Nutrition Guide

Contents

Introduction

For many years Hendrix Genetics has been breeding laying hens for the world market. The Hendrix Genetics breeds demonstrate an ever-increasing genetic potential, both in technical and economic performance, as the result of a balanced breeding program.

The full genetic potential of these birds will only be achieved through good management and the know- how of experienced poultry farmers. The phenotype (e.g. the performance of your breeders or laying hens) is the combined result of the genotype (e.g. the breed) and their environment (e.g. your management).

This manual is a guide to general and specific rules on nutrition as well as advice for both (grand)parent stock and commercial flocks in either cage or alternative housing systems. The objective is to help (grand)parent stock farmers, pullet growers and egg producers to achieve optimum results. The information and suggestions contained in this nutrition management guide should be used for educational and guidance purposes only. The nutritional recommendations contained in this manual are based on studies carried out by research institutions and field trials carried out by egg producers and other companies active in the egg production chain. Raw material quality and availability, nutritional matrix and the different production goals and achievement, environmental conditions and local disease pressure can require specific adaptations of feed management practices in order to achieve optimal flock results, therefore this nutrition management guide cannot cover all possible circumstances. Please ensure that you are always compliant with your local/national animal welfare regulations.

We trust that this nutrition management guide will make a positive contribution to the continuous improvement in the performance of breeder flocks and laying hens all over the globe. We hope that each reader can obtain some useful insights from this nutrition guide. For more detailed and tailor-made advice, please contact your local Hendrix Genetics representative.

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1 Genetic progress and nutritional consequences

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1.1 Introduction

The egg laying performance of brown and white egg layers has increased significantly through genetic selection over the last decades, as shown in Table 1. The significant increase in the total average egg production per hen housed has been achieved through increasing the level and time of peak production, improving egg laying persistency, further flattening the egg weight and body weight curves and improving livability, next to this, advances in farm management, vaccination and poultry nutrition have contributed to achieving the improved genetic potential. Continuous investments are being made to further increase the production cycles of the pure line birds beyond 100 weeks of age. As a result, more and more data is being collected at the R&D Farms, improving the accuracy of selection and increasing the pure line population sizes. One of the consequences of the improved productivity is a further reduction in the time between successive ovulations. In previous times, laying hens ovulated approximately every 26-27 hours, the ovulation period of modern hybrids has been reduced to 24 hours. The improvements related to egg production and reduced feed intake, have resulted in the reduction in feed conversion efficiency by more than 10%. This massive improvement can only be achieved if the external conditions, (i.e. the management nutrition, biosecurity, etc.) of the laying hens is optimal. Some argue that today's performance could have been further improved by continuing advances in sexual maturity (the onset of lay). However, we have recognized that the potential benefit of more eggs at early age can come at the cost of ease of management, egg laying persistency and average egg size, especially for (grand) parent stock, and laying hens kept in cage-free housing systems. For this reason, genetic selection has been kept constant for sexual maturity, and more selection pressure has been given on traits like egg laying persistency, egg quality, feather cover and livability.

Table 1 Genetic progress in White and Brown egg layers

Traits	White layers		Brown layers	
Year	2000	2020	2000	2020
Egg numbers hen housed (at 75 weeks)	324	364	319	361
Egg numbers hen housed (at 90 weeks)		444		440
Egg numbers hen housed (at 100 weeks)		505		495
Maximum lay rate (%)	95	97	95	97
Egg mass (kg. at 75 weeks)	20,5	22,7	20,0	22,6
Egg mass (kg. at 90 weeks)		28		27,7
Egg mass (kg. at 100 weeks)		32		31,4
Daily feed intake (grams)	110	109	114	112
Feed conversion (gr. feed/gr. egg mass)	2,18	1,98	2,31	2,07
Liveability (% at 90 weeks)	94	95	93	94

1.2 The impact of genetic progress on nutrition

The realized genetic progress has made a considerable influence on the birds' dietary amino acid requirements. Therefore, it is important to supply the daily nutrients required for the production results of today. The nutritional requirements during rearing should be based on the body weight achieved, while the nutritional requirements during egg production should be based on the average daily egg mass per hen produced , not on the age of the birds.

Classically, daily nutrient requirements have been expressed in mg/day/bird. While this type of expression may be very easy for the nutritionist to use, it does not meet the right needs for genetic progress, nor for genotypic differences. The flocks that produce large eggs have higher daily nutrient requirements compared to flocks that produce small eggs when producing at the same rate of lay (%). Most researchers agree to use the expression of nutrient requirements in mg per gram of daily egg mass produced while taking into account the nutrients that are required for maintenance. To express the nutrient requirements per gram of egg mass produced is currently a well proven and widely adopted method in the egg industry.

1.3 Good nutrition

Nutrient intake, nutrient composition, the type of feed ingredients and feed management are all affecting overall hen health and overall nutrient utilization (e.g. digestion and absorption). Improper diet composition or contaminated feed stuffs can have a big (negative) impact on the health, development and productivity of the hens.

In chickens, the gastrointestinal tract has different functions: including transport of feed, nutrient digestion and absorption and a barrier function for entero-pathogens. Despite of its important functioning, proper gut integrity can be easily affected by several factors, like damage of the mucosal layer, affected epithelial cells, stress, poor management, health status, anti-nutritional factors, infectious agents (i.e. bacteria, parasites and worms), the gut microbiome, toxins and other dietary factors. Worm infestations are of a higher risk in chickens kept outdoor, think of free-range, organic and low-input systems. Stress, as a result of suboptimal housing conditions, competition to water or feed, disease pressure, vaccination response, etc. can result in problems as enteritis or a leaky gut. Stress can result in malabsorption and a decrease in breeder performance, egg laying performance, increased feed intake, decrease in feed efficiency or even mortality.

Good nutrition is essential for proper nutrient utilization and so performance. Dietary factors have a direct effect on the maintenance of gut integrity and the microbial population. Within the dietary factors, it is important to select feed ingredients of the right quality, with a high digestion rate and the correct particle size. For example, it is known that undigested protein that are reaching the hindgut, alter microbial composition. As a result, the microbial composition might have a negative effect on the gut integrity and result in issues including necrotic enteritis. There are several options to prevent undigested feed stuff reaching the hindgut, like improving nutrient absorption and reducing the passage rate of the digesta. Furthermore, a heat and/or an acid treatment of the diet can reduce the microbial load of the feed and so the risk of Salmonella entering via the feed. There is a large variety of feed additives available on the market, which can influence and enhance gut health, like pre- and probiotics, acidifiers, enzymes, toxin binders and phytogenic products. It is important to gain the right advice and carefully consider the potential effects prior to adding additives to the birds' diet. This will help you in making the right and timely decisions to further optimize the diets and your feed management.

Despite continuous genetic improvement, laying hens remain very adaptable to management changes to optimize egg number and egg size. Over the last decades, egg producers have recognized the need to produce the correct egg size to meet market requirements and have altered their management practices accordingly. It is crucial to already manage your flock in rearing according to the egg size targets later in lay. Body weight at the point of light stimulation has a direct influence on the future performance of the flock regarding average egg size. Always manage your flock in rearing based on body weight, body weight gain, and flock uniformity, never on age.

2 The rearing period

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2.1 Basic rules of our feeding program during rearing

Modern laying hens have the potential to generate more income than ever as the direct result of continuous genetic improvement. Today's laying hens can reach higher peaks of production and have drastically improved their egg laying persistency. Combined with improved egg weight curves, better interior and exterior egg quality, better livability and longer lasting feather cover, genetic selection has resulted in the longer production cycles. To achieve the full genetic potential of your flocks, it's more important than ever to have a well-balanced feeding strategy. This is the reason why this chapter will provide insight into the key factors that we, as a breeding company, recommend for a well-balanced feeding strategy during the rearing period.

Obviously, the first 16-18 weeks of the lifetime of a bird have a massive impact on production results later in the hens' life. At the onset of lay, there is an increase in the hens' growth and maintenance needs as well as a fast increase in the flocks' daily laying percentage. As a consequence this results in the fast increase in the need of essential nutrient requirements. If the hens' feed intake is not high enough or the feed composition is limiting, there is a good chance that the hens will suffer from a nutrient deficiency. This deficiency will have a negative impact on the hens' productive performance and her wellbeing.

To maintain good egg laying persistency up to 100 weeks of age and beyond, it is essential to take good care of your chicks during the rearing period and to make sure they are well prepared at the moment they arrive at the production houses. After the onset of lay, it is much more difficult to make corrections than during the rearing period. Unfortunately, despite todays' extensive knowledge, the importance of rearing is not always acknowledged sufficiently in the field.

One potential consequence of neglecting the importance of the rearing period is the inability to reach target body weights at key phases in the development of the chickens. The body weight profile during rearing is especially important; body weight development at 5 weeks of age, as well as the bodyweight at the time of transfer to the production house, are both key indicators during the rearing period that have a long-lasting impact on the hens' performance later. Any delay in growth during the first few weeks in rearing will be reflected in a reduced bodyweight at 15-17 weeks and in later life performance. It is, therefore, extremely important to use a starter diet for the first 4 to 5 weeks, as the starter diet has an amino acid/protein ratio similar to the diets given to broilers. Any amino acid deficiency will result in a reduction in growth rate and a negative impact on the feed conversion ratio (FCR).

This is clearly demonstrated by the high correlation between egg weight and the chick's development during the rearing period. The better the body weight development during rearing (i.e. a good body frame), the bigger the egg size from the start of lay onwards (and vice versa). Moreover, body weight at the end of rearing has a positive correlation with laying persistency towards the end of the production period.

As the rearing phase involves many stressful activities for the birds, including housing, beak treatment, vaccinations, weighing, transfer, etc., it is important to monitor body weight, feed consumption and flock health. If necessary, the change in feed phases should be delayed to improve the weight gain. However, if it is necessary to extend the change for 2 weeks or more, it may indicate that management adjustments are necessary.

One important aspect of rearing is the uniformity of your pullets, which can either be maintained or lost during rearing. Ideally, uniformity should be over 85% for brown egg layers and over 90% for white egg layers. This will help to maintain the peak of egg production for a longer period and will boost production later in life, as the overall nutrient requirements and the management of the individuals within the flock will be more similar, allowing you to better meet their actual needs.

We have identified two critical phases in the life of the pullet which have the greatest effect on final performance:

- The first four to six weeks.
- The time from onset of lay until peak production.
- During both these times, body weight development is crucial if you want your flock to perform according to the breed standards.

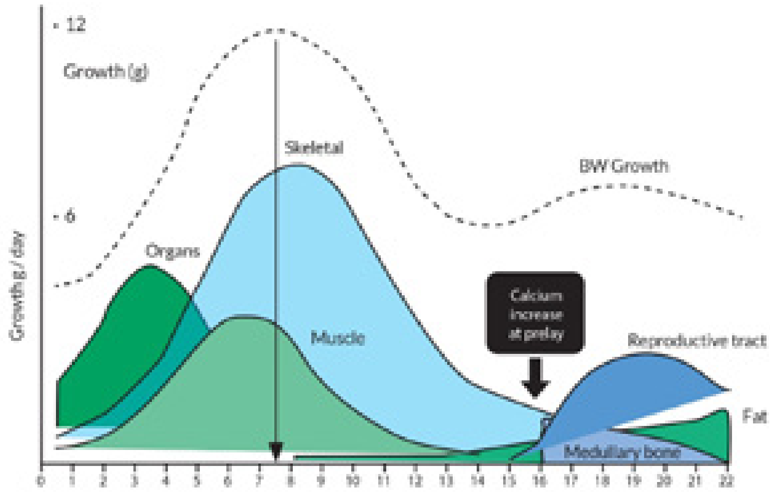
2.2 (Pre) starter phase

Feed intake will be limited during the first few weeks of the chick's lifetime, this is due to the limited capacity of the gastrointestinal tract. At this stage, birds are still not able to regulate their energy intake according to the energy level of the feed. When the feed is provided in a crumb or micro pellet form, young pullets can more easily increase their feed intake, thereby increasing energy and amino acid intake. If a beak treatment has been applied, the beak will be more sensitive, both crumble or micro pellets have proven to be more comfortable for the chick to consume. The energy intake can also be increased by increasing the energy levels in the diet.

Don't forget that chicks are born poikilothermic (it is hard for them to maintain their internal temperature) and that it takes around 4-5 days before the chick becomes homeothermic. Preparing and keeping the rearing farm at the proper temperature is of key importance during the first week after arrival, as it will prevent chicks from laying down without eating or drinking, this is also known as "non-starters". To give the chicks a good start , it is necessary to pay attention to the availability and consumption of water. Providing fresh and clean drinking water, with the right water temperature, ensuring the right height of the water system, and providing sufficient water pressure, will help your chicks with a good start.

During the first 5 weeks of age, feed particle size and feed management (feed consumption) should be uniform so all the feed particles are consumed by the chicks. Observing flock behavior closely, and monitoring barn climate, will indicate abnormalities in housing conditions. Regularly check for sufficient feeding and drinking system availability and monitor the effect on the chicks of treatments like vaccination.

Figure 1 body weight development during rearing and start of lay



During the (pre) starter period, the focus is on organ development, as shown in Figure 1. Therefore, it is necessary to provide a highly concentrated and high-quality feed that meets the chick's daily nutrient requirements. Providing a crumble encourages feed intake and therefore growth. With a crumble, the nutrient intake will also be more homogenous, which will also better meet the daily requirements of the chicks.
If feed intake and body weight growth with a starter diet is not sufficient, it might be wise to add a pre-starter diet, with a higher concentration of protein and energy, in the form of a micro pellet (2mm) or crumble for the first two weeks.

2.3 Grower phase

If the body weight is up to the desired standard, it is advised to switch from a starter feed towards a grower feed. Grower feed has a lower energy level than starter feed, as this will stimulate the chicks' feed intake and therefor also chick development. As the chicks are increasing their feed intake, the protein level can be slightly reduced; this will encourage the maximum growth of the chicks in the period of 6 to 10 weeks of age.

If mash diets will be given to the birds during the production period, the grower phase is the period when feed structure needs to be changed. Preferably, mash should contain a maximum of 10% fine (below 0.5 mm) particles and no coarse (over 3.2 mm) particles. Coarse particles can increase selective eating, while too much fine particles can result in longer eating time, which will both result in reduced feed intake and consequently in reduced pullet development and reduced uniformity of the flock.

2.4 Developer phase

The developer phase, from 10 weeks of age till the pre-lay phase, is the period to train your birds to eat and to further stimulate the development of the gastrointestinal tract. In this phase, the chicks are able to regulate their energy intake according to the energy level of the diet, . Be aware that various management actions might induce stress on the birds, for example stress as the result of chick handling, vaccination, or transfer of pullets. These stresses can result in reduced feed consumption. Underconsumption during that period is often the result of poor feed presentation. By this time, most of the body frame and the skeleton have already been developed. Therefore, a high increase in body weight during this period often results in an increase in fat deposition instead of an increase in the size of the frame. A second reduction in the energy and protein content of the feed will increase the birds' feed intake whilst maintaining a lean pullet. The energy level in the developer phase should be at least equal, but preferably lower compared to the pre-lay and layer 1 phase. It is easier to reach this by increasing the fiber content of the feed. Besides, coarse insoluble fiber will stimulate the development of the crop and will also increase the birds' eating time.

The objective during the period of 10 to 17 weeks of age is to train the pullets to develop the gastrointestinal tract, by both developing the gizzard for optimal digestion and by training the pullets to eat. If the pullets are well trained to eat, it will help them to increase their feed consumption by approximately 40% in the first few weeks of lay and is therefore associated with a much smoother transfer towards the laying phase. It is important to develop the digestive system during this period; this can be achieved by using diets with an energy concentration less than or equal to that of the layer's diet.

2.5 Pre-lay phase

Whether or not a pre-lay diet is being used, feed intake from the end of rearing until the peak of production should increase by 40%, while body weight should increase by 30%. Part of the increase in body weight can be explained by the development of the reproductive organs, as shown in Figure 1. This development of the reproductive organs also results in an increase in the birds' water intake. As such, it's important to ensure that fresh good quality drinking water is always available during the rearing period. It is important to pay sufficient attention to management and environmental conditions so that the birds' adaptation from the rearing barn to the production house is as stress-free as possible. The flock must be able to consume drinking water and feed as quickly as possible.

Another part can be explained by medullary bone development, which main role is to act as the strategic reserve of calcium, before the first ovulation. The total calcium contained in the medullary bone is around 1.5 to 2 grams. A pre-layer feed with a higher calcium level is needed to establish this medullary bone reserve. The pre-lay diet must be introduced around 10 days before the first eggs are being produced (approximately 15-17 weeks of age) until approximately 2% of hen-day of egg production. Layer 1 feed can be introduced with the appearance of the first eggs, this to avoid early decalcification in the laying hens that already started to produce.

As a result of this calcium deficiency, the hens will stop producing eggs, or reduce gg laying for some days, or they can produce soft shelled eggs. These hens can develop osteoporosis, and show signs of cage layer fatigue later in life. The characteristics of a pre-layer feed are similar to those in layer 1, but with a lower level of calcium; 2.20-2.50%. Calcium is a nutrient in high demand during the production phase, mainly utilized for egg shell formation and maintaining bone integrity in poultry. However, the most important sources of calcium, such as calcitic limestone, take up a lot of the total feed formula space and this increases the need for the inclusion of ingredients with a high nutritional quality, to meet all nutritional requirements.

2.6 Feed specifications during the rearing period

The suggested feed specifications during rearing are mentioned in Table 2. Depending on the body weight development of the pullets, the start of a new feed phase can be introduced earlier or postponed.

Table 2 Nutrient requirements during rearing

	Diet units	Starter[1] 0 - 5 weeks 1 - 35 days	Grower 6 - 10 weeks 36 - 70 days	Developer 11 - 16 weeks 71 - 112 days	Pre-lay 17 weeks to 1st egg
Metabolizable energy	Kcal/kg	2950-2975	2850-2875	2700-2750	2700-2750
	MJ/kg	12.3-12.4	11.9-12.0	11.3-11.5	11.3-11.5
Crude Protein	%	20.50	19.00	16.40	16.80
Lysine	%	1.16	0.98	0.76	0.82
Methionine	%	0.59	0.47	0.38	0.41
Methionine + Cysteine	%	1.00	0.85	0.66	0.71
Threonine	%	0.85	0.72	0.56	0.60
Tryptophan	%	0.26	0.22	0.18	0.19
Valine	%	1.00	0.85	0.67	0.72
Isoleucine	%	0.88	0.74	0.59	0.65
Arginine	%	1.19	1.01	0.79	0.85
Apparent faecal digestible amino acids					
AFD Lysine	%	1.00	0.85	0.66	0.71
AFD Methionine	%	0.54	0.43	0.35	0.38
AFD Meth. + Cystine	%	0.87	0.74	0.58	0.62
AFD Threonine.	%	0.70	0.59	0.46	0.49
AFD Tryptophan	%	0.22	0.19	0.15	0.16
AFD Valine	%	0.85	0.72	0.57	0.61
AFD Isoleucine	%	0.76	0.64	0.51	0.56
AFD Arginine	%	1.05	0.89	0.70	0.75
Standard Ileal Digestible amino acids					
SID Lysine	%	1.03	0.87	0.67	0.73
SID Methionine	%	0.56	0.45	0.36	0.39
SID Meth. + Cystine	%	0.89	0.75	0.59	0.63
SID Threonine.	%	0.71	0.60	0.46	0.50
SID Tryptophan	%	0.23	0.19	0.16	0.17
SID. Valine	%	0.87	0.74	0.58	0.62
SID Isoleucine	%	0.77	0.65	0.52	0.57
SID Arginine	%	1.08	0.91	0.71	0.77
Major minerals					
Available phosphorus	%	0.44 - 0.61	0.39 - 0.39	0.38 - 0.55	0.38 - 0.55
Retainable phosphorus	%	0.37 - 0.52	0.33 - 0.47	0.32 - 0.47	0.32 - 0.47
Calcium	%	0.8 - 1.1	0.7 - 1.0	0.7 - 1.0	2.2 - 2.5
Ratio Ca : aP		1.8 : 1.0	1.8 : 1.0	1.8 : 1.0	
Ratio Ca : retP		2.1 : 1.0	2.1 : 1.0	2.1 : 1.0	
Chloride	%	0.15 - 0.25	0.15 - 0.25	0.14 - 0.24	0.14 - 0.24
Sodium	%	0.18 - 0.21	0.16 - 0.21	0.16 - 0.20	0.16 - 0.20

[1] Preferably for at least 2 weeks in the form of a crumble or micro pellet
[2] Supply 50% of the calcium in granular form (2-4mm diameter)

3 The productive period

3 The productive period

3.1 Basic rules of our feeding program during the productive period

Feeding the chickens must be simple, to reduce the risk of errors at all levels during the manufacturing and delivery process. There are also additional reasons which are directly related to the flock. For example, birds are very sensitive to presentation of the feed, and also to the introduction of new raw materials. For this reason, we recommend the implement a limited number of feed changes and to gradually introduce the inclusion of new raw materials. The close monitoring of the stock levels of raw materials, and the availability of raw materials is important to make sure feed formulation changes are limited. Bear in mind that fluctuations in ingredient quality can result in flock performance fluctuations.

The amino acid requirements depend largely on the productivity of the flock and the uniformity of the flock's productivity. The amino acid recommendations, provided in this guide, are based on an average productivity of 59.5g of egg mass per day till 40 weeks of age, 59g of egg mass per day between 40 and 65 weeks of age, 57 g of egg mass per day between 65 and 90 weeks of age and 56g of egg mass after 90 weeks of age. A large proportion of the flock can produce over 60g of egg mass for a long period. Therefore, it is recommended to change the amino acid level from one feed phase to another only when the daily produced egg mass is decreasing, while uniformity of the flock is maintained. When changing the diets too early, the first impact of a deficiency in amino acids can be seen in the reduction of egg weight, followed by a drop in egg production a few weeks later. It is highly recommended to keep a close look at your daily production parameters, this will help you to steer in time!

At the onset of lay, it is desirable to encourage nutrient consumption, as this will help to obtain eggs of marketable size quickly. For this, it is recommended to use a feed that is enriched in fat and to incorporate a minimum of insoluble fiber. After the onset of lay, a diet slightly lower in energy level and richer in insoluble fiber, will allow to obtain a good energy efficiency (expressed in kcal) and to maintain the plumage in good condition. This strategy could be particularly beneficial for alternative housing systems, especially in the absence of ground litter.

The daily nutrient requirements must be in balance with the observed feed consumption in order to get the optimal percentage in the feed. The equation for the calculation is as following:

$$\frac{\text{(daily requirement (g/d))}}{\text{(feed consumption (g/d))}} \cdot 100\% = \%\text{ in feed}$$

When feed intake is insufficient, there will be a short period of nutrient shortage at the onset of lay, meaning that the hens will consume less nutrients per day than they require at that specific moment. It is essential to keep this period as short as possible. Increasing the energy density from the developer phase into the pre-peak phase will help to shorten and flatten this period. Otherwise, the hens will need to consume even more feed to offset their higher requirements, as the energy concentration is lower.

When feed composition is not adjusted accordingly, feed in the pre-peak period will be diluted automatically compared with the developer diet, since the level of calcium in the diet is increased for the formation of the eggshells. As calcium has no added value for energy, this will automatically reduce the energy content of the feed (i.e. it will dilute the feed). Because of this, it is extremely important to adjust the level and the type of energy rich components (such as oil) in the feed.

For the production phase, it is important to continue feeding the first phase until the moment that the produced daily egg mass starts to go down. It is advised to monitor carefully the performance on a daily basis. The body weight development of your flock should be monitored weekly till the peak of egg production, followed by monthly monitoring afterwards. This will allow to feed your flock according to their needs. The balance between feed consumption, the birds' physiological requirements and the nutrient availability will result in the balance between productivity and feed costs.

3.2 Layer 1

The layer 1 feed must be used from the start of egg production till 40 weeks of age, or till the moment when the daily egg mass starts to decline. It is advised to formulate for higher energy levels (+ 75-100 kcal per kg feed) in the production phase compared to the developer phase. The Layer 1 feed must meet all the amino acid requirements during the first few weeks of egg production, and it must meet the energy levels required for further body weight growth and egg production at a time where the feed consumption is still low. Please keep in mind that the hen's growth is not yet finished at the start of egg production and that this growth will continue till 30-35 weeks of age. When looking to the protein levels, the requirement for growth is added next to the requirement for egg production. At the onset of lay, feed consumption is lower because the birds have not yet reached their adult bodyweight and the digestive system is not yet prepared and trained to cope with such high levels of feed intake. On average, feed consumption needs to increase by 40% in a very short period of time!

At the onset of lay, it is desirable to encourage nutrient consumption in order to quickly obtain eggs of marketable size. For this, a layer feed enriched in fat allows to improve the presentation of the diet which results in an increase in feed consumption. Oils that are rich in polyunsaturated fatty acids, or mainly linoleic acid, are responsible for a large increase in egg weight. From a practical point of view, the dilution effect of raw materials which are rich in insoluble fiber and of low density can be compensated by the addition of fat. Feed granulometry also affects nutrient consumption, too fine feed particles lead to a reduction in feed consumption.

When taking into account the persistency in lay, the individual variation within the flock and the egg weight curves, it can be stated that the bird's amino acid requirement does not fall throughout the laying period. In an economic context, it may be worth reducing the safety margins slightly. However, the best results, in terms of productivity and feed conversion ratio, are achieved when the amino acid intake level is maintained. Any amino acid imbalance, no matter the type, results in a reduction in performance. 2/3 Of this reduction is due to a reduced rate of lay, the remaining 1/3 is the result of a decrease in the mean egg weight. Therefore, it is not possible to reduce the egg weight towards the end of lay by reducing the amino acid concentration without sacrificing the rate of lay.

3.3 Layer 2

Depending on the daily egg mass produced, the Layer 2 feed must be used from 40 till 65 weeks. It is advised to formulate for lower energy levels (-25 kcal per kg feed) in the layer 2 feed compared to the layer 1 feed. As laying hens have daily requirements for amino-acids and minerals, it is important that the percentage of nutrients must be defined according to the daily feed consumption and the production results observed. The feed consumption is highly determined by the energy requirements and the climate observed by the hens. Before changing the diet composition, monitor the average egg weight and the body condition of the hens closely. For example, if higher egg weights are requested, nutritional adjustment might be necessary.

3.4 Layer 3

Depending on the egg mass produced, the Layer 3 feed must be used from 65 weeks till 90 weeks of age, or till the end of lay. It is advised to formulate for lower energy levels (-25 kcal per kg feed) in layer 3 compared to layer 2.

3.5 Layer 4

Depending on the egg mass produced, this feed must be used from 90 weeks of age till the end of lay. It is advised to formulate for lower energy levels (-25 kcal per kg feed) in layer 4 compared to layer 3.

3.6 Feed specifications during the production period

The suggested feed specifications during production are mentioned in Table 3. Depending on the egg mass produced, the start of a new feed phase can be delayed. Please make sure the changes between the different phases are gradual changes.

Table 3 Recommendations for amino acids expressed as total and digestible amino acids during production in White and Brown layers and given for alternative feed intake levels in unit per kg feed.

Layer 1 - From 2% lay to 40 weeks	Grams intake		95	100	105	110	115	120
	Pounds intake		20.9	22.0	23.1	24.2	25.4	26.5
Energy cage			2800 - 2900 kcal / 11.7 - 12.1 MJ					
Energy alternative			2800 - 2950 kcal / 11.7 - 12.3 MJ					
Protein		%	18.0	17.7	17.3	17.0	16.6	16.3
Total amino acids	**mg/h/d**							
Lysine	945	%	0.99	0.95	0.90	0.86	0.82	0.79
Methionine	490	%	0.52	0.49	0.47	0.45	0.43	0.41
Meth. + Cys.	850	%	0.89	0.85	0.81	0.77	0.74	0.71
Threonine	685	%	0.72	0.69	0.65	0.62	0.60	0.57
Tryptophan	225	%	0.24	0.23	0.21	0.20	0.20	0.19
Valine	825	%	0.87	0.83	0.79	0.75	0.72	0.69
Isoleucine	740	%	0.78	0.74	0.70	0.67	0.64	0.62
Arginine	935	%	0.98	0.94	0.89	0.85	0.81	0.78
Apparent faecal digestible amino acids								
AFD Lysine	805	%	0.85	0.81	0.77	0.73	0.70	0.67
AFD Methionine	450	%	0.47	0.45	0.43	0.41	0.39	0.38
AFD Meth. + Cys.	740	%	0.78	0.74	0.70	0.67	0.64	0.62
AFD Threonine.	555	%	0.58	0.56	0.53	0.50	0.48	0.46
AFD Tryptophan	195	%	0.21	0.20	0.19	0.18	0.17	0.16
AFD Valine	700	%	0.74	0.70	0.67	0.64	0.61	0.58
AFD Isoleucine	645	%	0.68	0.65	0.61	0.58	0.56	0.54
AFD Arginine	840	%	0.88	0.84	0.80	0.76	0.73	0.70
Standard Ileal Digestible amino acids								
SID Lysine	835	%	0.88	0.84	0.80	0.76	0.73	0.70
SID Methionine	460	%	0.48	0.46	0.44	0.42	0.40	0.38
SID Meth. + Cys.	755	%	0.79	0.76	0.72	0.68	0.66	0.63
SID Threonine.	555	%	0.58	0.56	0.53	0.50	0.48	0.46
SID Tryptophan	195	%	0.21	0.20	0.19	0.18	0.17	0.16
SID Valine	705	%	0.74	0.71	0.67	0.64	0.61	0.59
SID Isoleucine	645	%	0.68	0.65	0.61	0.58	0.56	0.54
SID Arginine	850	%	0.89	0.85	0.81	0.77	0.74	0.71
Minerals								
Av. phosphorus	375 - 445	%	0.39 - 0.47	0.38 - 0.45	0.36 - 0.42	0.34 - 0.40	0.33 - 0.39	0.31 - 0.37
Ret. phosphorus	320 - 380	%	0.34 - 0.40	0.32 - 0.38	0.30 - 0.36	0.29 - 0.35	0.28 - 0.33	0.27 - 0.32
Calcium	3400 - 3900	%	3.58 - 4.11	3.40 - 3.90	3.24 - 3.71	3.09 - 3.55	2.96 - 3.39	2.83 - 3.25
Sodium min.	180	%	0.19	0.18	0.17	0.16	0.16	0.15
Chlorine	170-260	%	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.27
Layer 1 respected a daily egg mass of 59.5 gram								

Layer 2 - From 40 to 65 weeks	Grams intake Pounds intake		100 22.0	105 23.1	110 24.2	115 25.4	120 26.5	125 27.6
Energy cage					2775 - 2875 kcal / 11.6 - 12.0 MJ			
Energy alternative					2775 - 2925 kcal / 11.6 - 12.2 MJ			
Protein		%	17.3	17.0	16.6	16.3	15.9	15.6
Total amino acids	mg/h/d							
Lysine	930	%	0.93	0.89	0.85	0.81	0.78	0.74
Methionine	485	%	0.49	0.46	0.44	0.42	0.40	0.39
Meth. + Cys.	840	%	0.84	0.80	0.76	0.73	0.70	0.67
Threonine	675	%	0.68	0.64	0.61	0.59	0.56	0.54
Tryptophan	220	%	0.22	0.21	0.20	0.19	0.18	0.18
Valine	815	%	0.82	0.78	0.74	0.71	0.68	0.65
Isoleucine	735	%	0.74	0.70	0.67	0.64	0.61	0.59
Arginine	915	%	0.92	0.87	0.83	0.80	0.76	0.73
Apparent faecal digestible amino acids								
AFD Lysine	790	%	0.79	0.75	0.72	0.69	0.66	0.63
AFD Methionine	445	%	0.45	0.42	0.40	0.39	0.37	0.36
AFD Meth. + Cys.	730	%	0.73	0.70	0.66	0.63	0.61	0.58
AFD Threonine.	545	%	0.55	0.52	0.50	0.47	0.45	0.44
AFD Tryptophan	195	%	0.20	0.19	0.17	0.17	0.16	0.16
AFD Valine	695	%	0.70	0.66	0.63	0.60	0.58	0.56
AFD Isoleucine	640	%	0.64	0.61	0.58	0.56	0.53	0.51
AFD Arginine	815	%	0.82	0.78	0.74	0.71	0.68	0.65
Standard Ileal Digestible amino acids								
SID Lysine	825	%	0.83	0.79	0.75	0.72	0.69	0.66
SID Methionine	455	%	0.46	0.43	0.41	0.40	0.38	0.36
SID Meth. + Cys.	740	%	0.74	0.70	0.67	0.64	0.62	0.59
SID Threonine.	545	%	0.55	0.52	0.49	0.47	0.45	0.44
SID Tryptophan	195	%	0.20	0.19	0.17	0.17	0.16	0.16
SID Valine	695	%	0.70	0.66	0.63	0.60	0.58	0.56
SID Isoleucine	640	%	0.64	0.61	0.58	0.56	0.53	0.51
SID Arginine	835	%	0.84	0.80	0.76	0.73	0.70	0.67
Minerals								
Av. phosphorus	355 - 400	%	0.36 - 0.40	0.34 - 0.38	0.32 - 0.36	0.31 - 0.35	0.30 - 0.33	0.28 - 0.32
Ret. phosphorus	300 - 340	%	0.32 - 0.36	0.30 - 0.34	0.29 - 0.32	0.27 - 0.31	0.26 - 0.30	0.25 - 0.28
Calcium	3700 - 4200	%	3.70 - 4.20	3.52 - 4.00	3.36 - 3.82	3.22 - 3.65	3.08 - 3.50	2.96 - 3.36
Sodium min.	180	%	0.19	0.18	0.17	0.16	0.16	0.15
Chlorine	170-260	%	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.27
Layer 2 expected a daily egg mass of 59 gram								

Layer 3 - From 65 to 90 weeks	Grams intake Pounds intake		100 22.0	105 23.1	110 24.2	115 25.4	120 26.5	125 27.6
Energy cage			2750 - 2850 kcal / 11.5 - 11.9 MJ					
Energy alternative			2750 - 2900 kcal / 11.5 - 12.1 MJ					
Protein		%	17.0	16.7	16.4	16.1	15.7	15.4
Total amino acids	**mg/h/d**							
Lysine	915	%	0.92	0.87	0.83	0.80	0.76	0.73
Methionine	475	%	0.48	0.45	0.43	0.41	0.40	0.38
Meth. + Cys.	825	%	0.83	0.79	0.75	0.72	0.69	0.66
Threonine	660	%	0.66	0.63	0.60	0.57	0.55	0.53
Tryptophan	220	%	0.22	0.21	0.20	0.19	0.18	0.18
Valine	805	%	0.81	0.77	0.73	0.70	0.67	0.64
Isoleucine	720	%	0.72	0.69	0.65	0.63	0.60	0.58
Arginine	905	%	0.91	0.86	0.82	0.79	0.75	0.72
Apparent faecal digestible amino acids								
AFD Lysine	775	%	0.78	0.74	0.71	0.67	0.65	0.62
AFD Methionine	435	%	0.44	0.41	0.39	0.38	0.36	0.35
AFD Meth. + Cys.	720	%	0.72	0.69	0.65	0.63	0.60	0.58
AFD Threonine.	540	%	0.54	0.51	0.49	0.47	0.45	0.43
AFD Tryptophan	195	%	0.20	0.19	0.17	0.17	0.16	0.16
AFD Valine	685	%	0.69	0.65	0.62	0.60	0.57	0.55
AFD Isoleucine	625	%	0.63	0.60	0.57	0.54	0.52	0.50
AFD Arginine	805	%	0.81	0.77	0.73	0.70	0.67	0.64
Standard Ileal Digestible amino acids								
SID Lysine	810	%	0.81	0.77	0.73	0.70	0.68	0.65
SID Methionine	445	%	0.45	0.42	0.40	0.39	0.37	0.36
SID Meth. + Cys.	730	%	0.73	0.70	0.66	0.63	0.61	0.58
SID Threonine.	540	%	0.54	0.51	0.49	0.47	0.45	0.43
SID Tryptophan	195	%	0.20	0.19	0.17	0.17	0.16	0.16
SID Valine	685	%	0.69	0.65	0.62	0.60	0.57	0.55
SID Isoleucine	625	%	0.63	0.60	0.57	0.54	0.52	0.50
SID Arginine	825	%	0.83	0.79	0.75	0.72	0.69	0.66
Minerals								
Av. phosphorus	340 - 365	%	0.34 - 0.37	0.32 - 0.35	0.31 - 0.33	0.30 - 0.32	0.28 - 0.30	0.27 - 0.29
Ret. phosphorus	290 - 310	%	0.31 - 0.33	0.29 - 0.31	0.28 - 0.30	0.26 - 0.28	0.25 - 0.27	0.24 - 0.26
Calcium	4000 - 4500	%	4.00 - 4.50	3.81 - 4.29	3.64 - 4.09	3.48 - 3.91	3.33 - 3.75	3.20 - 3.60
Sodium min.	180	%	0.19	0.18	0.17	0.16	0.16	0.15
Chlorine	170-260	%	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.27
Layer 3 expected a daily egg mass of 57.5 gram								

Layer 4 - From 90 to 120 weeks	Grams intake Pounds intake		100 22.0	105 23.1	110 24.2	115 25.4	120 26.5	125 27.6
Energy cage			2725 - 2825 kcal / 11.4 - 11.8 MJ					
Energy alternative			2725 - 2875 kcal / 11.4 - 12.0 MJ					
Protein		%	16.6	16.3	16.0	15.7	15.4	15.1
Total amino acids	mg/h/d							
Lysine	890	%	0.89	0.85	0.81	0.77	0.74	0.71
Methionine	460	%	0.46	0.44	0.42	0.40	0.38	0.37
Meth. + Cys.	795	%	0.80	0.76	0.72	0.69	0.66	0.64
Threonine	650	%	0.65	0.62	0.59	0.57	0.54	0.52
Tryptophan	210	%	0.21	0.20	0.19	0.18	0.18	0.17
Valine	785	%	0.79	0.75	0.71	0.68	0.65	0.63
Isoleucine	700	%	0.70	0.67	0.64	0.61	0.58	0.56
Arginine	880	%	0.88	0.84	0.80	0.77	0.73	0.70
Apparent faecal digestible amino acids								
AFD Lysine	760	%	0.76	0.72	0.69	0.66	0.63	0.61
AFD Methionine	425	%	0.43	0.40	0.38	0.37	0.35	0.34
AFD Meth. + Cys.	695	%	0.70	0.66	0.63	0.60	0.58	0.56
AFD Threonine.	530	%	0.53	0.50	0.48	0.46	0.44	0.42
AFD Tryptophan	185	%	0.19	0.18	0.17	0.16	0.15	0.15
AFD Valine	665	%	0.67	0.63	0.60	0.58	0.55	0.53
AFD Isoleucine	610	%	0.61	0.58	0.55	0.53	0.51	0.49
AFD Arginine	795	%	0.80	0.76	0.72	0.69	0.66	0.64
Standard Ileal Digestible amino acids								
SID Lysine	790	%	0.79	0.75	0.71	0.69	0.66	0.63
SID Methionine	435	%	0.44	0.41	0.39	0.38	0.36	0.35
SID Meth. + Cys.	710	%	0.71	0.68	0.64	0.62	0.59	0.57
SID Threonine.	535	%	0.54	0.51	0.48	0.47	0.45	0.43
SID Tryptophan	185	%	0.19	0.18	0.16	0.16	0.15	0.15
SID Valine	665	%	0.67	0.63	0.60	0.58	0.55	0.53
SID Isoleucine	610	%	0.61	0.58	0.55	0.53	0.51	0.49
SID Arginine	805	%	0.81	0.77	0.73	0.70	0.67	0.64
Minerals								
Av. phosphorus	330 - 355	%	0.33 - 0.36	0.31 - 0.34	0.30 - 0.32	0.29 - 0.31	0.28 - 0.30	0.26 - 0.28
Ret. phosphorus	280 - 300	%	0.29 - 0.32	0.28 - 0.30	0.27 - 0.29	0.25 - 0.27	0.24 - 0.26	0.23 - 0.25
Calcium	4300 - 4700	%	4.30 - 4.70	4.10 - 4.48	3.91 - 4.27	3.74 - 4.09	3.58 - 3.92	3.44 - 3.76
Sodium min.	180	%	0.19	0.18	0.17	0.16	0.16	0.15
Chlorine	170-260	%	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.27
Layer 4 expected a daily egg mass of 56 gram								

3.6 Mineral specifications during the production period

Shell weight increases with age throughout the entire laying period, while the hen's efficiency to absorb calcium declines with age. For that reason, we strongly advise to start with relatively low calcium concentration in the diet at start of production and gradually increase when the laying hens are getting older. Further information about minerals can be found in the chapter on Mineral recommendations.

3.7 Amino acid requirements

Laying hen requirements and the formulation of diets should be made in terms of digestible amino acids. By formulating in digestible amino acids, one is better able to satisfy the requirements of the hens, to reduce the necessary safety margins, and to assess the raw materials according to their true biological value. Formulation according to total amino acids leads to the same nutritional value being given to all raw materials irrespective of their digestibility. Often, feed formulation is based on digestible amino acids, either apparent fecal digestibility or standard ileal digestibility. Therefore, crude protein levels can be lower compared to the given recommendation if the right amino acid level and balance is available.

It is well known to formulate according to the main limiting amino acids in layer nutrition. The limiting amino acids are: : lysine, methionine, cysteine, threonine and tryptophan. To reduce the total crude protein content, the formulation of layer diets can be adjusted by introducing Isoleucine and Valine, as nutritional constraints. If this is not possible, it is necessary to keep a constraint for the minimum of protein, to reduce the risk of a protein deficiency. Raw materials vary in their levels of specific amino acids; therefore, it is important to know the limiting factors of your raw materials. For example, Isoleucine and Valine levels are rather low in wheat and meat and bone meal,, while methionine is limited in soy products. On the other hand, Arginine does not appear to be limiting in layer diets.

The amino acid concentration of the diets depends on:
1. Potential daily egg mass produced, which determines the daily requirements.
2. The daily feed consumption which determines the amino acid concentration.

Persistency in egg production has improved considerably (e.g. 30 to 50 weeks above 90% lay). An analysis of the individual performance over the period from 44 to 66 weeks shows that 65% of the hens were performing above average, as shown in Table 4. The 40% best egg layers had produced on average 153 eggs in 156 days, resulting in a daily egg mass of 58.5grams.

Table 4 Production levels of birds in a flock: the average versus best performing

Quintile	Rate of lay	Egg Mass (gram per day)
1st	98.5	59.4
2nd	97.7	58.0
3rd	96.7	58.0
4th	97.5	58.3
5th	95.1	56.5
Average	95.8	57.1
% of pullets above the average	64.7	52.5

Source: Internal research (2025). It can be noted that the eggs produced by the birds that are present in the 1st Quintile (highest producing birds) were smaller compared to the eggs produced by the birds in the 2nd Quintile.

3.9 AFD versus SID

Apparent Faecal Digestibility (AFD) and Standardized Ileal Digestibility (SID) are different methods of assessing the nutritional requirements of poultry. The main difference between these methods is the site of measurement. Where AFD evaluates nutrient digestibility based on faecal output, which includes the effects of microbial fermentation in the hindgut and does not correct for endogenous losses and may therefore underestimate the actual digestibility of amino acids. Whereas SID measures digestibility at the ileum, before microbial activity can alter amino acid content and corrects for endogenous amino acid losses, providing a more accurate estimate of amino acid availability. When formulating poultry diets, either AFD or SID values can be used, but it's important to match the values with the appropriate nutrient matrix. The nutritional data for ingredients must correspond to the digestibility method used to ensure accurate diet formulation.

3.10 Energy requirements

In general, energy regulation is not breed specific, but due to differences in body weight, it can be slightly higher (+ 25 kcal) for brown egg layers compared to white egg layers. Further, it depends on the dilution methods used and the energy requirements for growth, daily maintenance and egg production. The feed density (gram per liter) seems to be the limiting factor in ingestion regulation, especially during the early rearing and early production period, or during stressful periods.

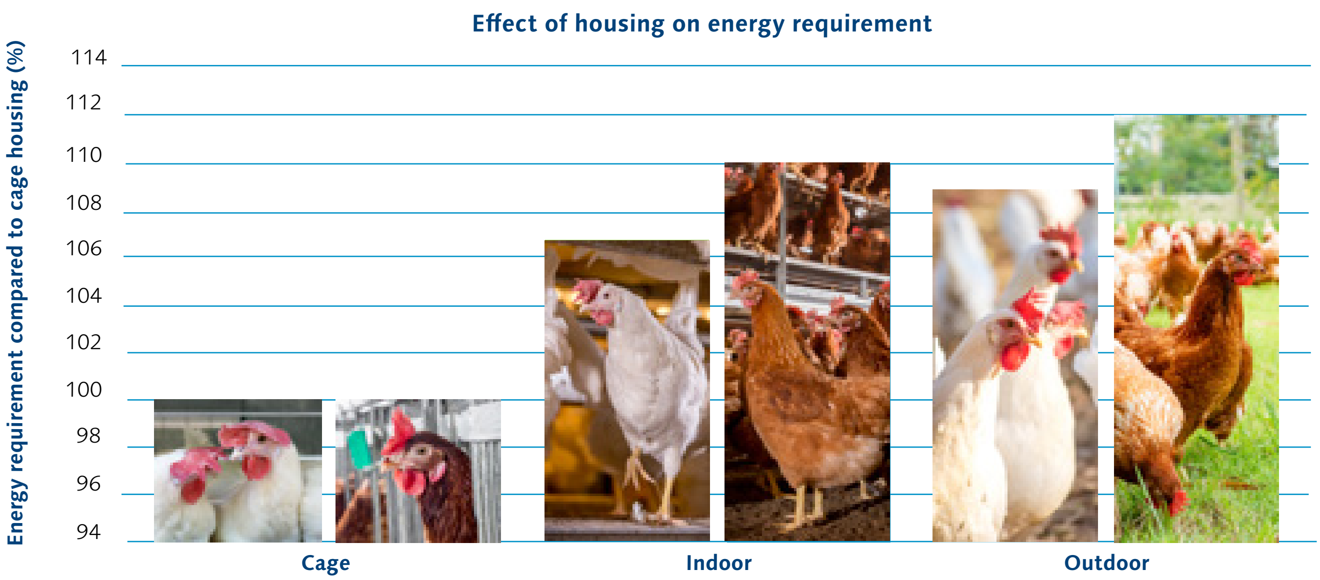
The addition of fat to the diet results in an improvement in feed palatability and thus an increase in the ingestion of energy in proportions which can be very significant. Energy and calcium can compete in space and interact in feed formulation. High levels of oil inclusion in combination with high levels of calcium in the diet can reduce the absorption rate of both, due to the saponification effect. The increase in egg weight is just one of the effects for added oil. These effects are dependent upon the quality, dosage and the type of fats added to the diet. An energy surplus or energy deficiency can affect the productivity, feed intake and body condition of the hens. The diet should be adjusted according to each market's preference for egg size. To avoid that the size of the eggs is becoming too large towards the end of the laying cycle, we advise to gradually reduce the quantity of vegetable oil being used in the diet.

3.10.1 Feed intake

Feed intake is still a limiting factor at the start of lay and early rearing. The goal should always be to increase the birds' feed intake at start of lay to approximately 100 grams a day as soon as possible. But keep in mind, depending on how well the birds are trained to eat, and independent on the energy concentration of the diet, it can take several weeks to develop a proper feed intake.

The addition of fats seems to have a specific effect on the energy consumption due to an improvement in palatability and the physical form of the feed. In general laying hens adjust their feed intake according to the energy levels of the feed. But Please note, after a diet has been diluted, it takes several weeks for the laying hens to increase their levels of feed consumption. Furthermore, feed efficiency (e.g. feed conversion rate), expressed in grams of feed consumed per gram of egg produced, will always improve when the feed is more concentrated in terms of energy and amino acids.

Figure 2 The effect of housing on the energy requirement of White and Brown egg layers.
Housing types are (enriched) cage, indoor (barn and aviary) and outdoor (free range and organic).
Cage housing has been used as a reference for both white and brown laying hens.



The energy requirement is increasing in alternative housing systems, the amino acid requirement is only increasing in limited amount. Therefore it is important to increase the energy level of diet used in alternative production compared to a diet used for cage production, whilst maintaining the same requirements for both protein and amino acids.

3.10.2 Housing

Different housing systems require different daily energy requirements. Birds in alternative production systems are more active and, in case they have outdoor access, they also need to deal with variations in temperature. Depending on the type of housing system, the indoor and outdoor temperature, and the hens' feathering, feed consumption can be increased by even more than 20%. The nutritional requirement needed for the hens' activity and to maintain her thermoregulation is predominantly in the form of energy, which increases the maintenance requirement. White egg producing laying hens require 7% more energy in aviary and barn systems, and up to 10% more energy in free range and organic systems when compared to the requirements in cage housing. For brown egg producing laying hens this is 9% (for barn and aviary) and 12% (for free range and organic) respectively. The impact of housing on feed consumption can also be seen in Figure 2.

3.11 Stimulating egg size by nutrition

Remember that the actual egg mass that is being produced depends on the amount of nutrients received and absorbed. Therefore, it is of high importance to install a routine of monitoring the quality of the feed ingredients and the actual feed intake. Variation in egg size in young flocks can be related to management (e.g. the lighting programs and availability/ competition for feed and water), but also to the body weight and body weight uniformity. Variation in egg size in older flocks can be related with health aspects (e.g. worms, feather loss), body weight uniformity or restriction in /competition for feed and water.

It is known that both management and nutrition can influence egg weight. Key management decisions should be taken during the rearing period, as these decisions will influence the average egg size for the total laying cycle and this is the most effective period, not only regarding the response in egg size but also economically-wise. There are various other feeding techniques or adjustments via nutrition that can help to adjust egg size upwards or downwards in a shorter term.

There are several nutritional factors that will clearly influence egg weight, the most important are listed below:
-the level and balance of methionine + cysteine

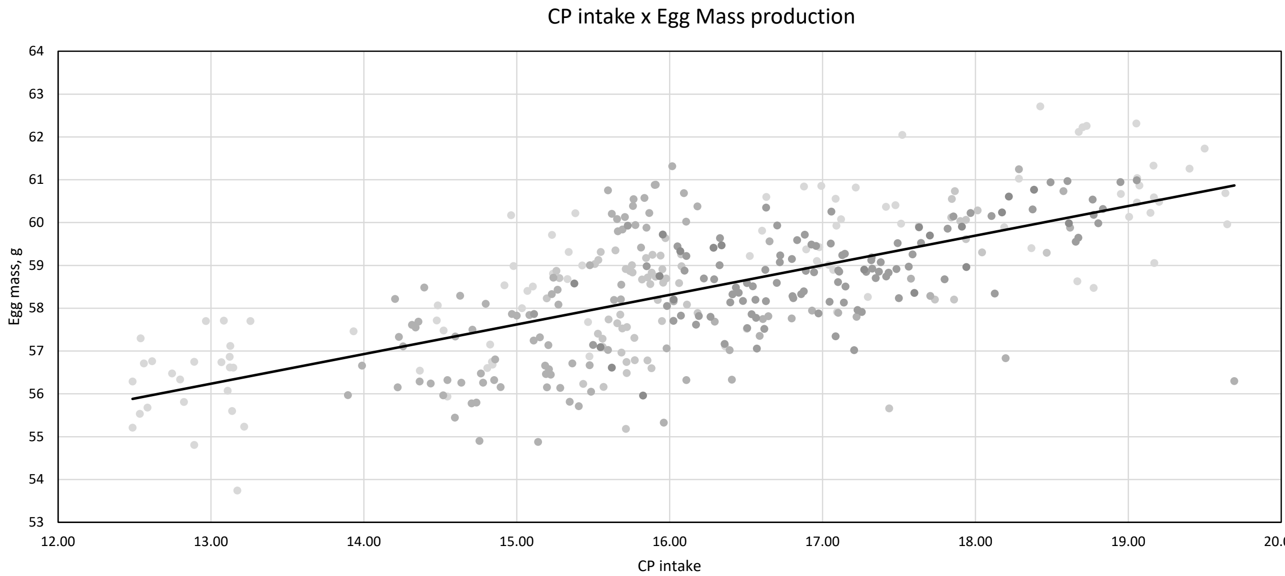
- The level and balance of lysine and other essential amino acids
- The total fat content
- The total linoleic acid content

At all times, protein and energy content in the diets should be properly balanced to ensure that daily requirements for the essential amino acids are met for optimum egg production performances.

Amino acid and crude protein intake, as shown in Figure 3, has a linear effect on total egg mass within a certain range, some of them playing a more important role in egg size, like methionine + cysteine and lysine, while others have a lower effect on egg weight, like tryptophan and threonine. Please note that all of them are essential to ensure adequate egg production. This means that formulating for a higher digestible amino acid intake will increase egg size but exceeding a certain level brings no further positive effect. In an opposed scenario, when the target is smaller egg size, reduction in amino acid levels is theoretically possible but there is a risk of amino acid deficiency which would negatively affect the daily egg production and the feed conversion ratio. Decreasing the amino acid levels at the end of the laying period in order to control egg size, if ever practiced, should be done gradually and always monitor your flocks laying rate properly.

Figure 3 The effect of crude protein (CP) intake (g/h/d) on egg mass (g/h/d)

The figure below, provided by Cargill Animal Nutrition and Health, showing the impact of dietary crude protein intake on egg mass weight in laying hens, with shades of grey representing different ages from wk 25 to 75. Hens were fed amino acid ratios according to Cargill recommendations, and Cargill ANH representatives in the local market can be contacted for more information.



Egg weight is also affected by the total fat content: revision of available research shows that there is a linear effect on egg size from 2 to 6% inclusion level. Using high levels of crude fat at the start of lay is recommended when larger egg sizes are desired. This positive effect can be partly explained by the improved palatability and higher energy levels of the feed, resulting in an increased daily energy intake. It will also help to stimulate growth towards the adult body weight at the onset of lay, despite of the limited feed intake at this age. The stimulation of growth will have a positive effect on egg size and the total egg laying performance of the flock.

Linoleic acid has a positive effect on egg size, but only within a certain range. The daily requirements of laying hens for linoleic acid are not high, around 1.2%. Higher levels of linoleic acid, up to 2.9%, can be used to obtain larger eggs. Raw materials that are used as sources of fat can vary greatly on their fatty acid profile, and will therefor have different effects. Vegetable sources, like soybean oil or sunflower oil, which are rich in unsaturated fatty acids (high linoleic acid content), are first choice ingredients in order to get your birds producing larger eggs.

4 Tropical conditions

4 Tropical conditions

Heat stress affects the nutrient utilization of laying hens via several ways. At first, when the birds are incapable of temperature regulation, they will reduce their feed intake to reduce the heat production from digesting the feed. Heat increment is highest for protein, therefore it is recommended to focus on digestible amino acids whilst minimizing an increase in crude protein levels to compensate for the reduced feed intake. At second, it is important to remember that chickens are not able to sweat like mammals can. Instead, to lose their heat they start panting, a process which requires energy and could result in respiratory alkalosis. As a consequence, the nutrient utilization is decreasing, as absorption rates are reduced.

Heat stress can result in a decreased feed intake, nutrient deficiency, respiratory alkalosis and poor eggshell quality. High temperatures will also rise the level of corticosteroids and this can result in oxidative stress. All the aforementioned, will affect the laying hens' performance and can result in increased mortality levels. The severity of the negative consequences of heat stress in a flock of laying hens depends highly on the intensity of the duration.

Depending on the air movement and the humidity, heat stress can lead to:

- A reduction in egg weight by ± 0.4% per °C between 23 and 27°C and by ± 0.8% per °C above 27°C.
- Growth at point of lay is reduced above 24°C, and is severely reduced above 28°C.
- The rate of lay is generally only affected above 30°C.
- Feed conversion ratio is minimum at a temperature of around 28°C; above 28°C it increases, because of the drop in egg production.

Under tropical conditions (high temperature and high humidity) there is a higher risk for rapid growth of bacteria and fungi on raw materials and poultry feed. The bacteria and fungi can produce mycotoxins which have a negative impact on chicken health. Toxic contaminants affect the immune response by decreasing the number and phagocytic capacity of leukocytes as well as decreasing the production of B and T lymphocytes. Furthermore, the developments of microorganisms in feed will cause an unbalance in the gut microbiota and it is known that commensal bacteria have a beneficial role in developing the intestinal host defenses and boosting the immune response.

4.1 Reduced feed intake and heat increment

When facing heat stress, laying hens will reduce their feed intake if they are incapable of temperature regulation, as both the consumption and digestion of feed will increase the production of body heat. Besides a decreased feed intake, nutrient digestion and absorption is reduced as well, due to an impaired intestinal health. Oxidative stress results in an impaired gut integrity. As a consequence, the microbiota can change which results in the occurrence of intestinal inflammation. The blood flow towards the intestines is reduced, resulting in a decreased protein absorption. Additionally, protein synthesis is decreased, resulting in reduced protein deposition and increased protein degradation. Together this can result in a nutrient deficiency. If this occurs, it will result in reduced growth during the rearing period and consequently delayed start of lay. All in all, this will result in an overall lower number of first quality eggs produced per hen housed, and lower egg sizes will be achieved during the production period.

Decreased feed intake	Reduced nutrient digestion	Reduced nutrient absorption	Nutrient deficiency	Reduced growth and production

4.2 Respiratory alkalosis and loss of electrolytes

Panting reduces the CO2 level in the blood and consequently increases blood pH (respiratory alkalosis). To compensate for the increased blood pH, the laying hen will increase her urine production and consequently lose moisture (resulting in dehydration) and electrolytes. Sodium and potassium are important electrolytes, which will be lost via urinating.

Panting	Reduced CO^2 blood level	Increased blood pH (respiratory alkalosis)	Increased urine production	Lose of moisture and electrolytes

4.3 Egg shell quality

As birds are losing CO2 by panting, their blood pH is increased, which the birds will compensate with higher levels of carbonate in the blood. Consequently the availability of calcium for the production of good quality eggshell is reduced. In addition, laying hens have a reduced feed (and calcium) intake, a reduction in calcium binding proteins (calbindin), and a reduction in estrogen and therefore activation of vitamin D3 in the kidney, all resulting in the reduced availability of calcium for eggshell formation.

Respiratory alkalosis	Affected calcium metabolism	Reduced activation of vitamin D3	Nutrient deficiency	Reduced egg shell quality

4.4 Strategies for reducing the negative effects of heat stress in laying hens by nutrition

Nutrition is the combination of feed formulation, water quality, and water and feed management. It is highly recommended to have a good and regular monitoring of feed quality in place, as fat oxidation, bacterial load and mycotoxins can be more critical during tropical conditions.

4.4.1 Feed formulation

Adaptation in feed formulation can help the laying hens to reduce the negative effect of heat stress. However, feed changes result in an extra stressor and can result in a temporary lower feed intake, therefore it is recommended to not change the feed formulation, when there is only a short-term heat stress.

Energy and protein

Replacing part of the carbohydrates by fat, will reduce the heat increment of the birds and therefore lower the heat production from digestion, as shown in Table 5. The addition of extra fat is increasing the palatability of the feed, and so stimulate feed intake. Increasing fat levels will help to increase the energy content of the feed, which can compensate partly for the reduced feed intake. It is strongly recommended to check the fat quality being used, as fat oxidation accelerates during higher temperatures.

As shown in Table 5, protein digestion will result in the increment of heat production. In addition, protein absorption is reduced as one of the effects on the metabolism due to heat stress. Therefore, it will help the laying hens to reduce part of the protein levels in the diet, whilst maintaining or increasing the amino acid level. Feeding higher digestible protein sources or a higher amount of synthetical amino acids will help the laying hens to maintain their daily amino acid intake. As amino acids are mainly deposited in the egg itself, the amino acids content in the feed should be adapted to the real feed consumption noticed.

Table 5 Heat increment of feeding (in % of ME) (Wu, 2018)

Nutrient	Chickens
Fat	10
Starch	18
Protein	44
Mixed ration	25-30

Vitamin and minerals

It is recommended to increase the level of carbonate via adding sodium bicarbonate to the feed, by formulating both on Sodium and Chloride levels. Sodium can be added via sodium bicarbonate in feed, but electrolytes can be added via the drinking water as well. Vitamin E and C can minimize oxidative stress and so cell damage. Choline and Betaine can help to maintain the osmotic balance to protect cells for dehydration. While magnesium and vitamin C can reduce the cortisol level. If vitamins are added on the water lines, pay attention to the dilution and water quality prior and after usage. After a water treatment with vitamins, it is advised to clean the drinking lines. Recommended levels of important vitamins during tropical conditions and their function related to tropical conditions are given in Table 6.

Table 6 Recommended vitamin level during tropical conditions and main function to reducing the negative effects of heat stress in laying hens.

	Function	Recommended level (mg/kg final feed)
Vitamin C	Antioxidant at cellular level	150
Vitamin E	Antioxidant at cellular level	100
Choline	Fat metabolism and protects against cellular osmotic stress	1000
Betaine	Protects against cellular osmotic stress	150

4.4.2 Feed management

After the night, birds are hungry, and they will start to consume feed in the morning. It is highly recommended to prevent feeding the birds during the warm periods of the day, so feed them in the morning and late afternoon. Make sure that feed is always available during the cooler periods, also early in the morning. Installing extra drinkers and feeders will stimulate feed and water intake, and will reduce competition and therefor improves flock uniformity.

If body weight targets are not reached during the rearing period, delay the shift from one feed phase to another (from starter to grower and from grower to developer) till the pullets have reached their target body weight. This will help

the pullets to develop proper during the rearing period. **Keep in mind, always change to a next phase based on performance (either growth and/or egg mass) and not based on age.**

Feed particle size and diet palatability

When severe heat stress occurs, it can help to feed a more palatable diet, to stimulate the feed intake. This can be done via adding some oil, molasses or water on the feed. Feeding a mash diet with less fines (max 10% below 0.5mm) will reduce the time that the birds spend eating and will increase feed intake. For the first 5 weeks of age, aa crumbled diet is recommended to achieve the right body weight development.

Midnight snack

In order to stimulate feed intake, midnight feeding can be implemented. This 1.5 to 2 hours of light in the middle of the dark period encourages water and feed intake and therefor growth. Furthermore, it helps to provide calcium during the period of intensive shell deposition. Providing light from 4 to 20 hours and at night from 23 hours to 1 o'clock in the morning appears to be the program adopted in most hot countries, between latitudes 20° north and 20° south.

Calcium management

To optimize eggshell quality, it is important to take the quantity of calcium in the diet into account, the size of the calcium particles and the time that calcium is provided. With a pre-lay diet (fed till approx. 2% production) you safeguard the development of medullary bone, which functions as a reserve for calcium. Preferably coarse calcium (2-4mm) is fed in the late afternoon, this will allow calcium to be available during the eggshell formation period. It is helpful to provide a higher level of calcium on top of the feed in the late afternoon, while correcting the daily calcium intake. Especially under tropical conditions, when feed intake is reduced during warmer periods of the day (including the afternoon). Additional calcium can be added manually, mixed, on top of the feed or in separate feeders, as shown in Figure 3 and Figure 4.

Figure 3 Laying hens in heat stress

Figure 4 Addition of calcium on top of the afternoon feed

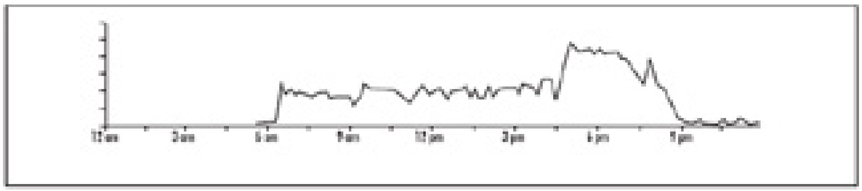
4.4.3 Water quality and management

Laying hens will increase their water intake during periods of heat stress. As water is used for controlling body temperature and therefore laying hens will eliminate body heat via evaporation. Therefore, the higher ambient temperature, the more water intake is observed. Water quality is extremely important under tropical conditions, since the bacterial load (e.g. E. Coli) are rapidly increasing during hot and humid conditions. This bacterial load not only affects the drinking water quality, but also litter quality if cooling via water spraying (evaporation) is applied.

Providing enough fresh and clean drinking water will encourage the birds to drink and consequently to eat. As shown in Figure 4, birds are consuming most of the water during the end of the day. It is important to provide clean, fresh drinking water of the correct temperature during the entire day, but especially at the end of the day. Flushing water lines will help to maintain the correct temperature of the water and to keep your water clear. Please note, the cooler the drinking water, the better the birds can tolerate the high environmental temperatures. Protecting the water reservoirs and the plumbing from direct sunlight is essential in keeping the water as cool as possible. When the water is collected in the piping system or the barn, the drinking water should be renewed periodically. Make sure this is not interfering with the water system or water availability.

It is very important to flush the water and drinking systems after adding electrolytes or vitamin supplementations on the water to support your birds to deal with heat stress. Flushing, potentially in combination with sanitizing the system, will help to prevent bacterial growth in the water lines and a possible change in the taste of the water.

Figure 4 Daily water intake pattern (lights on between 6.30 AM and 9.00 PM) (Leeson & Summers, 2005)



How to support your birds in hot and tropical climates?

- Feed texture: a coarse mash with added oil will reduce the time and energy spend on eating and therefore will stimulate feed intake compared to a fine mash.
- Feeding times: try to run the feeders in the morning and late afternoon, to encourage feed intake during the cooler periods of the day. A midnight snack can be an interesting tool to increase feed intake in the middle of the night, when the environmental temperatures are in general cooler.
- Water: flush the water system regularly, this will result in availability of fresh and cool water to the flock.
- Higher amino acid levels in the feed can support egg production, as feed intake is reduced and the daily nutrient intake equals the feed intake times the concentration. Do not increase the protein level.
- Replace part of the energy towards an oil or fat source instead of carbohydrates. As fat results in a lower heat increment compared to carbohydrates.

5 Feed management and feed presentation

5 Feed management and feed presentation

5.1 Feed and water management

The number of feeders and drinkers, feed distribution, the presentation of the feed and the farmers' management are strong contributors to ensure uniformity and good performance. Therefore, it is important to provide enough feeder and drinker space for your birds. More detailed information about management and recommendations of the drinker and feeder space at different ages and different housing systems can be found in our different management guides that are all publicly available.

5.2 Feed presentation

Feed consumption is determined to a large extent by feed presentation, feed concentration and the stage to which the digestive tract has developed. Presenting feed in crumb form or micro pellet (during the starter phase) makes it easier for the chicken to consume, reduces the time taken in eating, and encourages growth of the chick in the first weeks at the rearing farm. As a result, the lower energy cost needed for feed intake will give an improvement in the feed conversion ratio. This benefit of feeding crumbs will only be obtained when the birds have access to good quality crumbs in the feeders. A poor-quality crumb or micro pellet can lead to the accumulation of fine particles in the feeders, which can cause the opposite effect. On the other hand, if the feed is grinded into a fine mash which is used to produce a pellet or crumble, it has a very limited effect on the development of the digestive tract of the young birds.
As the digestive capacity during the early life is still limited, we recommend using a crumbled diet during the starter phase.

To stimulate the digestive tract development afterwards, we recommend using a good quality mash or a pellet with coarse ground materials from approximately 5 weeks onwards. Alternatively the feed structure can be changed from crumble or micro pellet to a mash or coarse pellet at 2 weeks of age, while feeding the same diet specification for another 3 weeks. This is minimizing stress by separating the feed structure change and the feed composition change. When the body weight is not according to desired target, it is possible to continue feeding crumble a bit longer. To avoid the risk of under-consumption at the beginning of the hens' sexual maturity, it is recommended to make the change in feed structure the latest when moving from the grower to the developer phase. Underdeveloped feed intake can be the result of a too late change from crumble to mash or pellets.

5.2.1 Pelleted or crumbled diets

- In theory, presenting a diet in crumb or pellet form will result in higher feed consumption. That presupposes that the feeding systems in operation and the raw materials used are providing the laying hen with a good quality pellet or crumb. Very often, the difficulties in obtaining a good quality crumb are responsible for under-consumption and certain technical problems because of:
- the breaking down of the crumb in the feed distribution system
- the build-up of fine feed particles in the feeders
- more shell quality problems related to the difficulties in using a granular limestone
- more feather pecking due to a shorter feeding time
- reduced nutrient utilization due to a less developed gastro-intestinal tract

Pellets and crumbles can result in increased manufacturing costs, due to the extra energy utilization. To develop a good digestive system, it is necessary to have coarsely milled feed. Because of this we recommend having at least 25% of the particles above 1.0mm after pelleting from 5 weeks onwards, This can be quite challenging and should be checked with a wet sieve analysis.

With the intention of keeping good shell quality we suggest:
- Use a granular calcium source if the particle size of the diet is adapted.
- Add some of the calcium source after pelleting.
- Reduce 3 to 4% of the granular calcium (2 to 4mm) in the feed and instead provide it separately in the poultry house each afternoon, either as a top dressing or in separate bins.

5.2.2 Mash diets

During the laying period, a good textured diet will allow the birds to increase their feed consumption, their production and their growth. In hot climates, a good textured feed can reduce the under-consumption experienced during the warmest season. That's why, we advise having at least 75 to 80% of the particles between 0.5 and 3.2mm. This type of diet is in fact easier and cheaper to produce. The attractiveness of the diet improves markedly if the fine particles are sticking together. That can be achieved by the addition of 1.5 to 2.5% vegetable oil.

Feed presentation affects the bird's appetite for feed and so the feed intake level. The suggested particle sizes are mentioned in Table 7.

Table 7 Feed particle distribution

Particle size	Starter and grower	Developer, pre-lay and layer
< 0,5mm	Max 10%	Max 10%
0,5 - 1mm	Max 15%	Max 10%
1,0 - 3,2mm	Min 75%	Min 70%
> 3,2mm	Max 0%	Max 10%

At least 75% (starter and grower diets) and 70% (developer, pre-lay, and layer diets) of the feed particles should fall within the range of 1 to 3.2mm.

For monitoring feed particle size and feed distribution or segregation we recommend to regularly sieve a representative feed sample. More detailed monitoring can be done via using a set of sieves and an agitation system. Too coarse or whole grains, especially for young birds, can indicate a hole in the sieve of the grinding system. Fine feed will increase the energy demand for the feed mill and reduce the milling capacity. It is recommended to monitor and maintain the feed processing equipment according to the maintenance manuals from the equipment manufacturer to maintain a good and constant feed particle size.

5.2.3 Raw materials

Raw materials, or feed ingredients, are the carriers of the nutrients. The main feed ingredients are either to provide energy, i.e. carbohydrates or fat, or protein to the diet. Next to those major raw materials, the minor raw materials, such as minerals and vitamins, are essential as well. Our laying hens are selected to cope with (certain levels of) several so called alternative protein and energy sources. The positive fact of using multiple raw materials is to spread the risk. For example, if you have two different energy containing ingredients in a 50:50 ratio, and one of these ingredients has a lower quality than expected, there is at least still half of the energy containing material with a proper quality present in the diet.
Nevertheless, it is necessary to have a proper feed quality monitoring and control system in place. This will provide information about the raw material quality, the nutrient content and the suitability to feed these ingredients to your chicks,

pullets and laying hens. Additionally, it will help to use the correct matrix when calculating the diet specifications in your diet formulation program.

Next to the chemical quality, the physical quality has a clear impact on the birds' feed intake and performance. It is highly recommended to check color variations between various feed batches, as these color variations can indicate variations in nutritional value. Avoid raw materials which are too dusty and do not grind ingredients which don't need grinding.

5.3 Fiber for layers

The presence of insoluble fiber appears to be essential. An appropriate supply of fiber results in a better feather cover, improved livability, good intestinal health, better digestion (of mainly starch) and drier manure quality. Livability is positively influenced by the presence of fiber because it increases the feeling of satiety in birds, which in turn results in quieter birds by eliminating the need for feather ingestion (which can induce feather pecking and cannibalism). Adding coarse fiber to the diet increases gizzard development, improves starch digestibility and limits feather pecking by reducing the need to ingest feathers. Diluting the feed by adding fiber helps to maintain a good energy balance in older birds and contributes in the prevention of fatty livers.

During the hen's productive life, they have a specific requirement for fiber. They must find fiber in the feed or in their immediate environment. It has been shown that birds that are deficient in fiber ingest feathers as a fiber source. Feathers may be taken from the floor or pecked from other birds. Monitor feather presence on the floor and if no feathers are found, check gizzards for feathers. This is a valuable tool to identify the origin of most feather pecking behavior in a flock.

Feed dilution forces hens to increase the volume and quantity of feed ingested and, therefore, to increase the feed consumption time. Ingredients with a reduced concentration or lower quality can be used to dilute the diet, but it will compete with the space available for adequate levels of fiber. There is no longer any doubt that feed dilution brings about an improvement in plumage and a reduction in feather pecking itself. This explains the mortality reduction observed in certain trials using diluted diets. This explains why feed in pellet form causes deterioration in plumage and increases feather pecking. Even though most researchers agree over establishing a relationship between consumption time and feather pecking, some recent studies show a specific requirement for insoluble fiber. The absence of insoluble fibers in the feed is responsible for the consumption of feathers and their presence in the gizzard, even when hens are housed in individual cages. Some studies make it possible to conclude that insoluble fibers do influence the quality of plumage and on mortality. The specific size of the fibers, especially in the case of lignin, seems to be of importance.

Characteristics of good fiber sources for layers are insoluble fiber of a coarse structure. Cellulose, hemicellulose and especially lignin are classified as insoluble fiber. These fibers are not digested or fermented in the gastrointestinal tract, and therefore serve as filling material that stimulate gastrointestinal movements without increasing the viscosity of the intestinal content. If fiber particles are small (finely ground), the effect on gizzard functioning and gastrointestinal
movements is limited. Therefore, the usage of coarse insoluble fiber is recommended. Inclusion rates of 4.5% of crude fiber are considered to be good for maintaining a nice feather cover in alternative housing systems. The crude fiber content can be increased during the developer phase and beyond the start of lay. The inclusion over 4.5%, preferably coarse, crude fiber (by for example adding oat hulls) can give good results in terms of development of the digestive tract, the different production parameters and in relation to livability. When feed changes are delayed in the rearing phase, the increase of fiber is delayed as well, as the starter diet has a lower fiber level compared to the grower or developer diet. It is recommended to understand the reason for the delay in feed changes and prevent this from happening, to give the chick enough time for the development of it's gastrointestinal tract.

Fiber can be included in the feed or provided in the direct environment. Preferred "in-feed" insoluble fiber sources are oilseed meals like sunflower meal and rapeseed meal, but also coarse material like oats and oat hulls. Cereal by-products (like bran) can be used as a source of insoluble fiber. However cereal by-products often have a fine structure and have therefore a limited effect on the gastrointestinal movements, which makes them less suitable as a fiber source. It is recommended to resource ingredients from suppliers that have demonstrated they can provide quality ingredients.

Fiber that is provided in addition to the diet can be coarse fiber such as straw, alfalfa (lucerne), wood shaving, rice/oat hulls, silage, etc. These materials must be available in the building through round feeders, or directly as a bale on the scratching area. Layings hens, kept in cage-free housing systems must always have free access to fiber sources. We advise not spreading the fibers directly on the floor, but preferably in bales, or feed troughs. Further, to prevent the incidence of floor eggs, fiber must be introduced after the peak of egg production, this will give the hens more time to train in using the nests.

5.4 Alternative ingredients

The use of alternative ingredients is seen in many regions as an opportunity to reduce feed costs, to lower the carbon footprint of egg production, thereby improving overall sustainability, and to compensate for the lack of a certain ingredients. However, increasing the number of raw materials will increase the complexity in purchasing, as well as management of the feed silos in the end, the nutritional content and the price of alternative ingredients will decide to include these ingredients to the diet.

The search for alternative ingredients must respect certain premises:
- Palatability for the birds
- Low nutritional variability within and between batches
- Measurable and/or neutralizable anti-nutritional factors
- The available options to handle, store and dose
- Safe for the birds (e.g. not causing metabolic disorders)
- Not interfering with the nutritional characteristics of the eggs (e.g. materials with high PFAS levels)
- Economically viable

5.5 Processing methods

Todays most used processors are the hammermill (grinding), the roller mill (rolling) and the multicracker (cracking). Particle size over hammermills is reduced by impact and attrition, particle size over roller mills is reduced by shear and compression and particle size over multicrackers is reduced by cracking. Fine grinding is more efficient with a hammermill, while a roller mill and multicracker is extremely efficient in larger and more homogenic particle sizes. Consequently, it is easier to produce a good structure mash with a roller mill or multicracker.

A well textured mash can be obtained by observing the following rules:
- Only mill those raw materials that require it, bypass the fine raw materials and mill the raw materials individually.
- Check the texture of the raw material at least twice a week.

It is possible to vary the grain size of the available ingredients via grinding settings, screen size, speed and single milling. Monitoring feed particle size is useful for controlling the grinding processes and monitoring maintenance need. In general, grinding finer particles will require more energy from the feed mill, while coarser particles might challenge homogeneity of the particles.

5.5.1 Hammermill

Hammermills contain two or more rotor plates attached to a main shaft with fixed or free-swinging hammers, surrounded by a screened grinding chamber, as shown in Figure 5.

The screen defines the maximum particle size of the grinded feed. In order to have coarsely grinded feed materials, it is recommenced to have a screen size between 8 and 10 mm and grind at low speed.

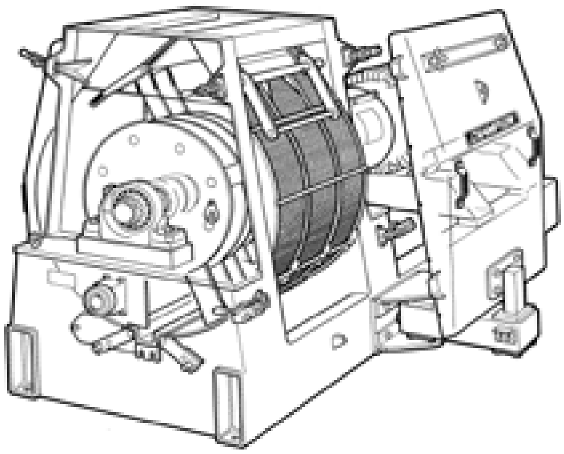


Figure 5 hammermill, containing two of more rotor plates, free-swing hammers and a screened grinding chamber (via (McKinney, 2006))

5.5.2 Rollermill

Roller mills can contain one, two or three pair of rolls, stacked and surrounded in a steel frame, as shown in Figure 6. Feed is passing between the rolls, therefore the speed difference and space between the rolls determine the particle size; more difference is more shear force, leading to smaller particles.

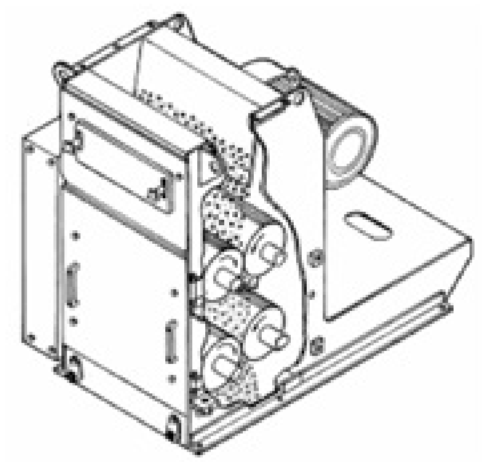


Figure 6 Roller mill, containing different pairs of rolls (via (McKinney, 2006))

5.5.3 Multicracker

Multicrackers contain multiple discs in two rows, stacked and surrounded in a steel frame, as shown in Figure 7. Feed is passing between the sets of discs, therefore the material of the discs, speed difference and space between the rolls determine the particle size. A multicracker results in slightly finer material compared with a roller mill, but more coarse compared to a hammer mill (Thomas, Hendriks, & van der Poel, 2018).

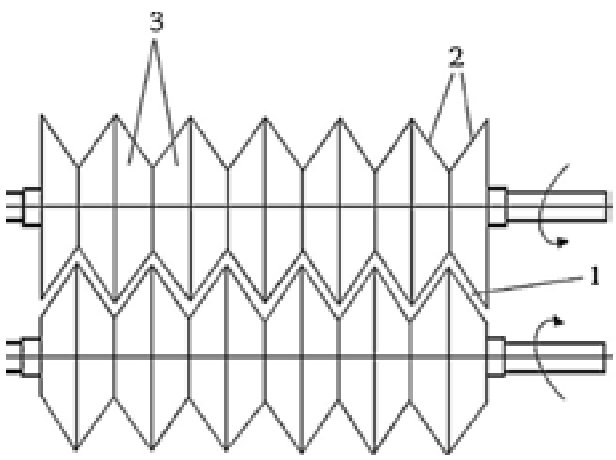


Figure 7 Multicracker, containing two parallel shifts (via Lyu et al., 2020)

5.6 Dosing

Ingredient dosing systems for feed production can be manual, automated or a combination of both. Depending on the inclusion of raw materials, the dosing is ranging from hundreds of kilos to a few grams. Each ingredient does have different characteristics, from fine to coarse, dry or liquid, bagged or in bulk. Depending on the dosing accuracy and formulation, there might be a difference between the formulation and the actual dosed composition. Several monitoring steps might help monitoring this, next to the guidelines of the equipment manufacturer:

- Checking the used and purchased raw materials with stock levels
- Include Standard Operating Procedures (SOPs) and monitoring plans
- Calibrate dosing equipment
- Maintain dosing systems

It should be remembered that the balance and nutrient availability should be respected to meet the needs of the developing pullet or the laying hen. Following the right balance will help to avoid wasting nutrients and avoid increasing feed costs.

5.7 Mixing

Microelements, like trace elements, vitamins and feed additives, are preferably mixed prior to be added to the other raw materials. Premixes are an outcome to have a proper pre-blend of these low inclusion materials, which should be dosed with an inclusion of minimum 0.3% or 3 kg per tonne. This will reduce the number of raw materials on stock and the number of materials required dosing, while improving the homogeneity of the final mixture. However, it will reduce the flexibility to adjust one or more elements within the premix.

Mixing is often done with different types of mixers. Mixing homogeneity is key to make sure all birds receive the same nutrients on farm. Mixing quality or cross-contamination can be checked by so-called microtracers, often small metal particles with a specific colour. With microtracers it is possible to finetune the process of mixing, including the mixing time and filling rate of the mixer. Every handling after mixing can affect the homogeneity of the diet, so carefully choose the sample spot. In feed it is recommended to use Manganese as a tracer.

It is advised to pay attention to the electrostatic insulation of the mixer. Friction between the metal parts of the mixer can generate electrostatic energy, which can attract vitamins and minerals to the mixer walls and cause intermittency and nutritional imbalance. Further it is advised to pay attention to the heat generation during mixing, as this can harm some of the ingredients, like the vitamins and enzymes. Your equipment supplier can further help you to prevent this from happening.

5.8 Feed delivery

After mixing, the feed should be transported to the destination silo. Therefore, pay attention to the route for manufacturing and transportation to avoid possible unwanted changes. In practice, the most critical changes occur when young hens receive feed from hens in production, which will affect total growth by reduced amino acid level and affect bone formation due to the suboptimal calcium and phosphorus ratio. Or, when laying hens in production receive feed destined for pullets, causing calcium deficiencies like reduced egg shell quality and the development of cage layer fatigue.

5.9 Feed segregation

Ingredients are the carriers for different nutrients, and each ingredient has a different particle size and density. In case by-products are being used, the ingredient particle size is often determined by the supplier. While the particle size of most of the grains can be determined by grinding. Afterwards, proper mixing is necessary to achieve a uniform feed composition.

Uniformity in the feed composition is important during mixing, but the goal is to maintain this uniformity till the feed is reaching the birds via the feeding system. Once the feed has been mixed in the mixers, it will be transported via elevators, conveyors, screw conveyors and trucks until it reaches the silos in the warehouses. The movement of the feed throughout this process can cause "demixing" of the feed, resulting in uniformity in the feed which can compromise performance (e.g. non-uniform egg weight and body weight). If demixing problems are identified, it is important to monitor the entire process and take measurements to minimize these problems. Measurements might include the addition of oils and the reduction of fine feed particles. Any ingredient segregation can compromise in flock performance and should therefore be prevented via feed management.

In the table 8 different nutritional compositions per sieve fractions are shown (Schreiter, Damme, & Feick, 2021). In general finer fractions include high levels of minerals and therefore ash, as the premix and minerals in general are finer materials. Depending on the size of the calcium source, the calcium level will be higher in the fine fraction or in the coarse fraction. The middle fractions include higher levels of protein, as most protein sources are a by-product from oil processing and therefore are pre-processed. The coarse fraction include higher levels of energy, as this include most of the grains. For this reason, the quality of the feed mix combined with feeding management techniques is important so that the hens consume all the ingredients provided.

Table 8 Nutritional composition in each particle size fraction (Schreiter, Damme, & Feick, 2021)

Content	Unit	Particle size fraction (in mm)					
		< 0.50	0.51 - 1.00	1.01 - 1.60	1.61 - 2.00	2.01 - 2.50	> 2.50
Dry matter	g/kg	907.2	900.7	906.5	884.1	880.6	876.4
AME_n	MJ/kg	10.3	10.0	10.0	12.2	12.4	12.5
Crude protein	g/kg	134.1	193.7	181.6	172.4	147.3	133.4
Crude ash	g/kg	218.8	181.7	197.4	82.3	77.2	57.7
Crude fat	g/kg	68.1	53.2	41.7	41.8	39.2	46.6
Crude fiber	g/kg	32.1	38.8	34.1	31.7	27.8	29.3
Lysine	g/kg	7.2	10.3	9.4	7.7	6.0	5.0
Methionine	g/kg	7.1	4.3	3.0	2.8	2.4	2.2
Cysteine	g/kg	2.1	2.8	2.9	2.9	2.8	2.5
Calcium	g/kg	70.3	61.8	67.5	21.3	23.1	14.7
Sodium	g/kg	4.5	2.7	1.0	0.3	0.2	0.2
Magnesium	g/kg	3.1	2.5	2.6	1.6	1.4	1.3

5.10 Storage and conservation

The major external influences on the quality of feed and feed ingredients are humidity, sunlight and high temperatures. During transport, storage and feed processing, it is important to identify water infiltration points and repair them. This includes moisture condensation that is having contact with ingredients or feed. A frequently seen cause of condensation is the differences between day and night temperatures.

Moisture feed is more difficult to transport and is an ideal source for fungi and bacteria proliferation, thereby increasing the risk for production loss and birds health issues. Increasing feed temperature is an indication for fermentation. Moisture, old and mouldy feed is often accumulated at the inside of the silo. It is therefore advised to check the silo status and if necessary (wet) clean the silos. High temperatures can reduce feed quality, as nutrients get denatured. Feed temperature can exceed 40°C when the (metal) silo receive sun rays. Air circulation in the silo can be considered to avoid excessive moisture and temperature inside the silo.

Moisture and heat can result in oxidation of raw materials, especially of fats and oils, causing rancidity. Anti-oxidants in the feed, like BHA, BHT, ethoxyquin can help reducing this impact. Oxidated feed can cause cell damage on the birds intestinal integrity, resulting in a higher need of anti-oxidant nutrients like vitamin C, E and A.

5.11 Feed management

Birds are grain eaters by nature, with a strong preference for coarse particles. Fine particles are more difficult for birds to eat; therefore, they spend more energy for the same quantity consumed. The accumulation of fine particles in the feeding system may result in under-consumption. To ensure that the birds get all the necessary elements of the diet, it is essential that the feeders are emptied once per week till 5 weeks of age and every day from week 5 of age onwards. This rule applies equally to the birds in rearing and in production.

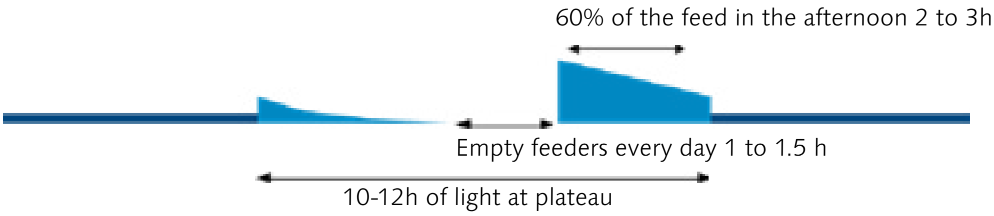
5.11.1 Feed management during the rearing period

The feeding techniques used between 5 and 16 weeks are designed to:

- avoid the build-up of fine particles in the feeders
- encourage the bird's crop development through rapid feed intake

Feed management in rearing has an impact on the nutrient consumption during the bird's productive life. The idea is to develop the digestive tract during the rearing phase, as this will help to prepare the birds to eat enough during the laying phase. This is especially important immediately after transfer, when feed intake should increase sharply in just a few weeks. The crop is the bird's feed storage organ. It allows the bird to eat enough feed in the evening to satisfy its nutritional needs throughout the night. High feed consumption in meal feeding during rearing leads to proper development of both the crop and gizzard. Therefore, feed consumption during the rearing period needs to be stimulated, the eating speed will depend mainly on feeding times and feed texture. Since birds naturally eat the most during the early morning and in the afternoon, it is important to take advantage of this natural behavior and get empty feeders during the middle of the day, as shown in Figure 8.

Figure 8 Management of feed distribution management in rearing



To encourage feed consumption and meal feeding, we recommend that 60% of the daily ration in rearing should be given about 2 to 3 hours before "lights off". At "lights on" the birds will eat finer particles, because the digestive system is empty. If the feeding system does not allow the entire daily ration to be given in one distribution, distribute 60% of the daily ration in the early afternoon and the 40% in the morning at "lights on". This feeding routine prepares your pullets for the feeding routine during the production period. This feeding routine can be started between 4 and 8 weeks according to the feeding equipment in use. The duration of which the feeders are empty, should be gradually increased, so that by around 10-12 weeks of age the feeders are empty for a minimum of 1 to 1.5 hours per day (or depending on day length). It is however possible, to give two distributions in the afternoon, provided that the feeding periods are kept short. Pullet feed, when presented in coarse particles, will stimulate the development of the gizzard.

We recommend using a feeding system which distributes feed rapidly throughout the house and enables the birds to finish all the feed distributed each day. This encourages the birds' intake capacity and avoids fine particle accumulation. Feed troughs with rapid chains are the best option and offer the easiest control of feed intake. If pan or tube feeders are used, they should be adapted specifically for this technique.

5.11.2 Feed management during the laying period

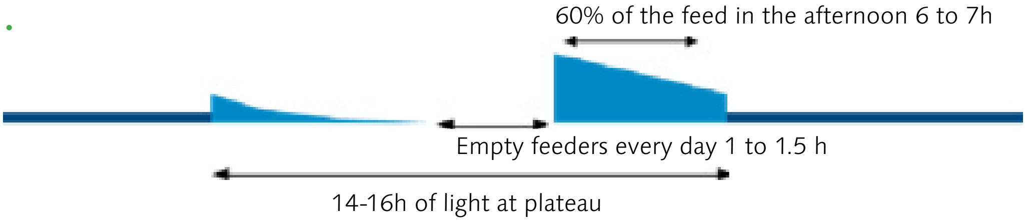
Feed management during the productive period should follow several simple rules:

- Preferably the birds should eat a greater part of their daily ration (60%) during the second half of the day. The fast accumulation of calcium in the eggshell starts at this time of the day and the birds can very effectively utilize the calcium from the feed to form a good eggshell.
- The last feed distribution, 1-2 hours before "lights off" also encourages laying hens in cage-free systems to go up on the slats, or in the aviary system, and to sleep there. The amount of feed distributed during the last feed distribution must be enough to cover the increased consumption during the next morning.
- Empty the feeders once a day for 1 to 1.5 hours, as shown in figure 9.
- Birds are very sensitive to the presentation of the feed and the introduction of new raw materials. For this rea son, we recommend a limited number of feed changes and a stepwise introduction of unknown or new harvested

raw materials.

- The amino acid requirements depend largely on the productivity of the flock and the uniformity of productivity. Our amino acid recommendations are based on an average productivity of 59.5g egg mass per day till 40 weeks of age, 59g egg mass per day between 40 and 65 weeks of age,57.5g egg mass between 65 and 90 weeks of age and 56 g egg mass after 90 weeks of age. Many laying hens can produce more than 60g of egg mass for a long period. Therefore, it is recommended to change from one feed phase to another only when the daily produced egg mass is decreasing. Monitor the flocks production parameters closely, as this information is of great value in steering feed management decisions.

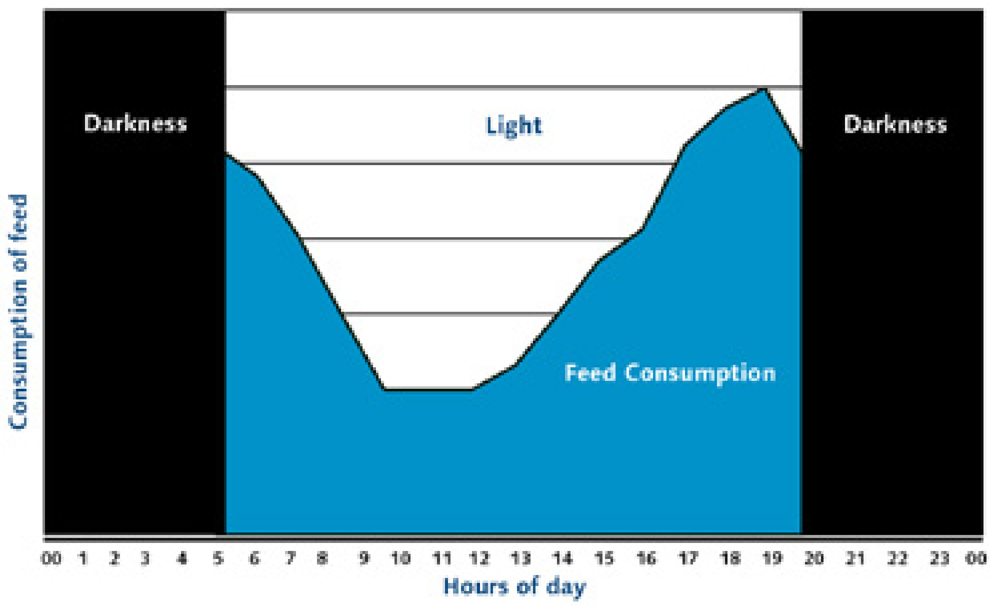
Figure 9 Management of feed distribution for birds in production



5.11.3 Feed distribution

When your birds are not eating enough the classic response is to increase the number of feed distributions per day . However, this practice encourages selective eating even more and does not solve the feed intake problem. To avoid selective eating, the feeder needs to be empty once a week before 5 weeks of age, and once a day from week 5 onwards. It is recommended to have the feeders empty by the beginning of the afternoon. Too early feed distribution during the laying period increases the prevalence of both dirty eggs and floor eggs. For eggshell quality reasons and in line with the natural behavioral pattern of the birds, a minimum of 60% of the feed needs to be distributed in the afternoon (see figure 10). The feed program needs to be adapted depending on your observations on the flock and the type of equipment used to distribute the feed.

Figure 10 The daily feed intake pattern after lights on (14h light pattern)



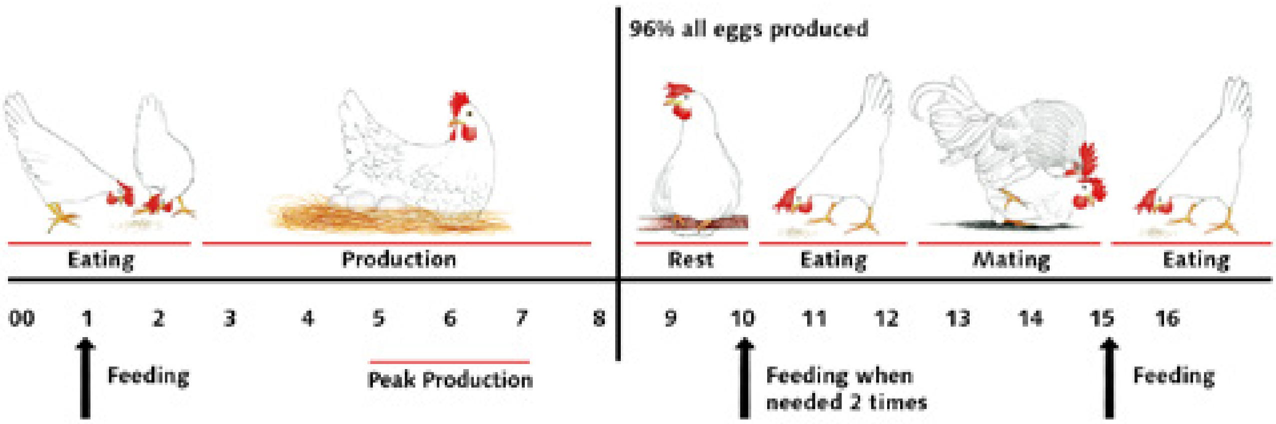
The amount of feed distributed must be enough to cover the increased feed consumption during the next morning: the birds will be hungry after the night period and will easily finish the less attractive fine particles. As the feed is not distributed in the early morning, the hens have time to find the way to their nests and produce the eggs without being disturbed by a new feeding round. The feeding system may stay empty for one or two hours, this will create enough appetite in the laying hens to start intensive feed consumption in the afternoon, as this is the time of the day that you want the laying hens to eat the most.

5.11.5 Feed distribution in (Grand) Parent Stock

The activity patterns of (Grand) Parent Stock flocks contain next to eating, egg production and resting some other activities, as shown in Figure 11. Mating is an important activity in the afternoon; therefore it is recommended to plan the feeding times as following:

- in the morning
- quite some time before the mating period
- shortly after the mating period

Figure 11 daily activity pattern of Parent Stock flocks



5.11.6 Block feeding

Block feeding is a method to have two feed runs short behind each other. It can be a tool to improve the uniformity of the flock, especially when there is competition for feed places available. In this case the more dominant birds can digest their meal, while the less dominant birds receive new fresh feed. Please keep in mind that it is important to empty the feeders once a day, this will help to prevent selective eating and maintain flock uniformity.

5.11.7 Mid-night lighting

Where local regulations and housing systems permit it, mid night lighting (1hr 30min to 2hr of light provided in the middle of the dark (night) period with the feeders running) is often used to encourage feed intake and growth at the beginning of production. If necessary, it can be introduced after transfer and then be gradually withdrawn, when birds have reached their adult body weight.

Midnight lighting is also useful during the hot season, as it can reduce the negative impact of high temperatures. It will allow the hens to eat during the cooler hours of the night, to make sure they get all the required energy and essential elements of the diet to stay healthy and in production. It can also be used during the rearing phase, as a tool to promote growth. But caution should be taken when introduced between 10 to 16 weeks of age, as it could interfere negatively with sexual maturity. However, this is a very efficient management tool especially at the onset of lay. In addition to this, midnight lighting helps to maintain a better eggshell quality by allowing the birds to ingest calcium at the end of the shell formation process. This has a beneficial impact on shell quality and hence on hatchability. The regular lighting program (time of "lights-on" and "lights-off") should not be changed when midnight lighting is applied. Mid night lighting may be used throughout the flock's life if necessary, but it can be also removed if not needed anymore (e.g. the body weight targets have been achieved, the hot period is over, etc.). When midnight light is withdrawn, the reduction should be gradual, in short steps, at a maximum rate of 30 minutes per week, to avoid any negative impact on daily feed intake.

6 Drinking water quality

6 Drinking water quality

Water is important for bird's survival and should always be accessible. It is often neglected as a source of nutrients, but water is a very important nutrient for all production animals. Water can be used for controlling body temperature, therefore water intake increases at increasing temperatures. Therefore, it is important to have enough water available from a good quality available. Besides, water can also be used as a carrier for vaccines and additives. But on the other hand, it can also be an important source of pathogens!

During the first 7 days of age, it should be avoided offering cold water to young birds, as this can negatively affect their body temperature. However, water should be constantly renewed to prevent too hot water, due to heating of the house and limited water flow due to the low intake.
Good quality drinking water is clean, clear, fresh, tasteless and free from contaminants. The birds can easily find, reach and drink it, and they can drink as much as they need. Other salient points are the source of the water and the type of drinking water system used in the houses (storage vessels, pipelines, drinkers).

Ask yourself the following questions: what is the source of the drinking water? Is piped water used or water from a bore hole? Is surface water used? Is the quality of the water checked before use, or is it treated in any way?

Water coming from a piped water system is normally a safe source but might differ in quality depending on the origin. Borehole water may need some water treatment to make it suitable for drinking. The quality of borehole water should always be checked on a regular basis (at least once per year a full test), as water quality can vary over the different seasons.

Once the source has been checked, look at the quality of the water at the point of delivery to the birds, at the end of the line, and directly from the nipples or drinkers. The water quality also depends on the hygiene of the water system. The water system in the houses should be regularly flushed, cleaned and disinfected. It should always be disinfected in between flocks and after water treatments. To keep the water system clean in longer production periods, it is strongly advised to check the water system regularly and if needed, to clean the water system during production. The frequency of checking should be at least once every 3 months.

If the system is disinfected during the production cycle, care should be taken to follow the sanitizer manufacturer's instructions. Especially regarding adequate flushing and correct dosing. Make sure the water system is closed and cannot be contaminated from the outside. Pay extra attention to storage vessels, when used.

Surface water should never be used as a source for drinking water, because of the risk of contamination with wild bird pathogens. Waterfowl travel freely over the globe, carrying diseases with them (i.e. avian influenza) and dropping large amounts of contaminated droppings on their resting places along their way.

Table 9 Water quality parameters

Parameter	Good Quality	Do not use
pH	5 - 8	< 4 and >9
Ammonium mg/l	<1.0	>2.0
Chloride mg/l	<200	>300
Coliform bacteria's CFU/ml	<10	>100
H2S	Non detectable	Detectable
Hardness in German degrees	>4 <15	>20
Iron mg/l	<0.5	>1.0
Magnesium mg/l	50-125	>125
Manganese mg/l	<0.5	>1.0
Nitrate mg/l	<100	>200
Nitrite mg/l	<1.0	>1.0
Oxidizable organic matter mg/l	<50	>200
Potassium mg/l	<20	>20
Sodium mg/l	<100	>200[1] and > 400[2]
Sulfate mg/l	<100	>250
Total dissolved mg/l	<1000	> 1000
Total germ count CFU/ml	<10000	>100000

[1]for laying hens under 20 weeks of age
[2]for laying hens above 20 weeks of age

In general, a good cleaning of the system during the empty period should be sufficient for the whole 16 weeks rearing period. During this period the chicks in rearing should get the chance to build up some immunity against normal environmental bacteria's like E. coli. Semi-continuous use of water sanitizers can interfere with the build up of this immunity.

Different products can be used for cleaning the system, both in-between flocks, when the houses are cleaned and disinfected, and during rearing or production. These products can contain (combinations of) acetic acid and hydrogen peroxide, chlorine, organic acids and inorganic acids. Be careful of the percentages used when using these products in drinking water. Also be careful with the taste and with the acidity of the water. If using acids, the pH should at 4.5, to achieve the disinfecting effect, while preventing becoming corrosive and reducing water intake. High levels of chlorine have the same effect on the birds. To have an efficient disinfection with chlorine, decrease the drinking water pH.

There must be no organic matter in the water, and a low iron and manganese concentration: if these conditions are not met, a proper water disinfection with chloride is not efficient. Using only organic acids as a water sanitizer for a longer period can be dangerous. You can see growth of yeasts and molt in the water. It is better to use acids and chlorine alternatively.

Chickens, at all ages, must always have easy access to good quality drinking water. The quality of the drinking water should be regularly checked, and contaminated drinking water can cause serious disease problems. When chickens don't drink, they won't eat and cannot grow or produce first quality eggs!

Once the water supply is clean, you need to check the following:

- Can the birds easily find and drink the water?
- For day-old chicks, is there enough light to find the water from the start?
- Is the water fresh (e.g. has the system been flushed shortly before the delivery of the day-old chickens)?
- Is the height of the drinkers correct? (adjust it over time as the chicks will grow)
- Is the system of drinkers used the same in the different phases of production (rearing versus lay)?
- What kind of nipples?
- Can the small birds easily activate the nipples?
- What is the nipple flow rate?
- Are there enough drinkers/nipples per bird installed?
- What is the water pressure?

Water is a very important nutrient, but it is also used as a carrier for drinking water vaccinations and for all kinds of in-water treatments. This means that the water quality must also be suitable for that. For (modified) live vaccines, no traces of disinfectants should be in the water during vaccinations. The solubility of some antibiotics and chemotherapeutics depends highly on the pH of the water and can be influenced by the presence of minerals. Together with these minerals, additives can form a biofilm inside the water tubes. Large amounts of bacteria can bind on this biofilm. This is the reason why the water system must always be cleaned after in-water treatments.

7 Mineral recommendations in relation to eggshell formation

7 Mineral recommendations in relation to eggshell formation

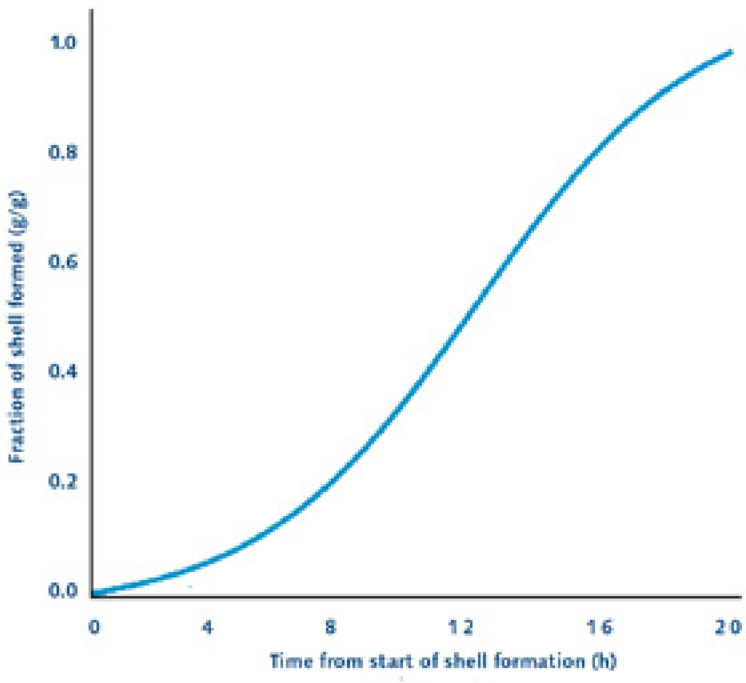
For decades, genetic improvements in the laying hens' productive performance have been achieved by reducing the time that it takes to produce an egg. Nowadays, the time taken to produce the egg is close to 24 hours. This 24-hour cycle enables egg producers to achieve very high rates of egg production with most of the eggs being produced in the morning. The total calcification of the eggshell takes about 20 hours before being completed, while the main calcification takes place in a time period of around 12 hours. Eggshell quality depends to a large extent on the quantity of available calcium in the digestive tract during the night, which depends on the form and solubility in which calcium carbonate is supplied to the birds. Differences between white and brown egg layers do exist, even when the same lighting program is applied.

7.1 Calcium absorption

During eggshell formation, the laying hen uses the calcium that is present in the digestive tract, it is dissolved by abundant secretion of Hydrochloric Acid. Regular contractions of the gizzard transport the calcium through the intestine. In the intestine, calcium can be absorbed via passive diffusion or via active transport. Both pathways require the presence of activated vitamin D3, also known as 1,25-(OH)2D3 or Calcitriol. Vitamin D3 can be supplied via the feed or via the drinking water. Vitamin D3 needs to be activated by the liver and the kidneys towards Calcitriol, it can be supplied as Calcidiol (25-OH-D3) and only need to be activated by the kidneys, or it can be supplied as plant-based 1,25-(OH)2D3 or Calcitriol. Always keep in mind that this first option requires healthy liver and kidneys, as this allows proper functioning for optimal activation of vitamin D3 and consequently proper calcium absorption.

When the quantity of calcium absorption is insufficient to meet the demands for eggshell formation, the laying hen will utilize the calcium reserves in her medullary bone: i.e. the calcium is deposited in the eggshell and the phosphorus is eliminated by the kidneys. Therefore, it is key to focus on the importance of the formation of the medullary bones at the end of the rearing period, and why a pre-lay diet, with higher levels of calcium, is advised at the end of the rearing period. It has been demonstrated many times that laying hens that are forced to utilize their bone reserves produce eggs with poorer eggshell quality, especially towards the end of the production cycle. Furthermore, this can also lead to reduced bone quality, negatively impacting the health and welfare of the laying hens, especially in laying hens that are housed in conventional cages: the laying hens can start to develop osteoporosis, which in turn could result in the development of cage layer fatigue, i.e. the bones are becoming to weak to support the laying hens.

Figure 12 Cumulative eggshell formation (Kebreab, et al., 2009)



Calcium deposition is slow during the first 5 hours after the calcium has entered the eggshell gland. This is followed by approximately 10 hours in which the rate of eggshell deposition is rapid and linear, as shown in Figure 12. Calcium absorption varies from approximately 30% to over 70% between periods without calcification and periods of eggshell formation. For this reason, every increase in the quantity of calcium available at the end of the night will directly lead in an improvement in overall eggshell quality.

7.2 Importance of large limestone particle size

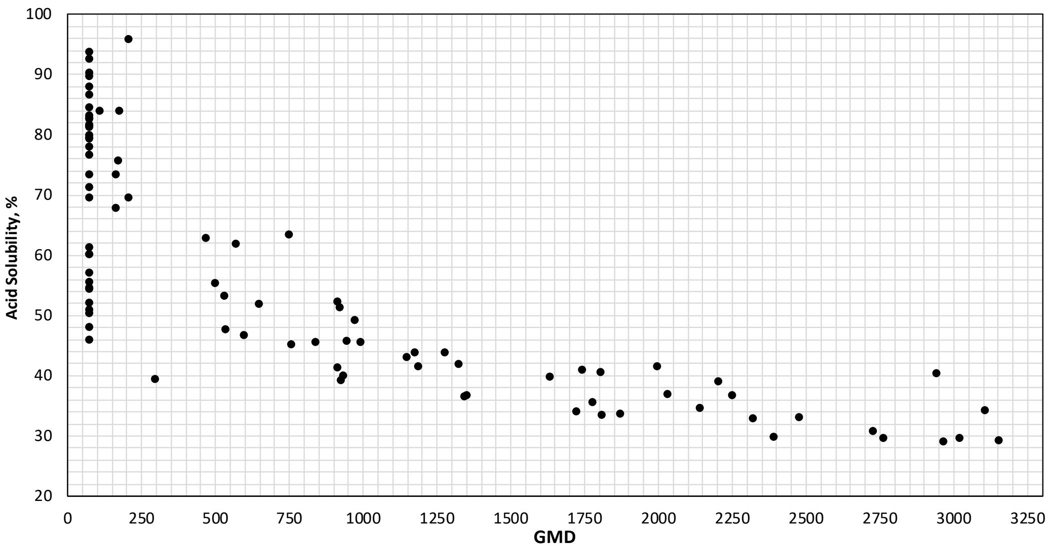
The availability of calcium at the end of the night period is improved by using a coarse calcium source with a low solubility. By using a low soluble coarse limestone, the quantity of available calcium during the beginning of eggshell formation is reduced and improved at the end of the night. The most important parameter is the solubility, i.e. the lower the solubility, the larger the calcium particle size and the slower the calcium release (Figure 13, Saunders-Blades, et al. 2009). Fine limestone shows more variation in acid solubility than coarse limestone (Cargill database, 2018). This is probably related to limestone type and purity of the limestone i.e. fine limestone that is very low in acid solubility may be polluted.

It is known that large size calcium particles (over 2mm) are retained in the gizzard and proventriculus and dissolved slowly during the shell formation, thereby providing a more regular release of calcium, as shown in Figure 13. Because of this slow release in calcium, there is more calcium available during the night as well. Consequently, less calcium coming from the bones will be mobilized whilst also a better eggshell quality will be achieved.

In the morning, limestone that quickly dissolves and which is high in acid solubility is needed for a quick calcium supply for the final stage of eggshell formation and to replenish the medullary bones.

Apart from particle size, also limestone source affects acid solubility and can be used as an indicator of limestone quality. By adding limestone with a low particle size, but relatively good available (so a relative high acid solubility), eggshell quality can be improved (van Eck et al., Cargill, EPC 2018).

Figure 13 Relation between calcium particle size and solubility (Cargill database, 2018)



7.3 Calcium particle size recommendations

Although there is not a 100% linear correlation between solubility and calcium particle size, calcium particle size can give a good estimation about its solubility. Besides this correlation, it is also known that laying hens are efficient in using large calcium particles (between 2.0 and 4.0mm) and using calcium powder (below 0.5mm). Intermediate sized calcium particles, between 0.5mm and 2.0mm, have a low absorption efficiency, consequently, most of these particles ends up in the feces. Therefore, it is recommended to use either fine (<0.5mm) or coarse (between 2.0 and 4.0mm) sized calcium particles. The recommended ratios of coarse and fine limestone are listed in Table 10. If only one source of calcium can be used, due to storage possibilities, it is recommend to use coarse limestone for laying hens and fine limestone for rearing pullets. The difference in recommendation between white and brown layers is explained in the next paragraph. In case both white and brown laying hens are fed with the same diet, it is recommend to follow the ratio for brown layers. As laying hens are getting older, dietary calcium levels must increase, it is recommended to add the extra calcium as coarse calcium or to maintain the same ratio.

Table 10 Ratios of coarse and fine calcium during the rearing and production periods

	Starter, grower and developer	Pre-lay	Production	
			brown layers	white layers
Fine (<0.5mm)	100%	50%	30%	40%
Coarse (2.0-4.0mm)	-	50%	70%	60%

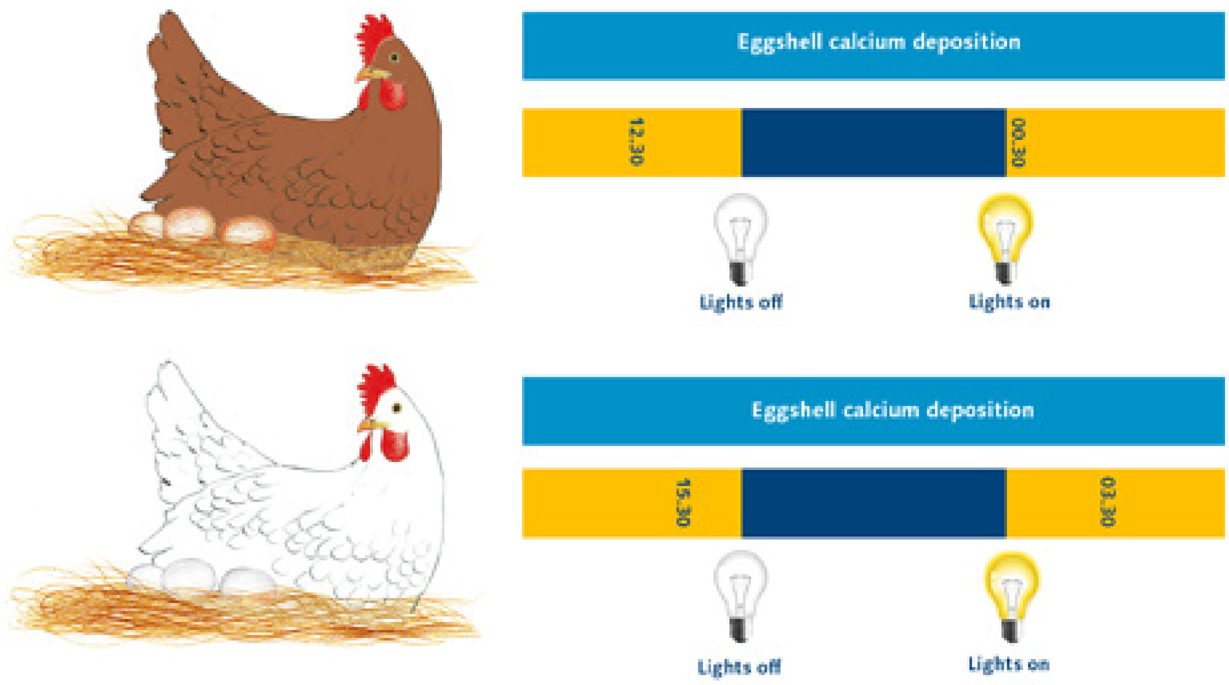
When using meat and bone meal in poultry feed, it is recommended to pay attention to the particle size of the ingredients and the presence of bone pieces. Meat and bone meal should be homogeneous in grain size and free of bone pieces. Mineral sources of phosphorus, such as phosphates, tend to be more uniform in terms of composition and granulometry. Uniformity in the granulometry and composition of calcium and phosphorus ingredients can compromise the development of flocks and their performance during the egg production period. Further it is recommended to evaluate the cost and availability of different ingredients available.

7.4 Difference between white and brown egg layers

Calcification of the eggshell is mainly realized during the night. A high percentage of brown egg layers stop the eggshell calcification at lights on or just after, while white egg layers finish their eggshell formation after lights on. This is resulting in a difference in time of calcification of approximately 3 hours, as shown in Figure 14.

At "lights-on", laying hens that have not yet completed the eggshell calcification should have access to powdered calcium, as this can be very rapidly dissolved and absorbed. Especially white egg layers are able to consume feed before finishing their eggshell, while the majority (60%) of the brown egg layers have already completed eggshell formation during the night. This requires a higher percentage of coarse limestone for brown egg layers, to prevent calcium mobilization from their bones.

Figure 14 Moment of calcium deposit for white and brown layers



7.5 Difference in housing systems in relation to calcium metabolism

Skeletal health and bone breaking strength are affected by numerous factors, including genetics, nutrition and housing systems. Different studies have shown a higher breaking strength in laying hens housed in alternative systems compared to cage housed laying hens. This is due to the physical activity of the laying hen, as they have more freedom to walk around and have short flights in alternative systems. Activity increases the biomechanical load which helps to reduce bone loss and hence increase bone stability. Please note that despite alternative systems reduce bone loss, there is a higher incidence of bone injuries, like broken keel bones when laying hens are interacting with the system.

Due to the difference in activity and therefore in bone metabolism, there is a difference in calcium and phosphorus recommendations, as shown in the feed specifications during the rearing and production period Laying hens that are housed in an alternative housing system have the ability to adjust their consumption of ingredients to meet their physiological needs. It is important to monitor your flocks closely, keep an eye out for unusual behavior from your flock. For example, in situations of mineral deficiency, laying hens will actively start looking for minerals in the litter, in the -range area, or can start pecking at the walls. During the rearing period the balance between Calcium and Retainable Phosphorus remains Ca: ret P 2.1 or a Ca : aP of 1.8 with an increased level of calcium for eggshell formation during the production period.

7.6 Aging of the flock in relation to calcium metabolism

While aging, the ability to metabolize calcium from the diet is gradually decreasing. With genetic improvements, this decrease is getting smaller in recent years, resulting in better eggshell quality at older ages. In practice the calcium levels in production are increased over time, to compensate for this loss. Recent research shows a beneficial effect on eggshell quality at the end of the egg laying cycle when using reduced calcium levels at the start of lay. As calcium absorption is a (partly) active process, the efficiency can be affected by the supply of calcium. Meaning, if we oversupply calcium from early production onwards, the laying hens are not trained to use it efficiently and by aging the efficiency will only decline.

It is important to monitor all organs related to eggshell formation, to minimize the decrease in calcium metabolism. In addition, monitoring eggshell quality and bone health will help optimizing the nutritional strategy in terms of calcium and phosphorus. Increased mortality, that is associated with bone fragility, can be a sign to optimize the calcium and phosphorus ratio, levels and sizes.

7.7 Feed management to maintain eggshell quality

In some occasions the calcium source is not meeting the needs, for example in size or solubility. In this case various feed management practises can be applied to minimize problems from occurring. For example, by replacing part of the calcium in the diet to supplemented calcium that is provided in the barn in the afternoon(usually between 4 and 6 hours before lights off), or implementing a midnight feeding. Both methods will increase the availability of calcium during the night period, which is the period with the highest calcium demand for eggshell formation. Hence explained in more detail.

1. Calcium supplementation in the late afternoon, to offer the birds a higher amount of calcium in the afternoon. This routine is usually performed at the end of the daily activities in the house, via:
    a. Conventional houses: Provide a top dressing of the calcium source in the feeder (between 2-4 grams/bird) on top of the feed.
    b. Automated feeding systems: Attach a calcium source silo between the feed silo and the feeding system inside the house.
2. Midnight snack by turning the lights on for 60 to 90 minutes in the middle of the dark period, so the laying hens have access to feed and water. This is especially useful in hot climate conditions, where laying hens have difficulties eating during the hot periods of the day. As both feed and water should be available, monitoring of leaks and rodent presents is recommended.
3. Give priority to calcium sources with lower solubility and in general coarse structure. By, including 50 to 70% of the calcium source in the form of coarse limestone with low solubility and a size of between 2-4 mm. When using pelleted feed, the coarse limestone should be added after pelletizing, as pelletizing will result to smaller particles due to friction and it can damage the equipment.
4. Offer two different feed compositions during the day. In this case the house should be equipped with two silos, receiving a diet with different nutrient levels for a morning and afternoon diet. Via higher protein, energy and phosphorus levels in the morning and higher calcium levels in the afternoon, it is possible to feed the laying hen closer to her nutritional needs. However, be careful in identifying the silos for the the morning and afternoon diets, and monitor that feed deliveries are stored in the correct silo and that the flock is fed from the right silo at the right time. Formulation errors or mixing the diets during transport, storage or use can have long term negative effects.
5. Strategically use of feed additives. Some feed additives can increase the calcium absorption rate, improve intestinal health, improve feed intake, etc. and can be used throughout the production cycle of the laying hen. Many feed additives have relatively low inclusion rates (0.1% or below), which increases the importance of monitoring dosing accuracy and mixing homogeneity.

Further factors damaging eggshell quality should be minimised, therefore keep in mind the following:

1. The rate of eggshell deposition is most intense 8-10 hours after the yolk is released from the oviduct and around 4 hours after the egg white and yolk arrive at the shell gland.
2. The rate of calcium absorption increases (close to 70%) when the laying hen is forming the eggshell
3. Around 30% of the calcium used to form the eggshell is mobilized from the medullary bones. When this occurs, the laying hen excretes the phosphorus resulting from this mobilization. Meaning, 70% of the calcium used to form the eggshell arrives via the feed.
4. In order to use the calcium from the feed, the calcium needs to be available in the crop or gizzard for a longer time, to be released during eggshell formation in the night period. The use of coarse and low soluble calcium sources increases the calcium availability during the night period
5. The development of the crop and gizzard during the rearing phase is important for later life eggshell quality. The laying hens should have a proper formed crop to be able to store calcium before the night and they should have a developed gizzard to be able to solubilize the calcium particles via muscle contractions.
6. The use of different techniques can be necessary due to different factors:
    - Unavailability of calcium sources with a coarser particle size or lower solubility
    - Sudden or temporary reduced feed intake in your flock
    - Availability of multiple feed silos per house, when using a split feeding technique
    - Adoption of automated feeders (e.g. pan feeders are less suitable for coarse calcium supply)
    - Diets where the inclusion of coarse calcium sources is more difficult, for example due to segregation of mash diets or pelletizing diets.

Regardless of the situation, it is key to keep in mind:

- The health status and integrity of the laying hens' gastrointestinal system is important as nutrients need to be made available, absorbed and metabolized in the right quantities and at the right times
- Monitoring zootechnical performance and egg quality facilitate the decision-making processes
- Correct pullet development, including body weight, medullary bone formation and feed intake capacity, is important to obtain and maintain eggshell quality during production
- Different strategies vary depending on local circumstances, concepts and availability. This should be revised as time and new research emerge. Feel free to contact your technical team to further discuss.

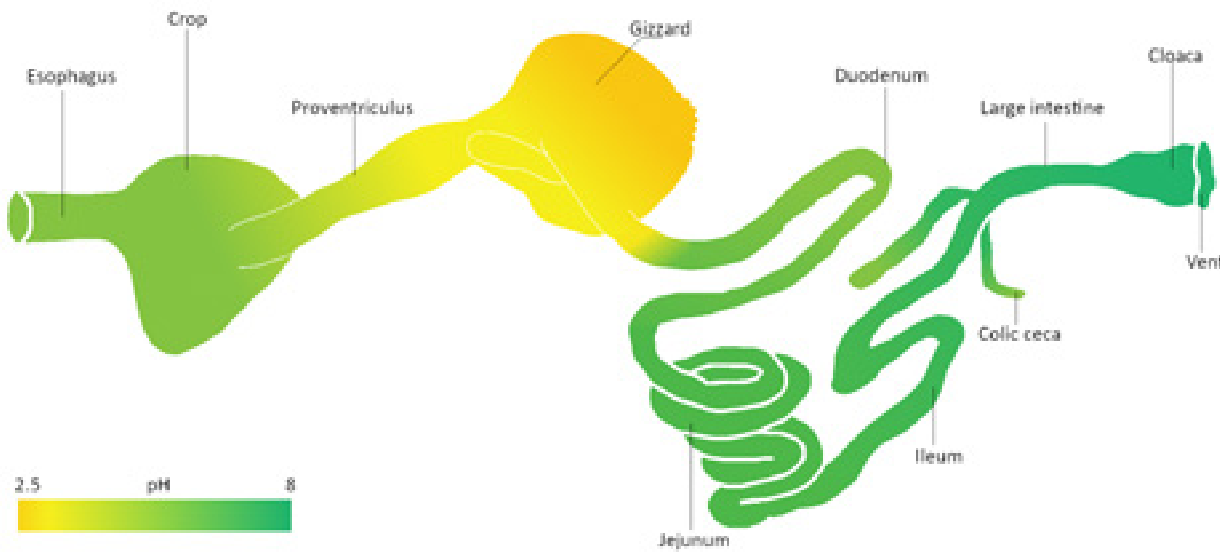
8 Gut health and fecal quality

8 Gut health and faecal quality

8.1 The importance of a good-functioning digestive system

The achievement of good growth and a rapid increase in feed consumption at the onset of lay depends highly on the pullets' digestive system. A high quality pullet with a well-developed digestive system is characterized by a good and strong gizzard, and correct pH levels in each of the different organs (as shown in Figure 15).

Figure 15 Digestive tract of a laying hen (Hendrix Genetics)



8.2 Crop

The crop is an essential part of the total digestive system, it is a diverticulum of the esophagus, with a similar muscular structure. Due to the slightly lower pH level (pH 5.5) it acts as the first defense for microorganisms. In the crop, the start of the digestion of carbohydrates is made, as this is activated by the moisture and amylase that is coming from the saliva, the feed and the water. The impact on digestion depends on the amount of feed and saliva, as well as the passage rate. The average passage rate is estimated at approximately 25 minutes in laying hens (Classen, et al., 2016). This passage rate is greatly influenced by the number of feedings, day length, and the gizzard, as the gizzard regulates the passage rate.

The crop can also be used as a practical check if birds are consuming feed and water. After placement, 80% of the chicks should have eaten after 10 hours, increasing to over 95% of the chicks after 24 hours. During examining the consistency of the content in the crop, you should be able to feel content, and it should feel soft. Via this simple but essential check you can make sure that the chicks, pullets or layers have consumed
both feed and water. When it is filled, but hard, the birds have not consumed sufficient levels of drinking water. Even worse is an empty crop, as this shows that the chicks, pullets, or hens have not consumed any water nor feed. Always check what might be the cause of an empty crop!

As the chicks are getting older, it is recommended to start feeding coarser diets. Fine diets, in crumbled or pelleted form, are associated with the development of a pendulous crop. With too fine diets, the feed intake is often high, while the movement from the crop to the proventriculus and gizzard is not stimulated.

8.3 Proventriculus and gizzard

Figure 16 Well developed gizzard of a hen in early lay (Hendrix Genetics)

The proventriculus is a rather small organ, with the main goal to produce the digestive acids pepsinogen and hydrochloric acid (HCL). HCL is reducing the pH of the proventriculus and the gizzard to approximately a pH of 2.5. As a result of this low pH, pepsinogen will be activated to pepsin. Pepsin is involved in the digestion of protein, which therefore starts in the proventriculus. Furthermore, the low pH is functioning as a barrier for microorganisms and it will help to dissolve calcium.

The gizzard is an extremely muscular organ with a thick cuticula layer as shown in Figure 16. Due to the muscular contractions, the gizzard has a grinding function. However, in order to function properly it is essential that the gizzard is stimulated with coarse particles, either grains or minerals.

Using feed of good particle size, providing grit during the rearing period and/or using partly coarse limestone from 10 weeks of age onwards, will all contribute towards good gizzard development. Between the proventriculus and gizzard there is a reflux, making sure that the digesta is properly mixed with the digestive acids and further grinded.

A decreased particle size, for example present in pelleted of crumbled diets, will result in a faster passage rate and so a reduced retention time in the gizzard. Consequently, mash diets result in heavier gizzards and lower pH levels in the gizzard when compared with pullets that are fed a crumbled diet. This is also shown in commercial trials, where chickens have been fed either with a diet in mash form or in pelleted form. In this research, chickens have been fed from day old till 17 weeks of age, the results of the trial are shown in Table 11.

Table 11 Influence of feed form on relative gizzard weight compared to body weight, digesta content of the gizzard and pH of the gizzard in pullets (Saldaña, et al., 2015).

	5 weeks		10 weeks		17 weeks	
	RW	pH	RW	pH	RW	pH
Mash	5.08[a]	2.97[a]	4.60[a]	2.72[a]	3.65[a]	3.26[a]
Crumble	3.79[b]	3.17[b]	3.26[b]	3.41[b]	2.38[b]	4.03[b]

When feeding pellets, it is advised to stimulate gizzard function with coarse calcium sources, coarse fiber and grit. Between 5 and 10 weeks, we recommend that 3 grams of grit per chick per week (particle size 2 to 3mm) are offered to the chicks. After 10 weeks, this can be increased to 4 to 5 grams of grit per pullet per week (particle size 3 to 5mm). It is also possible from 10 weeks onwards to use a diet in which 50% of the calcium is supplied in carbonate form, with a particle size of 2 - 4mm.

8.4 Intestines

Feed that has been grinded in the gizzard will enter the intestine in smaller portions. In the jejunum, i.e. the first part of the intestines, the pH becomes neutral as the acid digesta is getting balanced with bile salts. Next to the addition of bile acids, different enzymes, including lipase (an enzyme involved in fat digestion), amylase (an enzyme involved in starch digestion) and protease (an enzyme involved in protein digestion) are added. In the total intestine, further digestion and absorption of the nutrients takes place. The digesta is moving peristaltically and anti-peristaltically. The speed is called passage rate, which can be reduced by adding fiber to the feed.

8.5 Ceca

Feed particles that have not been absorbed in the intestines will enter the ceca. The absorption of water and electrolytes is one of the functions of the ceca. Furthermore, there is some microbial activity, which helps to break down the undigested feed particles and to synthesize vitamin B and K. A healthy balance in the microbes in the ceca is beneficial for your laying hens. But keep in mind, when a disbalance occurs it can have a serious impact on gut health!

8.6 Liver

The liver is a large and important organ, which has several functions in the utilisation of nutrients. It is involved in the metabolism of fat, proteins and carbohydrates. Furthermore, it can store some fat-soluble vitamins, such as vitamin A, D, E and K, several water-soluble vitamins (B1, B2 and B12) and minerals (Fe and Cu). The liver is also involved in activating vitamin D3 to stimulate the calcium absorption for eggshell formation. Besides, the liver is important for converting toxins into water-soluble waste products which can be excreted via the kidneys.

Fat is digested to fatty acids and absorbed in the intestines, most of the fatty acids enter directly into the blood system and consequently they reach the liver. The liver can store or metabolise fatty acids and the liver can convert glucose into glycogen and triglycerides to store as energy during higher blood glucose levels. The reverse can also be done, the liver can break down into glycogen which can be used as glucose when blood glucose levels are low. The liver can convert fats and amino acids into glucose as well. Catabolising protein is increasing heat production and therefore this results in a higher heat increment compared to using fat or carbohydrates for energy.

A healthy liver is key for keep on producing first quality eggs during extended laying cycles. For example, a fatty liver will result in less egg yolk production and consequently a lower egg mass or less eggs. Furthermore, the activation of vitamin D3 is impaired, which affects the calcium metabolism and consequently eggshell quality and so the number of first eggs. In order to prevent a fatty liver, make sure you have a proper monitoring of your flock's body weight and feed intake. Further, provide a well-balanced diet, including enough lipotropic factors, like Choline.

Choline

Choline is an essential nutrient for laying hens, playing a vital role in fat metabolism, cell integrity, neurotransmitter synthesis, and methyl group donation for the formation of methionine and lecithin. While chickens can synthesize choline, insufficient levels of choline can lead to symptoms such as poor body weight development in pullets and improper leg formation. During the production phase, an adequate supply of both choline and methionine is necessary to maintain the high egg laying performance. However, in older laying hens, methionine levels are often reduced, which may impact choline requirements. According to the National Institutes of Health (2022), one egg contains 147 mg of choline. In comparison, the choline content from raw materials in poultry feed averages around 1,000 mg/kg. With a daily feed intake of 100 to 120 grams, laying hens receive approximately 100 to 120 mg of choline per day from the raw materials alone. Since this amount is insufficient to meet the daily requirements for optimal egg production, the supplementation of additional choline is necessary.

Choline can be supplemented through synthetic sources, either in liquid or powder form, or through plant-based ingredients. Some raw materials, such as rapeseed meal, canola meal, fish meal, and soybean meal, contain high levels of choline. However, not all plant-derived choline is bioavailable for laying hens. For instance, the majority of choline in rapeseed is not readily absorbed. When raw material composition in the diet changes, the available choline content is affected. To ensure that laying hens receive the adequate levels of choline, it is preferable to focus on the amount of added choline in the feed.

8.7 Kidney

Kidneys play a crucial role in the production of first-quality eggs by supporting the activation of vitamin D3 and the excretion of phosphorus. Vitamin D3, usually consumed as cholecalciferol, undergoes two hydroxylation processes, first in the liver, followed in the kidneys, to have it become active. The active form of vitamin D3 enhances calcium absorption from the diet, which is essential for eggshell and bone formation.

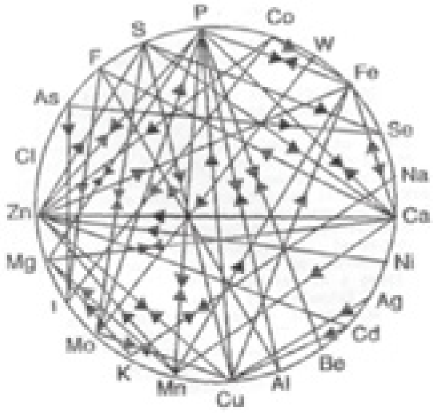
When dietary calcium is insufficient, laying hens can mobilize calcium from their medullary bones, particularly at night when eggshell formation continues. This process releases phosphate ions into the bloodstream, which must be excreted by the kidneys. Therefore, maintaining kidney health is essential for eggshell quality, as impaired kidney function can lead to an increase in second-grade eggs (such as cracked eggs) and higher flock mortality. Kidney problems can arise from nutritional imbalances (such as excessive calcium intake), diseases (like Infectious Bronchitis), or poor water quality with excessive minerals. Additionally, mycotoxins can cause cellular damage to the kidneys, like their effects on the liver. When feed mycotoxin analyses are inconclusive, histopathological examination of the kidneys and liver can help to diagnose egg quality issues in the field. Maintaining balanced mineral levels in the diet is crucial to avoid unnecessary feed costs and reduce environmental impact.

9 The premix composition

9 The premix composition

The mineral interaction wheel, see Figure 17, is an illustration of the complex interrelationships among various minerals that are essential within poultry nutrition. Each mineral has a different essential function in poultry health and production, but their interactions can influence absorption, metabolism, and overall effectiveness. For instance, an excess of molybdenum or iron can interfere with copper absorption, potentially leading to copper deficiencies even when dietary copper levels are adequate. Similarly, the balance between calcium and magnesium is crucial for healthy bone development and nerve transmission; an imbalance can disrupt these processes. In poultry nutrition, minerals are sourced from both feed and water. While feed formulations are designed to provide necessary minerals, water sources can introduce additional minerals, sometimes leading to imbalances. Therefore, understanding these interactions is vital to ensure optimal health, growth, and productivity of the flock.

Figure 17, the mineral interaction wheel, showing the complex interrelationships among various minerals (Leeson & Summers, 2005).



9.1 Suggested premix composition

The suggested premix specifications for commercial pullets and laying hens are mentioned in the Table 12 below. Adaptations of the premix levels can be necessary based on local circumstances.

Parent stock diets are often heat treated, to secure extra feed safety. Heat can have a negative effect on the premix stability and consequently decrease availability. Therefore, the use of vitamins with excellent stability and an additional antioxidant is highly recommended. In addition to heat treatment, other factors in feed processing can have a negative impact on vitamin stability, e.g. storage, conditioning, pelleting, expansion and extrusion. In Table 13, premix recommendations are given for both standard and heat-treated diets.. As longer hatching eggs storage times can negatively affect hatchability, it is recommended to increase the vitamin levels in parent stock diets to overcome the embryonic losses during egg storage.

Table 12 Suggested premix composition for commercial pullets and layers

		Rearing period		
		0-10 (weeks of age)	10 weeks – First egg	Laying period
		Added trace elements mg per kg of diet		
Manganese (Mn)	mg	85	85	100
Zinc (Zn)	mg	80	80	80
Iron (Fe)	mg	40	40	40
Iodine (I)	mg	1	1	1
Copper (Cu)	mg	10	10	10
Selenium (Se)	mg	0.3	0.3	0.3
		Added vitamins in IU or mg per kg diet		
Vitamin A[1]	IU	13000	10000	12000
Vitamin D3[2]	IU	3250	2500	3500
Vitamin E[3,4]	mg	75	50	50
Vitamin K3	mg	3	3	3
Vitamin B1 (Thiamine)	mg	2.5	2.5	2.5
Vitamin B2 (Riboflavin)	mg	10	5	6.5
Vitamin B6 (Pyridoxine)	mg	5	5	5
Vitamin B12	mg	0.03	0.03	0.03
Nicotinic Acid (Niacin)	mg	60	40	40
Pantothenic acid	mg	15	10	10
Folic Acid	mg	1	1	1
Biotin	mg	0.2	0.2	0.2
Added choline[6]		750	750	750
		Antioxidant added		

[1] Vitamin A: Legal limits needs to be observed: chickens up to 14 days max. 20.000 IU/kg feed (DM 88%) and chickens older than 14 days max. 10.000 IU/kg feed (DM 88%). Reference regulations (EU) 2015/724.
[2] Vitamin D3: legal limits need to be observed: chickens max 3.200 IU/kg feed (DM 88%). Reference (EU) 2019/849.
[3] Vitamin E can be increased up to 100 mg/kg under heat stress conditions.
[4] Vitamin E can be partly replaced by polyphenols with an antioxidant effect.
[5] Vitamin C can be added up to 150 mg/kg under heat stress conditions.
[6] Choline can be partly replaced by betaine.

Table 13 Suggested premix composition for Parent stock pullets and layers

	Unit	Rearing period		Laying period	
		standard feed	heat treated feed	standard feed	heat treated feed
		Added trace elements in mg per kg of diet			
Manganese Mn)	mg	85	85	100	100
Zinc (Zn)	mg	80	80	80	80
Iron (Fe)	mg	40	40	40	40
Iodine (I)	mg	1	1	2	2
Copper (Cu)	mg	10	10	10	10
Selenium (Se)	mg	0.3	0.3	0.4	0.4
		Added vitamins in IU or mg per kg diet			
Vitamin A[1]	IU	13000	15000	12000	13600
Vitamin D3[2]	IU	3200	3500	3500	3750
Vitamin E	mg	100	105	125	130
Vitamin K3	mg	3	5	3	5
Vitamin B1 (Thiamine)	mg	3	5	3	5
Vitamin B2 (Riboflavin)	mg	12	12	12	12
Vitamin B6 (Pyridoxine)	mg	5	6	6	7
Vitamin B12	mg	0.03	0.04	0.04	0.05
Nicotinic Acid (Niacin)	mg	60	66	50	55
Pantothenic acid	mg	15	17	15	17
Folic Acid	mg	3	3.4	3	3.4
Biotin	mg	0.4	0.4	0.4	0.4
Choline	mg	750	750	1000	1000
Vitamin C[7]	mg	200	200	200	
		Antioxidant added			

[1] Inorganic minerals can be (partly) replaced by organic minerals.
[2] Vitamin A: Legal limits needs to be observed: chickens up to 14 days max. 20.000 IU/kg feed (DM 88%) and chickens older than 14 days max. 10.000 IU/kg feed (DM 88%). Reference regulations (EU) 2015/724.
[3] Vitamin D3: legal limits need to be observed: chickens max 3.200 IU/kg feed (DM 88%). Reference (EU) 2019/849.
[4] Vitamin E can be increased up to 100 mg/kg under heat stress conditions.
[5] Vitamin E can be partly replaced by polyphenols with an antioxidant effect.
[6] Choline can be partly replaced by betaine.
[7] Vitamin C can be added up to 200 mg/kg under heat stress conditions.

9.2 Feed additives

Our laying hens are robust and are being selected on improved egg production without the support of modern additives. Though, depending on local circumstances there can be an interest to use additives. All over the globe, feed additives are included to help pullet growers and egg producers overcome various problems related to feed quality, laying hen production and health or egg quality. The most common feed additives are: vitamins, amino acids, fatty acids, minerals, probiotics, prebiotics, essential oils, organic acids, phytogenics, enzymes, mycotoxin absorbents, etc. Due to the risk of resistance, deworming and antibiotics should be used as a therapeutic use, not as general preventive practice!

The economic viability of using feed additives depends on the economic evaluation of the flocks, including the loss avoidance and loss occurrence, versus the cost of the feed additive, and the efforts that are being made in additional factors, like management, health and the environment. The recording and the interpretation of reliable zootechnical data is the first step towards making a conscious decision.

9.3 Toxicity of some minerals

Some minerals can have a toxic effect on the chickens when they are present in high levels. The maximum admissible levels for different minerals are listed in Table 14.

Table 14 the toxicity level of different minerals

Mineral	Toxicity level
Chlorine	5000 ppm
Copper	300 ppm
Iodine	300 ppm
Iron	1000 ppm
Magnesium	3000 ppm
Manganese	2000 ppm
Potassium	20000 ppm
Selenium	10 ppm
Sodium	5000 ppm
Vanadium	10 ppm (due to contamination from rock phosphates)
Zinc	1000 ppm

In addition to the toxicity of minerals, other substances can be toxic to birds as well (EFSA, 2024) , like fedegoso seed (Senna occidentalis) and cotton seed meal, which can cause serious production losses and increased bird mortality. Pesticides on ingredients or as pollution in drinking water sources can have a negative effect on flock performances as well. Be aware of agricultural activities in the neighborhood of the farm and watch out for sudden drops in performance (e.g. loss of production, loss of appetite or symptoms of poisoning).

Next to raw material challenges, some of the mineral toxicity enters via the raw materials as well, for example avoid using dolomite (calcium and magnesium carbonate), as the level of magnesium can reduce the eggshell quality. Knowing and auditing your raw material suppliers are important in minimizing the risks associated with the feed.

9.4 Mycotoxins

Mycotoxins are natural substances produced by molds and fungi, which are common in almost all farm environments. In total over 400 types of mycotoxins have been identified so far, from which 25 are extremely important as they can have a big negative impact on the bird's health. Mycotoxins can survive in many places and on many different types of feed sources. They can be formed on feed stuffs while growing on the field, during harvesting, during storage and transport. Mycotoxins are stored in the outer layers of a cereal, therefore by-products (as for example DDGS) often contain a higher level of mycotoxins compared to the full grain. Feed analysis can indicate the mycotoxins and levels present in the feed, however proper sampling is key to have a representative sample, as mycotoxins are present in spots instead of being homogeneous distributed. Histopathological examination of organs, like the tongue, gizzard, liver and kidneys can be a useful tool to identify the long-term effects of mycotoxins.

Rearing pullets and laying hens are susceptible to mycotoxins for various reasons. Mycotoxins are known to be immunosuppressive, reducing the immune response and therefore results in reduced antibody production, and resulting in an increased incidence and severity of disease. The longer production cycle makes them ideal candidates for chronic mycotoxicosis. This can be further influenced by the increased use of by-products in layer diets. The total effect is depending on the type of mycotoxin, the number of mycotoxins, the synergistic effect of the present mycotoxins, the level of mycotoxin(s), duration and health status of the animal. In chicks, pullets and laying hens it is known that mycotoxins can result in:

- Reduced feed consumption
- Poor growth rates
- Reduced egg production
- Reduced feed conversion efficiency
- Increased susceptibility to diseases
- Increased mortality
- Poor eggshell quality
- Increased number of blood spots

- Paler yolk
- Reduced fertility
- Reduced hatchability
- Reduced chick quality
- Leg problems
- Carcass condemnation

Since the discovery of the occurrence of mycotoxins in animal feed, the harmful effects of mycotoxins have been studied and reported in different scientific papers and by various authorities. Unfortunately the frequency and intensity of the problems related to mycotoxin toxicity are increasing, and the discovery of new mycotoxins and mycotoxin metabolites further emerging. Therefore it is advised to install and maintain a mycotoxin monitoring program for ingredients and finished feed. It is advised to implement timely, accurate and consistent performance data recording, but also to identify and analyze signs and symptoms of vomiting chickens, to find the early warnings.

In order to minimize the level of mycotoxins, it is recommended to add a cleaning and/or sorting process for the grains. This will remove quite a high level, but not all mycotoxins. For sure it is not recommended to dilute the mycotoxin level of your contaminated raw materials by adding clean raw materials. As mycotoxins are not spread homogenous and therefore toxic hot spots can still be present. As mycotoxins are rather heat stable, heat processing will not be a feasible option. In order to reduce the damage brought by mycotoxins, it is recommended to add a mycotoxin absorbent or neutralizer, for the specific mycotoxin and levels present, to your feed. The upper limits for different mycotoxins can be found in table 15. As often more complex mycotoxins are identified in poultry diets, it is recommended to use a broader spectrum of mycotoxin absorbents instead of a bentonite only.

Table 15 The upper limits for different mycotoxins in ppb

Mycotoxin	Rearing	Laying hens	Parent stock
Aflatoxin	5	10	5
Fumonisin	500	1000	500
Ocratoxin	2	4	2
Deoxyinivalenol (DON)	200	600	400
HT2 & T2	2	10	10
Zearaleone	10	50	50
Diacetoyscirpenol (DAS)	100	500	300

Young chickens are more susceptible to mycotoxins compared to laying hens, while parent stock birds can vertically transmit mycotoxins towards the embryo and therefore increasing embryonic mortality. Therefore different ages and different types of animals have different recommended upper limits. Remember that the upper limits for mycotoxins are based on individual occurrence, while the presence of multiple mycotoxins can extrapolate the effect. Further mycotoxin toxicity studies are performed in research facilities with a controlled environment. Often those studies are considered to focus on acute mycotoxin toxicity, not chronic toxicity which is often seen in practice. Therefore, it is possible to encounter problems in practice even with lower levels of contaminations, especially with the synergistic effect in a combination of mycotoxins.

Complementary laboratory tests, such as histopathology, is a useful tool in diagnosing mycotoxins. This should be implemented, when the sampling and analysis shows no contamination with mycotoxins, but the bird shows mycotoxin-related symptoms. Lower than expected serologies are also indicative of problems due to the immunosuppressive effect of mycotoxins.

Often, it is not possible to have a mycotoxin-free feed. Therefore, it remains important include procedures to reduce potential contamination and to protect the birds from possible contamination and to provide adequate nutritional support to minimize potential problem, and thereby reducing the negative impact, s related to mycotoxins.

10 Sustainability

10.1 Introduction

Sustainability has become a central focus in modern egg production as the egg industry works to balance efficiency, environmental responsibility, and long-term viability. With growing concerns about climate change and resource depletion, reducing the environmental footprint of egg production is a key priority. Although uncontrolled exploitation of natural resources and advancing urbanization of cities is taking place, it is important that the laying hen sector is involved in practices to encourage and enable the preservation of natural sources, while preventing clearance of forest or compromising in water resources. Therefore, poultry houses should not be built on fertile land, while adding vegetation barriers can minimize biosecurity and improve the local microclimate.

Governments are taking steps to make farming more sustainable, such as the European Green Deal and the Farm to Fork Strategy, while supermarkets and consumers have a decisive role in terms of sustainability. In poultry farming, the feed composition contributes significantly to greenhouse gas (GHG) emissions, making nutrition one of the most impactful areas for sustainability improvements.

A crucial regulatory development in this area is the Corporate Sustainability Reporting Directive (CSRD), introduced by the European Union. The CSRD expands sustainability reporting requirements, requiring companies within the EU, including those in the feed and poultry sectors, to disclose their environmental, social, and governance (ESG) impacts. The CSRD enhances transparency and accountability, encouraging businesses to adopt more sustainable practices in feed sourcing, production, and emissions reduction.

Within the EU, sustainability for food producing animals is based on the Product Environmental Footprint Category Rules (PEFCR), which are in place since April 2018. Those rules should result in a common way of measuring environmental impact. In total 16 environmental impact categories have been defined, including global warming, ozone formation, eutrophication, ecotoxicity, land use, resource scarcity and water use. Global warming is expressed in CO_2 equivalents, with the following formula: CO_2 equivalent = $1 \cdot CO_2 + 27 \cdot$biogenic $CH_4 + 29.8 \cdot$fossil $CH_4 + 273 \cdot NO_2$, where biogenic CH4 equals the methane from excretion. Within the PEFCR there is chosen to assess the impact of global warming on different ingredients by economic allocations. This means that a potential increase in the price for a certain by-product, often caused by an increased demand, will increase the CO_2 equivalent for this by-product.

The PEFCR is supported by the Global Feed LCA Institute (GFLI), providing a standardized Life Cycle Assessment (LCA) database to measure the environmental impact of various feed ingredients. GFLI forms a database with the environmental impact of the sourced feed ingredients, based on the ingredient origin, and is the EU standard to be used for calculating the effect on global warming. Depending on the sustainability goal, different KPIs can be defined. For example, with the goal to reduce the CO_2 footprint in animal feed, it will be reported in kg CO_2 equivalent per MT of feed. While a goal to optimize the resource use for improving circularity, will be reported in the percentage of by-products used in the total feed composition. So far, kg CO_2 equivalent per MT of feed or kg CO_2 equivalent per kg of eggs is the most used reporting KPI.

Several factors can impact feed efficiency and therefore sustainability:

- Quality of feed ingredients: poor-quality ingredients can lead to lower productivity, resulting in increased feed consumption and, consequently increasing the CO_2 equivalent per kg of eggs.
- Animal health and disease control: disease outbreaks, such as avian influenza, can lead to the mass culling of birds, wasting feed resources and exacerbating sustainability challenges.
- Productivity: loss of productivity independent on the cause, will increase the feed intake per egg produced and therefore increasing the CO_2 equivalent per kg of eggs.

In this chapter we focus on sustainability in egg production and the role of feed in reducing the egg sector's carbon footprint via the impact of land use change, nutrition, management and genetics.

10.2 Impact of land use change

Sustainability in egg production is heavily influenced by the selection and sourcing of feed ingredients. Today, a growing number of poultry feed ingredients are by-products derived from industrial processes, often the biofuel market (e.g. soybean meal is a by-product from soy oil production), making the egg production chain a sector that is taking advantages of ingredients which cannot be used in human nutrition. Ethanol and biodiesel are fast growing markets, providing good potential for by-products to be used in poultry diets. Even though, by-products do have an impact on carbon footprint, including Land Use Change (LUC), which is one of the key environmental concerns and largely driven by the demand for high-protein feed components such as soybean meal. LUC can result in deforestation, biodiversity loss, and significant carbon emissions, making it a critical factor in assessing the overall environmental footprint of poultry feed production. In general, areas that have been deforested more than 20 years ago, are defined as non-deforested and therefore Land Use Change free. Understanding the impact of LUC and adopting sustainable strategies is essential for reducing the carbon footprint of poultry feed while maintaining efficiency and productivity.

To reduce the environmental impact of LUC, several strategies can be implemented in poultry feed production:

1. Sourcing of ingredients: One of the most effective ways to mitigate LUC is by shifting the origin of protein sources from deforestation-linked regions to (certified) non-deforested areas. Certification programs ensure that soy and other raw materials are produced without causing further deforestation, thereby lowering their carbon footprint. Please note some certified soya and palm is originating from areas younger than 20 years deforested free. Therefore even with a certification there can be a CO_2 contribution on Land Use Change. The different certifications inlcluding cut-off date are listed in table 16. Carbon emissions related to deforestation can be removed 20 years after the cut-off date. This means that US SSAP, RTRS, Proterra, ISCC, Donau Soja, Europe Soya Caramuru Sustentar and Cargill triple S are most suitable to reduce emissions before 2030.

Table 16 Soy and palm certification including cut-off date for deforestation

Certificate name	Organization type	Scope	Cut-off deforestation
ADM – Responsible Soy Standard	Supplier-owned	Soy	2015
Amaggi – Origins Field	Supplier-owned	Various	2020
Bunge – Pro-S	Supplier-owned	Various	2016
Caramuru – Sustentar Programme	Supplier-owned	Soy	2008
Cargill – Triple S	Supplier-owned	Soy	2008
Donau Soja / Europe Soya	Third-party	Soy	2008
FEMAS – Responsible Sourcing Module 2021	Industry	Various	2020
ISCC	Third-party	Various	2008
LDC – Program for Sustainable Agriculture	Supplier-owned	Soy	2016
ProTerra	Third-party	Various	2008
RTRS	Third-party	Soy	2009
RSPO	Third-party	Palm	
SFAP – Sustainable Farming Assurance Programme	Third-party	Soy	2016
US SSAP – U.S. Soy Sustainability Assurance Protocol	Industry	Soy	2008

2. Alternative protein sources: Changing protein sources can reduce reliance on deforestation-linked protein sources like soya. Ingredients such as rapeseed meal, sunflower meal, and peas can serve as viable protein alternatives. However, the (consistency of) availability, anti-nutritional factors, digestibility, the transportation distance and quality losses during transportation should be taken into account.
3. Use of circular raw materials: Incorporating circular raw materials such as meat and bone meal (MBM), processed animal proteins (PAPs), dried distillers' grains with solubles (DDGS) and bakery by-products reduce the dependence on agricultural land expansion. These by-products from other industries contribute to a more circular economy, reducing waste while supplying valuable nutrients to poultry feed. However, their inclusion must be carefully managed to ensure biosecurity, nutritional balance, mycotoxin risk, quality variation between batches and supply consistency. Further the availability of those raw materials for poultry diets might compete with the petfood or biogas industry.

10.3 Impact of nutrition

Beyond raw material origin, optimizing feed efficiency or feed conversion ratio plays a crucial role in reducing the environmental footprint of egg production. Most nutrient levels, including amino acid levels, depend on the zootechnical performance of the flocks. Therefore daily monitoring of performance data, identifying symptoms of nutrient deficiency or excess is getting more and more important.

Protein source and matrix

The shift from total protein levels to digestible amino acids has led to reduced nitrogen excretion, with the help of the availability of synthetic amino acids. Development of new synthetic amino acids and further research towards amino acid levels allows a further reduction of crude protein. The right amino acid balance ensures efficient nutrient utilization, optimal zootechnical performance and therefore reducing the overall nitrogen excretion and environmental emissions.

To further optimize in total protein intake, one of the critical considerations is the shift from Apparent Fecal Digestibility (AFD) to Standardized Ileal Digestibility (SID) in amino acid formulation. AFD overestimates nutrient absorption due to microbial activity in the hindgut, whereas SID provides a more precise measure of amino acid availability at the ileum, enabling more efficient feed utilization and reducing nitrogen excretion into the environment.

Mineral impact

Calcium and phosphorus are probably the most studied and most oversupplied minerals in layer nutrition. Proper balance of calcium and phosphorus in rearing diets is essential for bone formation, while a right level of calcium and phosphorus in lay is essential for bone and eggshell formation, preventing cage fatigue and bird mortality. It is therefore important to carefully check the requirement for each mineral at any given age or development stage of the chicken, to optimize nutrient digestion and absorption, while maintaining or improving overall egg quality, egg production and hen health.

Studies about calcium include calcium sources, like granulometry, calcium levels, and solubility as well as the physiological demands or utilization rates. Excessive calcium levels compete with ingredients in the total diet, due to the limited space in formulation. Besides making the diet more expensive, interfering with the birds' calcium efficiency, it also results in an increased nutrient waste and impact on the environment.

Studies about phosphorus utilization include the continuous phytase improvements as well as different levels and physiological demands. Excessive phosphorus intake and phosphorus excretion contributes to eutrophication, while overuse of rock phosphate raises sustainability concerns due to its finite supply. Advances in phytases, reduced calcium levels and more precise phosphorus management help reducing environmental impacts from phosphorus while optimizing the hens' health.

Precision nutrition

In feed formulation, various information sources are being used, including: the nutritional matrix per ingredient, the difference in ingredients available, the minimum and maximum nutritional levels based on the requirement of the bird and the price of each ingredient. In general, feed formulation programs formulate based on the least cost formulation, increasing the price per kg of feed by any additional constraint. Therefore adding a constraint for carbon footprint will most likely increase the price per kg of feed. Precision nutrition means diet adjustment to ensure the daily nutrient supply equals with the daily nutrient requirement for the chick, the pullet or laying hen. These adjustments will often result in an increased amount of phases.

When minimizing the gap between the daily nutrient requirement and the daily nutrient supply, it becomes more critical to work with the correct nutrient matrix of the available raw materials. If ingredients contain less nutrients in the batch compared to the matrix, it will result in an undersupply of the nutrients and therefore a loss of performance. While, if ingredients contain more nutrients in the batch compared to the matrix, it will result in an oversupply of nutrients and therefore increased feed costs, increased performance (e.g. increased egg weight) or altered performance (e.g. abdominal fat accumulation). In general, for targeting lower variability in the quality of ingredients will allow to use a lower safety margin on the nutritional matrix and thereby reducing the gap between daily nutrient requirement and the daily nutrient supply. In raw materials with more fluctuations in quality, it remains advised to increase your feed quality monitoring programs if precision nutrition is applied.

Besides precision nutrition in nutritional matrixes of raw materials, precision nutrition can also be applied by real-time adjustments based on the hens' requirement. For example when working with dynamic models based on the zootechnical performance instead of working with static feed tables. It allows to finetune daily nutrient requirement and daily nutrient supply based on the requirements, including performance in egg laying and the various growth stages in pullet rearing. Precision feeding will improve nutrient efficiency and it minimizes environmental waste.

10.4 Impact of management

Egg farming has evolved significantly, transitioning from traditional floor housing to conventional cage systems, and now back in various parts of the world to alternative housing, including barn systems, aviary systems, free-range and organic. Each production system influences feed efficiency, manure management, and environmental impact:

- Cage systems: Initially improved egg quality and efficiency, as it is limiting labor and hen mobility, and therefore improved feed efficiency.
- Alternative indoor systems: Initially for animal welfare reasons, but the increased mobility results in higher energy demands, increasing feed intake and increasing the carbon footprint per kg egg produced.
- Alternative outdoor systems: Initially comparable with the alternative indoor systems. However, when birds have access to free-range, causing temperature variations and therefore more effect on feed intake. Free-range housing results in more interaction between manure and soil, affecting soil health.

Management decisions can affect sustainability of egg production. Longer production cycles reduce the need to rear new pullets, minimizing resource use and loweringthe carbon footprint per kg of egg. While, shorter cycles lead to more frequent flock replacements, increasing environmental impact. Several factors are involved to determine the depletion age of a flock. Flock profitability and the pullet schedule are the most decisive factors. However, when the productivity, liveability and egg quality is higher as expected, flocks are often extended, especially in case of a high egg price.

Manure management affects sustainability as well. In general chicken manure is a valuable fertilizer for different crops. However, chicken manure should be managed properly and environmental contamination should be prevented to enhance nutrient retention.

Every management factor which might result in a loss of performance, including poor water quality, heat stress, lack of drinking and feeding space, feed storage problems, etc. should be optimized, to prevent any loss of performance and therefore increase in the carbon footprint.

10.5 Impact of genetics

Via genetic improvement, the new generations of laying hens are better capable of producing more first quality eggs per hen housed. As genetic selection is improving overall robustness, the laying persistency, overall egg quality, feed efficiency and mortality. Improved egg production results directly to improved FCR and is therefore reducing the carbon footprint. At the same time, internal and external egg quality is improved resulting in a higher number of first quality eggs, causing less waste of resources. Collecting field data is the basis for validating the results of the breeding program, and is essential to have the carbon footprint of your own flocks' calculated.

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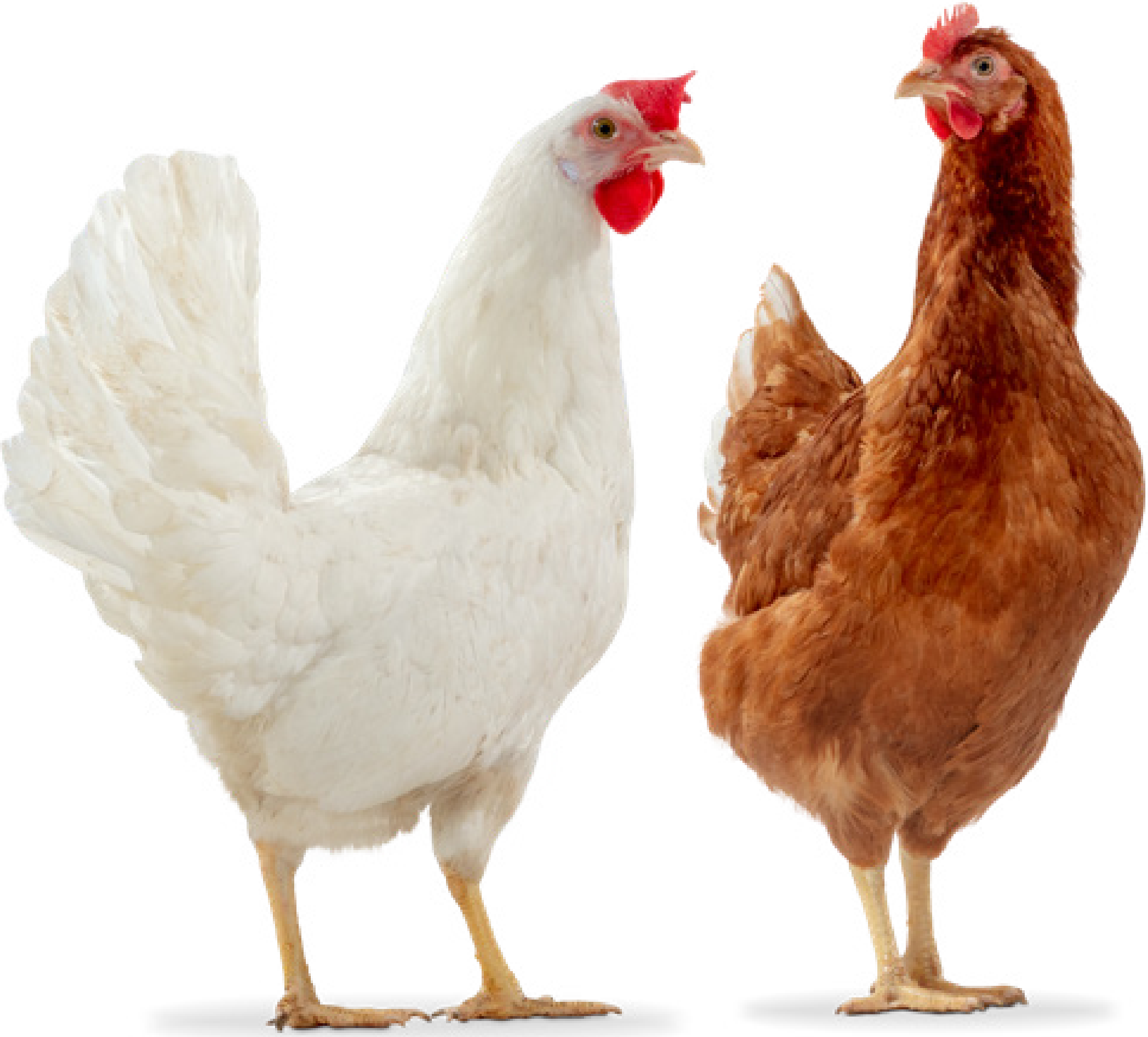
Notes



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