HENDRIX GENETICS

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 birds) is the combined result of the genotype (e.g. the breed) and the environment (your management).

This manual is a guide to general and specific rules on nutrition as well as advice for both parent stock and commercial flocks in either cage or alternative housing systems. The objective is to help 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 different production goals, environmental conditions and local disease pressure can require specific adaptations of feed management practices in order to achieve optimal 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 laying hens all over the globe. We hope that each reader will be able to find some useful information from this nutrition guide. For more detailed and tailor-made advice, please contact your local representative.

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1 Genetic progress and nutritional consequences

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1.1 Introduction

The performance of brown and white egg layers has increased significantly through genetic selection over the last century, as shown in Table 1. The increase in egg production has been achieved through advancing sexual maturity, increasing the level and time of peak production, improving persistency and improving livability. Big investments have been made to increase the production cycles of the pure line birds to 100 weeks. As a result, more selection pressure could be made by extending the production cycles and increasing the breeding populations. The consequence of this improved productivity is a reduction in the time between successive ovulations. Traditionally laying hens ovulated approximately every 26-27 hours when they were in production. The ovulation period of modern hybrids has been reduced close to 24 hours. The improvements related to egg production and reduced feed intake, resulted in a reduction in feed conversion by over 10%. This massive improvement can only be achieved if the environment (i.e. the management) of the hens is optimal. Today's performance could have been further improved by continuing advances in early maturity. However, it has been recognized that the potential benefit in egg numbers may have come at the cost of ease of management and average egg size. For this reason, genetic selection has been ceased for sexual maturity, and all focus is given on persistency of egg production, egg quality and liveability.

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 (grams feed/grams 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

Genetic progress has 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 egg production should be based on the average daily egg mass 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 formulator to use, it does not allow for genetic progress, nor for genotypic differences. The breeds that produce large eggs have larger daily requirements than those breeds that produce small eggs when producing at the same rate of lay %. Most researchers agree to use the expression of nutrient requirements in mg of amino acids per gram of eggs produced while taking into account amino acids for maintenance. To express the nutrient requirements in mg of amino acids per gram of egg produced is currently a well proven and widely adopted method in the egg industry.

1.3 Good nutrition

Nutrient intake, nutrient composition, type of ingredients and feed management are all affecting gut health and therefore nutrient absorption as well. Improper diet composition or contaminated feed stuffs can have a big (negative) impact on the health, development and productivity of the birds.

The gastrointestinal tract has different functions in the laying hens, 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, infectious agents (i.e. bacteria, parasites and worms), the gut microbiome, toxins and other dietary factors. Worm infestations are of a higher risk in outdoor raised chickens, like free-range and organic systems. Stress, as a result of suboptimal housing conditions, competition to water or feed, vaccinations, etc. can result in problems as enteritis or a leaky gut. This can result in malabsorption and a decrease in performance, increased feed intake, decrease in feed efficiency or even mortality.

Good nutrition is essential for proper nutrient utilisation 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, stimulate microbial growth. As a result, this microbial growth might have a negative effect on the gut integrity. There are several options to prevent undigested particles reaching the hindgut, e.g. improving nutrient absorption and reducing the passage rate of the digesta. Furthermore, a heat and/or an acidity treatment of the diet can reduce the microbial load and so the risk of Salmonella. 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 interpret prior to adding additives to the birds' diet, this will help you in making the right and timely decisions to optimize the diets and the nutritional management.

Despite continuous genetic improvement, birds 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 point of light stimulation has a direct influence on the future performance of the flock regarding average egg size.

2 Rearing Period

2 Rearing period

2.1 Basic rules of our feeding programme during rearing

Modern laying hens have the potential to generate more income than ever to egg producers as a direct result of genetic improvement. Today's hens can reach higher peaks of production and have drastically improved their laying persistency. Combined with improved egg weight curves, interior and exterior egg quality, better liveability and longer lasting feather cover, it has resulted in the longer production cycles. Additionally, the age of transfer and the onset of lay come earlier and faster compared to a few decades ago. Thus, in order to achieve the full genetic potential of your birds, 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 18 weeks of the lifetime of a bird have a massive impact on production results later in the birds' life. At the onset of lay, there is an increase in the birds' growth and maintenance needs as well as a fast increase in the flocks' daily laying percentage, which results in an also fast increase in the need of essential nutrient requirements. If the birds' feed intake is not high enough or the feed composition is limiting, there is a good chance that the birds will suffer from a nutrient deficiency. This deficiency will have a negative impact on the birds' production performance and wellbeing.

In order to maintain good egg laying persistency up to 100 weeks of age, it is essential to take good care of your birds during rearing and to make sure they are well prepared when 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, even with todays' 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. 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 impact on the birds' performance later. Any delay in growth during the first few weeks will be reflected in a reduced bodyweight at 17 weeks and in later performance. It is, therefore, extremely important to use a starter diet for the first 4 or 5 weeks, which has an amino acid/protein ratio similar to that of broiler birds. Any amino acid deficiency will result in a reduction in growth rate and an increase in the feed conversion ratio.

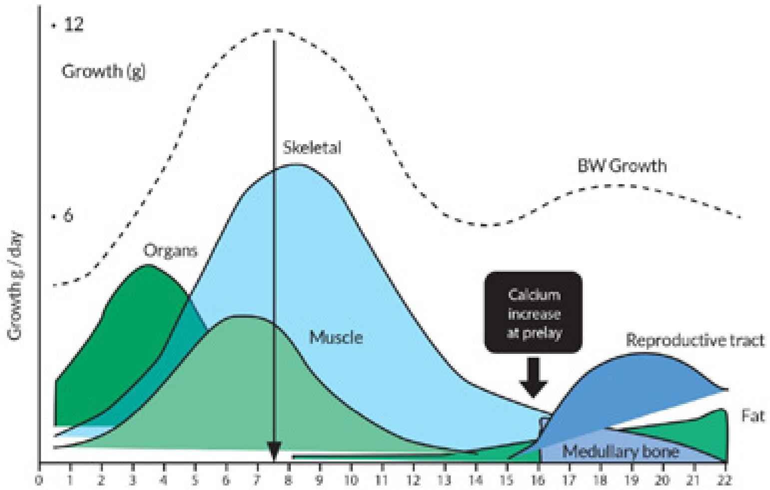
This is clearly demonstrated by the high correlation between egg weight and the bird's development during rearing. The better the body weight development during rearing (i.e. a good body frame), the bigger the egg size from the start of production onwards (and vice versa). Moreover, body weight at the end of rearing has a high correlation with laying persistency towards the end of the production period.
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 birds and over 90% for white birds. This will help to maintain the peak of production for a longer period and will boost production later in life, as overall nutrient requirements of birds within the same flock will be more similar, allowing you to better meet their needs.

There remain two critical times in the life of the pullet which will have the greatest effect on final performance, the first four to six weeks and 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 is still 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. During the first 8-10 weeks, any increase in the energy intake is accompanied by an increase in growth. When the feed is provided in a crumb form, young pullets are more easily able to increase their feed intake and so energy intake. The energy intake can also be increased by increasing the energy levels in the diet. Don't forget that chicks are born poikilothermic (hard to maintain their internal temperature) and it takes around 4-5 days before to become homeothermic. Keeping the brooding house 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".

Figure 1 body weight development during rearing and start of lay



During the 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 daily requirements.
If feed intake and body weight growth with a starter diet is not sufficient, it might be wise to add a pre-starter diet, which a higher concentration of protein and energy, in a micro pellet (2mm) or crumble form for two weeks.

2.3 Grower phase

If the body weight is up to the desired standard, feed composition switches from a starter feed towards a grower feed. Grower feed has a lower energy level than starter feed in order to stimulate the chicks' feed intake. As chicks increase 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 11 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 10% coarse (over 3.2 mm) particles. More coarse particles can increase selective eating, while more 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

This is the period to train your birds to eat and to further stimulate the development of the gastrointestinal tract. After 10 weeks of age chicks are able to regulate their energy intake according to the energy level of the diet. They can do this in both hot and temperate climates. 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 frame size.

A second reduction in the energy and protein content of the feed will increase the birds' feed intake without developing a fat pullet. Furthermore, 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 fibre content of the feed. Also, coarse insoluble fibre will stimulate the development of the crop and will 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 therefore 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 water is always available during the rearing period.

Another part can be explained by medullary bone development before the first ovulation. The total calcium contained in this medullary is around 1.5 to 2 grams. A pre-layer feed with a higher calcium level is needed to establish this bone reserve. It must be used from 10 days for the first eggs (approximately 16 weeks) till approximately 2% production. If the change is realized later, the earliest birds ingest around 1.8g of calcium while they need to produce a shell with 2g of calcium. As a result of this deficiency, they will stop or reduce laying eggs for some days, or they produce eggs without shell. These birds can exhibit cage layer fatigue later in life and develop osteoporosis towards the end of lay. The characteristics of a pre-layer feed are like the layer 1, but with a lower level of calcium; 2.10-2.50%.

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 delayed.

Table 2 Nutrient requirements during rearing

	Diet units	Starter 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 2% lay
Minimum Metabolisable 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	0.77	0.81
Methionine	%	0.52	0.45	0.37	0.40
Methionine + Cysteine	%	0.93	0.86	0.68	0.66
Threonine	%	0.80	0.66	0.54	0.58
Tryptophan	%	0.21	0.20	0.18	0.18
Valine	%	0.99	0.84	0.65	0.69
Isoleucine	%	0.89	0.76	0.59	0.62
Arginine	%	1.08	0.92	0.76	0.81
Apparent faecal digestible amino acids					
Dig. Lysine	%	1.00	0.85	0.66	0.71
Dig. Methionine	%	0.48	0.41	0.34	0.38
Dig. Meth. + Cysteine	%	0.84	0.74	0.61	0.59
Dig. Threonine.	%	0.69	0.59	0.46	0.49
Dig. Tryptophan	%	0.19	0.17	0.15	0.16
Dig. Valine	%	0.85	0.74	0.56	0.58
Dig. Isoleucine	%	0.78	0.65	0.51	0.59
Dig. Arginine	%	0.95	0.87	0.69	0.75
Major minerals					
Calcium	%	1.05 - 1.10	0.90 - 1.10	1.00 - 1.20	2.10 - 2.50[1]
Available Phosphorus	%	0.45 - 0.50	0.45 - 0.50	0.42 - 0.47	0.45 - 0.50
Retainable Phosphorus	%	0.38 - 0.42	0.38 - 0.42	0.36 - 0.40	0.38 - 0.42
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] Supply 50% of the calcium in granular form (2-4mm diameter)

3 Production period

3 Production period

3.1 Basic rules of our feeding program during production

Feeding the birds must be simple, to reduce the risk of errors at varying levels in the manufacturing and delivery process. There are also additional reasons which are related to the birds directly. For example, birds are very sensitive to the feed presentation and the introduction of new raw materials. For this reason, we recommend a limited number of feed changes and a gradual inclusion of new raw materials.

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 55 weeks of age, 57g of egg mass per day between 55 and 80 weeks of age and 53g of egg mass after 80 weeks of age. A large proportion of the flock 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. 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 4 to 5 weeks later.

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, a feed enriched in fat (1.5 to 2.5%) and incorporating a minimum of insoluble fibre is recommended. After the onset of lay, a diet slightly lower in energy level and richer in insoluble fibre, 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:

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

With an insufficient feed intake, there will be a short period of nutrient shortage at the onset of lay, meaning birds will consume less nutrients per day than they require at that 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 birds will need to consume even more feed to offset the higher requirement, 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 daily egg mass produced starts to go down. It is advised to monitor the performance and body weight development of your birds carefully weekly till the peak and monthly afterwards so you can feed your flock according to their needs.

3.2 Layer 1

This feed must be used from start of production till 55 weeks of age, or when 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. Layer 1 must meet the requirements for the amino acids and energy levels required for further growth and production at a time where the feed consumption is still low. Please keep in mind that the bird's growth is still not finished at start of production and continues till 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 such high levels of feed intake, while feed consumption needs to increase by 40% in that short period of time.

At the onset of lay, it is desirable to encourage nutrient consumption in order to obtain quickly eggs of marketable size. For this, a feed enriched in fat allows to improve the presentation of the diet which results in an increase in feed consumption. Oils 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 fibre 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, this feed must be used from 55 till 80 weeks, or until the end of lay. It is advised to formulate for lower energy levels (-25 kcal per kg feed) in layer 2 compared to layer 1. 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 feed consumption and the production results observed. The feed consumption is highly determined by the energy requirements and the climate observed by the birds.

3.4 Layer 3

Depending on the egg mass produced, this feed must be used from 80 weeks 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 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.

Layer 1 - From 2% lay to 55 weeks	mg/h/d	unit per kg feed	95	100	105	110	115
Energy Cage Housing		kcal			2800-2900		
Energy Alternative Housing		kcal			2800-2950		
Protein Minimum		%	18.0	17.6	17.2	16.8	16.4
Total amino acids							
Lysine	980	%	1.03	0.98	0.93	0.89	0.85
Methionine	510	%	0.54	0.51	0.49	0.46	0.44
Methionine + Cysteine	860	%	0.91	0.86	0.82	0.78	0.75
Threonine	665	%	0.70	0.67	0.63	0.60	0.58
Tryptophan	230	%	0.24	0.23	0.22	0.21	0.20
Valine	845	%	0.89	0.85	0.80	0.77	0.73
Isoleucine	770	%	0.81	0.77	0.73	0.70	0.67
Arginine	1000	%	1.05	1.00	0.95	0.91	0.87
Apparent faecal digestible amino acids							
Lysine	850	%	0.89	0.85	0.81	0.77	0.74
Methionine	470	%	0.49	0.47	0.45	0.43	0.41
Methionine + Cysteine	740	%	0.78	0.74	0.70	0.67	0.64
Threonine	595	%	0.63	0.60	0.57	0.54	0.52
Tryptophan	190	%	0.20	0.19	0.18	0.17	0.17
Valine	750	%	0.79	0.75	0.71	0.68	0.65
Isoleucine	680	%	0.72	0.68	0.65	0.62	0.59
Arginine	885	%	0.93	0.89	0.84	0.80	0.77
Minerals							
Available Phosphorus min	450	%	0.47	0.45	0.43	0.41	0.39
Available Phosphorus max	480	%	0.51	0.48	0.46	0.44	0.42
Retainable Phosphorus Min	380	%	0.40	0.38	0.36	0.35	0.33
Retainable Phosphorus Max	410	%	0.43	0.41	0.39	0.37	0.36
Total Calcium Min	3900	%	4.11	3.90	3.71	3.55	3.39
Total Calcium Max	4100	%	4.32	4.10	3.90	3.73	3.57
Sodium Minimum	180	%	0.19	0.18	0.17	0.16	0.16
Chlorine	170-260	%	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26	0.17-0.26
Layer 1 respected a daily egg mass of 59.5 gram							

Layer 2 - From 55 to 80 weeks	mg/h/d		100	105	110	115	120
Energy Cage Housing		kcal			2775-2875		
Energy Alternative Housing		kcal			2775-2925		
Protein Minimum		%	16.5	16.1	15.7	15.3	14.9
Total amino acids							
Lysine	935	%	0.94	0.89	0.85	0.81	0.78
Methionine	490	%	0.49	0.47	0.45	0.43	0.41
Methionine + Cysteine	830	%	0.83	0.79	0.75	0.72	0.69
Threonine	635	%	0.64	0.60	0.58	0.55	0.53
Tryptophan	220	%	0.22	0.21	0.20	0.19	0.18
Valine	808	%	0.81	0.77	0.73	0.70	0.67
Isoleucine	735	%	0.74	0.70	0.67	0.64	0.61
Arginine	963	%	0.96	0.92	0.88	0.84	0.80
Apparent faecal digestible amino acids							
Lysine	815	%	0.82	0.78	0.74	0.71	0.68
Methionine	450	%	0.45	0.43	0.41	0.39	0.38
Methionine + Cysteine	710	%	0.71	0.68	0.65	0.62	0.59
Threonine	570	%	0.57	0.54	0.52	0.50	0.48
Tryptophan	180	%	0.18	0.17	0.16	0.16	0.15
Valine	715	%	0.72	0.68	0.65	0.62	0.60
Isoleucine	650	%	0.65	0.62	0.59	0.57	0.54
Arginine	850	%	0.85	0.81	0.77	0.74	0.71
Minerals							
Available phosphorus min	400	%	0.40	0.38	0.36	0.35	0.33
Available phosphorus max	420	%	0.42	0.40	0.38	0.37	0.35
Retainable Phosphorus Min	340	%	0.34	0.32	0.31	0.30	0.28
Retainable Phosphorus Max	360	%	0.36	0.34	0.33	0.31	0.30
Total calcium min	4200	%	4.20	4.00	3.82	3.65	3.50
Total calcium max	4500	%	4.50	4.29	4.09	3.91	3.75
Sodium minimum	180	%	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
Layer 1 respected a daily egg mass of 59.5 gram							
Layer 2 respected a daily egg mass of 57 gram							

Layer 3 - From 80 to 100 weeks	mg/h/d		100	105	110	115	120
Energy Cage Housing		kcal			2700-2850		
Energy Alternative Housing		kcal			2750-2900		
Protein Minimum		%	15.5	15.1	14.7	14.3	14.0
Total amino acids							
Lysine	875	%	0.88	0.83	0.80	0.76	0.73
Methionine	440	%	0.44	0.42	0.40	0.38	0.37
Methionine + Cysteine	750	%	0.75	0.71	0.68	0.65	0.63
Threonine	590	%	0.59	0.56	0.54	0.51	0.49
Tryptophan	200	%	0.20	0.19	0.18	0.17	0.17
Valine	755	%	0.76	0.72	0.69	0.66	0.63
Isoleucine	690	%	0.69	0.66	0.63	0.60	0.58
Arginine	895	%	0.90	0.85	0.81	0.78	0.75
Apparent faecal digestible amino acids							
Lysine	760	%	0.76	0.72	0.69	0.66	0.63
Methionine	405	%	0.41	0.39	0.37	0.35	0.34
Methionine + Cysteine	645	%	0.65	0.61	0.59	0.56	0.54
Threonine	530	%	0.53	0.50	0.48	0.46	0.44
Tryptophan	165	%	0.17	0.16	0.15	0.14	0.14
Valine	670	%	0.67	0.64	0.61	0.58	0.56
Isoleucine	610	%	0.61	0.58	0.55	0.53	0.51
Arginine	790	%	0.79	0.75	0.72	0.69	0.66
Minerals							
Available phosphorus min	360	%	0.36	0.34	0.33	0.31	0.30
Available phosphorus max	380	%	0.38	0.36	0.35	0.33	0.32
Retainable Phosphorus Min	305	%	0.31	0.29	0.28	0.27	0.25
Retainable Phosphorus Max	325	%	0.33	0.31	0.30	0.28	0.27
Total calcium min	4300	%	4.30	4.10	3.91	3.74	3.58
Total calcium max	4700	%	4.70	4.48	4.27	4.09	3.92
Sodium minimum	180	%	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

Layer 1 respected a daily egg mass of 59.5 gram

Layer 2 respected a daily egg mass of 57 gram

Layer 3 respected a daily egg mass of 53 gram

3.6 Mineral specifications during the production period

Shell weight increases with age throughout the entire laying period, while the bird's efficiency to absorb calcium declines with age. For that reason, we strongly advise to increase the calcium concentration in the diet at start of production, at 55 weeks and 80 weeks of age, and if necessary, at other ages. Further information about minerals can be found in the chapter on Mineral recommendations.

3.7 Amino acid requirements

Bird 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 birds, to reduce the necessary safety margins and 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.

It is well known to formulate according to the main limiting amino acids in layer nutrition, to known as: lysine, methionine, cysteine, threonine and tryptophan. In order to reduce total crude protein content, formulation of layer diets can be by introducing Isoleucine and Valine, as nutritional constraints. If this is not possible, it is necessary to keep a constraint for minimum of protein, to reduce the risk of a deficiency in protein. Certain raw materials are lower in 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 meat and bone meal and wheat. Methionine is limited in soy products. On the other hand, Arginine do 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 lay has improved considerably (e.g. 30 to 50 weeks above 90% lay). An analysis of the individual performance over the period 40-66 weeks shows that 65% of the birds had performance above average, as shown in Table 4. The 40% best layers had laid 180 eggs in 182 days and/or 58.2g of egg mass per day.

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

Quintile	Rate of lay	Egg Mass (gram per day)
1st	99.7	58.2
2nd	99.0	58.2
3rd	98.1	57.3
4th	97.0	56.9
5th	92.0	54.0
Mean	97.2	56.9
% of pullets above the mean	65.4	52.9

Source: Internal research (2020)

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.

3.8 Energy requirements

Energy regulation is not specific to a breed, but due to body weight difference, it might 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 requirement for growth, maintenance and production. The feed density (gram per litre) seems to be the limiting factor in ingestion regulation, especially during the early production period, or during stressful periods.

The addition of fat to diet results in an improvement in feed palatability and thus an increase in the ingestion of energy in proportions which can be very significant. The increase in egg weight is just one of the effects. These effects are dependent upon the quantity and the type of fats added. The inclusion rate of oil for medium to large sized eggs is 2-3%. Markets that are requesting small to medium size eggs, a lower inclusion rate, is advised. Therefore, 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 reduce the quantity of vegetable oil being used.

3.8.1 Feed intake

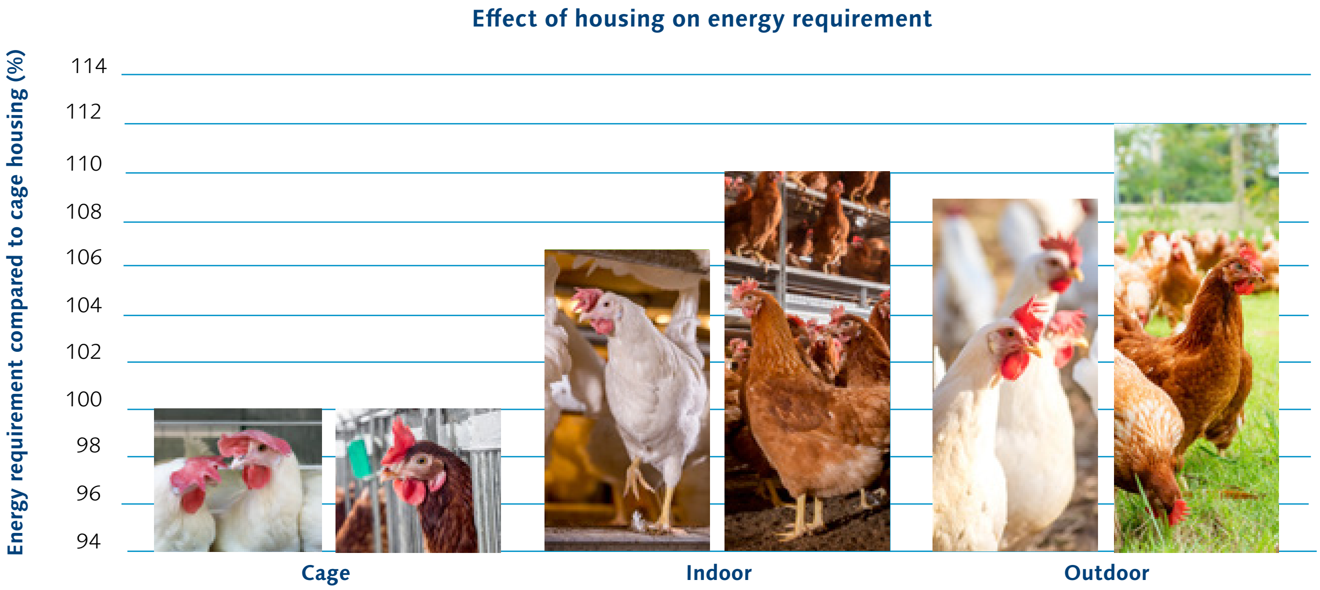
Feed intake is still a limiting factor at the start of lay. The goal should always be to increase the birds' feed intake to approximately 100 grams a day as soon as possible. But keep in mind, independent on the energy concentration of the diet, it can take several weeks to develop a proper feed intake.

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. After a diet has been diluted, it takes the laying hens several weeks to increase their levels of feed consumption. Furthermore, feed efficiency (feed conversion rate), expressed in grams of feed required per gram of egg produced, always improves when the feed is more concentrated.

3.8.2 Housing

Different housing systems require different daily energy requirements. Birds in alternative production systems are more active and, in case they have access to the range, they are confronted by temperature variations. Depending on the housing system, the temperature and the birds' feathering, feed consumption can be increased by 3 to 20%. The nutritional requirement needed for the bird's activity and their thermoregulation is mainly 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.

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.

3.9 Stimulating egg size by nutrition

It is known that both management and nutrition can influence egg weight. Key management decisions should be taken in advance, during the rearing period as they will influence average egg size for the total laying cycle and this is the most effective period (not only regarding response in egg size but also economically-wise), while other techniques or nutrition adjustments can be helpful 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 being methionine/cysteine, lysine and other essential amino acids, total fat and linoleic acid content of the laying diets. 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 production performances.

Amino acid intake has a linear effect in 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 lower effect in egg weight, like tryptophan and threonine, but all them are essential to ensure adequate 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.

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 is partly due to the improved palatability and higher energy levels of the feed leading to an increased daily energy. It will also help to stimulate growth towards the adult body weight at the onset of lay despite of having a limited feed intake at this age. The stimulation of growth will have a positive effect on egg size and the total laying performance of the flock.

Linoleic acid has a positive effect on egg size, but only within a certain range. Daily requirements of laying hens are not high, around 1.2%. Higher levels of linoleic acid, up to 2.9%, can be used to obtain larger eggs. Diverse raw materials used as source of fat will have different effect depending on their fatty acid profile: 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 Condition

4 Tropical condition

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 in order to reduce the heat production from digestion. At second, it is important to remember that birds are not able to sweat like mammals can. Instead in order to lose their heat they start panting, a process which requires energy.

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 results in oxidative stress. This all affects the laying hen performance and can increase mortality. The severity of the negative consequences of heat stress in a flock of laying hens depends 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 toxins 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, microorganism development 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 consuming and digesting 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 result 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. As a result a lower number of first quality eggs and lower egg size 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 CO^2 level in the blood and consequently increases blood pH (respiratory alkalosis). To compensate for the increased blood pH, the 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 CO^2 by panting, their blood pH is increased, and consequently the availability of calcium for the 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 a reduced amount 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 recommended to have a good and regular feed quality monitoring, as fat oxidation, bacterial load and mycotoxins are more critical during tropical conditions.

4.4.1 Feed formulation

Adaptation in feed formulation can help the layers 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 formulation, when there is 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.

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

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

As shown in Table 5, protein digestion results in a lot 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 birds to reduce part of the protein, whilst maintaining or increasing the amino acid level. So, feeding higher digestible protein sources or a higher amount of synthetical amino acids will help the birds to maintain the daily amino acid intake. As amino acids are mainly deposited in the egg, the amino acids content in the feed should be adapted to real feed consumption noticed.

Vitamin and minerals

It is recommended to increase the level of bicarbonate via adding sodium bicarbonate to the feed, by formulating both on Sodium and Chloride levels. Sodium can be added via sodium bicarbonate, 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. 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.

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 the 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, a 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 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 add extra limestone on top of the feed in the late afternoon, especially under tropical conditions, when feed intake is reduced during warmer periods of the day (including the afternoon). Extra limestone 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

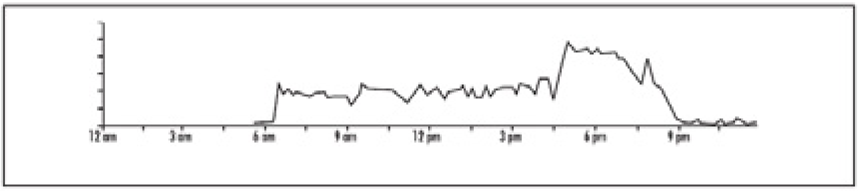
Figure 4 Addition of limestone on top of the afternoon feed

4.4.3 Water quality and management

Laying hens will increase their water intake, during periods of heat stress. 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 water spraying (evaporation) is applied.

Providing enough fresh and clean water will encourage the birds to drink and consequently eat. As shown in Figure 5, 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. 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 the system will help to prevent bacterial growth in the water lines and a possible change in the taste of the water.

Figure 5 Daily water intake pattern (lights on between 6.30 AM and 6.30 PM) (Leeson & Summers, 2005)



How to support your birds in hot and tropical climates?

- 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.
- 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 and the stage to which the digestive tract has developed. Presenting feed in crumb form (during the starter phase) makes it easier for the chicken to eat it, reduces the time taken in eating, and encourages growth of the chick. 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 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. In order 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. When the body weight is not according to desired target, it is possible to continue feeding crumble till 12 weeks of age but not later than that, as you need to avoid the risk of under-consumption at the beginning of the sexual maturity. This underdeveloped feed intake can be the result when the change from crumble to mash or pellets has been made too late.

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

Pellets and crumbles can result in increased manufacturing costs. 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 is quite challenging and can be checked with a wet sieve analysis.

With the intention of keeping good shell quality we suggest:

- use granular limestone if the diameter of the diet is adapted
- add some of the limestone after pelleting
- distribute 3 to 4g per bird of granular limestone (2 to 4mm) in the poultry house each afternoon.

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 15%
1,0 - 3,2mm	Min 75%	Min 70%
> 3,2mm	Max 0%	Max 5%

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. In case that this standard cannot be achieved, it is preferred to feed the birds good quality crumbs or pellets.

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 are the minor raw materials, such as minerals and vitamins, 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 different 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 quality monitoring and control. 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 programme.

Next to the chemical quality, the physical quality has a clear impact on the birds' feed intake and performance. 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 (pecking and cannibalism). Adding coarse fiber to the diet increases gizzard size, 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 to prevent fatty livers.

During the bird'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. 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 very 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% 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.

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 oats and oat hulls. Cereal by-products (like bran) are also a good source of insoluble fiber. However cereal by-products have a fine structure and have therefore a limited effect on the gastrointestinal movements, which makes them less suitable as a fiber source.

Fiber that is provided in addition to the diet can be coarse fiber such as straw, alfalfa (lucerne), wood shaving, rice/oat husk, silage, etc. These materials must be available in the building through round feeders, or directly as a bale on the scratching area. Birds must always have free access to fiber sources. We advise not spreading the fibers directly on the floor, also, in order to prevent the incidence of floor eggs, fiber must be introduced after the peak of production when the birds are trained well enough to use the nest.

5.4 Processing methods

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

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.

5.4.1 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 6.

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.

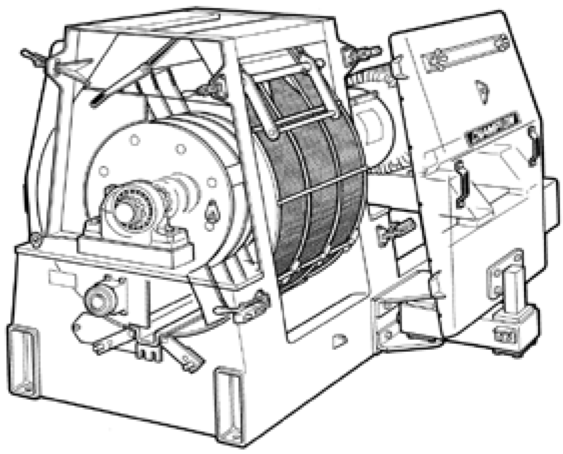


Figure 6 hammermill, containing two of more rotor plates, free-swing hammers and a screened grinding chamber (via (McKinney, 2006))

5.4.2 Rollermill

Roller mills can contain of one, two or three pair of rolls, stacked and surrounded in a steel frame, as shown in Figure 7. 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.

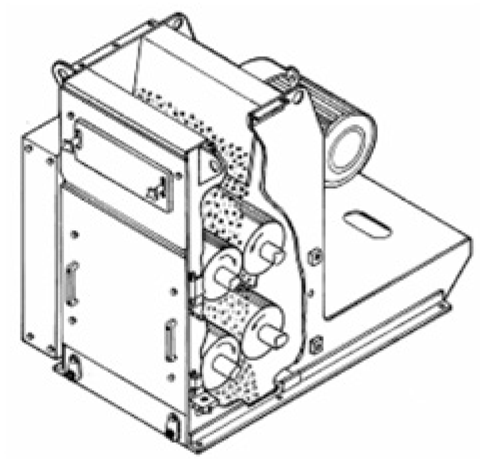


Figure 7 roller mill, containing different pairs of rolls (via (McKinney, 2006))

5.5 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. In order 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.

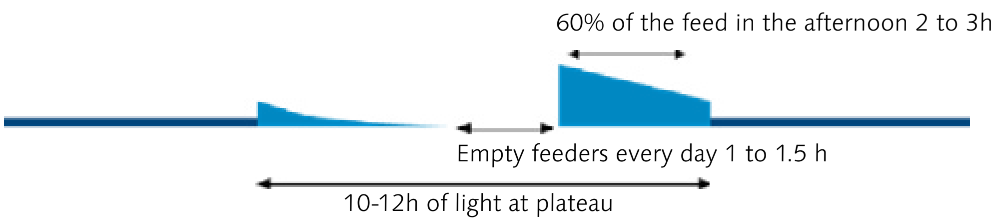
5.5.1 Feed Management during rearing

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 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.

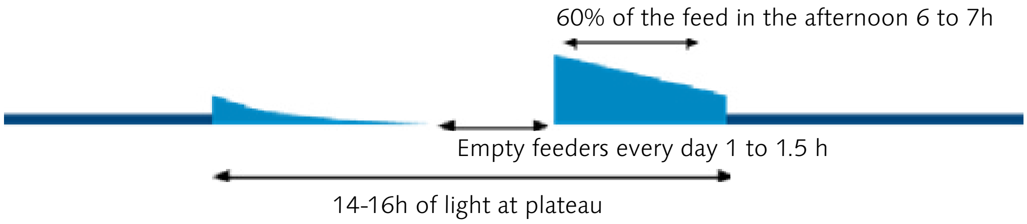
5.5.2 Feed Management during laying period

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 the birds to get to the house from the range onto the system (slatted area and perches) and to sleep there. The amount of feed distributed 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 reason, 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 55 weeks of age, 57g egg mass per day between 55 and 80 weeks of age and 53g egg mass after 80 weeks of age. Many birds are able to produce more than 60g of egg mass for a long period. Therefore, we recommend changing from one feed phase to another only when the daily produced egg mass is decreasing.

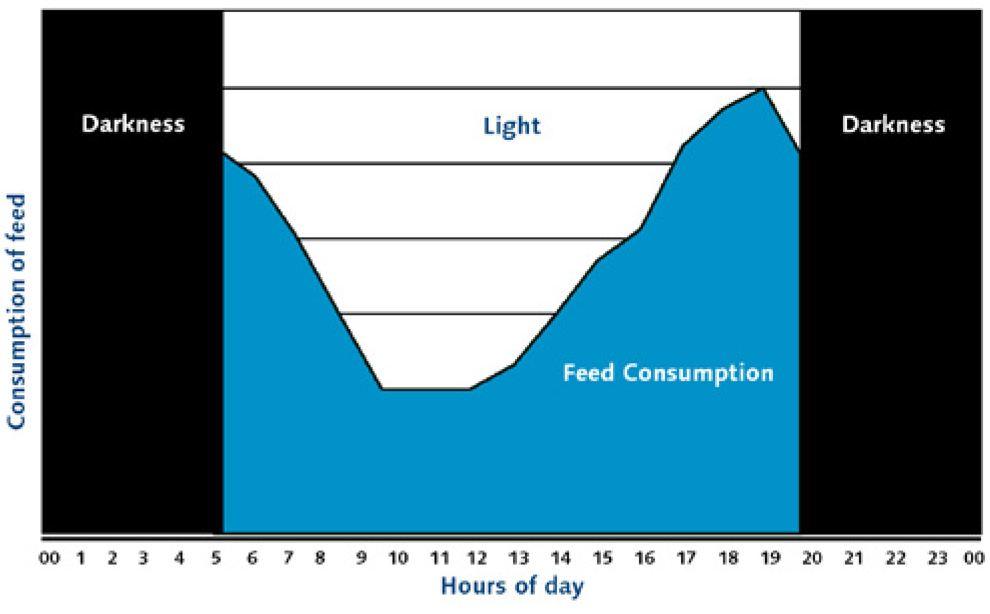
Figure 9 Management of feed distribution for birds in production



5.5.3 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 behavioural 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)



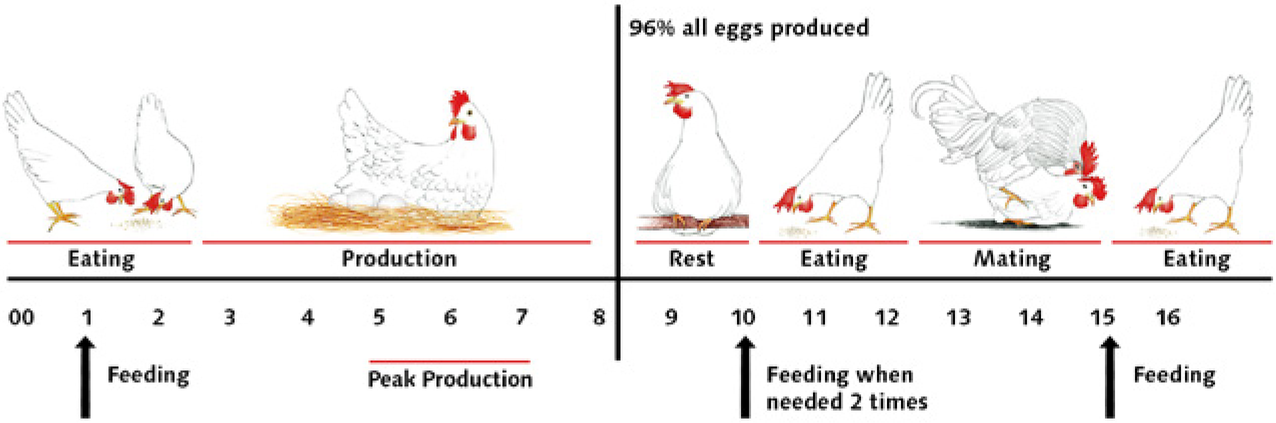
The amount of feed distributed must be enough to cover the increased feed consumption during the next morning: the birds will be hungry after the night period and will easily finish the less attractive fine particles. As the feed is not distributed in the early morning, the hens have time to find the 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 birds to start the intensive feed consumption in the afternoon when you want the birds to eat the most.

5.5.4 Feed distribution parent stock

The activity patterns of 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



5.5.5 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, to prevent selection and decrease flock uniformity.

5.5.6 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.

Mid night lighting is also useful during the hot season, as it can reduce the negative impact of high temperatures. It will allow the birds 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, mid night 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 mid night 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 (body weight targets have been achieved, hot period is over, etc.). When mid night 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

Often neglected as a source of nutrients, but water is a very important nutrient for all production animals. Besides, water can also be used as a carrier for vaccines and antibiotics/chemotherapeutics. But on the other hand, it can also be an important source of pathogens!

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 borehole? 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 every year.

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, 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 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.

Water quality parameters

Parameter	Good Quality	Do not use
pH	5 - 8	< 4 and >9
Ammonium mg/l	<1.0	>2.0
Nitrite mg/l	<1.0	>1.0
Nitrate mg/l	<100	>200
Chloride mg/l	<200	>300
Sodium mg/l	<100	>200[1] >400[2]
Sulfate mg/l	<100	>250
Iron mg/l	<0.5	>1.0
Manganese mg/l	<0.5	>1.0
Hardness in German degrees	>4 <15	>20
Oxidizable organic matter mg/l	<50	>200
H2S	Non detectable	Non detectable
Coliform bacteria's cfu/ml	<10	>100
Total germ count cfu/ml	<10.000	>100.000

[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 in the empty period should be sufficient for the whole 16 weeks rearing period and the rearing birds 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 this.

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. Using acids, pH should be below 4, to achieve the disinfecting effect and above 3.5, otherwise it becomes corrosive and the birds stop drinking. High levels of chlorine have the same effect on the birds. To have an efficient disinfection with chlorine, decrease the 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 moult in the water. It is better to use acids and chlorine alternatively.

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.

Birds, 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 birds don't drink, they won't eat and cannot grow or produce!

7 Mineral recommendations in relation to eggshell formation

7 Mineral recommendations in relation to eggshell formation

Year after year, improvements in the birds' productivity are 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 egg-shell takes about 20 hours before being completed, while the main calcification takes place in 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 in which calcium carbonate is supplied to the birds. Differences between white and brown egg layers do exist, even when the same lighting programme is applied.

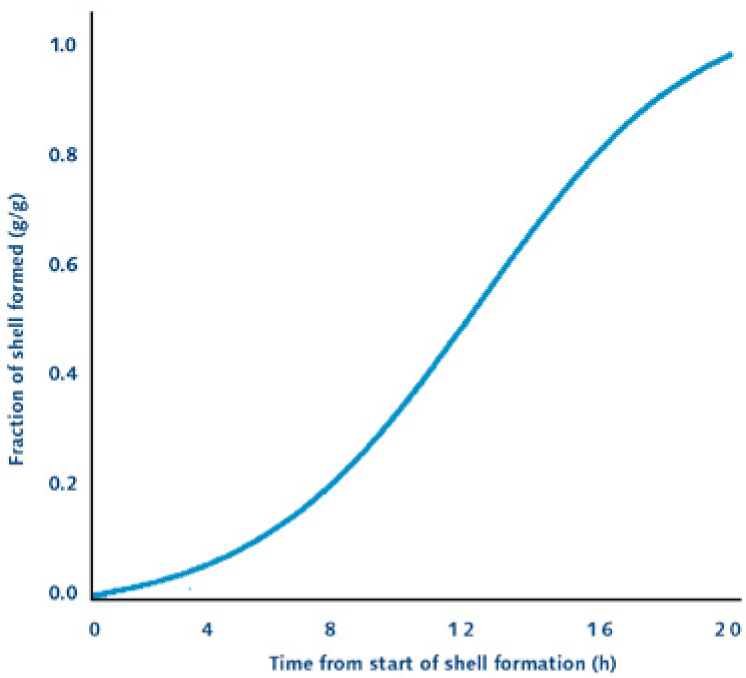
7.1 Calcium absorption

During shell formation, the bird 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 water. Vitamin D3 needs to be activated by the liver and the kidneys towards Calcitriol, or it can be supplied as Calcidiol (25-OH-D3) and only need to be activated by the kidneys. Always keep in mind that this first option requires healthy liver and kidneys, which allow proper functioning for optimal activation of vitamin D3 and consequently proper calcium absorption.

When the quantity of calcium absorption is insufficient, the birds' medullary bone reserves are used: i.e. the calcium is deposited in the eggshell and the phosphorus is eliminated by the kidneys. It has been demonstrated many times that birds that are forced to utilize their bone reserves produce eggs of poorer shell quality, especially at the end of the production cycle. Furthermore, this can also lead to reduced bone quality, especially in birds housed in cages (osteoporosis resulting in cage layer fatigue).

The deposition of calcium is slow during the first 5 hours after it enters the shell gland. Followed by approximately 10 hours in which the rate of shell 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 shell 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 shell quality.

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



7.2 Importance of large limestone particle size

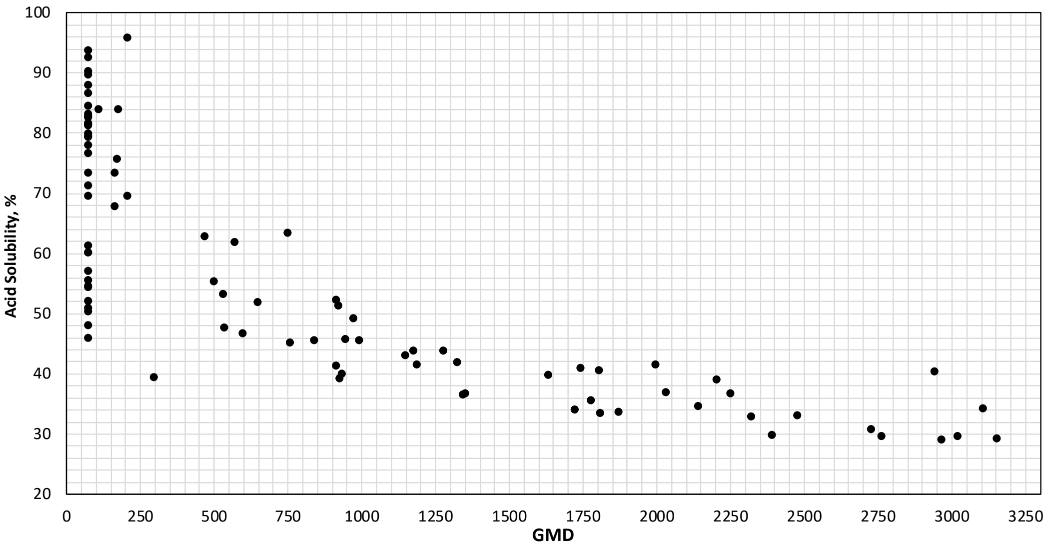
The availability of calcium at the end of the night period is improved by using a coarse calcium source with a low solubility. By using a low soluble coarse limestone, the quantity of available calcium during the beginning of shell formation is reduced and improved at the end of the night. The most important parameter is the solubility, i.e. the lower the solubility, the larger the particle size and the slower the calcium release (Figure 14, Saunders-Blades, et al. 2009). Fine limestone shows more variation in acid solubility than coarse limestone. 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 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 mobilised whilst also a better eggshell quality will be achieved.

In the morning, limestone that quickly dissolves and 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 gives 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 faeces. 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 8. The difference in recommendation between white and brown layers is explained in the next paragraph.

Table 8 Ratios of coarse and fine calcium during rearing and production

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

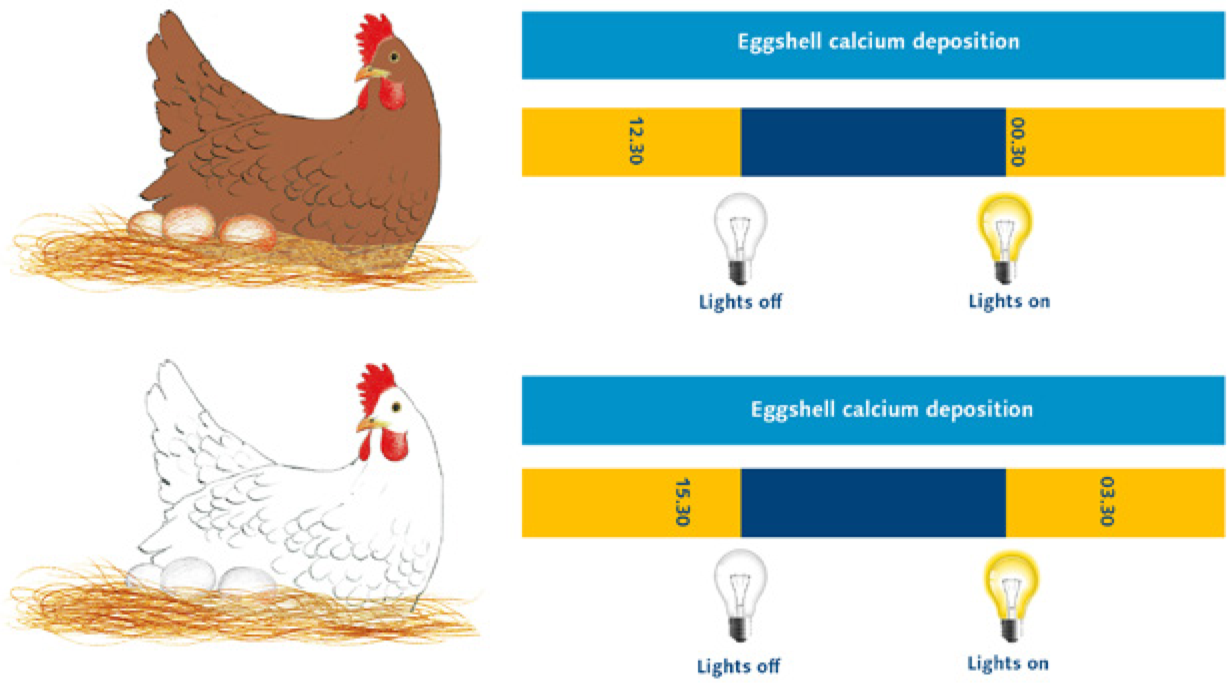
Please note when meat and bone meal is included in the diet, the proportion of calcium in granular form should be increased to 80%, as the calcium in meat and bone meal has a fine structure. The phosphates should be supplied as micro-granules.

7.4 Difference between white and brown layers

Calcification of the shell is mainly realised during the night. A high percentage of brown birds stop the eggshell calcification at lights on or just after, while white layers finish their shell after lights on. Resulting in a difference in time of calcification of 3 hours, as shown in Figure 4.

At "lights-on", laying hens that have not completed calcification should have access to powdered calcium, as this can be very rapidly dissolved and absorbed. Especially white birds are able to consume feed before finishing their eggshell, while the majority (60%) of the brown birds have already finished their eggshell during the night. This requires a higher percentage of coarse limestone for brown layers, to prevent calcium mobilisation from the 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 system. Different studies have shown a higher breaking strength in birds housed in alternative systems compared to cage housed birds. This is due to the physical activity of the birds, 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 birds are interacting with the system.

Although there is a difference in activity and therefore in bone metabolism, there is no difference in calcium and phosphorus recommendations. During the rearing period the balance between Calcium and Retainable Phosphorus remains Ca: ret P 2.4, with an increased level of calcium for eggshell formation during the production period.

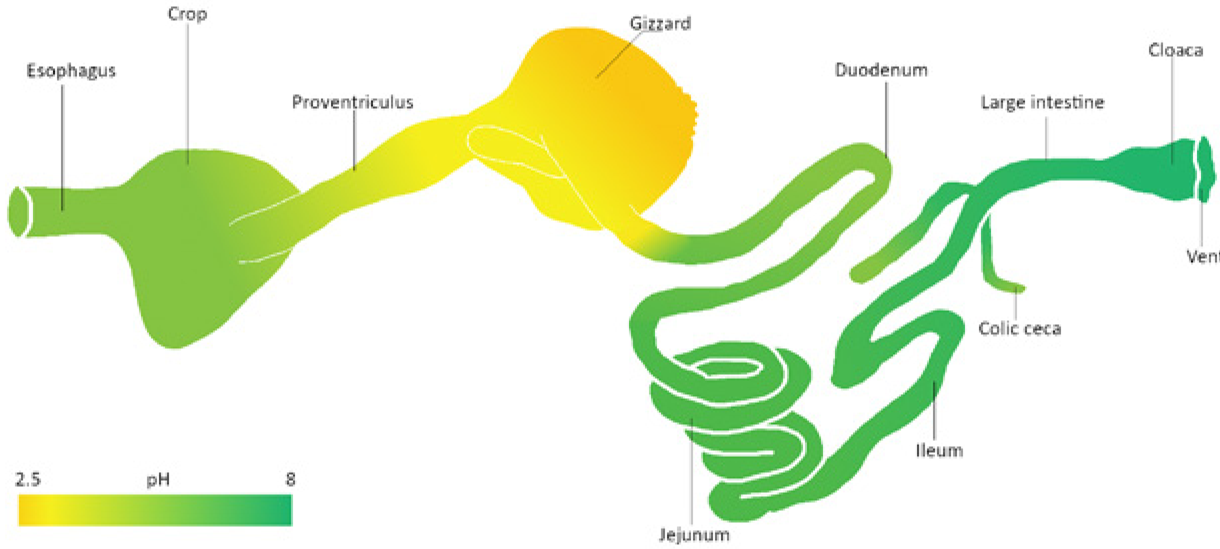
8 Gut health and faecal quality

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 birds' digestive system. A bird with a well-developed digestive system is characterized by a good and strong gizzard, and correct pH levels in each of the different organs (shown in Figure 15).

Figure 15 Digestive tract of a laying hen (Hendrix Genetics, 2020)



8.2 Crop

The crop is part of the digestive system, it is a diverticulum of the oesophagus, with a similar muscular structure. Due to the slightly lower pH level (pH 5.5) it acts as the first defence for microorganisms. In the crop, the digestion of carbohydrates gets started 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 for laying hens (Classen, et al., 2016). This passage rate is greatly influenced by the number of feedings, day length, and 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, the content should feel filled and soft in this case your chicks, pullets or layers have consumed both feed and water. When it is filled, but hard, the birds have had a low water intake. Even worse is an empty crop, as the birds did not consume water nor feed, always check what might be the cause of an empty crop!

8.3 Proventriculus and gizzard

The proventriculus is a rather small organ, with the main goal to produce the digestive acids pepsinogen and 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.

Figure 16 Well developed gizzard of a hen in early lay (Hendrix Genetics, 2020)

The gizzard is an extremely muscular organ with a white 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 rearing 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, results 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 compared with pullets fed a crumbled diet. This is also shown in commercial trials, where birds have been fed either with a diet in mash form or in pelleted form. As an example, birds have been fed from day old till 17 weeks of age, the results of the trial are shown in Table 9.

Table 9 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 bird 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 (enzyme involved in fat digestion), amylase (enzyme involved in starch digestion) and different enzymes involved for protein digestion are added. In the total intestine, further digestion and absorption of the feed materials 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.

9 Premix composition

9 Premix composition

9.1 Suggested premix composition

The suggested premix specifications for commercial pullets and laying hens are mentioned in the Table 10 below. Adaptations of the premix levels can be necessary based on local circumstances.

Table 10 Suggested premix composition for commercial pullets and layers

		Rearing period		Laying period
		0-10 (weeks of age)	10 weeks - 2% Lay	
		Added trace elements mg per kg of diet		
Manganese (Mn)	mg	85	85	100
Zinc (Zn)	mg	80	80	80
Iron (Fe)	mg	60	60	60
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	100	75	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	0.02	0.03
Nicotinic Acid (Niacin)	mg	60	30	40
Pantothenic acid	mg	15	10	10
Folic Acid	mg	1	1	1
Biotin	mg	0.2	0.2	0.2
Choline		1000	500	1000
		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.

Parent stock diets are often heat treated for extra feed safety. Heat can have a negative effect on 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. Therefore, premix recommendations are given for both standard and heat-treated diets in Table 11.

Table 11 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	60	60	60	60
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	100	105
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	0.3	0.3	0.4	0.4
Choline	mg	750	750	1000	1000
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.

9.2 Mixing

Trace elements and vitamins should be correctly mixed in a premix or other pre-blend before being added to the raw materials. The quality of mixing, dosing and handling can be checked by analysing Manganese as a tracer. In order to check the homogeneity of mixing.

9.3 Toxicity of some minerals

Some minerals can have a toxic effect when present in high levels, the maximum admissible levels for different minerals are listed in Table 12.

Table 12 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

9.4 Mycotoxins

Mycotoxins are natural substances produced by moulds and fungi, which are common in almost all farm environments. In total over 400 types of mycotoxins are known, 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, which can be up to three compared to the full grain.

Laying hens are susceptible to mycotoxins for various reasons. 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 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 layers 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 and hatchability
- Leg problems
- Carcass condemnation

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. Next to the cleaning and/or sorting process, it might be wise to add a mycotoxin binder for the specific mycotoxin(s) present in your feed materials.

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