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The embryonic and immediate post-hatch developmental period represents a significant phase in attaining quality broiler performance at marketing. An efficient transition period from late term embryo to a viable independent chick is necessary to achieve such results. Immediately, post-hatch birds must undergo a shift from egg and embryonic nutrients to exogenous feed. Under practical conditions, many birds have access to feed only 36 to 48 hours after hatching, and during this time body weight decreases, and intestine and muscle development are retarded. In order to overcome these limitations, a continuous feeding process can be established which would supply nutrients to the developing embryo, feed and water to the newly hatched chick within the hatchery, and a highly digestible pre-starter diet at placement. *In ovo* feeding stimulates intestinal development by enhancing villi, increasing intestinal capacity to digest and absorb nutrients and provides a basis for muscle growth. Immediate access to feed (1 hour after clearing the shell) initiates uptake and growth processes some 24 hours post-ingestion compared to poultry with delayed feed intake. The enhanced growth caused by early feeding improves nutritional maturity of the bird, stimulates yolk utilisation, increases intestinal development, and has long term metabolic effects. Providing highly digestible ingredients in the pre-starter diet increases body weight performance at day seven, and through to marketing. Together, these processes provide appropriate nutrition pre- and post-hatch which can accelerate gastrointestinal development, muscle growth and therefore result in increased performance. This paper will summarise studies dealing with the different approaches to early nutritional strategies in our modern, fast growing broiler.

Keywords: embryo; chick; in ovo feeding; early feeding

Introduction

Birds are precocial and will forage for feed immediately and begin to grow, whereas holding them without feed results in body weight loss for some 24 hours after poultry are fed (Moran, 1990; Pinchasov and Noy, 1993; Henderson *et al.*, 2008). Under commercial practice, eggs within a single tray will hatch over a 24 to 36 hour window, during which

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time the birds which have pipped are left without access to feed. The early hatching chicks are therefore at a disadvantage because of the prolonged fasting period and potential dehydration it causes (Tweed, 2005). Logistics within the hatchery as well as treatments such as sex determination, sorting, vaccinations, beak trimming, comb dubbing and transport to the farm involve a further holding period. During this time chicks' decrease in weight at an approximate rate of 4 g per 24 hours, due in part to moisture loss as well as yolk and pectoral muscle utilisation (Noy and Sklan, 1998; Halevy *et al.*, 2003; Tona *et al.*, 2003; Careghi *et al.,* 2005). Thus, birds are often held for 48 hours or more before initial access to feed and water which can have lasting negative effects (Tarvid, 1992; Knight and Dibner, 1998; Noy and Sklan 2001; Batal and Parsons, 2002; Juul-Madsen *et al.*, 2004). Delaying access to feed and water makes hatchlings more susceptible to pathogens (Dibner *et al.*, 1996), increased weight loss (Noy and Sklan, 1999b) and the development of critical tissues is restricted (Halevy *et al.*, 2000; Moore *et al.*, 2005). All of this leads to irreversible damage to muscle development and retarded growth through to marketing. These effects are more pronounced in the modern strains of meat–type poultry which are characterised by elevated metabolic rate compared to the older strains (Tona *et al.*, 2004).

Relevance of early feeding strategies for today's poultry

At present, broilers reach slaughter weight at a physiologically younger age and the embryonic developmental period as well as the first week after hatching represents a larger proportion (45%) of the whole life span (Anthony *et al.*, 1989; Bigot *et al.*, 2003). Thus, pre-hatch as well as the transitional post-hatch period must be achieved efficiently. It is known that body weight is increased three to four fold during the first week and considerable changes in gut, and muscle weight and morphology are observed (Jin *et al.*, 1998). Meat-type broilers are capable of achieving 70 g/day until 40 days. This achievement requires emphasis on early phase nutrition (*i.e.* pre-starter diets). The use of pre-starter diets assumes that starter diets are somewhat inefficient in providing balanced nutrients. Consequently, modern broiler strains require re-evaluation of nutrient provisions. Each gram of additional weight at 7 days of age translates to 5 g of extra body weight at day 49 (Leeson and Summers, 2001. Therefore, delayed feeding in the first few days of life reduces final bodyweight (Noy and Sklan, 1999b; Kidd *et al.*, 2007) and it probably affects immunological capacities (Dibner *et al.*, 1998). Early post-hatching feeding is therefore recommended to reduce these effects. In order to develop efficient early feeding techniques it is necessary to understand the physiological and metabolic changes which occur in the pre- to post-hatch period.

Physiological changes occurring during the pre- to post-hatch period

The pre-hatch period (last phase of incubation) is characterised by oral consumption of the amnion by the embryo, accumulation of glycogen reserves in muscle and liver tissues and glycogenolysis, initiation of pulmonary respiration, abdominal internalisation of remaining yolk, shell pipping, and emergence (Christensen and Biellier, 1982; Donaldson and Christensen, 1991; Donaldson *et al.*, 1991; Christensen *et al.*, 2001; Moran, 2007). During this time frame, dramatic physiological and metabolic changes occur, and any disturbances at this stage may markedly affect embryonic survival and its' subsequent performance (Christensen *et al.*, 1999; Collin *et al.*, 2007; Leksrisompong *et al.*, 2007). Some of the important metabolic pathways prior to hatch are described in a recent review (De Oliveira *et al.*, 2008) which emphasises the liver, pectoral muscle, hatching muscle and intestine, as most affected by changes toward hatching.

One of the major physiological processes during pre-natal development is the maintenance of glucose homeostasis. The glycogen reserves are withdrawn as embryos go through the hatching process. Researchers have suggested that insufficient glycogen and albumen forces the embryo to mobilise more muscle protein for gluconeogenesis thereby reducing early growth and development (Vieira and Moran, 1999a; 1999b). Glycogen reserves begin to be replenished when the newly hatched chick has full access to feed (Moran, 2007). Another significant physiological process occurs in the intestine. Exploration of this process shows that, towards the end of incubation, the gastrointestinal tract undergoes extensive morphological, cellular and molecular changes. Research in broiler embryos has shown that, during the last days of incubation, intestinal weight relative to embryonic weight increases from 1.4% at 17E to 3.4% at hatch (Uni *et al.*, 2003). Activity and RNA expression of brush-border enzymes which digest disaccharides (sucrase-isomaltase), small peptides (aminopeptidase) and major transporters (sodium-glucose transporter and ATPase) begin to increase a few days before hatch and this process continues on the day of hatch and thereafter (Uni *et al.*, 2003; Gilbert *et al.*, 2007). In the newly hatched chick the small intestinal mucosa appears to be immature. This is reflected in the organisation and establishment of the crypt region, several-fold increase in villus height and area, and the maturation of enterocytes and goblet cells (Uni, 2006).

The immediate post-hatch period is critical for intestinal morphological development in order to digest feed and assimilate nutrients. Intestinal growth occurs in delayed fed chicks but to a significantly lesser extent than in early fed birds (Noy and Sklan, 1999a; Bigot *et al.*, 2003). This indicates a preferential intestinal growth immediately post-hatch. Decreased intestinal development in chicks fasted for 36 to 48 hours post-hatch was reflected in the decreased enterocyte number, crypt size, the number of crypts per villus, crypt proliferation, villus area, rate of enterocyte migration, goblet-cell size and mucin dynamics (Geyra *et al.*, 2001; Uni *et al.*, 2002).

Therefore, the sooner the gastrointestinal tract achieves functional capacity, the more quickly the chick can utilise dietary nutrients and replenish its depleted energy status efficiently thus achieving genetic growth potential, while resisting infectious and metabolic diseases.

Addressing the problem: when can 'early feeding' begin?

A broad spectrum of knowledge has shown that chicks are capable of utilising nutrients prior to hatch, during the hatching process and in transport boxes. Our proposed concept is to set aside the 'traditional feeding model' of starter, grower finisher on-farm feeding and provide a 'nutrient link' between the embryonic and on-farm growth phases. The 'nutrient link' may include nutrient solutions injected into the fertile egg, feed and/or water in the hatcher and during transport as well as specially designed prestarter feeds.

FEEDING THE EMBRYO (*IN OVO* FEEDING)

In order to overcome the described physiological limitations and to improve the intestinal functionality and nutritional status of hatchlings, a methodology for feeding the embryo (*in ovo* feeding) was developed. A method of inserting nutrient solutions into the embryonic amniotic fluid was created for poultry and patented (Uni and Ferket, 2003). This method makes use of the knowledge that neonatal birds naturally consume the amniotic fluids towards hatch (Romanoff, 1960). Therefore, addition of a nutrient solution to the embryonic amniotic fluid delivers essential nutrients into the embryo intestine.

Many potential nutrient supplements can be included in the *in ovo* feeding solution. Carbohydrates can be used as a source for glucose, which is crucial for the hatching process and hatchling development (Moran, 1985). Sodium and chloride ions (Na^+, Cl^-) play a major role in the activity of apical and basolateral transporters and in the absorption of glucose and amino acids. β-hydroxy-β-methylbutyrate (HMB); a leucine metabolite which affects muscle satellite cells and increases carcass yield (Nissen *et al.*, 1994; Kornasio *et al.*, 2009), is a good candidate for the *in ovo* feeding solution, as are minerals and vitamins which support the development of skeletal, immune and digestive systems in chickens.

Studies have shown that the administration of 1 ml of *in ovo* feeding solution including dextrin (as a source of carbohydrates), Na^+, Cl^-, zinc-methionine and HMB leads to increased total liver glycogen in the pre-hatch period (by 75% on the day before hatch, and by 47% on the day of hatch) and markedly enhances enteric development (Tako *et al.*, 2004; Tako *et al.*, 2005; Smirnov *et al.*, 2006). Morphological evaluation of enteric sections from embryos and hatchlings revealed a significant acceleration of development 48 hours after *in ovo* feeding relative to non-injected controls. The *in ovo* fed birds exhibited increased pancreatic capacity for carbohydrate digestion, increased villus dimensions, higher levels of mRNA expression and activity of brush-border digestive enzymes and transporters (leucine-aminopeptidase, sucrase-isomaltase, sodium-glucose co-transporter, Na^+K^+-ATPase, zinc transporter). It can be concluded that, at the time of hatch, the small intestine of *in ovo* fed birds is at a functional stage similar to that in conventionally fed 2 day old chicks. Several experiments with offspring from young maternal flocks demonstrated that *in ovo* feeding increases hatching weights by 5% over controls and elevates relative breast muscle size (calculated as % of body weight) by 6%. These weight advantages were sustained throughout the experiments (25 days). Commercial practice can be adapted to use *in ovo* feeding methodology by using existing automated systems for *in ovo* vaccination. Adaptation of injection machines to inject 0.6 ml to broiler and turkey embryos at 18E and 24E respectively was done by Embrex-Pfizer and *in ovo* feeding solutions were formulated and tested.

In ovo feeding is expected to yield several advantages, among them reduced post-hatch mortality and morbidity, greater efficiency of feed-nutrient utilisation at an early age, improved immune response to enteric antigens, reduced incidence of developmental skeletal disorders, and increased muscle development and breast meat yield.

IMMEDIATE POST-HATCH FEED (FEED AND/OR WATER IN HATCHER AND IN TRANSPORT)

A series of studies provided chicks at hatching (within one hour of clearing the shell) with nutrients and examined the effect on body weight until marketing day, as compared to chicks held for 48 hours. One such study addressed the effect of the form of the feed presented comparing solid feed, a liquid nutrient supplement or water to birds held for 48 hours on the body weight of chicks through to marketing (Noy and Sklan, 1997). Provision of caloric nutrients in solid or liquid form produced a considerable increase in body weight which was maximal between 4 and 8 days and then decreased. Supplying water alone also resulted in an increase in body weight, but this effect was smaller than that of feed and was no longer apparent after 8 days. Recent research by Fairchild *et al.* (2006) concurs that providing chicks with water during holding increases placement weight but does not influence broiler performance after first 2 weeks of grow out. At marketing, all birds with early access to nutrient or nutrient solutions were 8 to 10% heavier than those held for 48 hours or watered birds. The cumulative feed efficiency through to marketing was not changed by early nutrition, whereas the percentage of breast meat was increased by 7 to 9% in all fed birds (Noy and Sklan, 1999b).

Since provision of nutrients enhanced growth, the effect of applying specific materials by gavaging birds at hatch was examined using glucose, starch, protein, fat or mixtures at hatch and then returning the birds to the incubation trays. Gavaging with all nutrients enhanced body weight post-hatch, although glucose produced the lowest and most transient response (Moran, 1990; Pinchasov and Noy, 1993; Noy and Sklan, 1997). In an additional trial, the effect of administering a single immediate posthatch intubation of nutrients to offspring of either mature (65 weeks) breeder flock or young maternal flock (28 weeks) was compared to held birds. Intubation significantly improved body weight performance especially in offspring from young maternal flocks (Noy and Pinchasov, 1993).

Additional techniques to reduce the adverse effects of delayed feeding have recently been researched. These include the usage of supplements known as 'early feeding supplements', whose aim is to provide the neonate with additional nutrient sources prior to full access to feed and water. Various commercial methods of immediate feeding have been investigated. Use of Earlybird™ showed that significant increases in body weight (2.7%) can be seen at 21 and 42 days of age (Henderson *et al.*, 2008). Oasis™ decreased body weight loss in the 48 hour post-hatch period and treated chicks maintained this advantage through 21 days and 39 days of age with a higher breast yield (Noy and Sklan, 1997; Batal and Parsons, 2002). Additional research involved usage of Oasis™ on female broiler breeders and indicated increased initial body weight growth (Boersma *et al.*, 2003). Thus providing an early feeding supplement may help decrease negative effect of delayed feeding.

SPECIFICALLY DESIGNED 'PRE-STARTER FEEDS'

On the farm, feed is provided for the newly arrived chicks. However, optimal nutrition during this period must take into account the contribution of the yolk nutrients, and the ability and necessity to effectively utilise exogenous feed by the immature developing intestine. Thus, formulating pre-starter diets for quick growing meat type broilers requires use of 'highly digestible' ingredients. The aim of the pre-starter diet is to pre-condition the chick such that it can digest complex substrates or provide more digestible substrate until enzyme development matures. Chicks provided with highly digestible ingredients have achieved a 7 day body weight of 200 g, as compared with 160 to 170 g with conventional corn-soybean diets. This increase in body weight is maintained through to marketing (Leeson, 2008).

Conclusions

'Early' access to feed stimulates body weight growth and maintains this advantage through to marketing. Early nutritional strategies offer the promise of sustaining progress in production efficiency and welfare of commercial poultry. A better understanding of the transition period from embryo to chick will further develop this nutrient link.

In order to achieve broiler potential we must make several unconventional changes:

- Supplying nutrients to the developing embryo before hatch.
- Supplying feed within hatchery.
- Developing highly digestible prestarter diets.
- Integrate all of the above to create a continuous feeding process from several days prior to hatch, during hatch and till farm placement where first feed is provided.

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