Optimum vitamin nutrition for poultry

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Classical deficiency signs and non specific parameters (for example, lowered production and reproduction rates) are associated with vitamin deficiencies or excesses. Vitamin nutrition should no longer be considered important only for preventing deficiency signs but also for optimising animal health, productivity and product quality.

What quantities of supplemental vitamins should be provided to poultry diets? One suggestion would be to meet vitamin requirements based on the National Research Council or other agency nutrient recommendations. A second choice would be to provide higher levels as recommended by poultry industry groups.

This article attempts first to dispel the concept that only meeting NRC requirements will provide poultry optimum production and health protection. Some poultry industry groups are recommending optimum vitamin supplementation.

Intake of vitamins

Vitamin dietary intake and utilisation is influenced by many factors, including particular feed ingredients, bioavailability, harvesting, processing, storage, feed intake, antagonists, least cost feed formulations and other factors.

1**Agronomic effects and harvesting conditions.**

Vitamin levels will vary in feed ingredients because of crop location, fertilisation, plant genetics, plant disease and weather. Harvesting conditions often play a major role in the vitamin content of many feedstuffs. Vitamin content of corn is drastically reduced when harvest months are not conducive to full ripening. In one study, vitamin E activity in blight corn was 59% lower than in sound corn and activity of the vitamin in lightweight corn averaged 21% lower than in sound corn. The rate of oxidation of natural tocopherol was higher in high moisture corn than in low moisture corn due to increased peroxidation of the lipid.

1**Processing and storage effects.**

Vitamin	170°F (77°C)	180°F (82°C)	190°F (88°C)	200°F (93°C)
A beadlet	90-100	90-100	90-95	85-90
D_3 beadlet	90-100	90-100	90-95	85-90
E acetate	90-100	90-100	90-95	80-90
E spray dry	90-100	90-100	90-95	85-90
K (menadione sodium bisulphite)	50-60	40-50	40-50	35-40
K (menadione nicotinamide bisulphite)	80-90	70-80	65-75	65-75
Thiamin monohydrate	90-100	90-100	90-95	85-90
Thiamin HCl	90-100	85-95	85-95	70-80
Riboflavin	90-100	90-100	90-95	85-90
Pyridoxine	90-100	90-100	90-95	80-90
Vitamin B_{12}	90-100	80-90	70-85	60-80
Ca Pantothenate	90-100	90-100	90-95	85-90
Niacin	90-100	90-100	90-95	85-90
Niacinamide	90-100	90-100	90-95	85-90
Folic acid	90-100	85-90	80-90	70-80
Biotin	90-100	90-100	90-95	85-90
Vitamin C ethycellulose	50-80	40-70	30-60	20-40
Vitamin C phosphorylated	90-100	90-100	90-95	90-95

Estimates based on 20-30 second conditioning time (Ward, 2005).

Table 1. Range in estimated stability of vitamin products at different pelleting temperatures.

Many vitamins are delicate substances that can suffer loss of activity due to unfavourable circumstances encountered during processing or storage of premixes and feeds.

Stress factors for vitamins include humidity, pressure (pelleting), friction (abrasion), heat, light, oxidation-reduction, rancidity, trace minerals, pH and interactions with other vitamins, carriers, enzymes and feed additives. Humidity is the primary factor that can decrease the stability of vitamins in premixes and feedstuffs. Humidity augments the negative effects exerted by choline chloride, trace elements and other chemical reactions that are not found in dry feed. Corn is often dried rapidly under high temperatures, resulting in losses of vitamin E activity and other heat sensitive vitamins. When corn was artificially dried for 40 minutes at 88°C, losses of α-tocopherol averaged 19% and when corn was dried for 54 minutes at 107°C, losses averaged 41%.

After three months of storage, the vitamin A retention was 88% under low temperature and low humidity, 86% under high temperature and low humidity and 2% under high temperature and high humidity.

Humidity was significantly more stressful than temperature. Vitamins that undergo friction or are mixed and stored with minerals are subject to loss of potency. Friction is an important factor because it erodes the coating that protects several vitamins and reduces vitamin crystals to a smaller particle size. Hazards to vitamins from minerals are abrasion and direct destruction by certain trace elements, particularly copper, zinc and iron; manganese and selenium are the least reactive.

Table 2. Performance of broilers at 51 days of age as affected by vitamin level[a].

Vitamin level	Body weight (kg)	F/G	Mortality (%)
NRC	2.186[d]	2.219[d]	11.0[c]
Low 25%	2.382[c]	2.069[c]	8.7[b]
Average	2.436[b]	2.023[b]	7.4[a]
High 25%	2.454[ab]	2.014[ab]	7.6[ab]
High 25 + 25%	2.463[a]	1.999[a]	7.4[a]

Ward, 1994, [a]Performance averaged across three stress levels (minimal, moderate, relatively high) [b]P<0.05 within column.

Some vitamins are destroyed by light. Riboflavin is stable to most factors involved in processing; however, it is readily destroyed by either visible or ultraviolet light. Vitamin B_6, vitamin C and folacin can also be destroyed by light. While pelleting generally improves the value of energy and protein carriers in a feed, this is not true for most vitamins.

During pelleting of feeds, four elements destructive for a number of vitamins are applied in combined action: friction, heat, pressure and humidity. Increasing the pelleting temperature or conditioning time generally enhances redox reactions and destroys vitamins. Vitamins A, D_3, K_3, C and thiamin are most likely to show stability problems in pelleted feeds. Feed manufacturers have increased pelleting temperatures for all animal feeds in order to control salmonella organisms and increase digestibility and are using steam pelleting, prepelleting conditioners and feed expanders, which lead to increased vitamin degradation. Table 1 shows typical losses of commercial form vitamins under a range of pelleting conditions.

1**Reduced feed intake.**

When feed intake is reduced, vitamin allowances should be adjusted to ensure adequate vitamin intake for optimum performance.

Restricting feed intake practices and/or improved feed conversion will decrease dietary intake of all nutrients, including vitamins.

Restricted feeding of broiler breeders and turkey breeder hens may result in marginal vitamin intake if diets are not adequately fortified. Reduced feed intake may also result from stress and disease.

Use of high energy feeds, such as fats, to provide diets with greater

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nutrient density for higher animal performance requires a higher vitamin concentration in feeds. Poultry species provided diets ad libitum consume quantities sufficient to meet energy requirements.

Thus, vitamin fortification must be increased for high energy diets because animals will consume less total feed. Feed consumption was compared in broilers receiving metabolisable energy ranging from 2,800-3,550kcal/kg of feed. Feed and vitamin consumption were each 19.1% lower in broilers consuming the diet with greater energy density compared to those consuming the lowest energy diet.

Ambient temperature also has an important influence on diet consumption, as animals consume greater quantities during cold temperatures and reduced amounts as a result of heat stress. Vitamins, as well as other nutrients must, therefore, be adjusted to reflect changing dietary consumption.

Vitamin variability and insufficient analysis.
Tables of feed composition demonstrate the lack of complete vitamin information, with vitamin levels varying widely within a given feedstuff.

Variability of vitamin content within ingredients is generally large and difficult to quantify and anticipate. It is well recognised that vitamin levels shown in tables of vitamin composition of feedstuffs represent average values and that actual vitamin content of each feedstuff varies over a fairly wide range.

Feed table averages are often of little value in predicting individual content of feed- stuffs or bioavailability of vitamins. Vitamin E content of 42 varieties of corn varied from 11.1-36.4 IU per kg, a 3.3 fold difference. For 65 samples of corn, biotin varied between 0.012-0.072ppm, a six fold difference.

Vitamin bioavailability.
Even accurate feedstuff analyses of vitamin concentrations do not provide bioavailability data needed for certain vitamins. Bound forms of vitamins in natural ingredients often are unavailable to animals.

Bioavailability of choline, niacin and vitamin B_6 is adequate in some feeds but limited or variable in others. For example, bioavailability of choline is 100% in corn but varies from 60-75% in soybean meal; that of niacin is 100% in soybean meal but zero in wheat and sorghum and varies from 0-30% in corn; that of vitamin B_6 is 65% in soybean meal and varies from 45-56% in corn. For alfalfa meal, corn, cottonseed meal and soybean meal, bioavailability of biotin is estimated at 100%.

However, biotin availability is variable for other feedstuffs, for example, 20-50% in barley, 62% in corn gluten meal, 30% in fish meal, 20-60% in sorghum, 32% in oats and 0-62% in wheat.

Vitamin level	Minimal	Moderate	Relatively high
NRC	2.395[cd]	2.075[i]	2.088[i]
Low 25%	2.548[b]	2.424[ef]	2.174[h]
Average	2.583[a]	2.483[cde]	2.241[g]
High 25%	2.600[a]	2.485[c]	2.275[f]
High 25 + 25%	2.610[a]	2.494[c]	2.286[def]

Ward, 1994, [a]P<0.05 within column.

Table 3. Body weight of broilers at 51 days of age as affected by stress and vitamin level[a].

Many of the earlier established requirements for poultry relied heavily on purified feed ingredients.

Swine data showed that responses to vitamins may differ depending on whether vitamins are being added to a purified or natural diet.

Requirements of the pig for niacin, riboflavin and pantothenic acid were considerably higher on a natural diet than requirements established earlier from experiments using purified diets. This shows that results obtained with purified diets must also be verified with natural diets and that bioavailability of vitamins may be greater in purified diets.

Computerised least cost feed formulations.
Vitamins are not usually entered as specifications in computerised feed formulations. Therefore, vitamin rich feedstuffs – such as alfalfa, distiller's solubles or grains; brewer's grains; fermentation products and meat, milk and fish byproducts – are often excluded or reduced when least cost feed formulations are computed. The resulting least cost diet consisting of a grain and soybean meal is usually lower in vitamins than a more complex one containing more costly vitamin rich feeds.

Vitamin requirements

There are many factors affecting vitamin requirements and vitamin utilisation.

Physiological make-up and production function.
Vitamin needs of animals and humans depend greatly on their physiological make-up, age, health, and nutritional status and function, such as producing meat or eggs.

Breeder hens have higher vitamin requirements for optimum hatchability, since vitamin requirements for egg production are generally less than that for egg hatchability.

Higher levels of vitamins A, D_3 and E are needed in breeder hen diets than in feeds for rapidly growing broilers. Selection for faster growth rate may allow animals to reach much higher weights at much younger ages with less feed consumed. Since genetic potential has improved at the rate of 0.8% feed conversion yearly and most of the NRC vitamin requirement data is 20-40 years old, vitamin requirements determined several decades ago may not apply to today's poultry.

To compare the potential effects of stress conditions on vitamin requirements, Ward, fed five levels of vitamins to 9,600 broilers over a 42 day period: NRC, low 25% industry, average industry, high 25% industry and high 25 + 25%.

Birds were subjected to three levels of stress (minimum, moderate and relatively high) based on different levels of coccidia, E. coli, placement density and nutritional plane.

The results showed that as degree of stress increased, bird performance declined. Furthermore, although the highest level of vitamins did not completely overcome the detrimental effect of stress, clearly the higher levels of vitamins did improve performance over the lower levels (Tables 2-4).

Disease or adverse environmental conditions.
Intensified production increases stress and subclinical disease level conditions because of higher densities of animals in confined areas. Sell et al. suggested that NRC levels of vitamin E are probably sufficient for grazing turkeys that are 'free of disease'. Stress and disease conditions in animals increase the basic requirement for certain vitamins. A number of studies indicate that nutrient levels that are adequate for growth and egg production may not be adequate for normal immunity and for maximising the animal's resistance to disease. Higher than recommended levels of vitamin A to layer chickens under heat stress was beneficial to laying performance and immune function. High levels of vitamin E maintained antibody production in chicks.

Table 4. Feed conversion of broilers at 51 days of age as affected by stress and vitamin level[a].

Vitamin level	Minimal	Moderate	Relatively high
NRC	2.138[cd]	2.284[f]	2.234[e]
Low 25%	2.025[b]	2.032[b]	2.150[d]
Average	1.958[a]	2.005[b]	2.105[c]
High 25%	1.959[a]	1.950[a]	2.121[cd]
High 25 + 25%	1.927[a]	1.963[a]	2.121[cd]

Ward, 1994, [a]P<0.05 within column.

Supplementing the diets of live turkeys with vitamin E can reduce the chance of transmission of Listeria monocytogenes, a major human bacterial food borne pathogen found in poultry.

Turkeys supplemented daily with vitamin E (100-200IU) had elevated levels of several types of lymphocytes (T-cells) when infected with Listeria monocytogenes. Therefore, vitamin E stimulates live turkeys' immune responses (via lymphocytes) and enhances clearance of the micro-organism from the gut.

Diseases or parasites affecting the gastrointestinal tract will reduce intestinal absorption of vitamins, both from dietary sources and those synthesised by micro-organisms. If they cause diarrhoea or vomiting this will also decrease intestinal absorption and increase needs.

Vitamin A deficiency is often seen in heavily parasitised animals that supposedly were receiving an adequate amount of the vitamin.

Mycotoxins are known to cause digestive disturbances such as vomiting and diarrhoea as well as internal bleeding and interfere with absorption of dietary vitamins A, D, E and K.

In broiler chickens mouldy corn (mycotoxins) has been associated with deficiencies of vitamins D (rickets) and E (encephalomalacia) in spite of the fact that these vitamins were supplemented at levels regarded as satisfactory.

Mortality from fowl typhoid (Salmonella gallinarum) was reduced in chicks fed vitamin levels greater than normal. Vitamin E supplementation at a high level decreased chick mortality due to Escherichia coli challenge from 40-5%. Coccidiosis produces a triple stress on vitamin K requirements as follows:

- Coccidiosis reduces feed intake, thereby reducing vitamin K intake.
- Coccidiosis injures the intestinal tract and reduces absorption of the vitamin.
- Treatment with sulfaquinoxaline or other coccidiostats causes an increased requirement for vitamin K.

The current NRC vitamin K requirement for growing chicks is 0.5mg per kg of diet. It was concluded that as much as 8mg of vitamin K per kg of diet was needed for chicks with coccidiosis.

Heat stress.
The decreased nutrient intake by poultry at high temperatures also has repercussions on the intake of vitamins and also affects metabolism such as for vitamin A, E and C which play important roles in performance and immune function.

Supplementation of these vitamins is helpful for maintaining performance and immune function of heat stressed birds. High dietary vitamin E provided to broilers reduced negative effects of heat stress (32°C).

Vitamins A (15,000mg/kg) + E

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(250 mg/kg) reduced heat stress related decreases in broilers. Both vitamins E (65mg/kg) and C (1,000mg/kg) enhanced in vitro lymphocyte proliferative responses of heat stressed hens.

High dietary supplemental vitamin E (250mg/kg) is beneficial to egg production at high temperatures. Broilers under heat stress conditions found increased levels of vitamin E (100-200IU/kg) to improve live performance of birds, as well as the digestibility of crude protein, ether extract and gross energy.

Optimum responses in growth, feed efficiency and/or liveability in broilers under heat stress seem to occur with supplements of vitamin C. For laying hens under stress, there are improvements in liveability, food intake, egg production and egg quality with vitamin C concentrations in the range of 250-400 mg/kg. Production responses in poultry confirm that dietary supplementation with vitamin C generally only benefits birds under stress.

- **Vitamin antagonists.**

Vitamin antagonists (antimetabolites) interfere with the activity of various vitamins. The antagonist could cleave the metabolite molecule and render it inactive, as occurs with thiaminase and thiamin; it could complex with the metabolite, with similar results, as happens between avidin and biotin; or by reason of structural similarity it could occupy reaction sites and, thereby, deny them to the metabolite, as with dicumarol and vitamin K.

The presence of vitamin antagonists in animal and human diets should be considered in adjusting vitamin allowances, as most vitamins have antagonists that reduce their utilisation. Some common antagonists are as follows:

Vitamins	Control (mg/kg)[a]	OVN (mg/kg)[b]
Vitamin A (retinol)	13,000 IU	12,500 IU
Vitamin D_3	2,600 IU	4,000 IU
Vitamin E (alpha-tocopherol)	18.90	225.00
Vitamin K_3 (menadione)	2.20	4.00
Thiamin	1.40	3.00
Riboflavin	6.20	9.00
Vitamin B_6	3.00	6.00
Vitamin B_{12}	21.20	40.00
Niacin	33.00	60.00
Pantothenic acid	10.40	15.00
Folic acid	0.68	2.00
Biotin	0.07	0.25
Vitamin C	0	100

[a]*Average vitamin concentrations used in Spanish broiler operations.*
[b]*Optimum vitamin nutrition, increased vitamin fortification.*

Table 5. Composition of experimental vitamin premixes for determining the nutritive value of broiler meat.

- Thiaminase, found in raw fish and some feedstuffs, is a thiamin antagonist.
- Dicumarol, found in certain plants, interferes with blood clotting by blocking the action of vitamin K.
- Avidin, found in raw egg white, and streptavidin, from Streptomyces molds, are biotin antimetabolites.
- Rancid fats inactivate biotin and destroy vitamins A, D, and E and possibly others.
- Mycotoxins increase requirements for fat soluble and other vitamins (for example, biotin, folic acid and possibly others).

- **Use of antimicrobial drugs.**

Some antimicrobial drugs will increase vitamin needs of animals by altering intestinal microflora and inhibiting synthesis of certain vitamins. Certain sulphonamides may increase requirements of biotin, folacin, vitamin K and possibly others when intestinal synthesis is reduced.

- **Levels of other nutrients in the diet.**

The level of fat in the diet affects absorption of the fat soluble vitamins A, D, E and K, as well as the requirement for vitamin E and possibly other vitamins. Fat soluble vitamins may fail to be absorbed if digestion of fat is impaired.

Polyunsaturated fatty acids (PUFA) and oxidised sources of fats can influence individual vitamin allowances. For example, high dietary PUFA increases the vitamin E requirements by 3IU per g of PUFA.

Many interrelationships of vitamins with other nutrients exist and, therefore, affect requirements. For example, prominent interrelationships exist for vitamin E with selenium, vitamin D with calcium and phosphorus, choline with methionine, and for niacin with tryptophan.

Optimum allowances

The NRC requirements for a vitamin are usually close to minimum levels required to prevent deficiency signs and for conditions of health and adequate performance, provided sufficient amounts of all other nutrients are supplied.

Most nutritionists usually consider NRC requirements for vitamins to be close to minimum requirements sufficient to prevent clinical deficiency signs and they may be adjusted upward according to experience within the industry in situations where a higher level of vitamins is needed.

Commercial supplementation levels of most vitamins for poultry often reflect stresses encountered under production practices. Over 90% of the broilers, turkeys and laying hens were included in a broad survey of vitamin supplementation rates; levels for most vitamins were substantially higher than NRC. The 1993 supplementation values were not found to change much in a more recent survey, with the exception that vitamin E levels virtually doubled.

Allowances of a vitamin are those total levels from all sources fed to compensate for factors influencing vitamin needs of animals. These influencing factors include:

- Those that may lead to inadequate levels of the vitamin in the diet.
- Those that may affect the animal's ability to utilise the vitamin under commercial production conditions.

The higher the allowance the greater is the extent to which it may compensate for the influencing factors. Thus, under commercial production conditions, vitamin allowances higher than NRC requirements may be needed to allow optimum performance.

Generally, the optimum supplementation level is the vitamin concentration that achieves the best growth rate, feed utilisation and health (including immune competency) and provides adequate body reserves. Barroeta et al. defines optimum vitamin nutrition as 'vitamin levels above minimum requirements to optimise genetic potential and improve immune status in the bird, leading to an improvement in production and egg quality'.

The concept of optimum vitamin nutrition under commercial production conditions is illustrated in Fig. 1. The marginal zone in Fig. 1 represents vitamin levels that are lower than requirements that may predispose animals to deficiency.

The requirement zones are minimum vitamin quantities that are needed to prevent deficiency signs, but may lead to suboptimum performance even though animals appear normal. The optimum allowances in Fig. 1 permit animals to achieve their full genetic potential for optimum performance. In the excess zone, vitamin levels range from levels still safe, but uneconomical, to concentrations that may produce toxic effects. Usually only vitamins A and D, under practical feeding conditions pose the possibility of toxicity problems.

Optimum allowances of any vitamin are depicted as a range in Fig. 1 because factors influencing vitamin needs are highly variable and optimum allowances to allow maximum response may vary from animal to animal of the same species.

It should be emphasised that sub acute deficiencies can exist although the actual deficiency signs do not appear. Such borderline deficiencies are both the most costly and the most difficult to cope with and often go unnoticed and unrectified, yet they may result in poor and expensive gains, impaired reproduction or depressed production.

Also, under farm conditions, one will usually not find a single vitamin deficiency. Instead, deficiencies are usually a combination of factors, and often deficiency signs will not be clear cut.

If the NRC minimum requirement for a vitamin is the level that barely prevents clinical deficiency signs, then this level moves in relationship to the level required for optimum production responses. This means that if a greater quantity of a vitamin is required for an optimum response (because of the influencing factors), a greater quantity would also be required to prevent deficiency signs (Fig. 2).

Optimum poultry performance required under modern commercial conditions cannot be obtained by fortifying diets to just meet minimum vitamin requirements.

Establishment of adequate margins of safety must provide for those factors that may increase certain dietary vitamin requirements and for variability in active vitamin potencies and availability within individual feed ingredients.

The actual minimum nutritional requirement for vitamins is difficult to access as it is most often determined under favourable experimental conditions. In 1994, the NRC reported the most recent vitamin requirements for chickens.

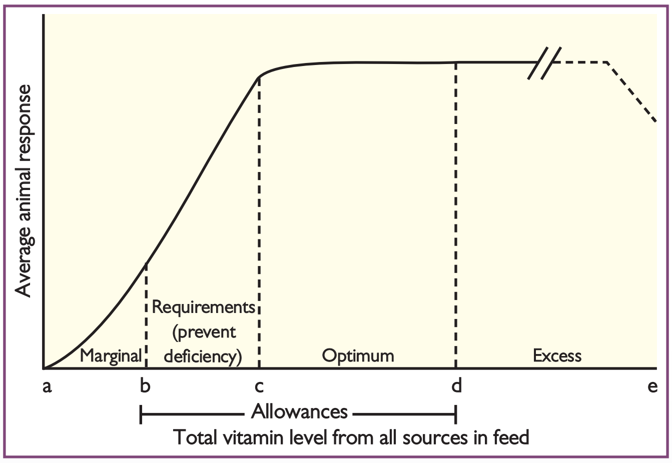


Fig. 1. Optimum vitamin nutrition for animals under commercial production conditions. Allowances are for total vitamin levels from all sources fed to compensate for factors affecting animals' vitamin needs.

These were determined under optimal rearing conditions, thereby, implying that these levels should be increased under 'field conditions'.

Supplementation allowances need to reflect different management systems and be high enough to allow for fluctuation in environmental temperatures, energy content of feed or other factors that influence feed consumption.

Riboflavin and other vitamins play an important role in skin development, tensile strength and healing rates. A deficiency in riboflavin can slow epithelialisation of wounds by 4-5 days, reduce collagen content by 25%, and decrease tensile strength of wounds by 45%. Riboflavin deficiency can increase skin homocysteine by 2-4 fold, which ultimately impairs the cross link formation of collagen.

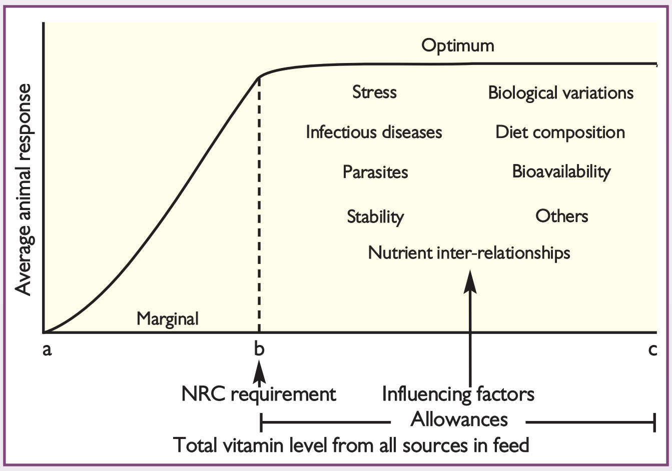
Marginal field deficiencies of riboflavin could increase skin tears and cause longer healing times, and ultimately increase costly downgrades. Vitamin requirements for egg production as suggested by the NRC have changed little over the last 30-50 years.

However, during this time period layer feed conversion rates have dramatically improved by approximately 40% based on a higher egg mass production (approximately 30%) and lower feed consumption (approximately 10%).

Broiler vitamin requirements have likewise changed little in recent years. However, for the last 30 years broiler feed conversion rates have improved dramatically, more than 20%, due to a much higher body weight in a shorter production period. On the other hand, modern broiler production systems often place animals under high stress conditions so that an optimum level of vitamins in feed is essential to allow birds to achieve their full potential while maintaining good health.

Although NRC poultry vitamin requirements have changed little in the last 30-50 years, the poultry industry has more closely attempted to recommend higher supplementation levels for poultry diets. The industry vitamin average allowances have increased significantly (30-500%) to keep pace with greater genetic potential, faster growth rates, better feed efficiency, poorer quality ingredients, larger poultry houses and generally higher disease levels, all of which caused increased stress. A reasonable amount of logic would suggest that vitamin requirements determined decades ago may not apply to today's poultry feeds.

Fig. 2. Optimum vitamin nutrition for animals under commercial production conditions and influencing factors.



Recent research

A trial was done to study the effects of two different vitamin levels in broiler diets on production parameters, vitamin deposition in meat and meat quality. One diet contained average vitamin concentrations used in Spanish broiler operations vs optimum vitamin nutrition (OVN) levels as recommended by DSM, formerly Roche Vitamins (Table 5).

Breast meat was also analysed for vitamin content and oxidative stability (Thiobarbituric reactant substance, TBARS). As an additional treatment effect, broilers were also subjected to density stress conditions (12.7 vs 16.4 animals/m^2).

Chickens fed the higher OVN diets were significantly heavier (increased final weight by 2.7%), ate more and obtained better average daily gains than those receiving more typical vitamin concentrations.

High density stress conditions reduced gains with OVN birds best counteracting this stress. Breast lipid oxidation was reduced by the OVN premix. Higher levels of vitamins E, thiamin and pantothenic acid in breast meat resulted from the OVN diets. Research from France also evaluated OVN diets on broiler performance.

The OVN premix produced a significant improvement in growth and feed efficiency throughout the entire rearing process. Higher vitamins improved the weight and fillet and bird to cook/live carcase yield.

With the OVN diet, vitamin E was dramatically increased in meat (for example, in fillets 12.5 vs 5.4mg/kg).

Optimum vitamin nutrition levels were tested in Spain to evaluate the value of additional vitamins for laying hens. Compared to the average vitamin concentrations provided to hens in the Spanish feed industry, eggs from OVN treated hens had significantly higher concentrations of vitamins A, E, thiamin, riboflavin, pantothenic acid, biotin, folic acid and vitamin B_{12}. In addition to improving the nutritive value of eggs, lipid oxidation of eggs from hens fed OVN were not statistically affected, but showed numerically lower TBAR values (0.274 vs 0.301mmol/g) than hens fed control diets.

The vitamin D_3 metabolite, 25-hydroxy vitamin D_3 (25-OHD_3), was used as part of an OVN investigation to evaluate egg production parameters and egg quality com-

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pared to the control of the average vitamin concentrations used in the Spanish egg production industry.

Vitamin D in the OVN diet was provided as 1,500 IU/kg D_3 and 1,500 IU/kg of 25-OHD_3 (commercial name Hy-D). Using a combination of OVN + Hy-D resulted in a dramatic increase of performance parameters for laying hens (Table 6). Hens receiving OVN + Hy-D significantly improved production at a favourable cost (cost to benefit ratio of 1:9).

Production parameters were as follows:

155% benefit from higher laying rate.
124% benefit from bigger egg size.
115% benefit from lower feed intake.
16% benefit from less broken eggs.

There was also better egg quality with lower susceptibility to oxidation in fresh and 28 day stored eggs and lower egg weight losses after storing eggs for 21 days at room temperature.

A study with turkeys evaluated the impact of 25-OHD_3 (Hy-D) as a partial substitute for vitamin D_3 in two levels of vitamin dosage, control (typical vitamin levels) or OVN (an enhanced dose of 13 vitamins).

During the first part of the experiment the birds receiving an enhanced vitamin dose (OVN), and particularly without Hy-D, grow better. However, after 12 weeks the dietary dosage of Hy-D for the heavy turkeys, made it possible, whatever the vitamin dose, to achieve growth, bone development and body constitution and to improve percentage of fillets.

	Control	OVN + Hy-D	Difference (%)
Egg weight (g)	65.88	66.36	+ 0.7
XL eggs (%)	7.5	10.1	+ 25.4
Broken eggs (%)	1.43	1.14	- 20.3
Daily feed intake (g/d)	117.2	114.5	- 2.3
Lay (%)	80.2	82.4	+ 2.7
Egg mass (g/d)	52.84	54.68	+ 3.5
Cumulative feed conversion	2.218	2.094	- 5.6

Table 6. Performance parameters of laying hens (41-67 weeks of age) fed average vitamin supplementation concentrations (control) compared to those receiving Optimum Vitamin Nutrition and 25 hydroxy cholecalciferol (Hy-D).

Conclusions

Optimum concentrations of vitamins in poultry diets allow today's poultry to perform to their genetic potential. Vitamin requirements established decades ago do not take into account the modern genetically superior birds with increased growth, egg production and improved feed efficiency.

Vitamin intake per unit of output is continually declining. The yearly decline for layers is around 1% per egg produced, while for broilers has been 0.6-0.8% per kg body gain. Also vitamin allowances today need to take into account modern management procedures that increase bird densities and stress conditions for the producing birds. Vitamins are important for maintaining optimum immune response. Higher levels of vitamins (for example, vitamins A, E and C) have been shown to increase overall health by improving disease resistance as a result of improved immunity.

Optimum vitamin nutrition from recent studies with broilers have shown increased growth, feed efficiency, increased oxidative stability of meat and better resistance to high density stress conditions. For laying hens OVN diets increased egg weights, number of large eggs, lower percentage of broken eggs, higher percentage of lay and improved feed efficiency.

A higher level of vitamin E is particularly important for improving lipid stability in meat. Supra-nutrition supplementation of vitamin E (400 mg/kg) was highly effective at inhibiting the lipid oxidation development in all raw products including breast, thigh muscle and skin.

Likewise, this same high level of vitamin E was much more effective at reducing the lipid oxidation of cooked chicken patties than control dietary vitamin E (400 vs 33mg/kg). Beneficial effects of vitamin E are not restricted to lipid protection, and it has also been demonstrated that they protect proteins present in turkey meat from oxidation provoked by different oxidation methods.

The most common bone diseases of economic importance to the poultry industry are tibial dyschondroplasia (TD) and rickets. The NRC recommends 200-300IU vitamin D_3/kg feed to broilers and breeders. However, studies with different classes of poultry have shown benefits from considerably higher dietary concentrations of the vitamin. Atencio et al., indicates that 2800-3000IU vitamin D_3 should be present in the diets of broiler breeders for maximum production and the requirement may be higher for optimum body ash of progency.

Chicks fed 3,200IU vitamin D_3/kg feed had the highest body weight and tibia ash and the lowest TD and approximate rickets incidences. Fritts and Waldroup, observed a decrease in TD incidence and severity by supplementing vitamin D_3 up to 4,000IU/kg in diets of broiler chicks.

McCormack et al reported that 10,000IU of vitamin D_3/kg of diet can prevent TD almost completely. It is suggested that the activity of the vitamin D metabolite 25-OHD_3 is almost twice that of vitamin D_3. It would seem logical to use 25-OHD_3 alone or in combination with vitamin D_3 for improved supplementation programmes. Research indicated that 25-OHD_3 was effective to reduce TD in broilers, when Ca was less than 0.85%.

Optimum vitamin nutrition programmes have used 3,000IU/kg of vitamin D (0.5 D_3 and 0.5 25-OHD_3) to evaluate egg production parameters. Hens that receive the OVN (including 25-OHD_3) had greatly improved laying rate and egg size, reduced broken eggs, better feed efficiency and lowered susceptibility to oxidation of fresh and stored eggs. Turkeys receiving 25-OHD_3 (Hy-D) were able to achieve growth with good bone development, without lameness disorders.

Not only does the OVN improve poultry production and health, likewise human nutrition for those consuming poultry products is benefited. An egg can provide anywhere from 100% of human requirements for vitamin K to only 0.3% of requirements for niacin. Higher levels of vitamins E, thiamin and pantothenic acid were determined in broiler meat for birds receiving OVN.

In addition to having poultry meat with higher vitamin content, OVN can even more dramatically increase vitamin content of eggs. The recent OVN studies with laying hens resulted in significantly higher egg concentrations of vitamin A, E, thiamin, riboflavin, pantothenic acid, biotin, folic acid and vitamin B_{12}. Sheehy et al., showed a linear relationship between diet α-tocopherol and its accumulation in muscle.

Additionally, research confirms the ability to elevate folic acid in eggs. Enrichment of eggs with folate is possible when dietary folic acid levels are increased. The NRC requirement for folic acid is 0.25mg/kg of diet. Folic acid in eggs can be increased approximately three fold by increasing dietary folic acid to 2-4 mg/kg.

Eggs are among the few potent natural sources of vitamin D for humans. Recent research has indicated that vitamin D_3 content of eggs can also be further increased by supplementing hen feed with vitamin

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D_3. For groups of hens that received 6,000 or 15,000IU/kg feed, egg yolk, vitamin D_3 ranged from 9.1 to 13.6 and from 25.3 to 33.7µg/100g, respectively.

It is important to realise that vitamin content of eggs today is lower than it was in 1995. Feeding the same levels of vitamins, Pérez-Vendrell et al reported vitamin A, vitamin E and vitamin B_{12} decreasing by 25.1, 37.5 and 33.0% compared to the concentrations in 1995.

The reason for lower vitamin content in recent years is likely due to improvement of layer feed conversion as a result of better poultry genetics and management.

Obviously, a lower total feed intake due to improved feed efficiency will make less quantities of vitamins available to be transferred to eggs. This would apply to production of poultry meat as well. Greater feed efficiency limits the amount of vitamins transferred to meat.

Therefore, poultry diets now need higher levels of dietary vitamins to just have the same nutritional value as in the past.

For the purpose of cost reduction, there is the 'false economy' concept that vitamins should be removed from finisher diets. However, Gwyther et al reported that NRC vitamin recommendations were much too low to maintain broiler performance. This study indicated that broiler vitamin requirements exceed those recommended by the NRC and that the elimination of vitamin supplementation from broiler diets would severely impair performance.

Withdrawal of riboflavin from the diet during the last weeks of a finisher diet reduced content in the breast muscle by 37%.

Teeter and Deyhim eliminated vitamins and/or minerals from broiler diets for the last 21 days of life, during which time the birds were exposed to heat stress.

There was significant reduction in live bird and carcase performance. Performance tended to be poorest when the diet contained added trace minerals and no added vitamins, suggesting oxidation of the vitamins already present. n

References are available from the authors on request.

Summary

- Vitamin requirements (for example, NRC) established decades ago have changed little and do not reflect greatly improved genetic selection and changes in management procedures of modern poultry operations.

- Vitamin supplementation allowances need to be set at levels that reflect different management systems that are high enough to take care of fluctuations in environmental temperatures, energy content of feed and influencing factors (for example, infectious diseases, stress, parasites, biological variations, diet composition, bioavailability and nutrient interrelationships) that might influence feed composition or vitamin requirements.

- To allow poultry to express their genetic potential and to account for not always ideal farm management conditions, optimum levels of vitamins are necessary. Top poultry industry leaders recognise the need for optimum vitamin nutrition (OVN).

- Performance benefits from OVN diets for meat production include increased growth, feed efficiency, oxidative stability of meat, resistance to high density stress and prevention of bone problems with vitamin D_3 and/or 25-OHD_3. For laying hens OVN diets improve all phases of egg production (for example, increased egg numbers, egg weights, percentage lay and increased feed efficiency).

- Eggs and meat are excellent sources of bioavailable vitamins. Due to lower feed intakes, as a result of improved feed efficiency, vitamin levels have decreased in meat and eggs in recent years. Use of OVN concentrations in poultry feeds will improve human nutrition as poultry products will be a dependable source of bioavailable vitamins.

- 'Risk versus benefits economics' should be considered in reviewing and adjusting the vitamin fortification of poultry rations. The cost of fortifying the ration with the essential vitamins and increasing vitamin fortification levels should be weighed against the risk of losses from vitamin deficiency conditions and sub-optimum performance. For the modern successful poultry operation, OVN is essential.