone B were 0.43 and 0.70, respectively. The findings indicate that laying hens digest Ca more efficiently than broilers which may be attributed to a high demand of Ca for eggshell formation in laying hens. Figure 3 illustrates the effect of bird-type on the ileal Ca digestibility of the two limestones.

Digestible Ca to digestible P requirements of broiler starters

Using the digestible Ca content of Ca sources measured at our facility and published data, a growth study was conducted to estimate the standardised ileal digestible (SID) Ca requirement for 1 to 10 day-old broilers fed different dietary concentrations of both SID Ca (3.3, 3.9, 4.4, 5.0 and 5.5 g/kg) and SID P (4, 5 and 6 g/kg). Based on response surface models, growth performance and bone mineralisation of broiler starters were optimised at 5 g/kg SID P concentration, which is closer to the current Ross 308 (2019) recommendation for available P (4.8 g/kg).

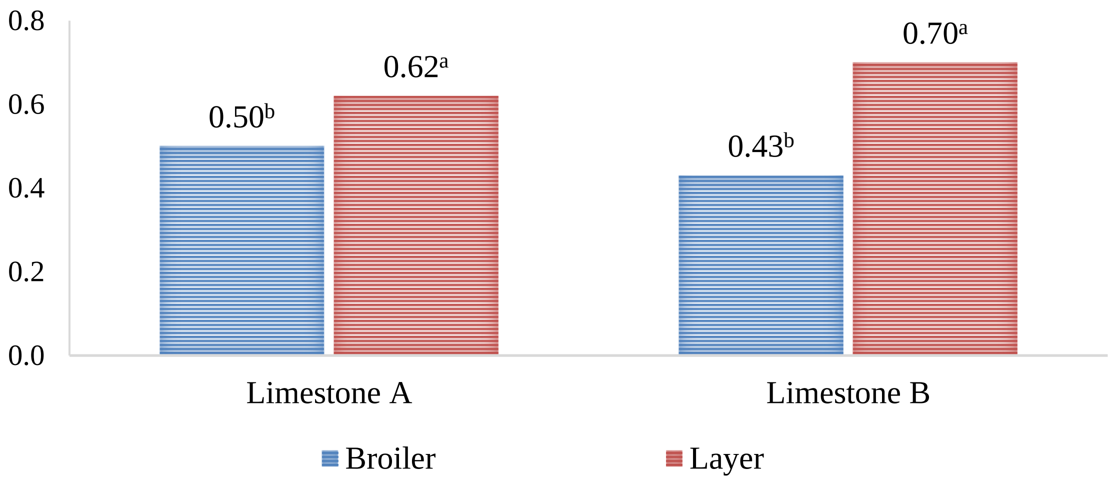

Figure 3. Effect of bird-type on the apparent ileal calcium digestibility coefficient of two limestone sources.

The concentrations of SID Ca that maximised body weight gain and tibia ash were estimated to be 3.32 and 4.51 g/kg, respectively, which corresponded to SID Ca to SID P ratios of 0.66 and 0.90, respectively. The SID Ca requirement for maximum growth performance (3.32 g/kg) of 10-day old broilers is equivalent to a total Ca concentration of 7 g/kg, which is less than the Ross (2019) recommendation of 9.6 g/kg total Ca. However, the bone mineralisation was maximised around the current recommendation (8.9-9.8 g/kg total Ca). These data showed that bone mineralisation requires more Ca than growth performance which is in agreement with those from pig studies (González-Vega *et al*., 2016; Merriman *et al*., 2017. Further studies are being planned to determine the requirements of digestible Ca and digestible P for other growth phases of broilers, namely growers (11-24 days) and finishers (25-35 days). Figure 4 illustrates (both interaction and response surface plots) the body weight gain and tibia ash concentrations in broilers fed different concentrations of SID Ca and SID P.

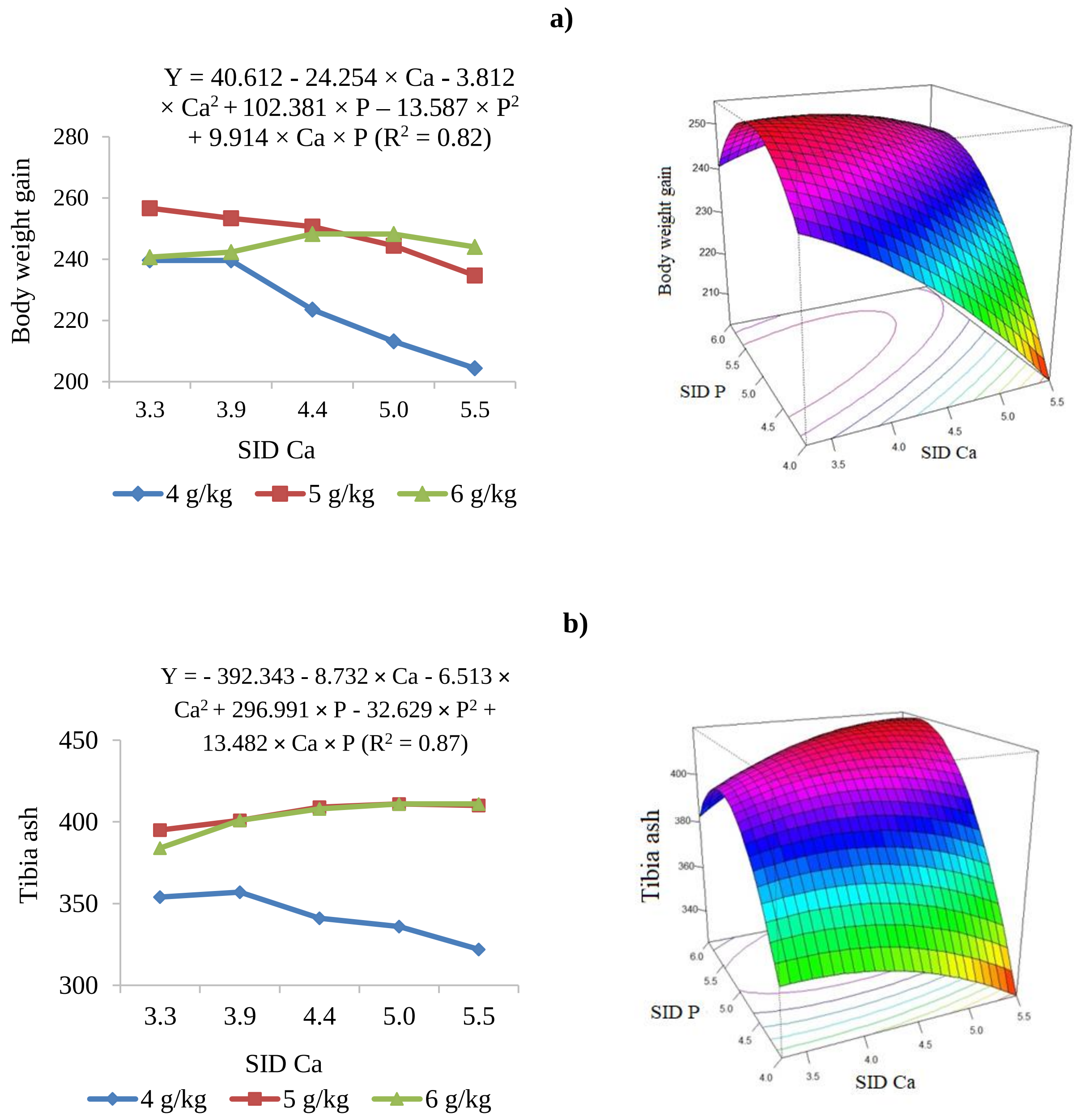

Figure 4. (a) Body weight gain (g/bird) and (b) tibia ash concentration (g/kg dried defatted matter) of broiler chickens fed different standardised ileal digestible (SID) calcium (Ca) and SID phosphorous (P) concentrations (4, 5 and 6 g/kg) from day 1 to 10.

Conclusions

Most current data on Ca digestibility procedures and digestibility estimates have been generated from Massey University. These findings were novel and not examined hitherto. Considerable data are available now on the Ca digestibility of ingredients to move towards the digestible Ca formulation system. The accuracy of our Ca digestibility data was further confirmed by the similarity between calculated and determined SID Ca contents in the Ca requirement study. The requirements of digestible Ca, digestible P and the ratio of digestible Ca to digestible P for broiler starters (0-10-day old) have been estimated in our study. It was demonstrated that the digestible Ca requirement for 0-10-day old broilers is somewhat closer to the current Ross (2019) recommendation for total Ca.

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Influence of Age on the Standardised Amino Acid Digestibility of Cereal Grains in Broilers

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INTRODUCTION

Notable changes occur in the morphology and development of the gastrointestinal tract during the first few weeks of life that can potentially influence the digestion and absorption of nutrients, including amino acids (AA). The secretion and activity of different protein digestive enzymes like trypsin, chymotrypsin, intestinal peptidase and dipeptidase are also variable depending on age (Jin et al., 1998). Despite the possible age effect, a few studies have reported the age-related standardised ileal digestibility (SID) of AA only at two or three specific ages (Adedokun et al., 2007; 2008; Szczurek et al., 2020). Therefore, the current study was designed to determine the standardised ileal digestibility coefficients (SIDC) of nitrogen (N) and AA in wheat and sorghum at six different ages (d 7, 14, 21, 28, 35 and, 42) of broilers.

MATERIALS AND METHODS

The experimental procedures were approved by the Massey University Animal Ethics Committee. Two experimental diets were formulated with similar inclusions (938 g/kg) of either wheat or sorghum, as the only source of AA in the diet. The diets were steam-conditioned at 70 ºC for 30 seconds and pelleted. Titanium dioxide (5 g/kg) was incorporated in the experimental diets as an indigestible marker. Day-old male broilers (Ross 308) were raised in floor pens and fed a commercial broiler starter diet from d 1 to 21 and a commercial broiler finisher diet from d 22 until d 42 in pelleted forms.

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A total of 696 birds were used in this experiment. 168 chicks were individually weighed on d 1, and allocated to 12 battery brooders (n = 14 chicks per replicate) so that the average body weight per replicate was similar. The remaining chicks were allocated to 12 battery brooders on d 7 (n = 12 birds per replicate), and 12 replicate cages per age group on d 14 (n = 10 birds per cage), d 21 (n = 8 birds per cage), d 28 (n = 8 birds per cage), and d 35 (n = 6 birds per cage), respectively. The test diets were offered for 4 d prior to ileal digesta collection. On d 7, 14, 21, 28, 35 and 42, all birds were euthanised and the digesta were collected from the lower half of the ileum, pooled within a cage. Representative samples were analysed, in duplicate, for dry matter, Ti, N and AA. The apparent ileal digestibility coefficients (AIDC) data were standardised using the basal endogenous N and AA losses measured in a previous experiment at different ages (d 7, 14, 21, 28, 35 and 42) of broiler (Barua et al., 2021). Data were analysed by the GLM procedure of SAS (version 9.4; 2015; SAS Institute, Cary, NC) for each grain. Differences were considered significant at $P < 0.05$. Orthogonal polynomial contrasts were performed to determine the linear and quadratic effects of age.

Results and discussion

The influence of broiler age on SIDC of N and AA in wheat and sorghum is presented in Tables 1 and 2, respectively. The SIDC of N and, average digestibility of indispensable (IAA) and dispensable AA (DAA) in wheat ($P > 0.05$; Table 1) was unaffected by age. The broiler age, however, tended ($P = 0.092$) to linearly influence the average of TAA. Among IAA, the SIDC of Met (quadratic; $P < 0.05$) increased from d 7 to 21, and then plateaued. The SIDC of Trp increased linearly ($P < 0.001$) with advancing age. Among the DAA, a linear effect of age was observed for SIDC of Asp ($P < 0.001$), Cys ($P < 0.001$) and Glu ($P < 0.05$). Szczurek et al. (2020) measured the ileal AA digestibility in wheat, triticale and barley at two ages (d 14 and 28) of broilers and did not notice any age effect on the SID of AA in wheat.

Table 1. Standardised ileal digestibility coefficients[1] of nitrogen (N) and amino acids of wheat at different ages of broilers[2]

	Age (day)							Orthogonal polynomial contrasts	
Parameter	7	14	21	28	35	42	Pooled SEM	Linear	Quadratic
N	0.950	0.904	0.931	0.949	0.947	0.933	0.0088	0.393	0.586
Indispensable amino acids									
Arg	0.953	0.909	0.914	0.933	0.928	0.914	0.0089	0.197	0.162
His	0.904	0.896	0.899	0.919	0.919	0.913	0.0085	0.079	0.975
Ile	0.929	0.899	0.907	0.939	0.929	0.921	0.0105	0.333	0.718
Leu	0.934	0.910	0.920	0.953	0.944	0.937	0.0088	0.051	0.938
Lys	0.839	0.824	0.840	0.884	0.859	0.863	0.0186	0.097	0.705
Met	0.886	0.868	0.921	0.949	0.933	0.923	0.0103	0.001	0.017
Thr	0.965	0.891	0.911	0.905	0.931	0.900	0.0139	0.083	0.066
Trp	0.852	0.859	0.898	0.915	0.918	0.911	0.0127	0.001	0.070
Val	0.899	0.876	0.894	0.917	0.914	0.905	0.0108	0.075	0.903
IAA	0.910	0.881	0.900	0.924	0.919	0.909	0.0108	0.141	0.987
Dispensable amino acids									
Ala	0.881	0.857	0.865	0.887	0.873	0.863	0.0131	0.862	0.922
Asp	0.813	0.779	0.855	0.885	0.882	0.864	0.0162	0.001	0.119
Cys[3]	0.896	0.879	0.917	0.928	0.939	0.926	0.0085	0.001	0.282
Glu	0.981	0.969	0.963	0.974	0.969	0.967	0.0039	0.047	0.144
Gly[3]	0.894	0.853	0.868	0.892	0.889	0.881	0.0104	0.448	0.334
Pro	0.972	0.949	0.957	0.966	0.966	0.957	0.0043	0.712	0.372
Ser	0.948	0.905	0.926	0.931	0.943	0.928	0.0101	0.819	0.273
DAA	0.912	0.885	0.907	0.923	0.923	0.912	0.0092	0.101	0.950
TAA	0.909	0.882	0.903	0.923	0.921	0.911	0.0099	0.092	0.902

[1] Apparent digestibility values were standardised using the following basal ileal endogenous flow values (g/kg DM intake), determined by the feeding N-free diet at different ages (Barua et al., 2021).

[2] Each value represents the mean of six replicates (14, 12 and 10 birds per replicate for 7, 14 and 21-d old birds, respectively; eight birds per replicate for 28 and 35-d old birds; and six birds per replicate for 42-d old birds).

[3] Semi-indispensable amino acids for poultry.

IAA = Average digestibility of indispensable amino acids; DAA = Average digestibility of dispensable amino acids; TAA = Average digestibility of all amino acids.

Unlike wheat, in sorghum, the highest SIDC of N, average SIDC of IAA, DAA and TAA were determined at d 7, declining at d 14 and then plateauing (linear or quadratic, $P < 0.05$; Table 2). Among the IAA, a quadratic decline ($P < 0.05$ to 0.01) was observed for the SIDC of Arg, His, Thr and Val with advancing age. The SIDC of Ile, Leu, Lys and the average of IAA were linearly decreased ($P < 0.05$ to 0.001) with advancing age, with the highest SIDC values being recorded on d 7. Except Cys, the SIDC of all individual DAA, and average of DAA was influenced by bird age either linearly or quadratically ($P < 0.05$ to 0.001). A linear decrease ($P < 0.05$ to 0.001) was observed in SIDC of Ala, Asp, Glu and Pro as birds grew older. The SIDC of Gly, Ser and average DAA reduced with advancing age, but the decline was greater between d 7 and 14 resulting in a quadratic effect ($P < 0.05$ to 0.01). The average SIDC of TAA declined linearly ($P < 0.01$) with advancing age, from 0.903 at d 7 to 0.828 at d 42.

Table 2. Standardised ileal digestibility coefficients[1] of nitrogen (N) and amino acids of sorghum at different ages of broilers[2]

	Age							Orthogonal polynomial contrasts	
Parameter	7	14	21	28	35	42	Pooled SEM	Linear	Quadratic
N	0.933	0.860	0.842	0.872	0.848	0.845	0.0164	0.003	0.037
Indispensable amino acids									
Arg	0.961	0.869	0.857	0.913	0.885	0.879	0.0173	0.043	0.031
His	0.837	0.793	0.748	0.795	0.757	0.771	0.0156	0.005	0.034
Ile	0.915	0.875	0.837	0.869	0.836	0.843	0.0170	0.004	0.109
Leu	0.906	0.905	0.872	0.878	0.849	0.865	0.0115	0.001	0.345
Lys	0.934	0.847	0.841	0.877	0.808	0.814	0.0252	0.003	0.353
Met	0.874	0.842	0.855	0.895	0.852	0.859	0.0164	0.988	0.866
Thr	0.967	0.817	0.792	0.824	0.818	0.799	0.0246	0.001	0.003
Trp	0.869	0.848	0.821	0.862	0.842	0.849	0.0192	0.637	0.339
Val	0.891	0.839	0.810	0.849	0.819	0.826	0.0183	0.031	0.009
IAA	0.906	0.849	0.826	0.862	0.829	0.834	0.0167	0.011	0.089
Dispensable amino acids									
Ala	0.912	0.913	0.870	0.872	0.844	0.859	0.0115	0.001	0.232
Asp	0.916	0.839	0.845	0.874	0.851	0.844	0.0173	0.048	0.149
Cys[3]	0.810	0.725	0.729	0.800	0.786	0.781	0.0207	0.554	0.095
Glu	0.927	0.924	0.874	0.878	0.848	0.863	0.0113	0.001	0.116
Gly[3]	0.911	0.795	0.723	0.797	0.765	0.756	0.0234	0.001	0.003
Pro	0.873	0.837	0.802	0.825	0.792	0.799	0.0146	0.001	0.105
Ser	0.943	0.838	0.827	0.857	0.843	0.841	0.0209	0.012	0.014
DAA	0.899	0.826	0.810	0.843	0.819	0.820	0.0176	0.014	0.045
TAA	0.903	0.844	0.819	0.854	0.825	0.828	0.0164	0.007	0.059

[1] Apparent digestibility values were standardised using the following basal ileal endogenous flow values (g/kg DM intake), determined by the feeding N-free diet at different ages (Barua et al., 2021).

[2] Each value represents the mean of six replicates (14, 12 and 10 birds per replicate for 7, 14 and 21-d old birds, respectively; eight birds per replicate for 28 and 35-d old birds; and six birds per replicate for 42-d old birds).

[3] Semi-indispensable amino acids for poultry.

IAA = Average digestibility of indispensable amino acids; DAA = Average digestibility of dispensable amino acids; TAA = Average digestibility of all amino acids.

During SIDC estimates, the AIDC are corrected for the basal endogenous AA (EAA) losses from various digestive secretions, pancreatic and enzymatic secretions (Ravindran, 2021). In this study, age-appropriate EAA flows were used to standardise the apparent digestibility estimates (Barua et al., 2021). Correction of AIDC values using age-appropriate EAA losses resulted in an increase of 23.8% in the SIDC of average TAA in wheat in d 7, which was almost twice than the increase in d 14 to 35 (10.8-11.5%), and three times more than d 42 (7.43%). Similar trends were recorded for the average SIDC of TAA in sorghum at d 7 being 20.9% higher than the average AIDC of TAA. The magnitude of uplift in the average SIDC of TAA at d 14 to 35 and d 42 were 10.7-11.4% and 7.25%, respectively.

Conclusions

The present study, for the first time, provides information on the SIDC of AA in wheat and sorghum from hatching to the end of growth cycle of broilers. These results suggest that the age effect on AA digestibility is variable depending on the grain type and specific AA. The correction of apparent AA digestibility values using age-specific EAA flows resulted in substantial differences in SIDC at different ages. Because the use of a single EAA value for birds of different ages might underestimate the SIDC in early life and overestimate in older birds, application of age-specific EAA values for standardisation should be considered to improve the precision of feed formulations.

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Using Network Data in the New Zealand Poultry Industry: Promises, Pitfalls, and Future Prospects

Sabrina S. Greening and M. Carolyn Gates

INTRODUCTION

Understanding how an infectious disease spreads through a population is a fundamental step in developing more effective surveillance and control strategies. In recent years, social network analysis (SNA) has become a popular framework for characterising the complex and heterogeneous contact structures inherent in host populations with network models providing valuable insight into the mechanisms of disease transmission and disease transmission dynamics. However, efforts to construct realistic network models are often hindered by a lack of detailed demographic information and contact data.

In New Zealand, attempts have been made to characterise the contact network within the commercial poultry industry (Lockhart et al., 2010) and to use the underlying contact structure to inform a network-based simulation model for *Campylobacter* (Greening, 2020). However, both of these studies highlighted that the current systems used to capture data on commercial poultry populations in New Zealand are inadequate for using network-based approaches to infer disease transmission dynamics. An additional challenge is that many households across New Zealand also keep a small number of non-commercial poultry (*i.e.,* backyard poultry), but there is currently no national organisation that represents non-commercial producers and take responsibility for collecting population-based data. Consequently, little is currently known about the demographics, management, and health status of backyard poultry making it difficult to include them in any network-based models or disease risk estimates.

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This paper briefly explores the use of network-based simulation models in infectious disease epidemiology before discussing how network data could be used in New Zealand to study disease transmission in both commercial and non-commercial poultry populations, and how the current information systems could be improved to ensure the data collected supports network-based approaches.

Population contact networks - A brief history

The use of infectious disease models in epidemiology has a rich history (Brauer, 2017). Compartmental models, such as a Susceptible–Infectious–Removed (SIR) model, have a long history of being used to describe the transmission dynamics of a disease within a population, with the earliest mathematical models depicting the work of Daniel Bernoulli (1700- 1782) on the inoculation of smallpox (Bernoulli, 1760). However, it is widely recognised that one of the major limitations in many of these models is the simplifying assumption of homogeneous-mixing (Keeling et al., 2008). This assumption that all individuals within the population mix both uniformly and randomly overlooks how heterogeneities in the host population contact structure can significantly shape population-level disease dynamics (Anderson and May, 1992). Fast forward to today and there are now numerous methods capable of incorporating these heterogeneities into epidemiological models including several modifications of the long-standing SIR compartmental model (Tolles and Luong, 2020) as well as many network-based approaches which in recent years have grown in popularity (Keeling and Eames, 2005; Craig et al., 2020).

Basic contact networks are generated with a set of elements, often referred to as nodes, vertices, or actors, which represent the unit of interest, and edges or contacts to show the links between them (Figure 1). For example, in infectious disease studies, nodes often represent an individual (*i.e.*, a human or an animal) or a larger epidemiological unit, (*i.e.*, a hospital or a farm),, which are connected to other nodes via different contact pathways that are known to be important for disease transmission such as the transfer of a patient between two hospitals or the movement of an animal between two farms. The structure of a network can be described using a number of analytical approaches which fall within the scope of SNA (Croft et al., 2008; Farine and Whitehead, 2015). In infectious disease research, this includes a large assortment of individual-level and population-level network metrics that are associated with disease transmission dynamics. For example, measures of node centrality such as node degree, node closeness, and node betweenness, help determine the importance of each individual node in a network. In comparison, measures of cohesion such as network density, average path length and the clustering coefficient, can be used to determine the level of connectivity over the entire network, allowing the network resilience to be assessed by removing individual nodes or edges. These measures offer a comparative way to summarise the structure of contact networks and can be manipulated in network-based simulation models to understand the impact of heterogeneities in the host population contact structure on disease transmission dynamics (Shirley and Rushton, 2005; Gates and Woolhouse, 2015).

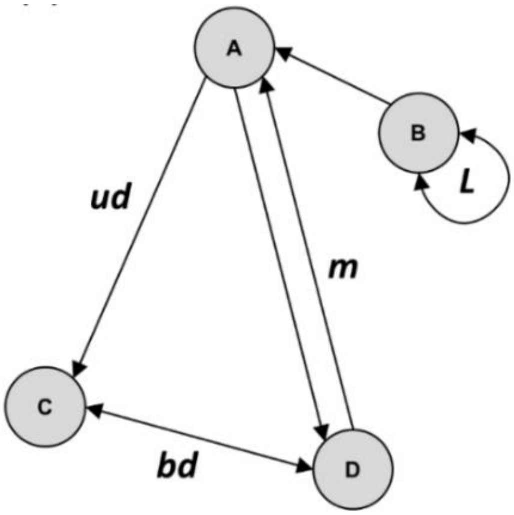

Figure 1 (left). A simple contact network showing a set of nodes otherwise known as vertices or actors (A, B, C and, D) connected by multiple edges that represent a different relationship between each node including a unidirectional edge (ud), multiple edges (m), bidirectional edges (bd) and loops (L).

Network simulation models

Broadly, network models can be divided into two categories: data-driven network models or synthetic network models. The difference being, data-driven models use the characteristics in an observed network to construct a model with matching properties, while synthetic models stochastically simulate entire networks based on a minimum set of rules which can then be used to study the influence of different network properties on disease transmission. For many populations, synthetic network models remain the only option due to a lack of accurate, up-to-date contact data.

Nevertheless, in many cases even when using a synthetic network, network models have been shown to outperform more traditional compartmental models. For example, in a study by Schley and colleagues (2012), a range of epidemiological models, including both network-based models and compartmental models were compared to determine which models performed best in capturing real-world outbreak data. Results from the study showed that the observed heterogeneity of contacts within the population was best captured by full network simulations which were shown to successfully reproduce the key features of the outbreak such as the epidemic size (Schley et al., 2012). Similar to the study by Schley and colleagues (2012), it is common practice to validate network models, both data-driven and synthetic, using disease data from an observed outbreak (García Álvarez et al., 2011). However, for many diseases this data is lacking particularly if the disease dynamics are unknown or if the disease can be transmitted across multiple host species making it difficult to validate network models.

Network models in poultry populations

Multi-host transmission is a concern for many of the economically important diseases in the poultry industry, which in part may explain why network-based approaches in poultry populations have largely been limited to the use of SNA to identify patterns of live bird movement that might influence the spread of avian influenza (AI) albeit at different spatial and temporal resolutions (Dent et al., 2008; Fiebig et al., 2009; Poolkhet et al., 2013; Molia et al., 2016; Kurscheid et al., 2017; Sun et al., 2018). These studies, although limited in their approaches, have highlighted important issues to consider when collecting data for network analysis in poultry populations. For example, in a study by Nickbakhsh and colleagues (2011), significantly different farm connectivity patterns were found across the British poultry industry when network estimates incorporated demographic data provided within the Great Britain Poultry Register (GBPR) in comparison to estimates that only incorporated data provided within the Poultry Network Database (PND) that only targets larger poultry premises. These results show that while targeted sampling can capture the characteristics of more vulnerable sectors of a population, it can also bias the picture of population-level disease risk (Nickbakhsh et al., 2011). It is also widely recognized that most poultry data systems fail to capture information on non-commercial or “backyard” producers (i.e., individuals who keep a small number of animals for personal consumption or as a hobby), adding further bias to risk estimates.

Within the New Zealand poultry industry, SNA analysis has been used to describe contact patterns between commercial poultry producers using responses from an industry-wide survey questionnaire (Lockhart et al., 2010). Results from this study suggest that the commercial poultry network can be characterised by a small number of network hubs that are responsible for providing goods and services to a large number of producers. A smaller number of intermediary enterprises were also identified and were shown in many cases to act as bridges between isolated hubs suggesting that they would likely be influential in determining how quickly a disease might spread through the industry. In addition to the commercial poultry network, SNA analysis has also been completed on backyard poultry sales data from the online auction site TradeMe® (Greening et al., 2021). Results from this study showed a highly active backyard trade network with the potential to contribute significantly to the spread of disease across New Zealand. However, despite the contribution of these networks to our understanding of the risk landscape in New Zealand poultry populations, both studies have also shown that for current network-based approaches to continue to develop, significant improvements are needed in the collection and maintenance of demographic and contact data for both commercial and non-commercial poultry populations.

The future of network modelling in the New Zealand poultry industry

Currently, in the New Zealand poultry industry, there are a small number of population-based databases that have been created to meet the needs of different organisations such as FarmsOnline maintained by the Ministry for Primary Industries (MPI) and Agribase hosted by AsureQuality. For commercial poultry producers with over 99 birds, there is also a requirement to register their flock with the industry governing bodies, this is the Egg Producers' Federation (EPF) for layer flocks and the Poultry Industry Association of New Zealand (PIANZ) for broiler flocks. Registered producers are regulated by 4 food-related laws (i.e., the Agricultural Compound and Veterinary Medicines Act 1997, the Animal Products Act 1999, the Food Act 2014, and the Animal Welfare Act 1999) that ensure they meet regulatory requirements for MPI including Risk Management Plans (RMPs) and Whole Flock Health Schemes (WFHSs). However, none of these systems single-handedly capture the relevant contact information needed to construct the population contact network. Furthermore, due to the different structural properties between each database and the level at which data is collected (i.e., individual flock data versus farm data or producer data), it is often difficult to integrate the data captured across the databases (Jewell et al., 2016).

In addition to commercial producers, registered with either PIANZ or EPF, there are also semi-commercial poultry producers who are not required to register their flock but still have some commercial value. These producers will generally have less than 99 birds and are able to sell products in very localised settings such as farmer markets, or directly from the farm door. These smaller independent producers may also group together to form part of a larger cooperative group whereby they sell their product under one name. However, due to the lack of regulation within this sector, their exact number remains unknown. Similarly, the number of non-commercial backyard flocks in New Zealand is uncertain, and even though many of the current data initiatives are voluntary for semi-commercial and backyard producers, many have struggled to achieve good uptake for reasons including the lack of trust in government agencies and failure to provide appropriate incentives to motivate participation.

Looking at some of the limitations discussed above in the current databases and the challenges faced in capturing population data for both commercial and non-commercial poultry populations in New Zealand, it is clear that more needs to be done if network-based approaches are to form part of the epidemiological toolkit. This includes a need for evaluating the current data captured on commercial poultry producers to ensure it is not only meaningful and serves a purpose, but the correct systems are also in place to keep it up-to-date. In addition, it will be important for New Zealand to develop more proactive and innovative methods for engaging both semi-commercial and backyard producers in order to be able to fully characterise disease risk within the poultry industry.

Conclusions

The use of network-based approaches in the study of infectious diseases has provided valuable insight into how population contact structures can influence the spread of diseases, In particular, network modelling can be used as a tool to test hypotheses on the mechanisms of disease transmission and test disease control strategies. However, in order to construct a network model, reliable up-to-date data is needed on both the population demographics and contact pattern. In the New Zealand poultry industry, the collection of this data often relies on information collected from producer surveys which have varying and often low response rates. To create more opportunities for network modelling in the future, careful consideration is needed on how to develop database systems that engage both commercial and non-commercial producers.

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NZ Meat Chicken Industry – the Early Years: 1958 to 1978

John McBride

"What came first, the chicken or the egg?" This question is the bane of anyone involved in the poultry industry generally, but in this country, we may have an answer! It could be said that New Zealand's chicken meat industry began when the explorer James Cook released some chickens onto both the North and South Islands in the year 1773. It is assumed that egg production was the intended purpose of the birds' lifestyle, but it would be obvious that the food value of the carcase would also be good for barter and sale purposes.

My own involvement here did not start until I joined Tegel Foods' predecessor General Foods Poultry in 1973, but I was fortunate to begin my poultry career in the UK in 1958, where I became involved with Dungannon Park Limited, now known as Moy Park Limited, one of the largest chicken meat producers in Europe. This gave me familiarity with early methods of broiler production, similar to those developing here. I will first be commenting on the pre-1958 scene, and then summarise some of the key changes occurring in the developing broiler industry during the following twenty years. My presentation is via a PowerPoint presentation, which will highlight just a few of the key listings in my paper, along with some personal memories of those early years. I pay tribute to my friends and colleagues who contributed so much in my search for information, and apologise for the inability to reproduce much of the supplied technical data. I understand most of the suppliers are agreeable for any statistical figures I hold to be forwarded to PIANZ to hold for anyone else investigating a similar scenario.

Research into the early days of the New Zealand chicken meat industry very quickly reveals that such disciplines as breeding techniques, incubation, nutrition, disease control, housing and equipment were developing in common for both layer and meat breeds. However, differing needs

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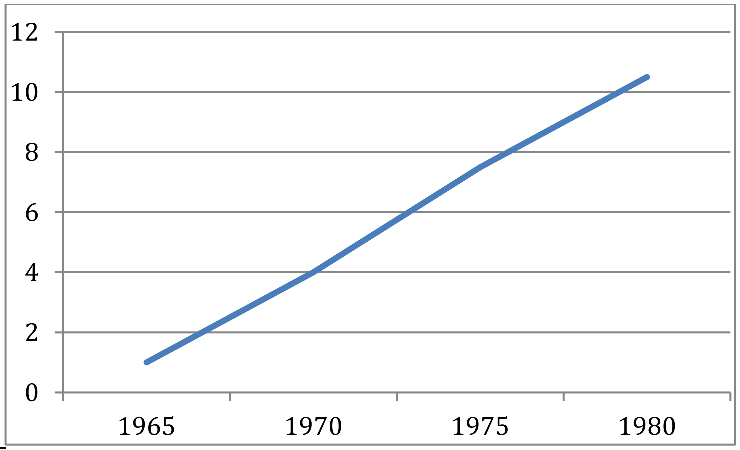
were soon identified for the new special breeds of chicken being bred and selected for higher performance in both eggs and meat, and this led to a more distinct pathway for each particular type. Prior to 1958 the depopulation of egg laying flocks supplied the majority of poultry meat to consumers, although a smaller proportion would also come from ducks, geese and turkeys. Around this time the ratio of egg layer numbers to human population sufficient to supply the demand for eggs became established at around 1:1, thus explaining why it was only an annual treat for many people to eat a chicken.

TOTAL NZ CHICKEN MEAT CONSUMPTION

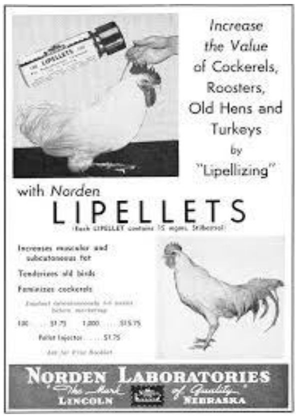
Kg per person 1965 TO 1980



Increased consumption from then on was entirely due to the advent of the “broiler” chicken, with its faster growth rate, lower FCR and good liveability, coupled with the new supermarkets and fastfood outlets.

The initial stimulus for a more succulent meal than an old-depleted layer hen came from American forces stationed here during the Second World War, who brought with them a demand for what they called “broiler” chickens, which were already being produced in their home country as a new tasty type of product. Attempts to meet the demand here for a more succulent chicken got underway in the 1950’s, where the off-sex males from laying stock day olds were being fed a fairly basic fattening diet, but this was only partly effective in the case of the heavier breeds, such as Light Sussex and Australorp, and their crosses with lighter breeds like the Leghorns.

The practice of caponising to tenderise the meat, whereby a pellet of female hormone was inserted under the skin at the back of the head, persisted until it was banned in the early 1960’s.



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the Value
of Cockerels,
Roosters,
Old Hens and
Turkeys
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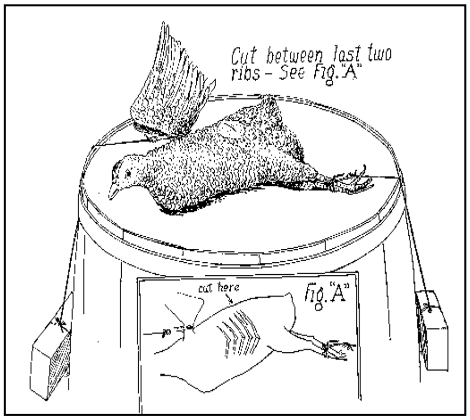
"The Mark of Quality"
LINCOLN NEBRASKA

The method of surgical caponising understandably never really became popular.
It is these memories which persist in the minds of the public today, and necessitate the risible labels on chicken products claiming, “No Added Hormones”!



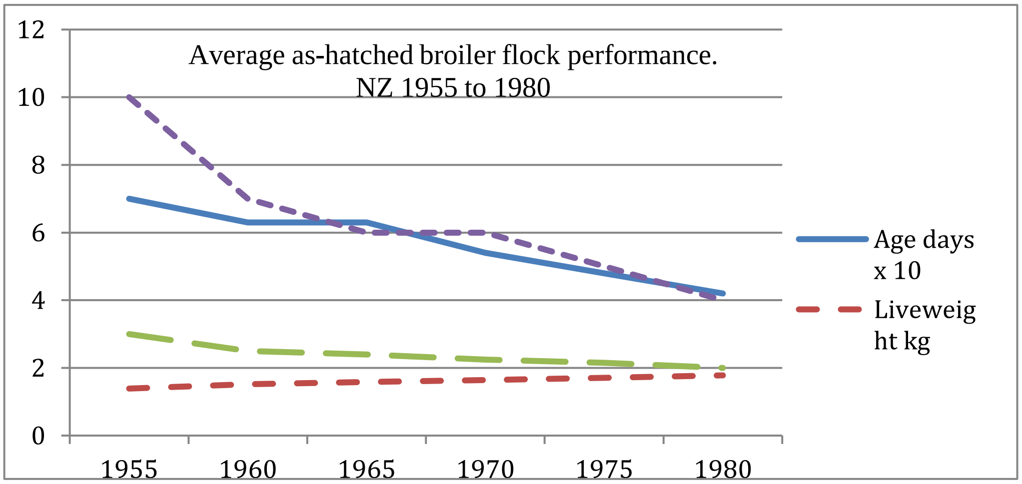
In the 1930’s Henry Wallace and the Pioneer Hi-Bred Corn Company in the USA had developed a plant breeding programme which utilised the technique of cross- breeding lines of closely in-bred strains of corn, i.e., hybridisation, which resulted in progeny surpassing the overall performance of their ‘parent’ sources. Eventually applying the same procedures to poultry breeding, the company then was able to bring about the same results in the form of the Hyline layer and the Hybro broiler in the 1950’s.

Demand for knowledge about the new ‘broiler’ bird type was met through visits made by developers to Australia, the USA and UK, and speakers brought to seminars in New Zealand, along with the establishment of a team of Ministry of Agriculture Poultry Advisors. Company newsletters like PCL’s ‘Advance Poultry’ disseminated new ideas on broiler feeding, and management manuals were being produced to ensure some standardisation of production methods.

The establishment of the New Zealand branch of the WPSA in 1960 started its progressive work here in education, industry organisation and research, encouraging exchange visits of people with Australia to learn of new ideas. The first Australasian Poultry Science Convention was held in Auckland in 1972, and subsequent seminars at Lincoln and Massey Universities included top speakers from around the world. Massey especially was quick to include poultry as a major part of its agriculture programme, and became instrumental in research and extension work. The Poultry Research Centre starting there before being brought into the Monogastric Research Centre, which is now internationally recognised through the hard work of Professor Ravi Ravindran and Dr Reza Abdollahi.

New Zealand was soon able to "cash in" on what had been happening overseas for some time, leapfrogging the experimental challenges of many early trial efforts, especially in the fields of nutrition and stock housing and management. The country's immigration policy encouraged the importation of qualified and experienced people, mainly from the UK, who brought with them knowledge of modern broiler production methods which had been going there since the mid 1950's.

Around 1958 the industry here was in what is known as an "horizontal" state, where breeders and hatcheries produced mainly egg laying stock, but also sold some off sex chicks to independent farms for fattening. These then sent the finished bird to a processing plant already established for dealing with depleted layers, and which could market the whole birds directly, or use other retail outlets. Housing, feed and equipment were built or bought independently where available.



In the 1960's the rapid growth of the broiler side over the next few years resulted in its proponents driving the development of design and techniques for all aspects of poultry production, and it became the incentive in the early days for bigger and better facilities and procedures in all disciplines, with performance similar or better than other countries.

A summary of key industry happenings 1958 to 1978

Breeding.

- Restrictions on the import of poultry breeding stock to protect the country from exotic diseases delayed access to overseas hybrid stock until 1970's.

- Local breeders crossed meat type breeds like White Rock and Indian Game with laying stock to develop a more meaty finish.
- In 1968 grandparent stock from Australia coupled with expertise from both A. A. Tegel Pty Ltd and the Scientific Poultry Breeders resulted in the Silver Star and Tegel Meat broilers being produced.
- The introduction of a Marek's vaccine in the 1970's and the relaxation of import restrictions allowed for the importation of Cobb and Ross stock from overseas, starting the industry on a production programme similar to the rest of the international scene.

Housing/environment.

- Early growing sheds were small with dirt floors, electric heaters, tube feeders and leaky drinkers, but by 1968 shedding was appearing as a more controlled environment type.
- Lighting was continuous, with two hours red alternating with two hours blue to combat feather picking. Rapid improvements came with various types of controlled environment houses, cement floors and shaving for litter. No standby generators until the 1970's.
- Progressive changes occurred in ventilation from roof extract or positive pressure to more controllable side and cross air flow. Significant electrical savings made in the 1970's with a move from incandescent to fluorescent lamps, and intermittent lighting programmes.
- Heating for brooding moved up through spot gas units to whole house blowers, diesel or gas, and part shed curtains.
- Special egg handling and processing equipment developed quickly for breeding farms.

Hatching.

- Hatching of increasingly large numbers of day olds speeded up the installation of the larger cabinet type machines, with automatic turning, easier setting and transfer equipment.
- Conveyor systems to ease movement of chicks for sexing and sorting.
- New sex-linked features assisted in sorting breeders and eventually the broiler chicks as well.
- Fumigation and aerosol procedures introduced.
- Special module systems used for egg collection and chick delivery.

Nutrition and feeding.

- Restrictions on the importation of feed ingredients initially limited the potential of new meat type diets. Challenges in making the most of local grains and minimising the high and variable levels of salt, calcium and phosphorous in the main protein source meat meal.
- Establishment of special analytical quality control laboratories.
- Use of analogue computers in the 1970's gave flexibility to formulation and reduced feeding costs.
- The introduction of pelleting in feed mills improved feed conversion efficiency, but initially caused some feather picking in growing breeders. The associated effect of increased feed intake and the heat treatment on bacterial control benefitted the broilers with their large appetites and high floor stocking densities.
- Registration of premix products in 1972 raised the overall standard of nutrition necessary to meet the fast-growing broiler and the restricted feed allowances of the broiler breeder.
- Both meat birds and layers were also fed diets with a large range of antimicrobial products to enhance performance and as preventatives in the absence of knowing enough about the increased number of disease conditions associated with intensive livestock housing.
- Many antibiotics were discontinued in the late 1960's and 70's with broilers mainly being left to battle with the public's view of their effect on human antibiotic resistance.
- The replacement of 80lb paper sacks by bulk delivery and storage in the 1960's significantly reduced labour requirements on the farms, although hand feeding was only superseded by automatic feeders in the early 1970's.
- Drinking water analysis and treatment introduced.

Disease.

- Major prevention work in the 1950's and 60's was aimed at eradicating Salmonella pullorum, which carried through the breeding and hatching process was decimating newly placed day olds.
- Broiler breeders, as egg producers, were susceptible to Mareks, ILT, IB and later ED76, and until vaccines were available for these in the 1970's performance and losses were high in both local and Australian produced stock. (See Addendum for vaccines and health products introduced during this period)

- Both broilers and breeders were susceptible to coccidiosis, the early in-feed chemical preventatives giving very poor control, as resistance developed quickly.
- The introduction of the ionophores in the 1970's revolutionised the whole poultry industry.
- Mg and Ms detection and eradication was intensified in the 1960's, with the heating of hatching eggs proving very effective.
- 1970 Chris Tempest, the first NZ veterinarian to specialise in poultry, enters the industry.

Processing.

- Early processing involved manual work at all stations: killing and bleeding cones, scald tanks (some dry plucking), rotary plucking machines, and manual evisceration, although freezers were available for storage and shipping.
- The main effect of rapidly increasing daily kill numbers of broilers was the implementation of faster and labour-saving methods of moving birds through the plant, and development of automatic machinery.
- The superior carcase finish required dictated much effort in standardising the hanging, killing, bleeding, scalding and plucking techniques, along with improved chilling, wrapping and freezing.
- The continuous chain system was a main contributor to a much lower cost of production, resulting in a supposedly luxury meat product being sold increasingly cheaply, and sales soaring.
- Despite this, in the 1960s the industry experienced oversupply issues, price wars and significant instability associated with this.
- Up until the mid 1970's over 90% of the broilers were being processed and sold as frozen.
- The introduction of fresh cut portions for the fast-food outlets quickly led to selective changes in the sizes of birds required each day, and the introduction of manual carcase cut up teams.

Regulations and controls.

- The 1960's saw the introduction of many regulations governing the working of farms and poultry operations generally, but it would be some time before more specific poultry controls would evolve in the 1980's.

- Regarding welfare, the 1884 the Cruelty to Animals Act, eventually involving the SPCA, was to stay in force until the Animal Protection Act in 1960, Both tended to cater almost completely for the large livestock industry, and included Ministry of Agriculture inspectors as well as the SPCA.
- Changes in handling day olds, birds housed, catching, transporting and processing caused by intensification of broiler production were mainly under procedures supervised by the industry itself.
- Up until the end of the 1970's these would include trimming of combs, wings, spurs and toes for some breeding day olds, and beaks for some growing breeders.
- All catching for processing plants up until the mid 1970's involved catching and carrying birds to fixed cages on a truck, or putting in crates to be carried and loaded outside.
- This work, coupled with removing the birds at the plant required careful supervision, and abuse did occur.
- Continuing triaaling was carried out on stocking densities to determine an optimum, which changed frequently with advances made in growth rates.

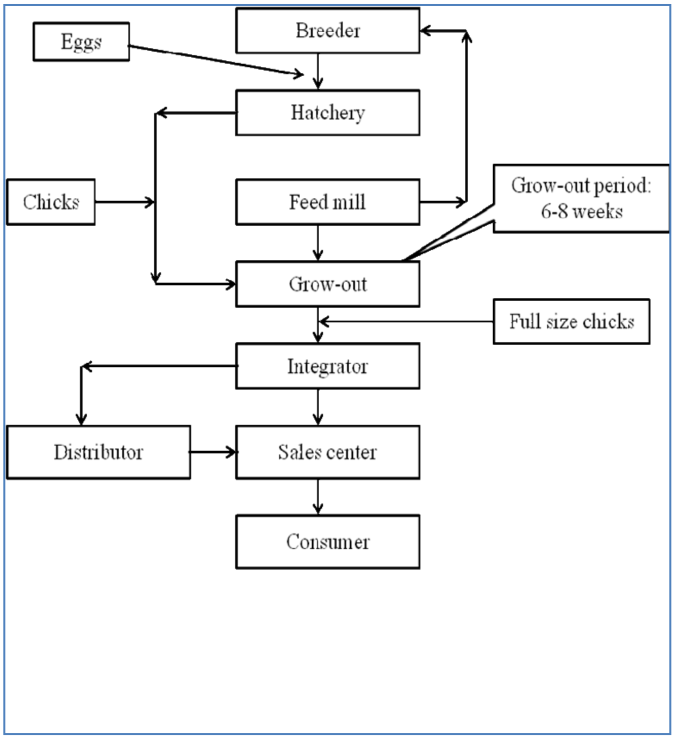
Planning and communications.

- Early programme planning and record keeping were entirely in written or printed form, with the first portable computer not arriving until the 1980's, followed by portable phones and e-mail later still.
- Telex was the first communication tool in the 1970's, followed shortly by the fax system.

Production development.

- The 1960's saw the establishment of an industry branch dedicated specifically to producing a broiler meat chicken.
- This coincided with the new language of "agri-business" and "vertical integration". Both these concepts suited the ease with which a single livestock product, rapidly reproducible, could be linked directly with all the contributing resources required to breed, reproduce, grow, process and market it.

- By the mid-1970s, the industry had evolved into its modern state with the implementation of nutritional discoveries, disease eradication programs, genetic improvements through traditional breeding, and mechanization and automation technologies.
- The first moves to vertical integration were made by the hatcheries, associated breeders, growers and processing plants, to ensure a steady supply of a consistent product.
- This was quickly followed by feed mills, which along with the hatcheries could not afford to wait too long for their invoices to be paid by growers at the end of their runs, and were able to have them settled monthly by the processor.
- Initially these ‘collectives’ were linked by franchises and agreements, sometimes by shared ownerships, but they eventually would consolidate into a main trading identity under one administration.
- Feed mills and processing plants were also willing to finance growers, and to purchase or subsidise housing and equipment for the further growth of hatcheries and farms.
- In New Zealand there was a gradual change to this form of ‘merging’ during the 1960’s in a number of regions, some by the grouping of existing production units together, and others by their individual efforts to build each sector progressively themselves.



This is the "vertically integrated" structure developing chicken meat companies were aiming for, where all the production resources, administration, and often the sales outlets as well, were linked together in such a way as to remove or minimise the involvement of a "middleman". Two NZ regional organisations managed to achieve this in quite differing ways to achieve their present multi-functional production outfits.

Region 1: Manawatu/Wellington. Wescon Industries and Golden Coast Poultry

In 1962, Jack Siddall of Fairfield Hatcheries Levin and Graham Walker, a poultry processor from Te Horo on the Kapiti (Golden Coast) attended the WPSA conference in Sydney and decided the way forward was purpose bred meat chickens. In 1967 Fairfield Hatcheries Levin, Ohinewai Hatchery in the Waikato, Williams from Christchurch and Petterson of Invercargill, combined to set up a new hatchery and breeding farm near Levin. Subsequently Graham Walker, Golden Coast Poultry, was contracted to take the birds at his end of lay processing plane at Te Horo, and Don Evans to supply feed from the Levin Feed Mill. Breeding stock was provided from the nucleus of Australorp and Leghorn strains already in Levin plus a variety of coloured meat type strains until 1968, when Australia provided the first grandparent stock in the form of a Dominant type of White Plymouth Rock male line, resulting in the Silver Star broiler.

By the 1970's company parent stock and contracted growing farms were established along the coastal areas, and in 1974 Wescon Industries was formed, embracing Veterinary Chemicals, Fairfield Hatcheries, Speyside Poultry Farm and Hatchery, and Golden Coast Poultry (feed supply and processing). Silver Star meat chicks were distributed across New Zealand and the Pacific Islands. In the mid-1970's the company set up some fast food "Chicken Spot" stores in the Wellington area, in competition with KFC. In 1978 Wescon was the largest wholly privately owned poultry Company in the country, producing and processing around 70,000 birds per week.

Region 2: Taranaki. Broomham Chicken Company, General Foods Corp. and Tegel Foods.

- 1958 Bruce Burmester starts a small private meat chicken growing operation in Bell Block, Taranaki. Day olds were supplied from Salisbury's Hatchery in Upper Hutt, and by 1959 Bruce had built a 4000 bird shed, copied by some local dairy farmers. Product sold through Hellaby's in Auckland.
- 1961 Graham Salisbury and Ted Chambers join with Bruce to form Broomham Chicken Company, . Larger processing facilities built, but still manually operated, although freezers were included. Feed contracted from D. H. Brown's feed mill at Tariki. Processing 8000 birds per week.
- 1964 Processing facilities enlarged and largely automated, and installation of a glycol pre-freeze unit, to give enhanced skin finishes.. Growing facilities extended resulting in 20 sheds holding 15,000 birds each.
- 1965/68 Company hatchery and breeding farms built to allow independence of chick supply. Australian sourced Tegel TM4 and5 breeders to supply a more standard broiler chick via Salisbury's.
- Feed supply contracted now to the new PCL's New Plymouth mill.
- Establishment of Bell Block Engineering on site, which developed its own designs for farm feeders, strip drinkers, nest boxes, electric heaters, and processing equipment.
- Agreement with Refrigerated Freight Lines to transport product to outlets mainly in Auckland, as backloads to other frozen foods. Products were Tenderly Yours and Red Chick Chicken.
- 1966 The Broomham Chick Company and Salisbury's bought out by the General Foods Corporation, including the Tegel franchise. Both Bruce and Graham left the now large organization within a couple of years, to pursue activities more suited to their individual and personal natures.
- 1967 General Foods Corporation Poultry Division formed, and the NRM feed mill built near the Bell Block processing plant to supply feed for all types of stock, but soon took over the contract from PCL to then supply only General Foods feed needs..

- 1968 Osflo Spreading Industries contracted to supply wood shavings for litter and dispose of used litter as fertilizer.
- !970 A. A. Tegel Pty Ltd sets up a quarantine and breeding farm in the area to supply broiler TM 70 meat parent stock to General Foods.
- 1971 General Foods becomes a joint venture with KFC international, leading to a great boost in demand for cut portions of chicken meat.
- 1974 General Foods Corporation becomes a joint venture with Amatil Australia, and changes name to General Foods Poultry.
- 1970's General Foods purchases operations in both Auckland and Christchurch.
- 1975 Major expansion of all production facilities in the New Plymouth area.
- 1977 Erection of a byproducts plant to handle processing offal.
- 1975 Ross Poultry (NZ) founded and Ross stock replaces the Tegel breed, but permission obtained from A.A. Tegel Pty Australia to retain the **"Tegel"** name for the company's products.
- 1978 Company's New Plymouth branch processing 125,000 birds per week, and celebrates its 100,000,000th chicken produced.
- 1980's General Foods Poultry continued to incorporate chicken operations in Manawatu, Christchurch and Auckland, changing name to **Tegel Foods Poultry Limited.**
- From 1978 onwards the further rapid improvements in technology have kept the price of chicken meat well below other meats, and consumption continues to rise, despite the challenges ahead.

Performance yet to come – 1970+					
	1970	**2005**	**2010**	**2015**	**2020**
LW (kg @ 37 days)	0.90	2.35	2.50	2.60	2.70
FCR (2.0 kg LW)	3.20	1.52	1.47	1.42	1.35
Ave Kill Weight (kg)	1.50	2.15	2.50	2.55	2.60
Age @ kill (days)	60.00	35.00	36.00	36.00	37.00
ADWG (gm)	15.00	67.00	69.50	72.20	73.00
Liveability (%)	90.00	95.00	96.00	97.00	98.00

Addendum:

Poultry Health Products / Years of Introduction:

- 1967: Introduction of a large range of poultry health feed additives and pharmaceuticals from Salisbury Laboratories USA:
    - Coccidiostats: Novastat-90, Novastat-W, 3-Nitro, 3- Nitro-W, Sulquin 6-50, Tinostat,
    - Histomonostat: Histostat,
    - Growth promoters: Bactofac, Zinc Bacitracin
- Early 1970's
    - Sodium Sulfathiazole,
    - Vitamins & Electroytes for Poultry,
    - Wormers: Wazine Soluble, Wormal Tablets,
    - Manage & Lice Control, Malathion Dry Insecticide,
    - Polystat, Avi-Tab, Salfuride, Medic-Aid 2-50,
- 15 January 1970: AE-Vac a glycerinated avian encephalitis vaccine (first live virus vaccine to be imported into New Zealand).
- Early 1970's: A Duck Embryo Marek's Vaccine (Merck Sharpe Dome – discontinued)
- 1972: Registration of vitamin and mineral premixes.
- 1973: Erythromycin Soluble,
- 1974 – Pullorum Stained Antigen, Mycoplasma synoviae Antigen, Mycoplasma gallisepticum Antigen and Mycoplasma meleagridis Antigen
- 1974 onwards assist Ministry of Agriculture officers for salmonella pullorum re export.
- 1975 - Chick-N-Pox and Poxine – live virus fowl pox vaccines
- 1976 - Laryngo Vac – live virus ILT vaccine
- 1977 – Furazolidine Supplement
- 1977 – Furaltadone Soluble
- 1978 – MD Vac Lyophilized Live virus Marek's Disease vaccine

(Courtesy of Kent Deitemeyer, Pacific Vet).

Acknowledgements of information sources and support:

"What Came First?" (Including the Tegel Chicken story) Book by Graham Salisbury. Permission from Bryan and Roy Salisbury.

"The Pride of Poultrymen" A 50 Year History of Poultrymen's Co-operative Ltd. Supplied by, and permission from, Alan Gibbins. Previously Director, PCL.

"Personal Reminiscences" Bruce Burmester. Permission from Beau Burmester, New Plymouth.

Keith Jackson. Previously Director, Tegel Foods Ltd

Sue Clarke. Previously Livestock Manager, Golden Coast.

Roger Winter. Previously Livestock Manager, Tegel Foods. Christchurch.

Kent Deitemeyer. Pacific Vet.

Alan Gibbins. WPSA.

Michael Brooks. PIANZ

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Abbey Mathews. Aviagen (NZ) Ltd.

Brian Jones. Previously veterinarian, Inghams Enterprises (NZ) Pty.

Mike Cundy. Cundy Consulting td. Previously nutritionist PCL.

Many Tegel Foods growers and staff.

Emergence of *Salmonella Enteritidis* in New Zealand Poultry 2021

Kerry Mulqueen

The emergence of a Salmonella Enteritidis (SE) in New Zealand from a poultry source has been traced back to late 2019. There had been no reported SE isolations related to poultry in New Zealand reported before this incursion. The presence of the Poultry SE was first noted in human isolates in the Auckland City region with an outbreak associated with a restaurant and isolations in human patients. The ability of Health authorities to investigate SE was overtaken by the Covid response that was ongoing in early 2020.

Whole genome sequencing (WGS) of this SE has shown this to be a ST 11 with its nearest relation sequenced in Turkey. Phage typing has shown this be a phage type 8.

During 2020 there was a steady reporting of this SE in human isolates and then in February 2021 SE was detected in poultry via the National Microbiological Data base (NMD) testing. The NMD is a government regulated testing scheme that samples meats within NZ at meat processing plants.

Subsequent investigation and tracing resulted in two egg farms and nine broiler sheds, and some breeder sheds being depopulated and products not able to enter the food chain.

The human SE isolations of the poultry strain in the first half of 2021 was in the thirties and then only two isolations between June and December 2021. In Jan 2022 there has been four suspect Poultry SE strain human cases.

Poultry Industry Association New Zealand.
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The investigation was based around a chick borne source of SE and the Government tested 24-layer farms that supply 80% of the table eggs in NZ and these returned negative SE results. Broiler testing pre-processing has been a widespread practice for some processors since 2000.

As a result, due to the presence of SE in poultry there is now a regulated SE control scheme which commenced on the 6th of October 2021 and will run for a period of 6 months renewable for another six months and then reviewed. The scheme will renew and run till6th October 2022.

This will require testing on all breeder farms, hatcheries, rearing farms, broiler farms, and egg layer farms with more than one hundred hens, processors of chicken mat and secondary processors of eggs for Salmonella. Labs testing for Salmonella must report all SE isolates and they must be identified to a determine if they are SE.

As of Jan 2020, 26% of RMP registered layer farms have been sampled and tested, 100% of hatcheries, breeders and broilers are testing.

At present MPI are developing a scheme that will run post Oct 6th 2022 and is engaging with the Poultry Industry in the development of this scheme.

Control of *Campylobacter* in Poultry On-Farm and During Processing

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Campylobacteriosis is the most frequently notified enteric disease in New Zealand. Biosecurity interventions and changes to slaughter and processing by the poultry industry, together with the implementation of New Zealand Food Safety Authority *Campylobacter* Risk Management Strategy (the parent agency is now the Ministry for Primary Industries, MPI), led to a ~50% reduction in notifications of campylobacteriosis during the years 2006-2008. Annual notifications have declined more gradually since 2008 despite an increasing poultry consumption per capita. Nonetheless, poultry remains an important source for human infection by *Campylobacter*. The Poultry Industry Association of New Zealand (PIANZ) has been working alongside MPI to further reduce *Campylobacter* levels in poultry, and have commissioned two major projects toward this goal through the New Zealand Food Safety Science and Research Centre.

The first study involved a longitudinal broiler farm microbiological survey, designed to provide a better understanding of on-farm sources for *Campylobacter* infection of New Zealand broiler flocks. The survey followed a single broiler flock from the parent flock, through hatching, the entire life of the flock, to processing. The survey was timed to coincide with peak *Campylobacter* seasonal prevalence and took place during October-December 2019. Multiple samples were taken of

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[1] Institute of Environmental Science and Research Ltd (ESR), New Zealand.

[2] New Zealand Food Safety Science and Research Centre (ESR and Massey University are collaborators; PIANZ are members).

[3] Biggs Food Consultancy Ltd, New Zealand.

[4] Poultry Industry Association of New Zealand.

[5] Massey University, New Zealand.

[6] Tegel Foods, New Zealand.

[7] New Zealand Food Safety, Ministry for Primary Industries, New Zealand.

potential *Campylobacter* sources (e.g. wild birds, the farm and shed environment, the previous flock inhabiting the shed, another flock of the same age on the same farm, and the breeder flock), potential vectors for *Campylobacter* ingress into the broiler shed (e.g. farm workers, catching crews and equipment, rodents and insects), and the broiler flock under investigation (cloacal swabs, caecal contents and carcass rinsates).

Of the 738 samples tested, 200 (27%) tested positive for *Campylobacter* by cultural isolation. The species was determined for up to four isolates per positive sample, which included 316 *C. jejuni*, 39 *C. coli* and 8 *C. lari* isolates. The previous flock in the shed tested positive for *C. jejuni*, but *Campylobacter* was not isolated from the shed following cleanout. All samples from the study flock, as well as environmental samples from inside the broiler shed, remained *Campylobacter*-negative until after the first cut; at which time, a high proportion of catcher and catching equipment samples tested positive (44% at first cut and 45% of total catcher samples). After that time (at 35 days), a high proportion of bird and shed samples (including boot, surface and drinker swabs and insect samples) tested positive for *Campylobacter*.

While *C. jejuni, C. coli* and *C. lari* were identified from environmental samples, *C. jejuni* was the only species isolated from chickens from the study shed. A total of 199 *C. jejuni* isolates were characterised by whole genome sequencing (WGS) and data were analysed to identify links between isolates from sources, vectors and study chickens. The isolates comprised seven sequence types (STs); the most abundant was ST6964 (105 isolates) which is a fluoroquinolone- and tetracycline-resistant ST and one of the most frequently isolated STs from New Zealand poultry flocks and human cases in recent years. Most isolates arising from the study flock were ST6964 (44 isolates) or ST50 (27 isolates). These closely matched 11 ST6964 and one ST50 isolate from the previous flock and isolates from an age-matched control flock on the same farm. These results indicate that there was either carry-over contamination from the previous flock, or there was a common source of *Campylobacter* that was contaminating multiple sheds and flocks.

There were six different STs among catching crew and equipment isolates. The most prevalent were ST6964 (19 isolates) and ST50 (21 isolates), many of which also closely matched chicken isolates. The close genetic match, high *Campylobacter* prevalence in catcher samples, and the timing of flock infection occurring closely following catcher presence in the shed, support the proposition that catchers and equipment might also cross-contaminate the shed and flock from prior flocks that they visited. There was no evidence for wildlife, feed, drinking-water or the shed litter as sources of the *Campylobacter* genotypes colonising the broiler flock.

A *Campylobacter*-specific metabarcoding method was developed as a complementary approach to WGS for the analysis of on-farm study samples. Metabarcoding is a culture-independent method that involves amplifying a short genetic region (the amplicon) that is present in all organisms of interest (i.e., *C. jejuni* and *C. coli*), but has a high level of sequence diversity between different *Campylobacter* species and STs. The generated amplicon is then sequenced, and sequence reads are compared against a reference database to provide a more comprehensive picture of the *Campylobacter* species and STs and their prevalence in samples. Metabarcoding allows for the detection of non-viable and viable but not culturable cells, STs that are present in low numbers in mixed populations, and slower-growing STs that might be outcompeted during culture; thereby, increasing the potential for making linkages between sources and birds.

A selection of enrichment broths from samples (prioritised by collection prior to evidence of flock colonisation) were tested using the *Campylobacter*-specific metabarcoding method. Metabarcoding results were in accordance with WGS-based results but also provided new insights. In samples from which *Campylobacter* was isolated and metabarcoding performed, metabarcoding detected most of the *Campylobacter* STs that isolation did, plus additional STs which had not been isolated. Metabarcoding detected *Campylobacter* from samples at earlier timepoints than cultural isolation, including detecting ST6964 from shed samples following clean-out and prior to the new flock placement, which had been culture-negative. However, metabarcoding does not differentiate between live and dead cells, and the *Campylobacter* detected might not have been viable. STs detected by metabarcoding from the previous flock and following cleanout were also detected in cloacal samples from chickens at 10 days old, whereas no *Campylobacter* was cultured from cloacal swabs or caeca until chickens were 35 days old. Consistent with a high *Campylobacter* prevalence and the wide range of STs isolated from catcher samples, metabarcoding detected multiple STs in these samples. Results support the utility and complementarity of this metabarcoding approach alongside WGS for future applications characterising the diversity and population structure of *Campylobacter* in experimental studies.

Taken together, this study identifies key areas where the poultry industry might focus on-farm risk management practices to reduce colonisation of broiler flocks by *Campylobacter*. These are carry-over from the previous flock and chicken catching crews and equipment. Reservoirs and vectors for *Campylobacter* contamination of flocks will vary to some degree by farm location, seasonality and housing system. Therefore, analogous longitudinal surveys on different broiler farms might identify additional relevant areas for interventions by the poultry industry, toward the goal of reducing the food safety risk for poultry consumers.

The second study involved a longitudinal study at processing facilities of the three major poultry processors in New Zealand. The objective was to evaluate and assess the efficacy of current broiler poultry processing steps and interventions in controlling *Campylobacter* numbers on poultry meat. During January and February 2021, broiler carcasses and portions were sampled at key points along primary and secondary processing chains to establish the numbers of *Campylobacter* at each point and determine the impact of processing steps on these numbers. Five rinsate samples were collected from carcasses at eight primary processing steps and from seven product types from secondary processing, at each of six sampling visits per plant. A total of 1,350 poultry rinsate samples were enumerated for *Campylobacter* spp.

The primary processing steps resulted in an average ~6-log reduction in *Campylobacter* numbers, with *Campylobacter* not detected in 76% of samples at the end of primary processing (<29 colony forming units (CFU)/carcass). The biggest reductions were between the post-inside-outside bird wash and post-spinchill (~3.5-log reduction) processing steps, followed by between pre-scald and post-scald (~1 to >2-log reduction). Data from primary processing are being used to construct quantitative risk models so that industry can estimate the effect of improvements at individual primary processing steps on the numbers of *Campylobacter* present on product.

A similar study was carried out in 2013, focusing on *Campylobacter* numbers on carcasses at the equivalent primary processing steps at one plant (secondary processing product was not tested in the 2013 study). The mean *Campylobacter* counts at the start of processing were similar between studies. However, at each subsequent processing step, *Campylobacter* numbers were lower in the 2021 study compared with the 2013 study, with approximately two-log lower numbers at the end of primary processing (~6-log reduction in 2021 and ~4-log reduction in 2013). These numbers partly reflect different detection limits between studies at the final processing step (400 CFU/sample for the 2013 study, 29 CFU/sample for the 2021 study). However, 18% of the 2013 samples from this step had no detection of *Campylobacter* (<400 CFU/sample), while all 2021 samples had <400 CFU/sample and 77% had no detection (<29 CFU/sample). Results indicate a significant improvement in pathogen control at multiple steps since 2013.

For product tested at secondary processing, *Campylobacter* numbers differed by plant. For whole bird samples, numbers were the highest from Plant F which has separate primary and secondary processing premises. Rinsates from drums had lower *Campylobacter* numbers than all other portion types. This might be because carcasses are hung by the legs during processing; thus, any cross-contamination occurring during processing would be more likely to occur below the drums. *Campylobacter* numbers were previously found to be higher on skin than meat; however, we found no consistent reduction in numbers on skinless products. Therefore, cross-contamination during secondary processing may be occurring.

These data provide a benchmark from which to compare the efficacy of future interventions in the poultry industry. The findings from both studies support the poultry industry to further improve on-farm and processing procedures to reduce *Campylobacter* prevalence and numbers on product, toward a reduced risk for consumers.

Salmonella and Control of Critical Points in Production

Elizabeth Santin[1]

INTRODUCTION

Salmonellosis is one of the major foodborne health problems worldwide. *Salmonella* is estimated to cause more than 1.2 million illnesses each year in the United States, with more than 23,000 hospitalizations and 450 deaths. *Salmonella* infections in humans most often cause gastroenteritis which can range from mild to severe; invasive infections can be severe and potentially life threatening (CDC). At the European Union, in 2019 salmonellosis was the second most reported *zoonotic* disease in the EU, affecting about 88,000 people. Of the 66,113 samples of ready-to-eat foods – foods that do not need to be cooked prior consumption – 0.3% tested positive for *Salmonella*. Of the 191,181 non-ready-to-eat samples, 1.5% were positive. Eighteen of the 26 Member States reporting on *Salmonella* control programmes in poultry populations met all the reduction targets, compared to 14 in 2018 (EFSA). The latest communication about the Salmonellosis in Oceania that I found it was The OzFoodNet annual report for 2004 published in *Communicable Diseases Intelligence* Vol 29 Issue Number 2, and it communicate 7,842 cases total por 100.000 habitants.

Despites the many different source of the food contamination in salmonella cases, contaminated eggs and meat are described as mainly causes of the Salmonella human infection. Considering the importance of salmonellosis in poultry farming and public health, information related to the epidemiology of these bacteria is relevant to understand the evolution of these microorganisms and other particularities, allowing the development of new control methodologies. The microorganism is resistant to many environmental conditions and antibiotics, so the mainly control is based in establish the systematic evaluation of critical point based in a HACCP view. During this presentation we will describe the principal points of control and practice that we can apply to

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minimize the spread of this microorganism in poultry production. The control of the foodborne disease is one of the pillars to poultry sustainability.

Salmonella **in poultry**

The genus *Salmonella* belongs to the Enterobactericeae family and is composed of *Salmonella enterica* and *Salmonella bongori* species (Brenner et al., 2000) with more than 2,600 known serotypes (Grimont and well, 2007)). Most of the pathogenic serovars of *Salmonella* spp. are part of the *Salmonella enterica* species and are commonly named based on the geographical location or species in which they were isolated. *Salmonella* serotyping is important because it allows the identification of more pathogenic serovars as well as the study of epidemiological factors that may assist in the control of these agents in poultry production (Grimont and Weill, 2007). Two of these serovars are bird specific, responsible for causing Pullorum disease (*Salmonella* Pullorum) and Fowl typhoid (*Salmonella* Gallinarum), related to the occurrence of diarrhea, septicemia and high mortality rates in the animals (Barrow and Freitas Neto, 2011).

Non-typhoidal *Salmonellas* are represented by any serotype of the genus except *S.* Pullorum and *S.* Gallinarum. Most non-typhoidal *Salmonella* serovars do not significantly affect the zootechnical performance of birds, being, sometimes, asymptomatic to the host (Gast and Beson, 1995; Muniz et al. 2015). However, they are able to colonize the intestine, can reach the bloodstream, and thus can be identified in other organs such as spleen, liver, and ovary. Non-typhoidal *Salmonella* are able to colonize the intestinal tract, contaminate chicken carcass during slaughter and cause harm to consumer health.

The most important non-typhoidal serovars of *Salmonella* are Typhimurium and Enteritidis, but serovars such as Minnesota, Infantis, Heidelberg, Senftenberg and Mbandaka were emergent isolated around the world. There are many factors that could increase the susceptibility of poultry to *Salmonella,* but as a basic understanding, the good balance between the animal microbiota and immunity play an important role on this scenario. The balanced microbiota modulate the host immune system by different way and protect against *Salmonella*. The unbalanced microbiota and host immunity relation, know as dysbiosis, cause a mucosa inflammation and it can contribute for the advantage of *Salmonella* colonization and establish a state of tolerance to the disease turning the animal in a healthier carrier of this bacteria. Indeed, Muniz et al (2015) showed that even high performance broilers can carrier *Salmonella* in their gastrointestinal tract, which increase it is risk to contaminated carcass at slaughterhouse.

The welfare of animals also affecting animal immune system and increase their susceptibility for *Salmonella* infection. Studies showed that the combination of caloric stress and infection with *Salmonella* Enteritidis can disturb the intestinal barrier of birds, promote migration of the bacteria to other organs and cause intestinal inflammation, compromising the animal performance (Humprey, 2004; Quinteiro-Filho et al. 2012). An interesting manuscript from Jones-Ibarra et al. (2019) described that during the normal life cycle of broiler chickens, multiple routes of exposure to non-typhoidal salmonellae, including contaminated feed, water, litter, inhalation of pathogen-contaminated aerosols, as well as epidermal wounding by fighting or toe scratches, are known to exist and present risk of pathogen acquisition. The authors found that compared to gavage methods, transdermal challenge applied to skin with or without feathers on the breast and back muscles were capable of producing systemic infections within experimental birds. This suggested that scratches very common in high density barns could also be an entry door for the *Salmonella*.

Salmonella are able to produce biofilm in a multistep process involving attachment to a carrier surface, binding to the surface, the development of microcolonies, and the maturation of the biofilm. Biofilms allow *Salmonella* to survive in unfavorable conditions by attaching to abiotic surfaces, most commonly metal, plastic, or glass surfaces (Peng, 2016.) and the presence of this biofilm difficult the action of disinfectant on these surfaces.

Critical points in poultry production

Bacteria of the genus *Salmonella* are widely distributed in nature and can affect different reservoirs, as well as being extremely resistant and surviving in different types of environments. These characteristics make these easily propagated and their control becomes difficult. *Salmonella* is commonly found in intestines of production (swine, poultry and cattle) and domestic animals such as dogs, cats, birds and reptiles. Isolation of this microorganism in animal production facilities is common and therefore also present in feed.

One of the main risk factors associated with *Salmonella enterica* infection in poultry farms is animal density (Shivaprasad et al, 1990), since the bacteria excretion can infect the whole lot and even nearby lots without apparent clinical signs (Tack et al. 2019). The presence of other animals in addition to poultry farming may also represent a risk factor for *Salmonella enterica* infection in broilers, since transit of people between one breeding establishments can carry the bacteria, favoring agent dissemination.

One of the first route of poultry infection with Salmonella is the vertical transmission. The bacteria can survive in the reproductive tract of the hen and be transmitted to the progeny by trans-ovarium way during egg formation or through feces contaminated of the eggshell after laying. Normally the trans-ovarium transmission is different between *Salmonella* serovar (higher in S. Enteritidis compare to Thyphimurium for example), but once one egg is contaminated, the horizontal transmission at hatchery and transportation can be very fast and higher between chicks.

Once at the farm, the environmental (litter, equipment) could be source of *Salmonella* as the feed and the presence of other insects and/or animals as rodents, wild birds, dogs, cats and also the human being responsible for animal management and care.

Thaimes and Sukumuran (2020) described that, at slaughter, usual routes of contamination of poultry meat with *Salmonella* include, leakage of intestinal contents/feces during processing, contaminated processing equipment, water, and the hands of processing workers. Due to the high rate of cross-contamination during slaughter and processing, there are estimated risk levels for *Salmonella* outbreaks from these steps in broiler production to be 12% and 33.5%, respectively.

Another major concern is the formation of biofilms by *Salmonella* on processing equipment and surfaces that are more resistant to antimicrobials used for sanitation and persist in the processing facility for prolonged periods (Peng, 2016).

Finally, but not less important, there are highest percentages of contribution of toxi-infection related to the handling of the products at home. Improper refrigeration was involved in 48% of the outbreaks, preparing food one or more days before serving was involved in 34% of the outbreaks, and inadequate cooking was involved in 27% (Pintar et al. 2007).

Control of Salmonella in different critical points

The reduction of prevalence of *Salmonella* in poultry products requires detailed knowledge of risk factors in the poultry production system.

In 1996, Food Safety Inspection services mandated that processing plants under USDA regulation must have a written protocol following the seven HACCP principles (United States Department of Agriculture, Food Safety Inspection Service. 1996). The critical control points identified in the HACCP plan are utilized as locations/points in processing where control measures are applied to reduce/eliminate microbial hazards.

The follow of this HACCP principles for animal production is also very important at farm and feed mill. The first step is to start to make a flux of all the critical points and try to find measure to minimise their impact on the Salmonella spread. However, the daily control is much more complex that wull be described here, we can summarise an overview of the control as follow:

1- Breeders: the environmental control is essential with increase in biosecurity what included distance from other production, closed farms limits to avoid entrance of people and equipment from outside the production, *all-in-all-out* system, and also a good education of employees. The good control of the gut health of birds with good additives play an important role here, once that the balanced microbiota of the breeder would be transfer to the eggs and make a impact as the first colonization on gut intestine of the progeny.

2- Hatchery: The horizontal contamination at this point is very critical, once that one contaminated egg can transmit the microorganism to many other, and normally this animal that will be shipped to different farm after. So, the origin of eggs (from breeders free of *Salmonella*) and environmental control is recommended. The special attention to biofilm formation on surface of equipment and machines should also be observed and the mechanical cleaning of surface before chemical disinfection should be applied.

3- Broilers and egg layer farms: normally we understand that the biosecurity is lower compared to breeder farm but the same philosophy should be applied. The environmental control, good biosecurity and special attention to good measures of welfare avoiding the high density are high recommended. The environmental temperature out of the ideal for animal age increases animal stress and disturb the immunity, high density increases scratches in the birds which will be an entry door for this microorganism. The use of additives that help gut health are presented potential effective in control *Salmonella* and specially reducing the contamination at slaughtered house. At harvest period, where a withdraw of the feed is applied pre transportation to slaughterhouse is critical, because this could allow that asymptomatic birds that carrier Salmonella in the liver release the agent to the intestine and increase the possibility this spread to carcass during processing. The use of additives that control *Salmonella* in last feed and water could help in this period.

4- Feed Mill – The feed could also be a source of Salmonella for the animals at any phase. At begin only ingredients from animal (as fish, meat, feather meal) are suppose be associated to *Salmonella* contamination. However, the cross contamination inside the mill and the presence of rodents and wild birds increase the risk of spread *Salmonella* through different point at the feed mill to the feed up to the farms. Apply a critical point evaluation at the feed mill should also be part of the overall plan to control *Salmonella*. Use of organic acids and formaldehyde (allowed in some countries) to control *Salmonella* in feed and equipment have been prescript for some nutritionist associated to careful analysis and control of all raw material.

5- Slaughterhouse - post-harvest strategies to decrease microbial prevalence as the application of chemical antimicrobials is the most common intervention in poultry processing today, but is not all countries that allow this practise. According to a very good review of Thaimes and Sukumuran (2020), traditionally, chlorine was the industry standard as an antimicrobial treatment. However, compounds such as peracetic acid (PAA), cetylpyridinium chloride (CPC), acidified sodium chlorite (ASC), and trisodium phosphate (TSP) have become usual. The most common is also to have a specific HACCP plan for the slaughter and meat preservation. Recent studies have investigated the application of electrostatic spraying in antimicrobial treatments of broiler meat.

Take Home Message

As many other issues at poultry production, also for the control of *Salmonella* there is not a silver bullet that will solve all the problem. The *Salmonella* genus has two species and more than 1600 serovars that are divided in typhic (Gallinarum and Pullorum) and para-typhic (the rest of serovars), being the second the most important in foodborne cases. *Salmonella* is a very resistant microorganism that could be present in the intestine of many animals or in the body of insects. Also, it can make biofilm in different surfaces of equipment at farm, hatchery, feed mill or slaughterhouse. The *Salmonella* is also described to adapt to the host that develop a tolerance to the disease and could carrier the microorganism in a healthier state.

The healthy *Salmonella* carrier animals could growth well and produce well but, under stress condition, can spread this organism in a trans-ovary transmission (breeder/layer) or horizontal transmission. The overview of each critical point during poultry production is fundamental to look for specific solution for each point that could minimise the risk of contamination up to the meat and egg. The foodborne disease control is one of pillars of sustainability, the losses at slaughterhouse, the risk for public health (meat and egg consumers but also the workers at poultry production) affect all the chain of production and should be very careful controlled during all the poultry production process.

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Managing Salmonella in Feed and Via the Feed

Rick R. Carter

There are many possible Salmonella entry points including feed, drinking water, purchased day old chicks or pullets, eggs coming on to farms from other locations, litter, trucks, equipment and other fomites, pests (e.g., rodents and beetles), wild birds, other livestock and domestic animals, and people. The risks associated with these entry points should be assessed and managed accordingly.

Managing the vulnerability of the Salmonella hazard requires continual awareness, diligence and vigilance including deployment of the 'multiple hurdle' approach, i.e., placing multiple 'hurdles' in the way of Salmonella to progressively reduce the probability of contamination. When there is not constant awareness, diligence, and vigilance at each point along 'the chain', the chain can break and potentially present an amplified problem at points closer to the final consumer. Poor control of what may be considered a low-risk hazard may increase its risk. In relation to feed, unlike a chemical contaminant (e.g., pesticide, herbicide etc.), Salmonella can multiply (e.g., in warm, moist conditions such as feed bins, hoppers etc.) and spread, so can start in low numbers, but become high.

The presence of Salmonella in feed before arrival at the farm and whilst on the farm can contribute to Salmonella presence in food producing animals. MacKenzie and Bains (1976) reported a significant correlation between Salmonella serotypes isolated from feed ingredients and those from finished broiler chicken carcasses. References to primary breeders cited by Jones and Richardson (2004) referred to feed as a "major source of introduction" of Salmonella into commercial production and that "close to 80% of the Salmonella serotypes isolated during routine monitoring of feeds and feed ingredients were the same serotypes found weeks later during the monitoring of breeding flocks and their offspring (Jenson & Rosales, 2002)". It is theorized that *S. enteritidis* entered the primary poultry breeding companies in the UK in the 1970/80's via feed (R. Davies, pers. comm., 2020).

Whilst the non-host adapted Salmonella serotypes do not generally cause disease in poultry, some serotypes can cause 'significant clinical disease and mortalities particularly in day olds and

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young layers' in the presence of stressors (Scott, 2014). A mice plague in grain growing regions of Australia was linked to increased *S. typhimurium* contamination of grain and increased contamination of broiler feed and this was associated with high numbers of dead-in-shell embryos and high numbers of week one mortalities (Bains & MacKenzie, 1974).

The U.S. Food & Drug Administration state that "people commonly get infected with Salmonella by eating contaminated food such as raw or undercooked meat and poultry products, raw or undercooked eggs and egg products, raw or unpasteurized milk and other dairy products, and raw fruits and vegetables" (FDA, 2020). *S. typhimurium* DT160 was linked to extensive mortalities in sparrows and other wild birds in New Zealand in 2000, particularly around grain silos, with the same Salmonella strain also found in poultry feed and poultry houses, grazing livestock, small animals, and people (Alley *et. al.*, 2002). Crump *et. al*. (2002) referred to a large outbreak of human infections with *S. virchow* being attributed to chicken meat in England in 1968 with the same organism isolated from feed fed to the birds. The same authors referred to the rise in *S. agona* infections in people in the U.S.A. in 1972, predominantly in poultry growing states with the source being contaminated fish meal fed to the birds. The 'Through-Chain Salmonella Risk Identification' report from Australian Egg Corporation Limited states that "raw ingredients/pelleted feed can harbour human pathogenic Salmonella and can be an important source of Salmonella in the food chain" and that "contaminated raw ingredients/feed should not be used for hen feed" (Australian Egg Corporation Limited, 2016). In relation to attribution of human foodborne illnesses, Crump *et. al.* (2002) indicates that microbiological assessment of feed is rarely included in trace-back investigations and also explains how errors can be made when concluding that serotypes isolated from feed were not the cause of human illness.

Focus points for the 'feed to farm' link include:

- the production processes of feed ingredients and ingredient storage prior to arrival at the feed mill,
- the transportation of feed ingredients from the supplier's storage to the feed mill,
- the production processes at the feed mill, including feed ingredient storage through to finished feed storage,
- the transportation of feed to farm and on-farm storage of feed.

Feed ingredients and the feed mill process

A recent survey (Table 1) reported on the incidence of Salmonella positive feed ingredients from samples collected across 22 Australian feed mills between 2003 and 2018 (Parker *et. al*., 2019). Feed mill line surveys have also been published and Table 1 shows the combined results from 4 surveys, i.e., 10 mills in the UK (Davies & Wray, 1997), 3 mills in the U.S.A. (Jones & Richardson, 2004), 17 mills belonging to one company in Australia (Parker, 2008), and 22 mills belonging to the same company in Australia (Parker *et. al*., 2019).

Table 1: Feed ingredient and feed mill* survey data

Feed ingredient survey	**No. of samples**	**% +ve for *Salmonella***	**Feed mill surveys**	**No. of samples**	**% +ve for *Salmonella***
blood meal	278	2.9	intake pits/augers	1,336	3.7 - 24.1
poultry offal meal	39	7.7	mixer	2,026	0.8 - 11.8
meat & bone meal	1214	17.8	conditioner	1,497	0.7 - 7.0
canola meal	1246	17.7	pellet press	4,855	1.4 - 7.5
soybean meal	1257	4.5	cooler	5,052	2.6 - 20.2
whole grain	575	1.7	out-loading bin	882	0 -15.1

*Lowest feed mill survey Salmonella +ve values were from the Australian mills

There are many practical interventions that can be adopted in the feed mill and on the farm to manage the Salmonella hazard including hygiene and biosecurity practices and vaccines. The antibacterial/'preservative' actions of short carbon chain organic acids (mainly formic and propionic) are also used to assist the animal feed industry to minimize mould and Salmonella risk in feed ingredients and final feed over the common storage durations. A comprehensive and integrated preventative programme is needed in a feed mill (Kemin Industries, 2016). Jones (2011) wrote "… it should be recognized that in facilities where microbial control measures have been neglected, Salmonella can become endemic and extremely difficult to eradicate, possibly because of the formation of biofilms on equipment surfaces". However, biofilm formation is influenced by a range of factors including temperature, pH, nutrient supply, surface type and bacterial serotype (Laviniki *et. al*., 2015).

The 3 elements of a Salmonella control programme in a feed mill as proposed by Jones (2002) are (1) preventing Salmonella from entering the feed mill, (2) reducing Salmonella multiplication within the mill environment, and (3) having procedures in place to kill the bacteria. Items for consideration by feed mills are listed below for each of these 3 elements.

1. Prevent Salmonella from entering the mill –

- Approved suppliers should ideally have an audited quality management system that includes monitoring & controlling Salmonella; with no heat kill step in mash feed production, management of feed ingredients is paramount; feed ingredient delivery truck hygiene is also important; a thorough rodent and wild bird control programme is required, and other wild or domestic animals should not be allowed inside the feed mill boundary;

2. Reduce Salmonella multiplication within the mill environment –

- Each point along the milling process requires its own set of Salmonella preventative and corrective actions; Salmonella contamination commonly occurs within the manufacturing system (e.g. condensation caused by temperature variations provides moisture for areas of bacterial growth); aim to keep each point along the milling process dry and clean with minimal dust accumulation; rooves, ceilings and walls should not allow water ingression; maintenance of mill cleanliness should be a part of the mill's programme with physical cleaning being a normal component of daily work functions; where appropriate, have a bucket elevator boot clean-out schedule with addition of powdered inhibitor into cleaned boots; cleaning procedures should prevent build-up of organic material and fat accumulation (fat can afford physical protection to Salmonella) but account for the possibility that mill maintenance and repairs may dislodge caked contaminated material; feed or feed ingredient spills should be cleaned up immediately to promote a good 'cleaning culture'; with the combination of Salmonella being able to survive for long periods in dry material, dust recorded to have a higher Salmonella incidence than the feed/feed ingredients at points along the mill (Jones, 2002), and dehydrated Salmonella having increased heat resistance (Kirby & Davies, 1990), a programme of sampling feed material and dust (including surface swabbing) at points along the milling process is required to determine where microbial contamination and multiplication are occurring so that targeted corrective and preventative actions can be implemented; whilst monitoring finished feed for Total Enterobacteriaceae and Salmonella may be considered useful, testing finished feed to assess Salmonella contamination has been abandoned in some locations with the focus on sampling dust in feed ingredient intake pits, in dust collection filters, the top of pellet press coolers and the cooler area, and the tops of finished feed bins (Jones, 2011); sampling/swabbing should be done with clean, single use items; a powdered Salmonella inhibitor product can be flushed through the line or added at points along the feed milling process to contribute to overall mill hygiene;

3. Have procedures in place to kill the bacteria –
    - Exposure to heat during steam conditioning in the pelleting process can kill Salmonella; Salmonella inhibitor products are useful in mash feeds and are also used in pelleted/crumbled feed as a supportive chemical adjunct to the pelleting heat kill step; liquid inhibitor products may also be used to treat higher risk ingredients and contaminated ingredients; inhibitor products help to reduce contamination along the feed milling process line and help to reduce the risk of post-pellet press and post-feedmill contamination.

Examples of practical steps to consider in a feed mill's Salmonella control programme include:

- Feed ingredient supply -
    - Establish & maintain an approved supplier system that includes Salmonella control; ensure a delivery truck hygiene programme is in place and be aware of the previous loads transported by delivery trucks with the use of dedicated vehicles being an advantage;
- Feed ingredient receival -
    - Establish a sampling and Total Enterobacteriaceae Count(TEC)/Salmonella testing schedule; due to uneven distribution, multiple samples are needed to confirm that Salmonella is un-detectable in a feed ingredient mass (or final feed), hence TEC can be a useful 'proxy' for the likelihood of Salmonella being present; intake pits should be kept clean and dry; flushing of ingredient intake pits and augers with a powdered inhibitor product can be helpful as can powder fogging ingredient storage bins with a powdered inhibitor product; avoid storing feed ingredients in finished product areas;
- Treatment of higher risk feed ingredients with a liquid inhibitor product -
    - As a routine treatment, or as required based on testing &/or prior history; treat at the supplier's premises or at the feed mill; if treated at the mill, this may require designated

storage bins when the treated higher risk ingredients are to be used only in the more critical, sensitive diets; consider treatment of whole grain when used in post-pelleted broiler diets.

- Mixer & pellet press -
    - Have a mixer cleaning regime in place including removal of accumulated material and inhibitor product application; ensure the pellet press is operating at the required designated conditions; use press diversion or inhibitor product treatment of initial batches until operating conditions are achieved; with dust considered to be major source of Salmonella contamination in feed mills (Jones & Richardson, 2004), ensure dust control around the pellet press to prevent passage of un-heat treated feed particles to the cooler; ensure dust extraction units are kept clean; with the potential for mill operators being a source of cross-contamination, consider establishing 'clean' and 'dirty' areas to restrict movement of people, equipment and air between the areas;
- Post-pellet press hygiene –
    - Identify any equipment that allows build-up of feed and moisture penetration; flush the production line from the mixer with a powdered Salmonella inhibitor in carrier material (e.g., broll); maintain hygiene in and around coolers – contaminated dust plus condensation moisture in pellet coolers are considered to be a major post-pellet Salmonella contamination source; ensure air supply to coolers is appropriately filtered and not being sourced from inside the mill or from near raw material storage; inside surfaces of the cooler may be fogged with a powdered inhibitor; consider isolating coolers in a separate 'bio-secure' room; have cleaning schedules for out-loading bins, bag packing bins and bagged feed warehouse areas that can include fogging with a powdered inhibitor product;
- Treatment of the more sensitive diets with a Salmonella inhibitor product –
    - e.g., breeder feeds, starter/rearing feeds, mash feed;
- Feed delivery transport -
    - Feed delivery vehicles should not be used for feed ingredient transport; the use of dedicated vehicles is an advantage, e.g., breeder feeds; institute routine truck cleaning that can include fogging with a powdered Salmonella inhibitor.
- Feed mill pest control programme -

- Grounds around mills should be well drained with no long grass in or around the mill site; spilt feed and feed ingredients should be immediately removed from all locations and properly disposed of; intake pits should be covered when not in use; extensive and properly managed use of rodent bait stations is required – Salmonella contamination rates of rodent droppings can be very high, e.g. 25-50% (Jones, 2002) and a single faecal pellet may contain >100,000 cfu (Jones, 2011); have systems in place to prevent wild bird entry and roosting, e.g. at intake pits and out-loading areas (use mesh bird netting where practical) – 25% of wild bird droppings were found to be Salmonella positive (Jones, 2002); exclude domestic and wild animals.

The bird

Salmonella inhibitor products based on short carbon chain organic acids and organic acid-formaldehyde blends are principally aimed at assisting with ‘hygiene’ of the mill environment, of feed ingredients, non-heat-treated mash feeds, as well as pelleted feeds as an adjunct to heat treatment and to help mitigate against post-pellet press and post-mill contamination. A range of intestinal health products with varying modes of action have the potential to assist with *in vivo* Salmonella control, e.g., non-digestible oligosaccharide prebiotics, probiotic micro-organisms, and essential oils. Products containing ingredients that have been coated/’protected’ to help enable transit and activity along the digestive tract of the bird also have application, e.g., coated acids and essential oils. An assessment of a ‘protection’ technology was conducted in broiler chickens where the respiratory elimination of (^{14}C) CO_2 and intestinal tract disposition of radioactivity were monitored from calcium (1-^{14}C) butyrate in an un-protected form versus a protected form (Smith *et. al.*, 2012). The conclusion from the results of this study was that the protection method enabled the butyrate to interact with larger portions of the chicken gastro-intestinal tract than the unprotected form.

A ‘protected’ formulation of organic acids and essential oils was tested in Ross 708 broiler chickens at the ‘Instituto Zooprofilattico Sperimentale della Lombardia e dell’Emilia Romagna’ in Italy (Kemin Technical Literature). Sixty birds were randomly divided into 3 treatment groups: control feed and the same feed with 1 or 2kg of the test product. The birds were orally infected with a field strain of *S. enteritidis* on day 7. The in-feed inclusion of the acid-essential oils product resulted in significant reductions in *S. enteritidis* counts in the caecum at 7 and 14 days after infection (Figure

1), and numerical reductions in faecal counts were also recorded at 3 and 5 days after infection (Figure 2).

Figure 1. *S. enteritidis* caecal counts (log cfu/g) at 7- & 14-days post-infection

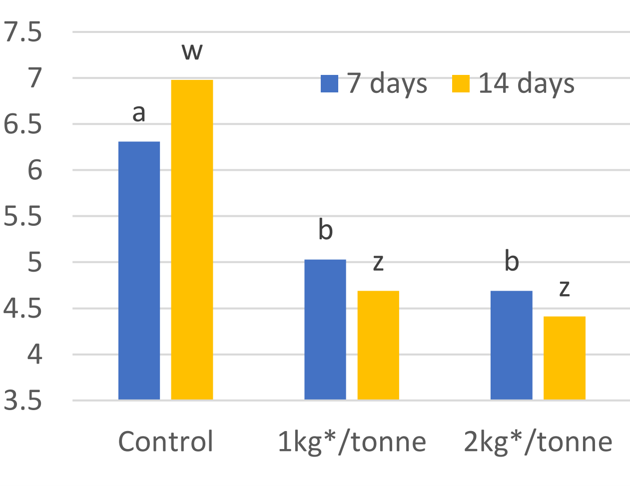
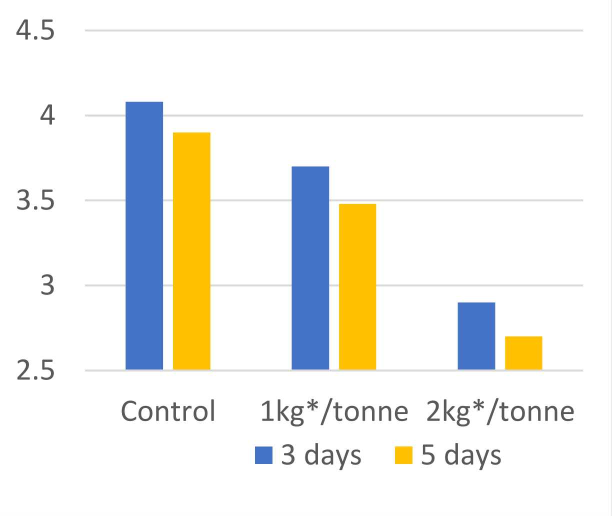


Figure 2. *S. enteritidis* faecal counts (log cfu/g) at 3- & 5-days post-infection



^{a,b} P<0.05 (7 days); ^{w,z} P<0.05 (14 days);*, proprietary product inclusion rate

In a similar study at the same research institute in Italy using broiler chickens orally infected with *S. enteritidis* at 11 days of age, the same 'protected' product included in feed at 750 grams and 1kg/tonne, significantly reduced the number of birds with Salmonella positive caecal samples and neck skin samples at day 40 (Table 2).

Table 2. Number of Salmonella positive caecal & neck skin samples from broiler chickens at 40 days of age after oral inoculation with *S. enteritidis* at 11 days of age (15 birds/group)

Sample	**Control**	**0.75kg/t**	**1.0kg/t**
Positive caecal samples	$7/15^{a}$	$2/15^{b}$	$2/15^{b}$
Positive neck skin samples	$6/15^{x}$	$0/15^{y}$	$0/15^{z}$

^{a,b,c}, $P<0.05$; ^{x,y,z}, $P<0.01$

Immuno-modulatory products are also being used to help manage animal health, e.g., beta-1,3-glucan from a specific micro-alga (*Euglena gracilis*) can 'prime' the immune system due to its recognition as a 'pathogen associated molecular pattern' (Horst, 2018).

When broiler chicks (50/group) were orally infected with *S. enteritidis* at 3 days of age and then sampled the next day, birds receiving feed that contained beta-1,3-glucan from *E. gracilis* had significantly reduced (χ^2, $P<0.05$) detection of *S. enteritidis* in the liver & spleen compared with challenged birds not receiving beta-1,3-glucan (table 3). A significantly reduced percentage (χ^2, $P<0.05$) of birds with liver and spleen detections of *S. enteritidis* was also found when the birds were challenged at 7 days of age and then tested 3 days later. These results indicate reduced trans-location of Salmonella from the gut into tissues when beta-1,3-glucan had been included in the feed. This study was conducted by the Agricultural Research Service of the United States Department of Agriculture (2015).

Table 3. % of birds with *S. enteritidis* detection in liver/spleen after *S. enteritidis* challenge

***S. enteritidis* challenge day (of age)**	**Liver/spleen sampling & testing day (of age)**	**Without β-1,3-glucan**	**With β-1,3-glucan (g/t)**
Day 3	Day 4	16%[a]	0%[b] (100g*/t)
Day 7	Day 10	98%[a]	58%[b] (200g*/t)

***,** proprietary product inclusion rate

Conclusions and summary

Vaccines, biosecurity, and hygiene all play key roles in managing Salmonella. An elevated risk of Salmonella contamination of the mill and feed delivered to farms may be linked to a low level of participation in feed mill and feed hygiene. Increasing levels of intervention and participation in preventative (and corrective) actions are likely to be associated with a progressively reduced risk. Whilst participation and interventions can be ratcheted up or down, the ‘default’ level of involvement options needs to be determined by analyzing and assessing the risk of the Salmonella hazard in relation to any adverse effects and consequences. Preventative and corrective actions are appropriate to help manage the Salmonella risk in feed and in the feed mill environment. The preventative programme should create multiple hurdles for Salmonella with the right combination of hurdles collectively and cumulatively helping to ensure the production of Salmonella free feed. Morrow (2001) stated that “it is no good to try and be completely Salmonella free if no feed decontamination is undertaken”. A variety of modes of action from a range of intestinal health products offer *in vivo* assistance in managing Salmonella in poultry.

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The Global Logic of Food Security: Addressing Challenges and Rethinking Opportunities

Amira E. Mahmoud

INTRODUCTION

Food is our energy source which is highly essential to sustain our daily activities. The limited access to food often causes severe implications in health and growth. Access to safe, nutritious, and sufficient food is a fundamental human right. Unfortunately, approximately one billion individuals in the world are malnourished and have lacked adequate food (Benelli, Canale, Raspi, & Fornaciari, 2014). Due to the increase in the world population, the food security situation has become more and more of a pressing issue for both developing and developed countries. Each country is adopting a different approach to secure food for their nation. However, most developing countries are copying the developed countries' techniques that are not necessarily successful for every social setting.

Apart from essential nutrition, food security is also associated with economic stability, long-term health, gender equity, and climate change. There have been significant efforts to improve the world state of food, yet most improvements are happening in urban cities while the poor primarily are located in rural areas. Additionally, climate change and extreme weather events worldwide tightened the grip around food production. On the one hand, the world population continues to rise to reach 9.7 billion by 2050 (Economic & Affairs, 2013). On the other hand, the extreme weather conditions challenge agriculture to meet the growing population's needs. In these given circumstances, the role of agriculture becomes crucial than ever.

In that sense, we will discuss the state of the world regarding food security and the main challenges facing different counties to achieve food security. Furthermore, presenting insect farms as

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a model for climate-smart agriculture (CSA) can help to alleviate poverty and increase food security worldwide.

What is food security

The 1996 World Food Summit defined food security as *"a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious foods that meets their dietary needs and food preferences for a healthy life" (Barrett, 2010).* This definition integrates several dimensions: availability of food, access to food, the safety of food, and preference of food to be culturally appropriate (Figur 1). Unfortunately, many factors in today's global environment exacerbate food security, such as increasing world population and global warming. Thus, although we are growing and producing more food than ever, and we have sufficient food globally, the food issue is inevitably a matter of access and fair distribution as well as culturally appropriate food (Havas & Salman, 2011). It must be stated that all countries share food insecurity to a certain extent and their local food access varied dramatically. That often happens due to income inequality within each country (Havas & Salman, 2011; Hazell & Wood, 2008).

Figure 1: Aspects included in the food Security definition according to the world summit in 1996 based on Barrett (2010)

Major drivers and underlying factors challenging food security

Many factors affecting food security worldwide include overpopulation, climate change, and urbanisation (Figur 2).

The **world population** is continuing to rise at an unprecedented rate. The lowest projection implies it will reach 9.6 billion in 2050, while the highest projection suggests that the world population will reach 10.9 billion in 2050 and 16.6 billion in 2100 (Economic & Affairs, 2013). In areas that suffer from a high-density population, the demand resources often exceed the given supply. As a result, they suffer from hunger, disease, and failed environmental management strategies such as soil infertility, water contamination, and all forms of ecosystem vulnerability (Havas & Salman, 2011; Singh, Singh, & Srivastava, 2016). As a result, the overpopulated countries often struggle to achieve food security for their nations.

Climate change has its toll on many regions around the world. For example, in many areas of Africa, droughts have become very common and of longer duration. As a result, it becomes challenging to continue farming in shortage or absence of water. Furthermore, global warming caused temperature fluctuation and increased extreme heat weaves, negatively impacting crop yields and shortening production seasons. These new circumstances made it extremely difficult for indigenous knowledge to practice farming and sustainably produce food, meeting the increasing demand (Havas & Salman, 2011).

Urbanisation is also another factor that contributes to food insecurity. The world economy exploits low-income labor to support emigration from rural to urban (Havas & Salman, 2011; Lioubimtseva, de Beurs, & Henebry, 2013). So, most of the mega-cities are mainly found in developing countries. Most jobs are created in the overpopulated cities cause resources depletion, yet the world economy often fails to produce basic needs for equal opportunities in rural areas. As a result, the rural farmers are left to supply food for urban cities in unfavorable conditions and meet the climate change challenges (Sarkar, Datta, & Singh, 2017).

Conflict, war, and instability are other threats to food insecurity. For example, markets increased in many countries due to conflicts and pushed them to famine in the past ten years (Conforti, Ahmed, & Markova, 2018). It was reported that almost 80 percent of stunted children and half of the undernourished people live in countries struggling with instability and conflict (World Health Organization, 2020).

Economic slowdowns and downturns are critical drivers behind rises in hunger worldwide. They can be driven by different factors such as market swings, trade wars, political unrest, or a global pandemic (i.e COVID-19). As a result, they hinder the progress in eliminating hunger and food insecurity.

Poverty and inequality are fundamental causes of food insecurity and malnutrition for all forms. They impact negatively on food choices and often result in unhealthy diets. Food insecurity and malnutrition are made worse by high and persistent levels of inequality of income, access to essential services, and wealth. Inequality has many shapes and conditions, including marginalized groups, ethnicity, indigenous people and people with disabilities (World Health Organization, 2020). The COVID-19 pandemic is also accelerating these levels of inequality.

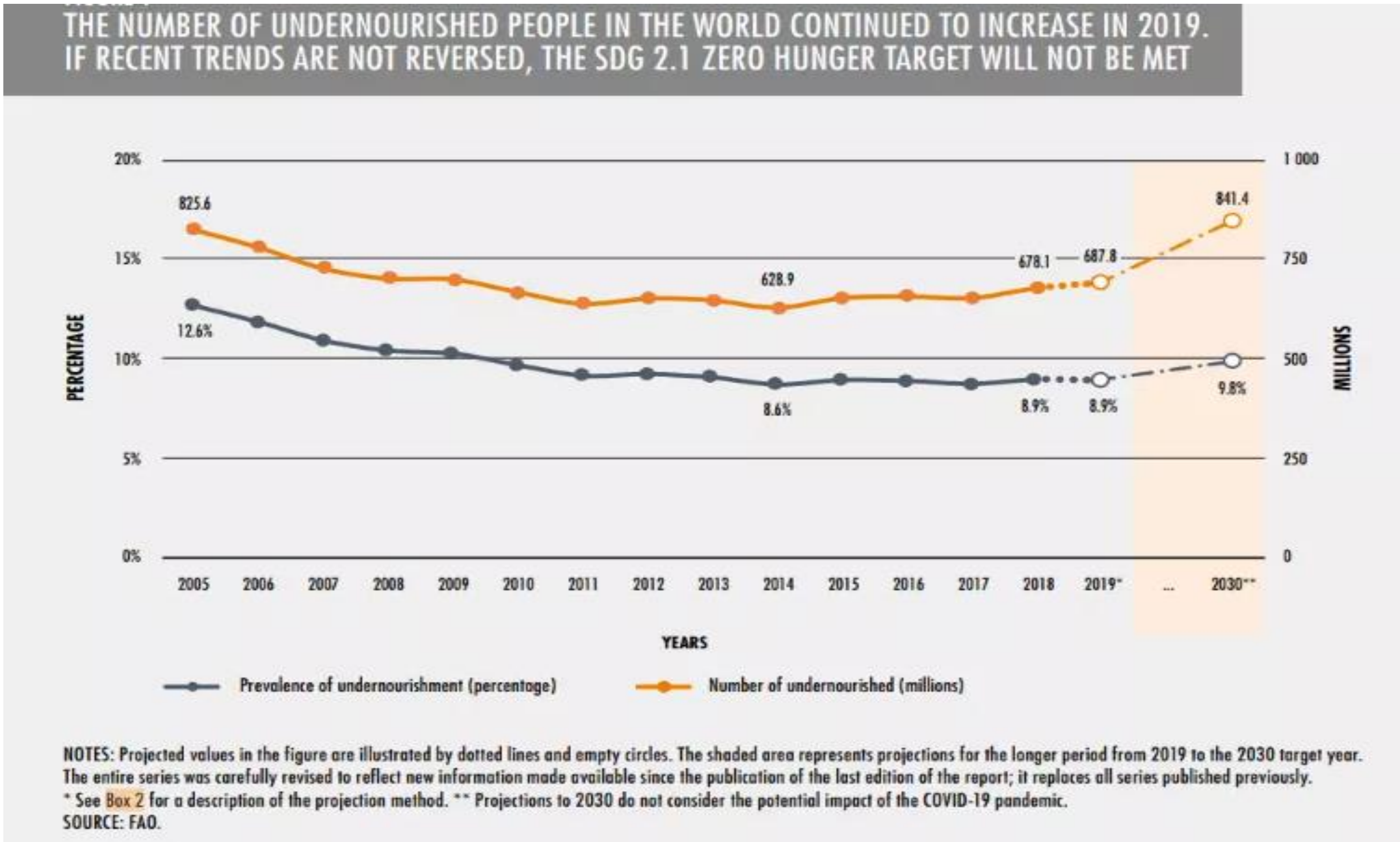
Figure 1: Major drivers and challenges affect the state of food security globally

Latest update and progress towards ending the hunger and ensuring food security

- After five years of stability in the numbers of hunger and undernourishment, food security dropped due to the pandemic outbreak of the COVID-19. Currently, the prevalence of undernourishment (PoU) increased from 8.4 to around 9.9 percent in just one year. As a result, the second goal of the sustainable development goals (SDG) about achieving the Zero hunger target by 2030 is highly tightened (World Health Organization, 2020) (Figur 3).

- A total of 2.37 billion people facing moderate or severe food insecurity, half is found in Aisa (1.2 billion), one-third in Africa (799 million), and 11 percent in Latin America and the Caribean (267 million) (World Health Organization, 2020).
- Due to COVID-19, the moderate or severe food insecurity ratio increased by 10 percent among women than men in 2020, compared with 6 percent in 2019 (World Health Organization, 2020).
- The number (3 billion) of people who have no access to a healthy diet in 2019 is slightly dropped compared to 2017.
- Only Africa and Latin America showed an increase in the unaffordability of healthy diets between 2017-2019. However, it's expected that the number will increase globally due to the COVID-19 pandemic.
- In 2020, the sharpest increase in moderate or severe food occurred in Latin America, the Caribbean, and Africa (World Health Organization, 2020).
- In 2020, food insecurity increased in Northern America and Europe for the first time since the beginning of FIES data collection in 2014 (World Health Organization, 2020).
- In 2020, about 12 percent of the global population was severely food insecure, representing 928 million people – 148 million more than in 2019 (World Health Organization, 2020).
- Feeding America project reported that in the USA in 2021, 42 million people, including 13 million children, may expect food insecurity. These figures are improved from last year's estimated 45 million people, including 15 million children (Hake et al., 2020).
- In New Zealand (one of the world’s wealthiest countries), nearly a quarter of New Zealand’s children and young people (up to 240,000 children) are growing up in households considered to be in poverty (Ardern, 2020).

World Health Organization (2020)



THE NUMBER OF UNDERNOURISHED PEOPLE IN THE WORLD CONTINUED TO INCREASE IN 2019. IF RECENT TRENDS ARE NOT REVERSED, THE SDG 2.1 ZERO HUNGER TARGET WILL NOT BE MET

NOTES: Projected values in the figure are illustrated by dotted lines and empty circles. The shaded area represents projections for the longer period from 2019 to the 2030 target year. The entire series was carefully revised to reflect new information made available since the publication of the last edition of the report; it replaces all series published previously.
* See Box 2 for a description of the projection method. ** Projections to 2030 do not consider the potential impact of the COVID-19 pandemic.
SOURCE: FAO.

Figure 2. Number of undernirshed people around the world

Common strategies to increase food security and reduce poverty

Each country is adopting a different approach to solve food security problems for their nations. Many strategies have been used, such as free-market policies, social welfare strategies, and subsistence production. However, climate-smart agriculture appeared to be more suitable given the challenge of global warming.

Climate-smart agriculture (CSA) to compact food insecurity

By 2050, an additional increase in world population is expected to be concentrated in developing countries, mainly in South Asia and sub-Saharan Africa. In these regions, agriculture is the main profession and already struggling with food security. About 75% of the world's poor live in rural areas and primarily working in agriculture (Lipper et al., 2014). In order to alleviate poverty and increase food security, it is crucial to improve and support agriculture in these regions. Raising agricultural productivity will improve the incomes of the smallholder, which is an essential driver of economic transformation not only in rural areas but also in urban settings (Lipper et al., 2014).

Climate change is already hampering agricultural growth. The effects are seen on crop production in several regions of the world. Average and seasonal maximum temperatures are projected to continue rising combined with higher average rainfall with uneven disruption globally. In many places of Africa, water scarcity and drought are already increasing. As a result, there have been improvements in the traditional agriculture system to cope with the climate change challenges. These new applications are referred to as climate-smart agriculture (CSA). CSA aims to support the local farming practices to global levels for sustainably using agricultural systems to achieve food and nutrition security for all people at all times (Lipper et al., 2014).

Three objectives for CSA for achieving this aim: (1) sustainably increasing agricultural productivity to support equitable increases in incomes, food security and development; (2) adjusting and building resilience to climate change from the local to national levels; and (3) adapting opportunities to reduce GHG emissions from agriculture (Mizik, 2021). CSA is not solely focused on environmental benefits but also addresses the economic aspects that directly affect farmers.

Case example of CSA- Insect farms

Due to the high demand for food and feed, several alternative protein sources are emerging, such as cultured meat, seaweed, and, most importantly, the emergence of insect farming (Van Huis, 2013). Traditionally, insect farms focused on beneficial insects that were mainly used for biological control in the agriculture sector, such as natural predators for pest control (Barragán-Fonseca, 2018; Barragan-Fonseca et al., 2017; Manzano-Agugliaro et al., 2012). Nevertheless, many species considered pests in modern agriculture remain a good source of food and feed, such as locusts, grasshoppers and black soldier fly (BSF) (DeFoliart, 1995; Zhou, Tang, Chi, Ni, & Buekens, 2018).

Mini livestock is another name for insect farm, which includes animal species that are typically smaller than traditional farm animals (sheep, pigs, goats, rabbits, poultry, etc.) but are used as food, animal feed or sources of revenue (Hardouin, 1995). Mini livestock includes small vertebrates (poikilotherms or ectotherms) as well as invertebrates (annelids and arthropods such as insects, spiders, and lobsters) that can be used as animal feed or food (DeFoliart, 1995; Hardouin, 1995).

An economically viable insect production system requires that the following parameters be optimised:

1. High yield

   Insects are poikilothermic, giving them an efficient feed conversion rate compared to protein from other animal resources. For example, cricket convert plants to biomass five times faster than beef (Khusro, Andrew, & Nicholas, 2012). On the contrary, a cow needs 75-300 kilo grass or grain to produce 1 kg protein (Mutafela, 2015).
   Insects have a short life cycle and relatively simple breeding requirements, especially in moderate and hot climate countries. They are also easy to adapt to a wide range of weather, temperature, and environment. A point of reference is the larvae of black soldier fly (BSF), which can consume and transform a wide range of organic waste materials into animal feed rich in protein, fate, and minerals in a relatively short time, 2-3 weeks (Joosten et al., 2020; MuHanda et al., 2019).

2. High quality

   The larvae of many insect species can provide cheap and high-quality protein sources for food and animal feed. A study was found that Mexican fruit fly larvae (*Anastrepha ludens*) contain 79.5% moisture, 9.8% protein, 6.2% fat, 2.3% ash, and 2.2% nitrogen-free extract (Del Valle, Mena, & Bourges, 1982). Mealworm larvae contain 5.39% moisture, 69.8% protein, 7.24% fat, and 8.34% ash (Khan, 2018) Table 1.

3. Low labour

   Insect farms are often smaller in space than traditional farms, and they would not require high labor intensity. Another benefit, some insects leave the feeding site when they are mature such as BSF. This ability can be used as a self-harvest system and therefore reduces labour requirement in mass production facilities (Diener et al., 2011; Sheppard, Tomberlin, Joyce, Kiser, & Sumner, 2002).

4. Low cost

   Insects are very efficient in their use of natural resources such as land and water. For instance, BSF farms can be started in glasshouses as small as 3m*3m (Diener et al., 2011). Usually, larvae and pupae are placed together with a feeding substrate in small trays that can be made of different materials such as wood, high-density polyethylene, or fiberglass. For instance, mealworm larvae can be reared in a standard 65_50_15 cm3 box, easy to handle and deep enough to prevent larvae or adults from escaping (Cadinu, Barra, Torre, Delogu, & Madau, 2020). A recent study based on an EU pilot mill designed to produce 17 tons of fresh mealworm larvae per year reports that mealworms can be reared with a density of 5 larvae cm^{-2} (Cadinu et al., 2020; Thévenot et al., 2018).

   Insects can be drought-resistant or survive on the moisture of organic waste (Van Huis, 2013). Beef production uses on average 22,000- 43,000 liters of water per kg produced. In contrast, many insects showed much lower figures. For example, the yellow mealworm and the lesser mealworm (*Alphitobius diaperinus*) are drought resistant, can be reared on organic side streams, and have efficient FCRs (Van Huis, 2013). Furthermore, BSF shows tolerance to lack of water and low water quality grade (Guido Bosch, Van Der Fels-Klerx, Rijk, & Oonincx, 2017; Van Huis, 2013). Insect farms are a great strategy to increase food security regardless of the county's development stage. For example, in some parts of Sub-Suhara, insects are often used for human consumption, while in developed counties and emerging economics, insects are considered feedstock.

Conclusions

The increase of the world population under limited resources tightens the chances of food production. In addition, climate change and global warming increased the challenge of agriculture to meet such demand. The world’s poverty indexes revealed that two-thirds of the poor live in rural areas, and their main activity is farming, prevalent smallholder and family farmers. Enhancing the potential of smallholder and family farms is critical in alleviating poverty and producing food for the world; they produce 80 percent of the world’s food production. Smallholder and family farms represent up to 500 million farms and occupy 70-80 percent of farmland. At the same time, they act as a catalyst for the local economy and are the primary source of labor worldwide.

Table 1. Nutrient contents of black soldier fly (BSF), mealworm (MW) and tuna by-product meal (TM) for Pacific white shrimp Litopenaeus vannamei

Nutrient contents	Ingredients		
	BSF	Mealworm	Tuna by-product Meal
Proximate composition (% of dry matter)			
Crude protein	41.7	69.8	60.0
Crude lipid	17.4	7.24	9.24
Ash	18.7	8.34	21.5
Moisture	4.39	5.39	7.00
Essential amino acids (% of protein)			
Methionine	0.27	0.23	1.35
Lysine	5.93	5.83	5.89
Arginine	5.36	5.23	4.71
Histidine	8.38	7.84	3.15
Isoleucine	4.78	5.00	3.64
Leucine	7.23	7.92	5.79
Phenylalanine	3.96	4.25	3.09
Threonine	4.15	4.12	3.42
Valine	6.70	7.09	4.11
EAA/NAA	0.88	0.99	0.54
Fatty acids (% of lipid)			
12:0	23.2	0.41	0.10
14:0	5.30	4.17	14.9
16:0	19.0	16.7	40.3
16:1	2.42	2.04	4.80
18:0	4.82	-	10.9
18:1n9	23.4	43.4	4.50
18:2n6	16.3	31.7	0.30
18:3n3	2.18	1.36	0.30
20:0	0.26	0.18	0.40
20:1	0.17	0.13	0.30
20:4n6	0.28	-	1.10
20:5n3(EPA)	1.32	-	12.2
22:0	0.18	-	0.10
22:6n3(DHA)	0.26	-	7.90
SFA1	52.8	21.5	66.6
MUFA2	26.0	45.6	9.60
PUFA3	20.3	33.1	21.9
Σn-34	3.76	1.36	20.4
Σn-65	16.6	31.7	1.40
n-3/n-6	0.23	0.04	14.6
Chitin (% of dry matter)	5.11	3.24	-

Source: Khan (2018)

Nevertheless, smallholder and family farmers are often prone to food insecurity and their indigenous knowledge cannot cope with the climate change challenges. The CSA application provides farmers with opportunities to improve their yields, generate income and achieve food security. Insect farms such as house flies, black soldier flies, and mealworms are great examples of CSA. Insect farms are an excellent food source for poor societies and feed for developed counties with high demand for animal products.

Note on contributor

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Use of a multi-strain *Bacillus* product in diets containing phytase and carbohydrase maintains performance of birds challenged with an overdose of coccidiosis vaccine

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Summary

The present experiment was conducted with the primary objective of assessing the efficacy of a three-strain *Bacillus* probiotic for combatting dysbacteriosis mediated necrotic enteritis and growth promotion in broiler chickens. The study also aimed to validate a mixed nutrient matrix application (0.199% Ca, 0.194% available P, 110 kcal energy and 0.704% CP) for a phytase, xylanase, amylase and protease combination in a corn-wheat based diet by comparing the performance of birds with the breed specifications.

INTRODUCTION

Phytase enzymes are commonly used in the poultry feed industry mainly to increase the availability of phosphorus (P) from plant ingredients. Additionally, phytase improves the availability of other nutrients such as Ca, digestible amino acids (AA), and energy (Dersjant-[26]Li et al. 2015a) by facilitating breakdown of phytate P and thus negating its anti-nutritional effects on nutrient digestibility. Combining Phytase with NSP enzymes has proven to be an effective practical strategy to improve productivity, reducing feed cost, and improving efficiency (Amerah et al., 2017).

In practice, with proper application of phytase and NSP enzymes (dose levels and type of enzymes) and diet management, more sustainable poultry production can be achieved by reducing use of inorganic P sources, to improve Return on Investment (ROI) and increase sustainability. It is critical to understand the matrices and associated contribution values of combined enzymes for proper application of various levels of matrix values for minerals, energy and amino acid fractions. Many

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studies have demonstrated that using a reliable full matrix value including digestible AA and energy can maximize the cost benefit with increased ROI. However, a realistic matrix value should be linked to actual feed formulation and dietary characteristics.

The other important subject is reduction and/or elimination of Antibiotic Growth Promoters (AGP) and implementing preventative measures to control, eradicate, and improve recovery of birds under challenge conditions. Increased pressure to reduce antibiotics use from both regulations and consumers, while maintaining or even improving animal performance, has resulted in probiotics gaining more attention for poultry production. *Bacillus* based probiotics have been shown to influence gastro-intestinal tract (GIT) microbial populations and reduce non-beneficial bacteria in the GIT of broilers. They have several different modes of action which include outcompeting non-beneficial bacteria, encouraging growth of beneficial bacteria and aiding development of the immune system (Ouwehand et al., 2010, Bento et al., 2013, Wealleans et al., 2017). Dersjant-Li et al. (2016) reported positive improvements in terms of inflammatory responses, enhancements of gut structure which would maximise surface area for nutrient absorption and bird performance in a challenge model study in broilers using an enzyme blend in combination with direct fed microbial containing three strains of *Bacillus*.

Multi-strain probiotics show positive impacts on broiler performance in terms of feed conversion and improved body weight (Flores et al, 2016) and the combination with an appropriate enzyme mix (Syncra Concept) has proven to be a practical and efficacious strategy to improve overall performance of broilers (Dersjant-Li et al., 2015 b). In this study, it was decided to investigate the effects of combinations of enzymes and probiotic on nutrient digestibility and bird performance in the presence of a challenge.

Materials and methods

Performance trial: A total of 480 one-day-old male Vencobb broiler chicks were allocated to 4 dietary treatments with 10 replicate pens per treatment (12 birds/pen). All diets were mixed grain based and were fed *ad libitum* as crumble during the starter and grower phases (1-28 days) and as pellets during the finisher phase (29-42 days). All diets included a *Buttiauxella* phytase at 1000 FTU/kg and a xylanase, amylase and protease combination dosed to provide 2000 U/kg xylanase, 200U/kg α-amylase and 4000 U/kg protease). Control diets were reduced by 0.199%

Ca, 0.194% available P, 110 kcal energy and 0.704% CP according to the full matrix recommendations for the enzymes. The control diet was fed either unsupplemented, or supplemented with 150 000 CFU/g feed of a 3 strain *Bacillus* DFM. The unchallenged control diet contained Salinomycin. On day 4, challenged birds were administered with 10 times the recommended dose of a coccidiosis vaccine (Livacox Q). Bodyweight and feed intake were measured on days 1, 21 and 42 for the calculation of performance parameters.

Digestibility trial: On day 28, 10 birds per treatment were placed in wire cages (2 birds per cage, 5 cages per treatment. On day 35 birds were euthanized and small intestine from merkels diverticulum to the ileo caecal junction was taken. Feed and digesta were analysed for nutrients and digestibility calculations carried out.

Statistical differences between treatments for all parameters were determined using ANOVA and Tukey means separation (JMP, SAS software).

Results

Results of the performance study are presented in Table 1. Average daily gain and final bodyweight were both significantly (P<0.05) improved by 3.7% with the addition of the 3 strain *bacillus* to the challenged control, compared to the challenged control alone, and was maintained compared to the unchallenged control. Liveability was significantly (P<0.05) improved by 0.6% with the addition of the 3 strain *bacillus* compared to the challenged control and was maintained compared to the unchallenged control. The performance of the unchallenged control birds was in line with breed performance recommendations. Dressed weight of carcasses was significantly decreased by 3.8% with administration of a coccidial challenge and was significantly improved by 4.6% with addition of the *Bacillus* probiotic to the challenged birds.

Results of the digestibility trial are displayed in table 2. Dry matter digestibility was significantly (P<0.05) improved by 3.7% and 4.2% with the supplementation of the 3 strain bacillus to both the unchallenged control and the challenged control respectively. Nitrogen digestibility was numerically improved by 3.0% and 2.1% for the birds fed *bacillus* probiotic versus their respective challenged or unchallenged control. Challenged birds fed the *Bacillus* maintained digestibility of all key nutrients at the level of the unchallenged control.

Table 1: 42 day Performance of challenged and unchallenged birds fed a diet supplemented with a 3 strain bacillus

Parameter	Unchallenged control (UC)	UC + B*acillus* probiotic	Challenged control (CC)	CC + *Bacillus* probiotic
Initial bodyweight (g/bird)	45.5	45.5	45.4	45.5
Final bodyweight (g/bird)	2962^{a}	2981^{a}	2862^{b}	2968^{a}
Average daily gain (g/bird/day)	69.4^{a}	69.9^{a}	67.1^{b}	69.6^{a}
Average daily feed intake g/bird/day)	110^{ab}	110^{b}	110^{ab}	113^{a}
FCR	1.59^{b}	1.57^{b}	1.64^{a}	1.62^{a}
Liveability	98.6^{a}	98.9^{a}	97.8^{b}	98.4^{a}
Dressed weight (g)	2180^{a}	2197^{a}	2097^{b}	2194^{a}
Yield (g/kg)	736	737	728	737

^{ab} Values without a common superscript are significantly different ($P<0.05$)

Table 2: Apparent ileal digestibility of nutrients at 35 days of age

Parameter	Unchallenged control (UC)	UC + B*acillus* probiotic	Challenged control (CC)	CC + *Bacillus* probiotic
Dry matter	0.837^{bc}	0.868^{a}	0.815^{c}	0.850^{ab}
Nitrogen	0.806^{ab}	0.823^{a}	0.787^{b}	0.811^{ab}
Calcium	0.551	0.599	0.546	0.571
Phosphorus	0.538	0.576	0.508	0.547

^{ab} Values without a common superscript are significantly different ($P<0.05$)

Discussion

The enteric challenge imparted in the study was robust enough to reduce the final BW and the 3 strain *Bacillus* alleviated the negative effects of the challenge to restore the BW to the level obtained with the unchallenged control group. The nutrient digestibility of challenged birds was maintained at the level of unchallenged birds when Bacillus probiotic was fed. This could be indicative of less damage to the gut structure of those birds meaning absorptive surface is maintained and aiding digestion of nutrients as seen in previous studies (Dersjant -Li et al, 2016). The BW difference between the unchallenged control and UC + *Bacillus* group was numerical which can be explained by the fact that gut acting growth promoters could elicit their full potential only in presence of some enteric challenge. Nevertheless, there was almost a 20 g difference observed between the Unchallenged Control and UC *Bacillus* groups which, from a commercial point of view is substantial.

The inferior FCR in the challenged group and the apparent inability of the *Bacillus* probiotic to sustain the FCR is intriguing. Plausibly, the birds ate to meet their target BW defined by their genetic potential and they failed to achieve that when the challenge was induced. The higher feed intake may be explained by an attempt made by the birds to compensate for the depressed BW. When the *Bacillus* probiotic was supplemented availability of nutrients at the tissue level ought to increase but that was perhaps not sufficient to maintain the BW and hence feed intake increased which in turn negatively affected the FCR.

Conclusion

It was concluded from the experiment that supplementation of a 3 strain *Bacillus* probiotic improved BW and feed conversion ratio in broiler chickens and it was possible to sustain performance following exposure to enteric challenges in the form of mixed *Eimeria* infection, an extremely common phenomenon in practical broiler farming systems.

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Practical Tips to Get the Best from Your Broiler

Mike Block

In an ever-developing poultry world where technology is continuing to come up with more innovative ways to monitor and grow our broiler chicken, along with a broiler chicken that has been bred to grow faster while eating less feed to achieve this and at the same time continuing to meet higher and higher animal welfare standards. As a result, it becomes even more crucial that we get the basics right to be able to make the most of these advances in both technology and breeding. This document will look to highlight some of the key areas of management and give some practical advice to help you achieve consistent results run after run. It first starts with the right attitude, as I believe many growers get distracted by things outside their control or have being doing the job for so long that they don't have the same drive they initially had. So they spend long periods of time dwelling on issues or other hobbies that they have little or no influence over and this just tends to distract them from the day to day management decisions that are required. You need to be accountable for everything that happens or takes place on your farm.

Tip 1- Only concern yourself with the things that you can control

Before the chicks arrive

Much of the hard work happen during this period:

- Maintenance on shed & equipment
- Auditing of the cleaning and sanitation process
- Biosecurity in place after sanitation- boot changing, hand sanitation etc
- Time enough for correct preheating
- Equipment checked and all in running order
- Brood setup

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To achieve all the above tasks and not be rushed you need to have a 12-14 day stand-down between cycles. All the maintenance to shed and equipment need to be completed either before the cleaning starts or after cleaning before sanitation (in which case you will need to do a final clean afterwards) in order to keep your biosecurity intact. Special attention needs to be given to concrete floors, filling any cracks that have developed otherwise it will just be an area that could harbor bacteria which could impact on the chick performance. Auditing the cleaning of your sheds is a must, regardless of whether you get in contractors or do it yourself. If the cleaning is not done properly then you compromise the efficacy of the sanitation. As soon as sanitation of your sheds has been completed then nothing must enter you shed unless it has been cleaned / sanitized and goes through the correct procedures. So all human traffic must do the appropriate boot changes, foot dips, hand sanitation etc, if going through the end doors then a change of boots needs be available to repeat the same level of access. So you need to have an end concrete pad to so that tractors, equipment can be cleaned and sanitized before going into the shed.

Tip 2- Audit the cleaning process, finish off all maintenance, sanitize shed and start biosecurity best practice

Preheating needs to be long enough to achieve a concrete floor temp of at least 28 degs, this will ensure your young chicks who at this age cannot regulate their own body temp do not get chilled. So depending on the weather, shed insulation, type of heaters, turnaround times, will determine how long it takes to achieve this, but in winter it would need at least 48 hrs. Having your brood set up and ready to go before the chicks arrive allows you to concentrate on meeting the needs of the chicks, instead of running around finishing last minute jobs. If you are short of time then you will need to bring extra labour to achieve this outcome. At chick arrival you need to give your chick’s 100% focus to decide if you need to make changes i.e. temperature, food and water availability etc.

You need to be aware of the impacts of your concrete floor sweating, so using the following formula:

Dew point = Operating temp - (100-RH)/5

So as an example - a shed temp of 32°C and RH of 60% then condensation could start forming at 26 °C, so need to be aware of this.

Tip 3 – Preheat long enough to achieve a concrete floor temp of at least 28°C

Bedding material needs to be kiln dried (from 10-15% moisture) and around 4-5cm deep. Any deeper and you can have too much of an insulating barrier and can require a lot more heating time unless you pre heat the shed prior to spreading the floor bedding. I have heard plenty of discussion around have floor material up to 10 cm deep, but I believe that is incorrect. You only have the same surface area available to absorb moisture, so unless you plan on forking the bedding every second day for a couple of weeks then you are wasting bedding material.

Tip 4 - Spread kiln dried bedding material evenly over floor to a depth of 4-5cm

Whether you brood in a confined area or whole house the chick needs to be treated if they are all from a young donor flock. Feed and water should be accessible from the paper as chicks like to stick to the paper for the first 24 hrs. Drinking and eating are learnt traits so you need to make it as easy as possible for them to reach both feed and water, if they have to travel over the bedding material in the first 24 hrs there will be a percentage of birds that will more hesitant and this will impact uniformity. We are all aware of the benefits or not of getting our young chicks off to a good start. Compromise the chick in the first week and you impact on:

-Gut development – shorter gut means the chick will not be able to absorb all the nutrients in the feed and will not have the ability to handle gut challenges e.g cocci
-Immune system
-Organ development

Tip 5 –Treat all flocks as if they are from a young donor, give more availability to feed & water

Water is always one of the key nutrients that gets overlooked because you can’t see any problems and you just turn on a tap to access. You need to be aware that environmental temperature has a direct impact on water consumption (Aviagen Brief, Water Quality Feb 2008), so the warmer the environment the more the chick will drink. So with the bulk of the water that is drunk by the chicken ends up back in the litter or atmosphere you need to be careful of overheating them.

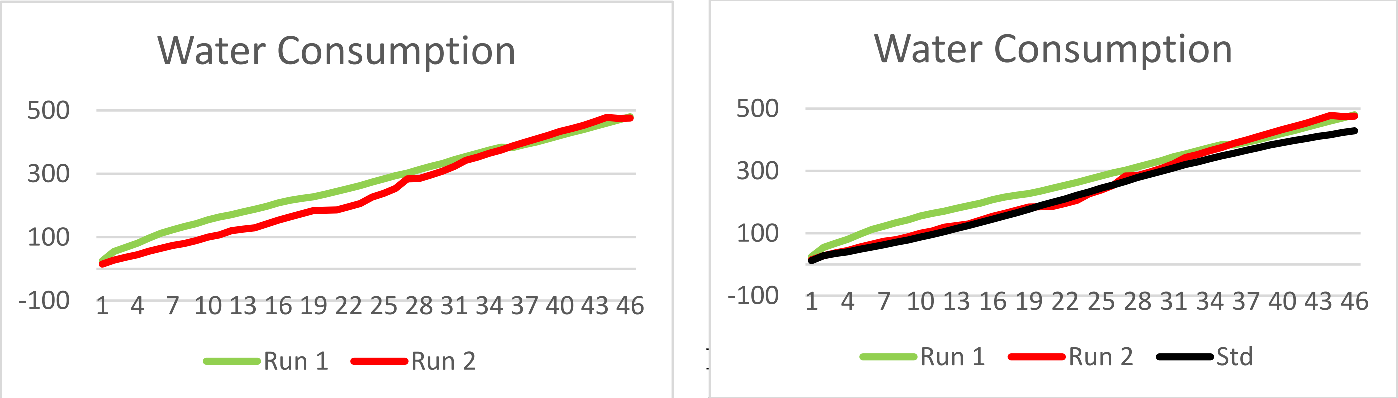
Water temperature can also play a big role in feed consumption. Ideally we want water temp between 18-21°C, but when it starts to get above 26.7°C (Becker & Teeter 1994) they saw a reduction in water consumption and thus daily weight gain. Work on our own farms shows that as soon as it gets to 24°C it will impact consumption, so need to be aware especially in the first week and those in hotter climates.

Tip 6 – Cool treated water is crucial- 18-21°C

Data collection is a big part of most poultry operations today, so it is important that we are collecting the right data that it is accurate, and we are using that data in your day-to-day management decisions. For me one of the most crucial ones is water consumption (mls/bird/day), as it is you best indicator of health, welfare and performance. Most controllers will track it for you but personally I like to see it manually plotted by the farmer, so that it guarantees he is looking at it every day and thus more likely to react to any changes. Break it down even further and look at what is happening each light pattern (B. Fairchild 2020, Hot weather series), are you seeing the same consumption when the lights come on at night as you see during the day, your ventilation setting may not be adequate for the different temperatures.

To get the best value from data it needs to be in context. So you are comparing your actual consumption vs a standard or your own previous flock average for example. But data alone is very hard to make any management decisions unless you are comparing it to something else. So if you look at the first graph (Figure 1) showing water consumption for Run 1 & Run 2, they are both very different profiles, but whether they are good or bad, you can’t tell. But when you add the water consumption standard in the second graph (Figure 2) then we have some context to the water consumption. So know we can make a more informed assessment by overlaying each flock performance to determine which water consumption profile will deliver the best results. Over time you will develop your own standards.

Figure 1. Water consumption for runs 1 & 2



and the standard water consumption

Tip 7 – Accurate data that is visible, in context should be used in day-to-day management decisions

Ventilation is not a set and forget process regardless of the controller you have so you will need to make daily tweaks. With each seasonal change you need to smoke your shed to check that the vent and fan settings are still the ones you need to get a good air flow following up your roof line. This may take some time, tightening cables, maintenance on fans and matching the right vent opening for the correct fans. We know colder air is heavier so in winter you may need to run a higher pressure to achieve the same air flow you would see in summer.

The use of cassette tape (or similar product) attached to your roof about 1mt in front of a vent running up to the apex of the roof about a meter apart. This will allow you to judge how your ventilation is running on a daily basis.

Tip 8 – Your ventilation system needs to be smoked seasonally to ensure it’s still accurate and be prepared to make daily changes to suit the bird’s needs

Bird activity is the key to how successful your ventilation management is going. At any stage the lights are on you should see about a third of your birds eating, a third drinking and a third resting. If you don’t see this then it means you need to make some ventilation or temperature adjustments to improve it. This will be an ongoing adjustment process as the birds grow and generate more and more heat. Then depending on cuts/thinning's you may need to increase the temperature to accommodate for the lost heat.

Tip 9 – Manage your environment to achieve good bird activity at all times the lights are on

If you are going to trial something different from the normal, then make sure you give it a fair trial. Doing it once is not a fair trial as they may be other outside influences that mask any potential gains e.g chick quality, feed changes, poor cuts etc so repeat your trial two or three times. Only make one change at a time and repeat two or three times to ensure you have given it a fair chance to be successful.

Tip 10 - Repeat trials or management changes and make only one change at a time

Feed plays a huge part in the performance of your bird and while you have no influence over the spec or manufacturing you can still ensure you are giving your bird the best opportunity to perform.

- Check that feed deliveries have gone to the correct silo
- Take a sample of every feed sample – in case something goes wrong after feeding
- Take a sample from inside your shed and do a sieve test if have capability
- Feed presentation to your bird is crucial – at least a daily cleanout from 12 days

Tip 11 - Manage feed deliveries and presentation to the bird for best feed intake

Continually monitor your environment and chickens on a daily basis, it is easy to get caught up being task orientated and not meeting the needs of your chicken. With the life of the broiler getting shorter and shorter you cannot afford to make any mistakes.

Feel the litter daily so you can see if the moisture content is building up, squeeze together in your hand and if it binds together then the moisture content is increasing, and you need to make some changes around ventilation or drinker management depending on location.

Pick up the birds and feel the breast muscling, is it firm or a bit loose, indicating weight loss. Look at the feathering this is a great indicator of your brooding practice, see Figure 3.

Figure 3. The tips of the feathers are deformed which indicates stress on the young birds at the time of development.

Observe the droppings daily as well, but can be very difficult in dry friable litter, but are they properly formed or are they holding too much moisture. Try to find the cecal dropping as well as they are both a good indicators of gut health. If you see anything abnormal, open up a few birds and try to understand what is happening, early detection is best. All growers should be able to perform a basic postmortem.

Tip 12 - Continually monitor the environment and bird for areas to improve and change

You need to take a holistic view on broiler management, looking to constantly improve both your performance and your own knowledge and this happens with trial and error. ‘You learn more from your failures then your successes’ a quote from Linda Resnick (1944), is so true to this day. Achieving top results does not come easy and requires a lot of work to meet the needs of new technology and a bird that is changing rapidly every year.

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Broiler Breeders: A New Zealand View

John Foulds

Any view of the future of broiler breeder management and nutrition needs to consider the current situation and an analysis of the market, technical and regulatory pressures emerging which will drive genetic direction and result in change in breeder management and nutritional specifications. It is clear that in affluent parts of the world community there are value driven changes being called for in terms of product range and an overarching common and strongly emerging call for environmental sustainability. In addition, and as standards of living across large parts of the developing world continue to improve, there is increasing demand for nutritious cheap protein which the poultry industry is in a strong position to provide. It is perhaps ironic that while the affluent community demands new additions to our product range, many of these result in poorer outcomes in terms of sustainability. This situation was extremely well addressed in a paper presented by Avendano et al (2017). Conventional broiler meat production with its emphasis on growth rate, feed conversion efficiency and meat yield, with a frame and physiology to support it, is more sustainable than any of the current product alternatives for the following "Environmental Burdens";

- Global warming potential (GWP measure of greenhouse emissions)
- Eutrophication potential (EP measure of damage to water and air from nitrates, phosphates and ammonia)
- Acidification potential (AP ammonia and sulphur dioxide emissions)
- Primary energy use (PE gas, diesel, petrol used in production and transport)

In summary, moving away from the current genetic direction will increase GWP by up to 30% (range; 10%-30%) and 45% for EP, AP and PE (range; 12%-45%). It is the welfare discussion which is resulting in the demand for new products and in addition also, questioning the industry's approach to broiler breeder rearing and production practices, although this issue is only starting to strongly emerge in Europe.

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In terms of broiler production, it will be the industry's short-term goal to try and address the welfare concerns of the conventional market by including selection criteria aimed at welfare improvement (leg strength, gait, FPD etc) at the expense of decreasing rates of improvement in efficiencies such as growth rate, FCR and yield. It is doubtful that governments will spend political capital to give the industry a clear sense of the future in terms of overarching concerns so the way forward, in practical terms, means much of the same going forward as has been in the past.

- Look to expand consumption with products suited to groups of people who currently consume little or no chicken meat. This will require niche genetic products from breeding companies.
- Continue to address the high-volume markets with the current genetic approach which has been modified to address welfare concerns to the satisfaction of that market.

If, as poultry producers, we look at the above situation in the context of PS breeding concerns, it would be logical to take a position which can be summarised as follows;

- Niche breeds appear to lead us backwards in genetic selection history, which logically may make management of PS easier as these are breeds that grow more slowly, probably have lighter mature body weights and have poorer yields relative to the high volume strains.
- The current genetic approach will continue to put pressure on breeding parameters and management as mature body weight, growth and yield continue to increase, albeit at a slower pace than in previous decades, due to welfare concerns.

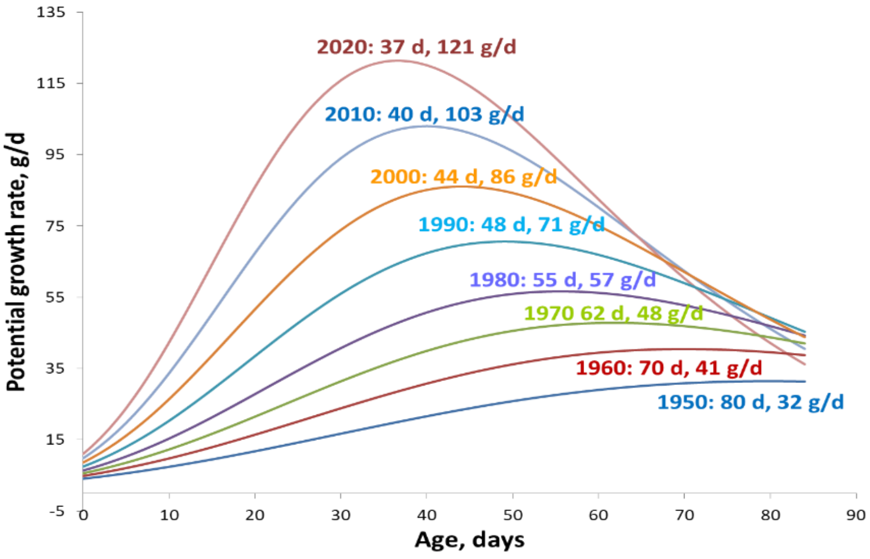
There is another issue which may become problematic as pressure on food resources internationally forces us to look at alternative dietary approaches. Some of this is already happening as vegetable proteins look to gain footholds into traditional meat markets. One large meat company has already invested in vegetable protein production. The reality is that in dry matter terms, meat production is quite inefficient with broilers being between 4.0 and 5.0 conversion. This means that it takes 4-5 kg of feed dry matter to produce 1 kg of human food dry matter. With plant protein being around 10% water this means 1 kg of vegetable protein source produces 0.9 kg dry matter for human consumption and more efficient as commodity supplies tighten. The costs of producing meat in an environment of high and volatile, commodity prices may also exceed the cost of producing vegetable substitutes. In my view this does not play well in the context of sustainability. However, this is not the subject of the presentation and will not be addressed.

The presentation addresses issues connected to the second point above.

There are effectively two breeding companies; Cobb-Vantress and Aviagen. Both service the international market and have strengths and weaknesses depending on the individual situations of different poultry producing companies. In general terms they serve the industry well and their products are competitive and continue to improve. Both are generally heading in the same genetic direction in terms of efficiencies.

Professor Rob Gous (personal communication 2019) has summarised progress over the last few years for broilers. These observations are from a recently completed trial in Brazil comparing both major breeders.

- Mature body weight has increased substantially (from 7 kg in 2009 to 8.5kg in 2019).
- The time taken to achieve mature body weight has not changed which means that the relative growth rate continues to increase. The graph below is taken from a presentation by Professor Gous in New Zealand (2014) and illustrates the progress made since 1950 and projected to 2020.



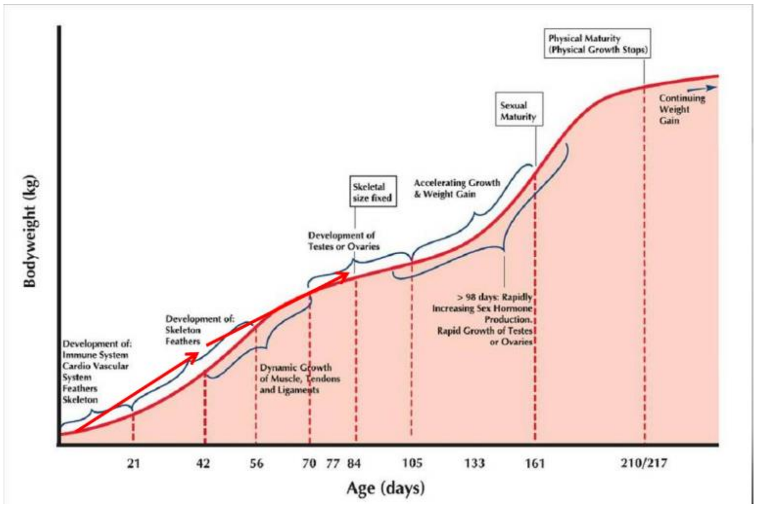
- The rate of maturing remains unchanged.
- The two major breeds in terms of the parameters above are essentially on an equal footing and can be treated as such.
- These changes in broiler characteristics will be reflected in broiler breeder stock. So as managers and nutritionists we are having to optimise the performance of PS demonstrating;
- Constantly increasing potential growth rates.

- Constantly increasing potential for meat production given that yield increases are predominantly from additional meat and mostly in the breast portion.
- Maturity being reached over the same time frame.
- AND exhibiting photorefractoriness (Lewis et al 2003).

The emphasis in PS production will always be on HE numbers and fertility. The foundation for achieving this is built during rear and depends on achieving uniformity of body weight, conformation and sexual maturity with the additional criteria that body weight is kept within breeder company guidelines. Zuidhof et al (2014) also report that broiler weights have increased 450% over the last 50 years while PS body weight recommendations have remained virtually constant.

We should all be familiar with the graph below which represents the desired growth curve of growing breeders and includes the sequence of physiological development. The industry has adopted the approach which was first introduced in the 1980’s by the late David Butler and was successful in focusing thinking around rearing programmes. In essence it highlights the three stages of development of the growing bird which in order are;

- Frame development
- Muscle/meat/reproductive organ development
- Fat deposition



This is still considered to be the guideline when dealing with developmental issues and helps to explain uniformity problems in PS populations. It may be useful to look at how genetics has changed expression of these three phases of growth.

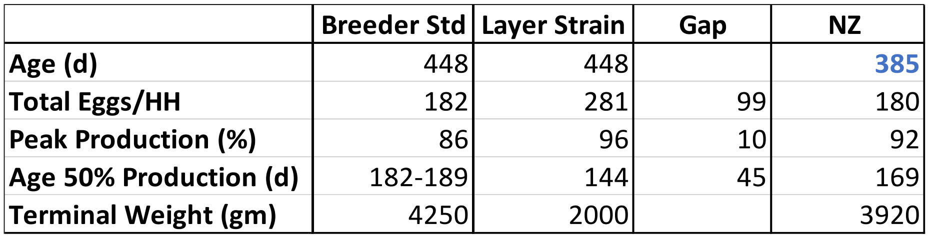
(1) Frame has strengthened over time and it is likely to have increased in size.

(2) Muscle production has increased significantly and continues to increase as measured by breast yields. Eitan et al (2014) found a 42% increase in breast meat for a 2000 PS strain compared to a 1980 strain.

(3) Fat deposition has actually declined. Eitan et al (2014) found 50% less fat in the 2000 PS strain compared to the 1980 strain.

Points 2 and 3 are important when considering how genetic changes may be affecting PS performance parameters.

Turning now to potential for production improvement, it may be appropriate to compare Broiler Breeder to Layer strain performances as an indication of the gap broiler breeders have in egg production. The table below is a summary taken from published standards but includes upper quartile NZ performance.



	Breeder Std	Layer Strain	Gap	NZ
Age (d)	448	448		385
Total Eggs/HH	182	281	99	180
Peak Production (%)	86	96	10	92
Age 50% Production (d)	182-189	144	45	169
Terminal Weight (gm)	4250	2000		3920

Clearly layer strains outperform Broiler PS and this is partly driven by the fact that Broiler PS is photorefractory, which results in a reduction in the laying period, predominantly that clutch lengths are shorter. It may be speculation but perhaps the genes which drive egg production are still present in the broiler breeder but are suppressed by other physiological demands.

It is tempting to think that genetic technology, could at some stage in the future, help us close the gap with layer strains. In the past the industry has signalled that genetic modification is not a part of their forward plan and unless public views change in much of the world, this will remain unchanged. Technologies outside of GM, such as markers, as I understand it, are being used to assist in selection and if there are advancements in the field of genomics, which will allow us to down regulate or mask gene function at the PS level while allowing full expression at progeny level, the industry would seemingly be in a position to take advantage of this development. For this to be a valid option, we would need a detailed understanding of how the genes work together and how expression could be modulated.

Looking at where the opportunities for the industry rest from the above table, they appear to rest with age at 50% production and total eggs. Looking forward at the first opportunity (age at 50% production), the broiler breeder requires an additional 45 days. Would it be possible to close this gap, which may be worth 20-25 HE given that this approach would represent an extension of economical production time? When the question was put to Gous recently he responded that it made perfect sense to rear the birds heavier and use lighting to bring them in earlier EXCEPT that the birds are photorefractory and require 18 weeks of short days before they will respond to light. His and Peter Lewis's attempts to achieve this were unsuccessful. However there were birds in the population which did respond, indicating that the characteristic could be selected for. The major breeding companies have not gone down this pathway which may indicate low heritability. If this is not the case then this might be regarded as a future opportunity.

Achieving **uniformity** in weight and sexual maturity is the key to improvement in peak and total egg production. Improving uniformity implies greater control across;

(1) Day old chick quality.
(2) Nutrition specifications and programmes.
(3) Daily feed intake control.

DOC quality of PS will not be covered in this presentation.

Nutritional specifications and feeding programmes for PS have changed over the years and will continue to change. These are being driven by rapid changes in growth phases 2 and 3. At PS level we need to control increasing potential for breast meat production through protein intake to restrict protein availability but also influence nutrient partitioning. The decrease in fat deposition is placing increasing pressure on the egg production potential of the bird. The need for getting this right is nicely illustrated by Rick van Emous (2015) indicating the benefits in the second half of lay of having sufficient fat deposits and controlling breast muscle deposition. (see graphs below).

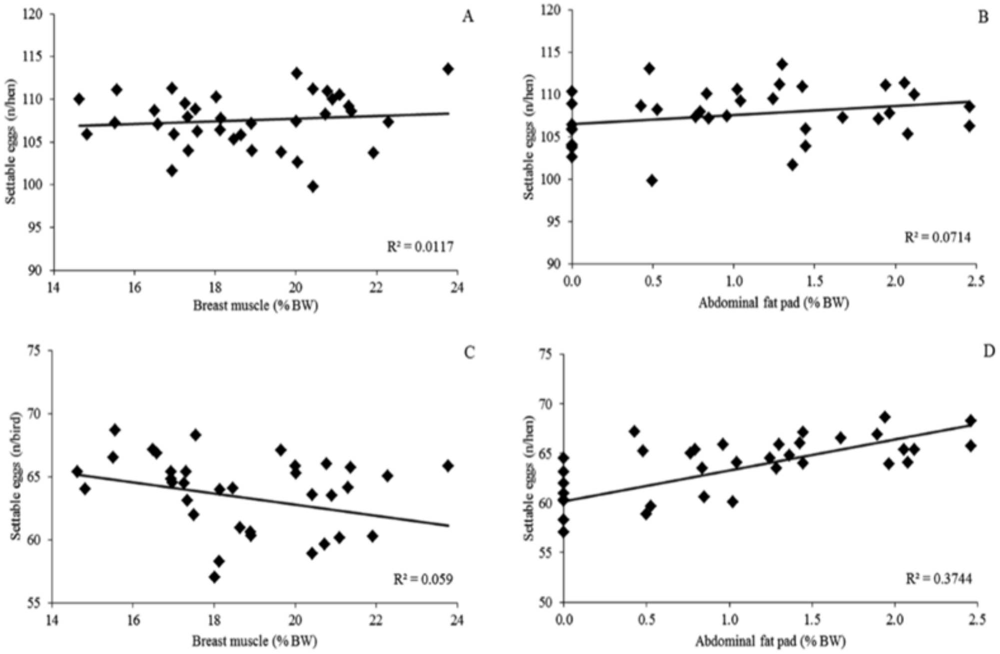


Figure 3. Relationship between breast muscle (panel A and C) or abdominal fat pad content (panel B and D) at 22 wk of age on settable eggs (n/hen) during the first phase of lay (panel A and B) or second phase of lay (panel C and D), based on the results in Chapter 5. Each point in the graphs is an individual pen.

We know that the use of high protein diets in broilers for the first 4-7 days will result in higher meat yields in older animals. In the NZ experience we can achieve similar 7 day weights in excess of 200 grams on a 1.18% and 1.28% available lysine diet. The difference is that a 1.28% diet will result in better yield at slaughter on similar finishing diet specifications. This indicates we can adjust nutrient partitioning in the young bird.

If we apply this to a young broiler breeder it would seem logical that we could restrict breast development and direct nutrients into the development of other important characteristics such as reproductive tract development. This would appear to be the direction behind some of the late Professor Brake’s suggestions where in both males and females he adjusts nutrient intakes to redirect nutrients resulting in less breast development and improved uniformity.

NZ experience would suggest that adopting this approach with females has resulted in a 20% improvement in uniformity measured as CV at 18 weeks (8% vs 10%), a big improvement in sexual maturity as per the number of old primary wing feathers at first egg (2-3 vs 4-8) and improved feathering characteristics. In addition, males from programmes adopting this approach carry less breast, are more upright and with more persistency of fertility.

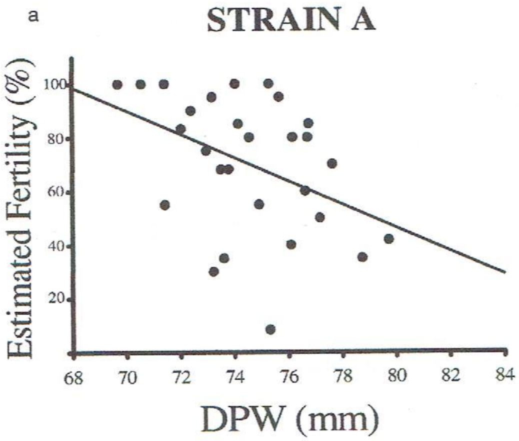
This experience would question why recommendations on the nutritional specifications of Starter feeds appear to favour increasing early levels of protein in the interest of getting birds onto the recommended weight line early or to resolve, in some cases, feathering issues during rear. This does favour the partitioning of nutrients towards breast development and in view of the resulting potential downsides to production, raises the question of whether getting birds onto the early growth recommendations is the best course of action.

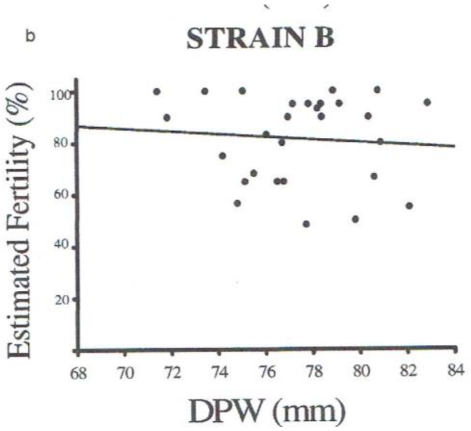
The approach changes the metabolic characteristics of the bird so that theoretically we might expect more nutrients to be available for egg production in lay which can benefit egg numbers or egg size or both. Because of improved uniformity we can expect an easier experience through feed reductions during production and mitigation of some persistency issues resulting in improved efficiencies.

Recommended weights for PS have increased little over the years although commercially some operations have eased standards upwards. Experimentally no difference in production was found between light and heavy PS (Gous personal communication 2019). It is postulated that the increase in body weight recommendations has primarily resulted in better uniformity as well as improved fat deposition assisting peak production and late persistency.

Most of us would recognise that the main issue driving uniformity is achieving uniformity of daily feed intake. Recent work by Zuidhof et al (2017) has achieved success reducing CV’s to less than 2% (compared to controls at 14%) by week 20, with a precision feeding system. But further work by Zuidhof (2018) indicated that precision fed birds had 1.2 times the breast muscle of the controls when fed 10 meals per day. Further work is needed but this approach when finally, refined and commercialised will result in significant gains in both reproductive performance and feed costs.
So far, the focus has primarily been on the female and little attention has been paid to the male. However, most of what has been said regarding weight control, daily feed intake control and uniformity etc applies equally to males. Comments made on development phases 2 and 3 largely also appear to apply to the male and in addition frame development appears to be important in ensuring sustainable fertility. McGary et al (2003) reported that dorsal pelvic width was correlated to fertility

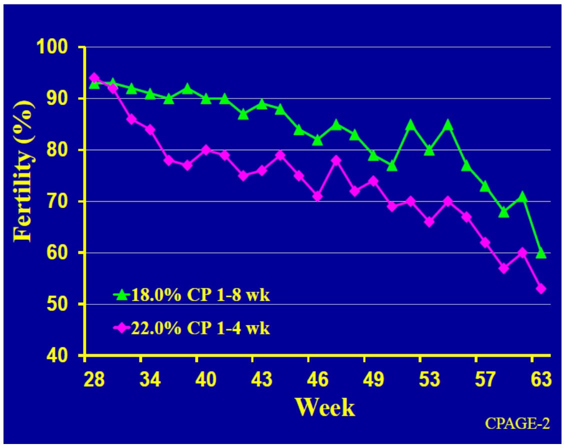
strongly in one broiler breeder strain (see graphs below) and suggested that alteration of this characteristic may impact on semen transfer.



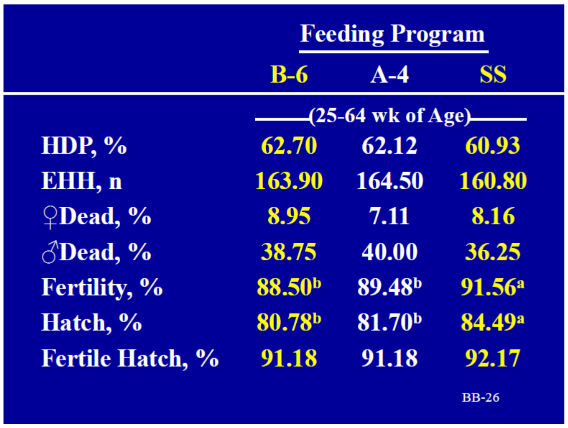


Note Fluctuating Asymmetry for DPW was higher in STRAIN B.

In terms of practical lessons from this work it simply highlights the importance of getting good early frame development of males without losing control of body weight. In this context the late Professor John Brake presented evidence on many occasions showing the influence of feeding programmes on fertility in both males and females which linked back to development during rear. In summary for males the trend to higher protein starter diets may be taking us the wrong way according to his work which appears to show high early intakes of protein are detrimental. These observations are likely due to higher protein promoting higher development of breast muscle.

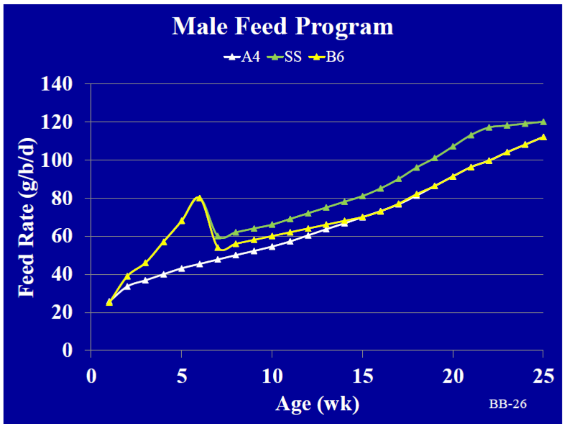


To overcome this Brake suggested a modified feeding program designed to limit breast meat development. Benefits accrued from the approach provided feed was not restricted too much at week 6.

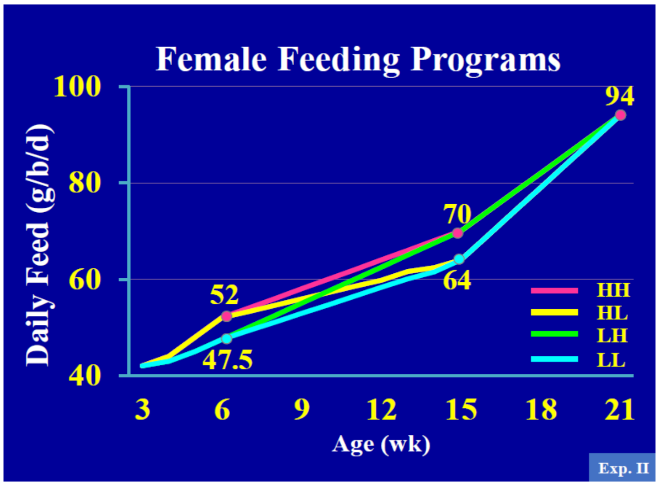


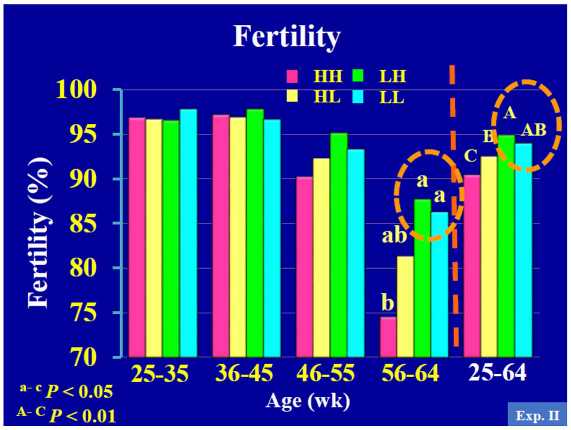
	Feeding Program		
	B-6	A-4	SS
	(25-64 wk of Age)		
HDP, %	62.70	62.12	60.93
EHH, n	163.90	164.50	160.80
♀Dead, %	8.95	7.11	8.16
♂Dead, %	38.75	40.00	36.25
Fertility, %	88.50^{b}	89.48^{b}	91.56^{a}
Hatch, %	80.78^{b}	81.70^{b}	84.49^{a}
Fertile Hatch, %	91.18	91.18	92.17

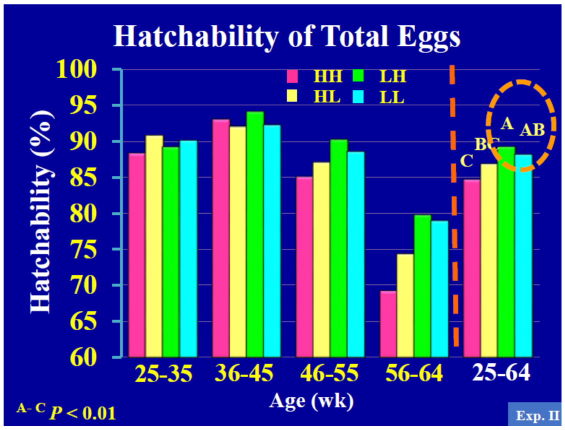
BB-26



Similarly nutritional manipulation of the growth phases in females appears to affect female fertility. The programmes tested are below with the results beneath this.







In terms of male fertility AI is an option. Parts of Asia have adopted this practice and keep broiler breeders in cages which is not necessarily acceptable in the rest of the world. Hatchabilities under this system are high and sustainable although expensive in labour. The benefits of course relate to;

- Allows rapid genetic improvement on the male lines.
- Decreases the number of males required.
- Promotes sustainable hatchabilities.

It is noted that AI is practiced in large flocks of breeding turkeys and perhaps the chicken industry might look at how their practices might be adopted. In summary the discussion around fertility is similar to the discussion around egg production and simply reinforces that as our breeds continue to improve in terms of growth rate and meat/breast yields at the same rate of maturity with all the breeding downsides this brings, then the industry must view the approach to rearing in terms of nutritionally manipulating the three growth phases as described by Butler. The emergence of precision feeding will offer us another tool in terms of controlling the development of the three phases.

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Thesis submitted in fulfilment of the requirements for the degree of doctor at Wageningen University by the authority of the Rector Magnificus Prof. Dr M.J. Kropff, in the presence of the Thesis Committee appointed by the Academic Board to be defended in public on Friday 6 February 2015 at 1.30 p.m. in the Aula.

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A Systems Approach to Tackling Poultry Nutrition

Paul Drew

Worldwide, poultry nutritionists need to consider welfare, performance, micro, macro-economics, operational health and safety, operational capacity/requirements, food/feed safety and environmental sustainability to create optimal dietary solutions for the operations they represent.

A system is a set of interrelated and interdependent parts and activities, which are arranged to process inputs into unified outputs. A systems approach is a way of thinking and or managing a department/business in order to achieve the given objectives. Poultry integrations and most business systems are open systems in that they are exposed to, are influenced by, and dynamically interact with the environment. The world of poultry production is complex and to maintain profitability and sustainability, smarter systems and approaches are required to ensure our industry is continually improving to meet the demands of customers, regulatory bodies and investors. Not innovating and improving may mean a spiral into irrelevance for those operations that do not meet those requirements.

A systems approach is beneficial in that:

- Life’s processes are complex and non-linear, and a systems approach does not look for simple cause and effects.
- It drives one to think relationally in terms of solving a problem or managing a process in a dynamic system that is ever changing.
- It gets much closer to solving problems, aids implementing sustainable management practices and driving continuous improvement in a sustainable manner.

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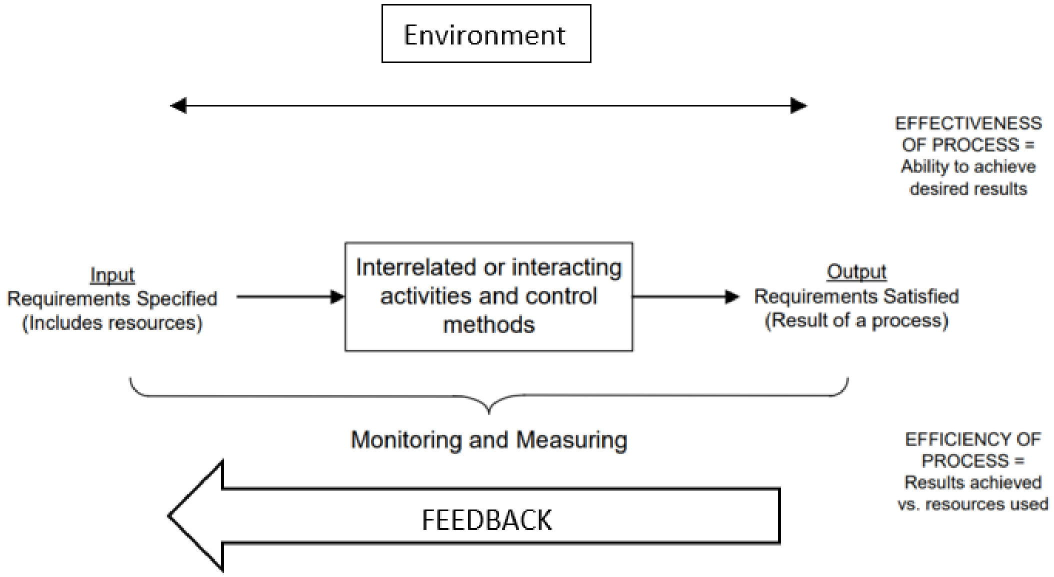

Figure 1. A generic process

(Adapted from ISO 9000 Introduction & Support Package, 2008)

Poultry operations are complex with many variables and processes that are interrelated and interdependent, that effect the unified outcome of that operation. When outcomes are not achieved, it is an error to assume a simple cause without understanding as to whether the variables and processes that drive and manage the outcome are in control or not. In fact, where outcomes do go drastically wrong, it is often caused by the sum of processes that are out of control. Successful operations identify control points that influence outcomes and ensure that a management system of monitoring, analysis and continuous improvement is in place, so that when a process steps out of control it is quickly identified and remedied. Reliability and consistency in meeting customer demands as well as consistency in managing risk, drives the modern poultry business. Variables impacting these need to be managed using a systems approach.

The PDSA (Plan – Do – Study/Check – Act) cycle or more widely known as the Deming's cycle forms the fundamental process of most management systems.

Feedback to drive nutritional improvement

Systems thinking for a Nutritionist is critical to ensure cost effectiveness of production, providing optimal diets to aid health and welfare, and to drive understanding of how other variables such as the environment impact growth, production and or health and welfare. What Nutritionists seek are the optimum economic dietary contents of each nutrient, and for this they need to know how populations respond to increasing dietary contents of the essential nutrients.

Descriptions of such responses, whilst taking account of marginal costs and revenues, are therefore invaluable in determining how to maximise or minimise the objective function chosen for any given commercial operation. Clearly, being able to predict these nutrient responses may be seen as the foundation of a successful nutritionist (Gous, 2007).

Variation also exists in the environmental conditions to which the birds are subjected, as well as the composition of the feed used. Each of these sources of variation need to be addressed when deriving a realistic population response for purposes of optimization (Gous, 2007). As the potential growth rate of broilers is increased by genetic selection, their inability to lose sufficient heat to the environment is becoming a major constraint in commercial broiler operations worldwide (Gous, 2007).

An important aspect of response prediction is dealing with constraints to performance: whereas it is relatively straightforward to simulate the potential performance of a broiler, such performance is often constrained by the physical, social and infectious environment, among others, providing a challenge to modelers attempting to predict actual performance. Some of these constraints to potential performance have not yet been adequately described, but are now receiving attention, suggesting that nutrient responses in poultry have the potential to be more accurately predicted in the future (Gous, 2007).

Good models have the potential to be of immense benefit to nutritionists, geneticists and other decision-makers in the industry. Actual operational and on farm feedback is critical for a poultry operation to understand whether these variables are in control. The ability to convert data to knowledge is critically dependant on both the quality and accessibility of the datasets (Gidley, 2021). The more accurate this data and the degree of analysis, will enable accurate determination of the major factors driving outputs as well as how nutrition impacts those outputs. This data should include health and welfare, environmental data, nutritional analysis, specification and feed quality data to understand the degree that these factors impact the overarching outcomes.

“Big data” principles where complicated algorithms and machine learning are making headway in helping poultry integrations to better predict performance, welfare and health of their livestock. Better predictability aids the company in reliably and consistently meeting customer demands. The right product at the right time drives profitability in a poultry operation.

However, there is value in utilizing this information to monitor nutritional impact as a feedback mechanism to optimizing dietary and feed quality specifications to achieve and improve on performance, health and welfare objectives. The analysis of this data may drive Nutritionists to challenge their own nutritional assumptions within their “nutritional system”.

Nutritional impacts on sustainability

The UN Sustainable Development Goals (of which New Zealand is party to) was agreed upon in 2015. Seventeen Sustainable Development Goals (SDG’s) and one-hundred and sixty nine targets were committed to and are to be achieved by 2030. They bring together the three dimensions of sustainable development: economic, social and environmental.

Environmental sustainability targets are now more commonly visible and are being reported increasingly more by companies. Expectations of regulatory bodies in meeting these targets are becoming more urgent and mandatory. More importantly, investors, customer and potential employees want to understand how the company creates value for them, not only financially and providing a product but how sustainability and social responsibility values align to their own fundamental beliefs. Environmental, Social and Governance (ESG) reporting, otherwise known as non-financial reporting, is now common in many corporate governance requirements or codes. The NZX updated their code of conduct in 2017, where one of the key aims of the Code is to promote issuer disclosure of ESG factors (NZX ESG Guidance, 2020).

Emission labelling and carbon labels are being used by some brands taking their own initiative in increasing customer visibility of environmental care and emission status. Although in its infancy and not without teething problems, the stage has been set for companies to market their environment and social care status at the point of sale.

Formulation of diets is fundamental to the Nutrition role. Multi-formulating diets for an entire feed mill to optimize available raw material usage on a least cost basis, has enormous value. Most large operations would be at least optimizing and formulating diets at this level. However, demands on sustainability management, lends opportunity to formulate on sustainability measures as a constraint, allowing management and further improvements of environmental targets. Enterprise or Global formulation, where optimization of raw material allocation for a large enterprise with numerous storage and feed mill facilities in various locations can be an incredible advantage in terms of optimizing enterprise profitability.

Optimising using environmental constraints at a “Global” level of an enterprise is an opportunity and becomes a powerful tool for an organization to manage their environmental footprint and responsibilities.

Conclusion and industry innovation

The science behind a global systems approach to the interactions and trade-offs involved in the use of planetary resources for agriculture and food production will continue to be refined over the next decade and is likely to affect both societal perceptions (and hence food choices) as well as government actions to safeguard planetary resources (Gidley, 2021).

In the near future, technologies will improve to bring new methods of reporting, visibility and assurance of food products. These technologies will force an increased focus from all elements and areas of a poultry business to ensure they are aligned to the specific outcomes of the business.

There is no better time to ensure that as poultry Nutritionists, it is understood that we are part of an interrelated and interdependent system both inside and outside of the entities we represent. New technologies will evolve and will be available to aid in our systems approach to poultry nutrition, to drive desired outcomes. The service that the poultry Nutritionist provides can be further reaching in aiding the entities they represent in achieving these objectives in a fast-changing world.

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