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Rick van Emous
rick.vanemous@wur.nl

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Rick van Emous*[1]

**Wageningen Livestock Research,Wageningen, the Netherlands*

[1]*Corresponding Author: R.A. van Emous, rick.vanemous@wur.nl*

Introduction

During the last six to seven decades, broilers have been successfully selected for maximum growth and feed efficiency (Zuidhof et al., 2014). Modern fast-growing broilers reach a body weight of 2.0 to 2.5 kg in 35 to 45 days with an average daily growth of 55 or more gram a day (Augère-Granier, 2019). In a study with different broiler strains representative of broilers in 1957 or 1978 were compared with a broiler strain from 2005 (Zuidhof et al., 2014). The 2005 strain showed, over a 56-day growth period, a 4.6 times higher growth rate and a 50% lower feed conversion ratio. Besides the improvement in growth performance of broilers, body composition has changed as well during the last sixty to seventy years. The selection on increased feed efficiency and growth rate, and decreased body fat content has not only affected the offspring but also the parent stock (broiler breeders) (van Emous, 2015). Although the poultry breeding companies have worked to maintain or even increase the rates of egg production and hatchability (Laughlin, 2009), achieving these potentials at the broiler breeder farm level on a consistent level has proven to be more challenging (Renema et al., 2013). Therefore, optimization of the diet and feeding management is necessary to achieve maximal reproduction (van Emous, 2015). The main objective during the rearing phase is to produce pullets of ideal weight, uniformity, condition and stage of sexual maturity. The main objective during the laying phase is producing fertile, good quality and clean eggs (van Emous et al., 2020).

Every day feeding in the rearing phase

Feed clean-up time under commercial rearing conditions in daily-fed birds is between 15 and 30 minutes which can cause worse BW uniformity. Especially when outdated feeding systems are used which distribute the limited amount of feed, slowing over the rearing house. Therefore, globally still feeding programs are applied to obtain BW uniformity in feed-restricted

pullets (Leeson and Summers, 2009). During the rearing phase, feed is provided daily or via different feeding programs with feed-less days (EFSA, 2010). These feeding programs can be in the form of skip-a-day (feed day followed by feed less day), 6/1, 5/2, or 4/3 feeding programs (1, 2, or 3 days without feed each week and a larger portion feed on the feeding days). In Europe, legislation does not allow feeding programs with feed-less days and most farmers apply daily feeding systems, whereas in North America feeding programs with feed-less days are still applied (de Jong and van Emous, 2017). A worse BW uniformity cand be still the case when pullets are reared in houses with insufficient feeder space and slow feed distribution (de Jong and Swalander, 2013). Modern pullet houses are equipped with enough feeder space and fast chain feeders (up to 30 m per minute) or pan feeders that guarantee an equal feed distribution within three seconds, instead of three to five minutes, in the entire rearing house (Aviagen, 2018; Cobb, 2018). Elevating the feeder system during filling and/or feed system filling in darkness are additional management measures to improve feed distribution (Abad, 2020).

Everyday fed pullets are shown to experience less stress than skip-a-day fed pullets, evidenced by lower corticosterone and insulin-like factor plasma levels (Ekmay et al., 2010). Moreover, daily feeding is 5 to 10% more efficient in terms of feed intake to obtain target weight at the end of rear compared to feeding programs (de Beer and Coon, 2007; Montiel, 2016). The reason for the difference in efficiency is that birds fed feeding programs must store nutrients (fat and protein) on feed days that must be utilized for maintenance and growth on the feed less day (de Beer and Coon, 2007; Leeson and Summers, 2009). This physiological process of deposition and re-utilization of nutrients is not 100% efficient resulting in a decreased efficiency and higher feed requirement. De Beer and Coon (2007) compared four different feeding programs (skip-a-day, 4/3, 5/2, and every day) and found that breeder pullets fed every day during rearing consumed 8% less feed to reach the same bodyweight with comparable BW uniformity. Improved feed efficiency and comparable uniformity was seen when applying everyday feeding (Zuidhof et al., 2015). De Beer and Coon (2007) found during the laying phase, earlier peak egg production and higher settable egg production in everyday fed pullets compared to feeding programs. Also, Montiel (2016) found a 9% decreased feed allowance during the rearing phase when applying everyday feeding compared to skip-a-day feeding.

Twice-a-day feeding and diet density during the rearing phase

Several studies have attempted to ameliorate this paradox through low nutrient density diets or multiple daily feedings (e.g. van Emous et al., 2014, 2015; de los Mozos et al., 2017). These studies however, mostly focused on the effects of these interventions on behaviour and welfare. Only a few studies have been published investigating the effects of feeding strategies during the rearing period on the performance of broiler breeders during subsequent rearing and laying periods. Studies in which pullets were fed diluted diets showed that birds compensated for the lower nutrient concentration by consuming more feed to reach BW target at the end of the rearing period, without affecting BW uniformity (Zuidhof et al., 2015; de los Mozos et al., 2017). Feeding low density diets during the laying period increased laying and egg weight as compared to control diets in an experiment by Enting et al. (2007a). Feeding breeder pullets twice a day reduced BW uniformity at 13 weeks of age (WOA) and increased feed intake as compared to feeding once a day in a study by van der Haar and van Voorst (2001).

Due to the lack on experiments, a study was conducted to determine the effects of feeding pullets two diets (control, diluted) at two frequencies (once a day or twice a day) in a 2 x 2 factorial arrangement on broiler breeder performance between 3 and 40 WOA (van Emous et al., 2021). A total of 960 female one-day-old chicks (Ross 308) were randomly allocated to 24 floor pens (12 pens in two rooms). On day 21 pullets were assigned to a 2 x 2 factorial arrangement including two diets (control (CON) or 16% diluted (DIL)) and two feeding frequencies (once (FO) or twice (FT) a day) with six replicates per treatment. Pullets were fed either once (FO) or twice (FT) a day. The FO pullets were fed at 0815 h (100% of the daily feed allowance). The FT pullets were fed at 0815 h (60% of the daily feed allowance) and 1215 h (40% of the daily feed allowance). From 23 WOA age onwards, all breeders received the same standard breeder-1 diet. Water was available between 0815 and 1530 h during the rearing period and between 0815 and 1630 h during the laying period. They concluded that diluting diets during the rearing period decreased the water/feed ratio, improved litter quality, but did not affect BW uniformity. No carry-over effects were found on reproduction performance. Twice a day feeding during the rearing period improved BW uniformity. A carry-over effect was found for improved fertility during the early laying period.

Floor feeding during the rearing phase

Chain feeders have been used in pullet houses for more than six decades Modern chain feeders, however, are much faster (up to 30 m/min vs. 6 m/min) to prevent pullets from eating while the system is running. Besides the increased speed of the chain feeder, feeding systems are often winchable. Before feed distribution, the chain feeder is winched up (sometimes in the dark), filled with feed, and brought to bird height after filling so all birds can eat at the same time. Four decades ago, pan feeders were introduced as a novel feeding system for poultry and are, after adjustments and improvements, still used in pullet houses. The distribution of feed on the litter has been adopted in several countries as a more equal and natural feed distribution method (de Jong et al., 2005; Zuidhof et al., 2015; Montiel, 2016). An improved innate immune response was found in broiler breeder pullets when they were fed on the floor (Montiel, 2016). Montiel found that everyday fed pullets on the litter cleared E.coli faster than birds that were skip-a-day fed and everyday fed in feeder pans, and exhibited lower Salmonella enteritis colonization rates towards the end of the restriction period (17-22 WOA). They postulated that this is possibly derived from feed competition and available feeding space in the skip-a-day fed or everyday fed in feeder pans programs, and perhaps due to fasting during off-feed days in the skip-a-day program or insufficient feed amounts delivered daily in the everyday fed in feeder pans birds. Transferring pullets from a spin feeder system to a laying house with a trough or pan feeder, however, may sometimes result in adaption problems of the new feeder system. In general, a spin feeder system shows good performance results, less mortality, fewer leg problems, improved litter condition, and more uniform body weight (Aviagen, 2018).

Twice-a-day feeding and split-feeding during the laying phase

A reduced eggshell quality, however, has a negative effect on the number of 1st class hatching eggs, hatching percentage and chick quality (Leeson and Summers, 2005). Eggshell quality in broiler breeders usually decreases at the end of the production period and therefore breeders are fed diets with an increased dietary calcium level from approx. 40 WOA, and moreover, they are often fed an additional calcium source to support shell quality (Leeson and Summers, 2005).

Broiler breeders are fed a single portion of feed in the morning which may impair the availability of nutrients at the correct time of the day (e.g. Cave, 1981). Especially the

availability of calcium during the evening and night is crucial for egg shell formation (Farmer et al., 1983a,b). Broiler breeders, with a single amount of feed in the morning, show a feed clean-up time within two to four hours (Backhouse and Gous, 2005). Feeding broiler breeders later in the day makes the calcium more available at the time for eggshell formation (Farmer et al., 1983a). This results in better calcium utilization (Farmer et al., 1983b; Roland and Farmer, 1984) usually reflected in an increase in egg specific gravity, shell weight and shell thickness. (Backhouse and Gous, 2006). Studies by Farmer et al. (1983a), Backhouse and Gous (2005) and Londero et al. (2015) showed that birds fed only in the afternoon had the best eggshell quality. However, experiments performed by Spradley et al. (2008) and van Emous and Mens (2021) showed no effect of feeding time on eggshell quality.

More recently a novel feeding strategy in layer hens is applied were birds were fed via a split-feeding (special morning and afternoon feed) program to facilitate egg and eggshell formation (de Los Mozos and Sanchez, 2014; Molnár et al., 2018). The study by de Los Mozos and Sanchez (2014) showed that providing split-feeding in laying hens between 95 and 98 WOA improved eggshell quality. Percentage of cracked eggs was 30% lower, eggshell weight was 1.3% higher, eggshell thickness was 1.3% thicker and eggshell weight per surface (mg/cm^2) was 9% higher.

Three experiments were conducted to investigate the effects of providing a standard diet twice a day or split-feeding (specific morning and afternoon diet) in broiler breeders on production performance, eggshell quality, incubation traits, and behavior. The first two experiments were carried out at the experimental facilities of Wageningen University and Research (van Emous and Mens, 2021; van Emous et al., paper in preparation) and the third at a commercial breeder farm (van Emous, non-published data). The birds in the experimental setup, followed three feeding strategies: 1) Standard breeder diet fed once a day (100% at 0730 h) (CON), 2) Standard breeder diet fed twice a day (50% at 0730 h and 50% at 1600 h) (TAD), and 3) Split-feeding fed twice a day, with a special morning (0730 h) and afternoon (1600 h) diet composition (SF). The morning diet contained more energy, protein and phosphorus (P) and less calcium (Ca) than the control and afternoon diet. The afternoon diet had a lower energy, protein and P and higher Ca content than the control and morning diet (Table 1; 2nd experiment). The first experiment was carried out between 50 and 60 WOA and the second between 45 and 65

WOA. The breeders at the commercial farm were fed a control or split-feeding diet between 49 and 60 WOA.

Table 1 Nutrients of control and split-feeding diets (2nd experiment)

	Control diet	Morning split-feeding diet	Afternoon split-feeding diet
AMEn (kcal/kd)	2,800	2,900	2,700
CP (g/kg)	139.0	146.3	131.3
Dig. Lys (g/kg)	5.30	5.70	4.90
Dig. M+C (g/kg)	5.48	5.82	5.12
Calcium (g/kg)	33.5	24.2	43.1
Available P (g/kg)	3.10	3.30	2.90

The researchers concluded in the first experiment that twice a day feeding improves behavior and split feeding improves both egg production and behavior in broiler breeders, however, no effects were observed on eggshell quality and incubation traits. The pullets in the second trial fed twice-a-day or split-feeding, tended to a lower water intake and water to feed ratio compared to the control birds (van Emous et al., paper in preparation). A tendency to a 2.1% higher egg production (%) was found for the split-feeding birds compared to the control birds, while the twice-a-day birds did not differ from the other treatments. No differences were found for other production characteristics, egg weight, eggshell quality, fertility, feather cover and embryonic mortality. Due to twice a day feed distribution, the twice-a-day and split-feeding birds showed a considerably different behavioral patterns than the control birds. The breeders in the on-farm experiment receiving split-feeding showed a 3.6% higher fertility at 60 WOA, what is probably caused by the higher activity at the end of the day. The last three to four hours of the day are very important in fertility, because the most matings are observed in that period (Harris et al., 1980; Bilcik and Estevez, 2005). The last three to four hours of the day is biologically and physiologically the optimal moment for egg fertilization (Løvlie and Pizzari, 2007). More activity and especially mixing of the females and males in the afternoon leads to more mating activity and thus a good fertility persistent while birds aging (van Emous, 2010).

Summary

Modern fast-growing broilers reach a body weight of 2.0 to 2.5 kg in 35 to 45 days with an average daily growth of 55 or more gram a day. Besides the improvement in growth performance of broilers, body composition has changed as well during the last sixty to seventy years. The selection on increased feed efficiency and growth rate, and decreased body fat content has not only affected the offspring but also the parent stock (broiler breeders). The main objective during the rearing phase is to produce pullets of ideal weight, uniformity, condition and stage of sexual maturity. The main objective during the laying phase is producing fertile, good quality and clean eggs. Feed clean-up time under commercial conditions in daily-fed birds during rearing is between 15 and 30 minutes which can cause worse BW uniformity. Therefore, feeding programs (skip-a-day, skip-another-day, 5-2, 4-3) are applied to obtain BW uniformity in feed-restricted pullets. Modern pullet houses, however, are equipped with enough feeder space and fast chain feeders (up to 30 m per minute) or pan feeders that guarantee an equal feed distribution in the entire rearing house within three seconds, instead of three to five minutes. In recent studies it is observed that daily feeding is 5 to 10% more efficient in terms of feed intake to obtain target weight at the end of rear compared to feeding programs. Moreover every day feeding during the rearing phase can result in improved BW uniformity and improved egg production.

Only a few studies have been published investigating the effects of feeding strategies during the rearing period on the performance of broiler breeders during subsequent rearing and laying periods. Therefore a study was conducted by Wageningen Livestock Research to investigate the effects of feeding pullets diluted diets twice a day. This study found that diluting diets during the rearing period decreased the water/feed ratio, improved litter quality, but did not affect BW uniformity. No carry-over effects were found on reproduction performance. Twice a day feeding during the rearing period improved BW uniformity. A carry-over effect was found for improved fertility during the early laying period.

Due to the need to feed pullet birds as quick as possible and to support natural eating behaviour, distribution of feed on the litter has been adopted in several (EU) countries as a more equal and natural feed distribution method. In general, a spin feeder system shows good performance results, less mortality, fewer leg problems, improved litter condition, improved BW uniformity, and improved innate immune response. Transferring pullets from a spin feeder

system to a laying house with a trough or pan feeder, however, may sometimes result in adaption problems of the new feeder system.

Eggshell quality in broiler breeders usually decreases, especially after 60 WOA, at the end of the production period. Broiler breeders are fed a single portion of feed in the morning which may impair the availability of nutrients at the correct time of the day. The availability of calcium during the evening and night is crucial for egg shell formation. Therefore, experiments were conducted to investigate the effects of providing a standard diet twice a day or split-feeding (specific morning and afternoon diet) in broiler breeders. Pullets fed twice a day or split feeding showed a tendency a lower water intake and water to feed ratio compared. A tendency to a higher egg production (%) was found for the split-feeding birds compared to the control birds, however, no differences were found for other production characteristics, egg weight, eggshell quality, fertility, feather cover and embryonic mortality. Due to twice a day feed distribution, the twice-a-day and split-feeding birds showed a considerably different behavioral patterns (higher activity end of the day) than the control birds which explained the higher fertility at 60 WOA at the on-farm experiment.

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