Broiler Vitamin Nutrition Guidelines

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DSM Nutritional Products
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Introduction

In a time of record feed prices, nutritionists and production managers continue to look for opportunities to lower growout costs. Even though their contribution seldom exceeds 1-2% of feed costs, vitamins are not immune to this cost-crunching scrutiny. Furthermore, in late 2017, an unparalleled drop in global vitamin supply resulted in sharply increased prices, and in some cases, outright shortages. Such events have placed pressure on vitamin fortification levels in broiler feeds.

Marginal vitamin shortages can be more costly than acute deficiencies. Seemingly trivial insufficiencies can translate in nothing more than a slight drop in target weights, or 1-2 point increases in F/G, or egg production or shell quality that lingers below expectations. These are difficult to differentiate from management and housing issues, hatchery problems, chick quality, and the list goes on. At today's feed prices, 1 point in feed conversion approximates to $2/ton feed.

Vitamin Requirements can be Dynamic

Nutritionists decide on the fortification rates based on a variety of criteria – bird age, production phase, field experience, research trials, and so forth. The rapid change in broiler genetics is probably the biggest factor that affects long-term fortification levels.

Broiler growth rates have climbed 3-4% every year with less feed being consumed/lb live gain (Zuidhof et al., 2014). To this end, the feed conversion ratio (FCR) improved by nearly 2 points/year over the past 10 years (NCC, 2021; Agri Stats, 2022). The days required to attain a 5.1 lb slaughter weight have declined from 52 days 1995 to 40 days today (Agri Stats, 2022), which reduces the time to correct missteps in nutrition, management, or health programs.

Faster growing strains generally experience more mortality and meat disorders, bone deformities, and contact dermatitis, as opposed to slow-growth strains. The boost in skeleton and body weight impact vitamin fortification requirements (Jiang et al., 2011; Mejia et al., 2014). Yet, commercial fortification levels did not change appreciably from 1993 to 2012 (Ward, 2012).

Vitamins are Not Equal

Vitamins perform within a complex metabolic system, and function in catalytic, developmental, and protective roles. Generally defined, this group of organic compounds is essential for life and is required in small quantities in the diet because they cannot be synthesized by the body. Still, individual vitamins vary in chemical composition and identity, and each serves a specific metabolic purpose often expressed during acute deficiencies.

Of the 13 commonly accepted vitamins, all but vitamin C are found in the egg (Combs, 2012), and serve as the only source of vitamins for the developing embryo. Many factors affect vitamin deposition in eggs such as dietary level, absorption rate, interactions with other vitamins and nutrients, and body storage characteristics – and not the least – the blood-to-egg transference efficiency. Whereas vitamin D3 can be elevated to super-high levels in the egg (Yao et al. 2013), other vitamins are far more restricted (Ward, 2017), which in turn, can have a pronounced effect on fertility, embryonic survival, and early chick performance.

Fat-soluble vitamins are hydrophobic and are emulsified in the upper intestinal tract through mastication and intestinal churning. Mixed micelles – a combination of free fatty acids, monoglycerides, and bile acids – deliver the fat-soluble vitamins to the microvilli surface. For some animal species, regional intestinal differences exist for absorption: proximal for vitamin A, medial for vitamin D_3, and distal for vitamins E and K (Goncalves *et al*., 2015). The uptake of vitamins D_3, E, and K by Caco-2 cells was adversely affected by the presence of vitamin A. Conversely, the individual presence of vitamins D_3, E, and K had less effect on vitamin A transport (Goncalves *et al*., 2015), a relationship generally mirrored in the accumulation of fat-soluble vitamins in eggs (Ward, 2017). The extent to which interactions occur among the fat-soluble vitamins is largely initiated by levels in the feed (Abawi and Sullivan, 1989).

The B or water-soluble vitamins are solubilized in the intestinal lumen. Absorption is influenced by molecular weight, ionization status, and whether the B vitamin is present as a weak acid or base (Basu et al., 2003). Intestinal uptake is favored by a small molecular structure and a weak ionic character. Hence, niacin (niacinamide), pyridoxine, biotin and vitamin C are readily taken up, whereas thiamin and B_{12} face greater difficulty. Thiamin, B_{12}, folic, and vitamin C are absorbed by a carrier-mediated mechanism, but as levels in the feed increase, simple diffusion plays a greater role (Basu et al., 2003).

Recent Vitamin Research

The B vitamins are important in energy, carbohydrate, and fatty acid metabolism, as well as DNA repair. Tufarelli et al. (2021) recently summarized research on the individual *in ovo* injection of several B vitamins (folic acid, riboflavin, pyridoxine, thiamin, and B_{12}), most of which elicited positive responses on hatchability, hatch weight, chick quality and other measurements. Insufficient pyridoxine or folic acid in breeder hens led to an impaired methionine/cysteine metabolism in 18-day embryos (Lu et al., 2021).

A nicely done collaborative study revealed that maternal or post-hatch supplementation of 25-OH D_3 notably improved the mitotic satellite cell formation and breast muscle formation, while reducing the severity of woody breast syndrome (Avila et al., 2022). The proliferation of satellite cells initiates skeletal muscle growth. Consistent with this, more breast meat *(P. major*) accumulation occurred with 25-OH D_3 *in ovo* injections (Fatemi et al., 2021), an effect recognized by University of Arkansas researchers and others by feeding 25-OH D_3 to broilers.

Folic acid significantly increased breast meat percent in broilers at a level roughly 10-fold higher than average fortification rates in the U.S. (Liang et al., 2022), as opposed to birds fed levels similar to commercial rates. Gene expression related to folic acid was consistent with muscle accretion, but more work is needed to understand commercial applications.

Vitamin E continues to show positive influences on male fertility. Shabani et al. (2022) reported that vitamin E at 250 IU/kg feed with 1% lecithin improved several fertility variables in Hubbard grandparent roosters.

Not all inclusive but other vitamin work reported in 2021-2022 includes topics on –

- Fat-soluble vitamins on liver and pancreas indices (Azadinia et al., 2022)
- Vitamin A and meat quality (Savaris et al., 2021)
- Vitamins A, D, E, and C on immunity (review; Shojadoost et al., 2021)
- Niacin and broiler productivity (review; Ahmadian et al., 2021)
- Vitamin D and lactic acidosis (Boroumandnia et al., 2021)
- Niacinamide and P, Ca absorption and excretion (Ren et al., 2021)
- Vitamin E for molted broiler breeders (Yang et al., 2021)

Vitamins and Intestinal Microflora

Studies indicate a positive relationship exists between vitamins and intestinal microflora in mammalian species (Pham et al., 2021). For poultry, one of the earliest studies noted that vitamin deprivation increased the ratio of pathogenic bacteria and decreased the diversity of cecal bacteria in 28-day old broilers (Luo et al, 2013). This work suggested that vitamins may have a role in "gut health" for poultry.

More recently, laying hens deficient in vitamin D_3 were noted to be particularly susceptible to *Salmonella enterica* and gut mucosal damage (Guo et al., 2022). Less favorable intestinal bacteria such as *Escherichia*, *Enterobacteriaceae*, and *Clostridia* were elevated in vitamin D_3 deficient hens, whereas *Lactobacillus* and *Bacilli* and other favorable bacteria became more predominant when vitamin D_3 was consequently supplemented (3,000 IU/kg).

In other work, dietary 25-OH vitamin D_3 (69 ug/kg) elevated intestinal indices in laying hens at high stocking density by increasing bacterial diversity and improving intestinal function (Wang et al., 2021). Villus height was significantly increased with 25-OH D_3 supplementation, as were oxidative capacity indices. Aged laying hens benefited with an increased abundance of beneficial ileal and cecal bacteria, along with an improved laying rate and egg quality, when supplemented with a 2-fold higher vitamin level (Gan et al., 2020a). This work was based on the hypothesis that today's laying hens require vitamin levels over and beyond today's standards.

Broilers challenged with *Salmonella enteritis* also gained from vitamin C at 500 mg/kg, primarily by ameliorating damage to villus structure (Gan et al., 2020b). Vitamin C enriched cecal microbial diversity, such as the *Firmicutes* to *Bacteroides* ratio on days 21 and 35. Under heat stress conditions, cecal *Lachnospiraceae* and *Ruminococcacaea* were elevated when broilers were supplemented with vitamin E at 250 IU/kg (about 5-fold higher than commercial average), along with an organic Se complex (Calik et al., 2022). Both cecal species are important butyrate producers from nonstarch polysaccharides and resistant starch.

While much of this work is encouraging, the relationship between selected vitamins and intestinal microflora and morphology needs further investigation to determine the commercial benefits of targeted changes in fortification rates.

Updated Vitamin Guidelines

We recently updated the DSM Optimum Vitamin Nutrition (2022 OVN®) vitamin guidelines for poultry. These are listed in Tables 1 and 2 along with those from Cobb and Aviagen. Generally, compared to the 2016 OVN, 5-6% increases are implemented for most vitamins, primarily to reflect the reduced feed intake to reach target weights. In some cases, these guidelines are based on controlled pen research trials, as well as field studies. Some of these and other trials are listed in support of these guidelines.

The recommendations for breeding hens generally reflect higher productivity for several variables as reported by breeder companies (such as +5-7% hatchability, +3-4% more chicks/hen housed, 1-3% improved peak production, and +4-7% improvement in FCR). Breeders continue to be focal point for profitability for commercial operations.

Commercial Broiler Vitamin Survey

Poultry feeds are commonly supplemented with fat- and water-soluble synthetic vitamins via a premix. A basic vitamin premix is composed of 4 fundamental components: vitamins, calcium carbonate (densifier), rice hulls or wheat midds (carrier), and 1-2% oil (to reduce dustiness; adhere vitamins to the carrier). Typical vitamin premixes today contain 12 vitamins, whereas not all were included as recently as early 1990s (Ward, 1993).

We recently completed a survey of vitamin levels used in commercial broiler feeds in the U.S. This survey was conducted in a very similar manner as the survey in 1993 (Ward, 1993), such that direct comparisons could be made. Over 90% of the broiler production for the U.S. contributed. Supplementation rates were categorized according to feed phase. All vitamins are reported on a pure vitamin level to eliminate any confusion for product dilution. There was no emphasis on distinguishing programs designated for large birds (say, >8-9 lbs) versus smaller birds around <4 lbs, although we expect to look further into this aspect. Categories are listed below –

- Starter (≈day 1-14)
- Grower 1/Grower 2 (≈day 15-28)
- Finisher (≈day 28-36)
- Withdrawal WD (≈day >36)
- Breeder

Emphasis was placed on age in days to differentiate the growout phases. There is some obvious overlap if the premix was designated 'grower/finisher' or 'finisher/WD', for example, as well as differences in days that might represent any grow phase.

Once collected, the following determinations were made for each vitamin in each phase –

- Overall average, standard deviation, % CV
- Low 25% average, standard deviation, % CV
- High 25% average, standard deviation, % CV

Figure 1 designates the actual vitamin premix addition rate in terms of lbs/2,000 lbs feed. From starter to WD, the addition rate declined from 1.06 lbs/ton to 0.68 lbs/ton, a decline of about 36%. A stepdown program that parallels the lower vitamin requirements as the bird ages is consistent with the decreasing addition rates. This was also notable occurrence in the 1993 commercial vitamin survey.

Table 3 lists the average vitamin fortification levels across starter to WD feeds. The decline from starter to WD parallels the reduction in requirements as the bird approaches market age. The greatest decline existed with WD folic acid being 52% of the starter level. The lowest reduction of several vitamins was similar, being 60-63% of the level in starter feed: vitamin A, vitamin D, niacin, pantothenic acid, and vitamin B12.

The breeder vitamin supplementation rates are also listed in Table 3. This usually consisted of one premix throughout the production period. The breeder fortification was higher than the starter feed fortification levels for all vitamins.

Listed in Table 4 is a comparison of vitamin levels from the current 2022 survey and the 1993 survey to give an idea on the changes that have taken place. In all cases, vitamin levels were higher, especially for vitamin E and biotin. Vitamin A, pantothenic acid and niacin showed the lowest change from 1993 until 2022.

Figure 2 illustrates the coefficient of variation (%CV; standard deviation divided by the mean times 100) by feed phase and within each vitamin category. Clearly, the lowest %CV existed within the starter feeds. Vitamin A and riboflavin exhibited the lowest %CV, indicating the greatest agreement among nutritionists for these two vitamins. On the other hand, vitamin E and vitamin B_{12} generally were the most variable across all feed phases.

Not shown is the relationship between the average lowest 25% and average highest 25% within each vitamin and feed phase. Consistently, the least difference between the lowest 25% and highest 25% existed with vitamin A from starter to WD. The greatest difference existed with folic acid up through finisher; and in the WD, vitamin B_{12} differed the greatest from lowest 25% to highest 25%.

Table 5 lists the high 25%, average, and low 25% for recent starter feed, and compares that to OVN 2022 guidelines for starter feed. Some vitamins (K, riboflavin, pyridoxine, and B_{12}) fell within the OVN range of vitamins in the high 25% category, while those within the low 25% group were notably lower. In fact, the low 25% averaged quite low values for several vitamins.

Does vitamin fortification level matter?

From a previous survey 2014-2015, we made a similar compilation in vitamins (ie, low 25%, high 25, average), and prepared a vitamin premix accordingly. We compared the low 25%, average and OVN 2016 when fed to 1,440 male broilers across 24 floor pens (8 reps/treatment) with 60 birds/pen taken to 48 days of age (Mejia et al., 2014; Table 6). Starter, grower, finisher, and withdrawal feeds were fed with the respective vitamin premix added to each. Relative costs for vitamin levels were $1.00 (low 25% commercial), $1.52 (average commercial), and $2.98 (OVN).

With the exception of feed intake and livability, birds fed the OVN vitamin levels outperformed (P<0.05) those fed the low 25% vitamin level. This held true for both live and carcass measurements. When considering the additional costs for OVN vitamins, the improved FCR gave a 4.4% improvement over feed costs. And when considering the value of the whole carcass, the OVN-fed birds gave a 11.1% advantage over feed costs. So, even though OVN vitamin costs were nearly 3-fold higher than the low 25%, profitability in feed costs and carcass weight was substantially higher. These results mirrored those from a similar study conducted with the 1993 vitamin survey where the low 25% fed birds significantly underperformed the High 25% group (Ward and McNaughton, 1994).

Summary

Vitamin fortification rates should be adjusted to correspond with progress or changes made in broiler genetics. The costliest vitamin shortages are those that are marginal when insufficiency effects are less apparent. Vitamins appear to affect the intestinal microbiome and “guy health”, but more information is required to determine the impact on commercial fortification guidelines. The 2022 DSM OVN Vitamin Guidelines for broilers provide a range to account for various commercial conditions and to offset improvements in feed conversion ratio. From 1993 to 2022, changes in commercial vitamin levels were not remarkable in several cases. Yet, we find vitamin levels in the high 25% category or OVN to outperform broilers fed levels in the low 25% category. During the past nearly 30 years, a huge difference in animal performance (body weight, feed intake, FCR, mortality, uniformity, yield, etc) has occurred. And it becomes apparent that levels of vitamins and other nutrients requires some adjustments.

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Table 1. Guidelines for vitamin level for broiler chickens (IU or mg/kg feed)

Source [1]	Unit	Starter (1-10 days)				Grower (11-24 days)				Finisher (25d-market)				REFERENCE
		Cobb 2022	Aviagen 2019	OVN 2016	OVN 2022	Cobb 2020	Aviagen 2019	OVN 2016	OVN 2022	Cobb 2020	Aviagen 2019	OVN 2016	OVN 2022	Author/year/level/benefit
Vitamin A	IU	13,000	12,000	12,000-15,000	12,600-15,700	10,000	11,000	10,000-12,500	10,500-13,100	10,000	10,000	10,000-12,500	10,500-13,100	Savaris et al., 2021 15,148 IU max weight gain 1-42 days; Shojadoost et al., 2021 **20,000 IU** better immune response
Vitamin D_3	IU	5,000	5,000	4,000-5,000	4,200-5,200	5,000	4,500	4,000-5,000	4,200-5,200	5,000	4,000	4,000-5,000	4,200-5,200	**Industry practice and breeding company recommendation.** Raza, et al., 2021 4,000 IU; Shojadoost 2021, **5,000 IU** better immune response
25OHD$_3$ (HyD®)	mg	-	-	0.069	0.069	-	-	0.069	0.069	-	-	0.069	0.069	Sakkas et al 2019, **0.075 mg**
Vitamin E [2] [4]	mg	80	80	150-200	160-210[3]	50	65	50-100	55-105[5]	50	55	50-100	55-105[5]	Niu, et al., 2017 200 mg; Desoky, 2018; Choi et al., 2020; Khalifa et al., 2021 100 - 300 mg; Ekunseitan et al., 2021 **400 mg** immune response and performance
Vitamin K_3	mg	3	3.2	3-4	3.2-4.2	3	3	3-4	3.2-4.2	3	2.2	3-4	3.2-4.2	Guo et al., 2020 **4 mg**
Vitamin B_1	mg	3	3.2	3-4	3.2-4.2	2	2.5	2-3	2.1-3.2	2	2.2	2-3	2.1-3.2	**Industry practice and breeding company recommendation.** Wei et al., 2003 2 mg performance
Vitamin B_2	mg	9	8.6	8-10	8.4-10.5	8	6.5	7-9	7.4-9.5	6	5.4	6-8	6.3-8.4	Jegede et al., 2018 **8 mg**; Suckeveris et al., 2020 **49mg** performance 18 days
Vitamin B_6	mg	4	5.4	4-6	4.2-6.3	3	4.3	4-6	4.2-6.3	3	3.2	4-6	4.2-6.3	Jegede et al., 2018 **7 mg**
Vitamin B_{12} [6]	mg	0.02	0.017	0.02-0.04	0.021-0.042	0.015	0.017	0.02-0.03	0.021-0.032	0.015	0.011	0.02-0.03	0.021-0.032	Alisheilkhov et al. 2000, **0.035 mg;** Suckeveris et al., 2020 **0.12 mg** performance 18 days
Niacin	mg	60	65	60-80	64-84	50	60	60-80	64-84	50	45	50-80	53-84	**Industry practice and breeding company recommendation.** Ahmadian et al., 2021 33 mg; Suckeveris et al., 2020 **298mg** performance 18 days
D-Pantothenic acid	mg	15	20	15-20	16-21	12	18	12-18	12.6-19	10	15	10-15	10.5-15.8	Latymer and Coates 1981, **25 mg**; Suckeveris et al., 2020 **98 mg** performance 18 days
Folic acid	mg	2	2.2	2-2.5	2.1-2.6	2	1.9	2-2.5	2.1-2.6	1.5	1.6	2-2.5	2.1-2.6	Gouda et al., 2020 1.5 mg in-ovo feeding; Suckeveris et al., 2020 **6.9 mg** performance 18 days
Biotin	mg	0.2	0.3	0.25-0.40	0.26-0.42	0.18	0.25	0.25-0.40	0.26-0.42	0.18	0.2	0.25-0.40	0.26-0.42	Sun et al., 2017 **1.5 mg**
Vitamin C [7]	mg	-	-	100-200	105-210	-	-	100-200	105-210	-	-	100-200	105-210	Jain et al., 2018 120 mg; Tavakoli et al. 2021, **200 mg**; Amer 2021 **200 mg** performance and intestinal morphology
Choline	mg	500	1,700	400-700	420-740	400	1,600	400-700	420-740	350	1,550	400-600	420-630	Igwe et al., 2015 **2,000 mg**; De Lima et al., 2018 **1,042 - 1,228 mg**

[1] Added per kg air-dry feed; Local limits need to be observed; OVN levels are ranges for consideration, depending on several factors, such as husbandry conditions and health status [2] When dietary fat is higher than 3% then add 5 mg/kg feed for each 1% dietary fat [3] For optimum immune function increase level up to 300 mg/kg [4] Under heat stress conditions increase level up to 200 mg/kg [5] For optimum meat quality increase level up to 200 mg/kg [6] Use upper level as reference for animal protein free diets and when cobalt is supplemented at very low levels or removed [7] Recommended under heat stress condition; Use ROVIMIX® STAY-C35 for reducing loss during processing

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Table 2. Guidelines for vitamin level for broiler breeder chickens (IU or mg/kg feed)

Source [1]	Unit	Layers & male breeders (19 weeks-end)				Poultry breeders references
		Cobb 2020 (+19 weeks)	Aviagen 2021 (5% lay-351 d)	OVN 2016	OVN 2022	Author/year/level/benefit
Vitamin A	IU	13,000	15,000	12,000-15,000	12,600-15,700	Squires and Naber, 1993, **16,000 IU** egg hatchability; Yuan et al., 2014, 15,000 IU, egg fertility
Vitamin D_3	IU	3,500	5,000	3000-5000	3,150 - 5,200	**Industry practice and breeding company recommendation.** Atencio et al., 2005, 4,000 IU, heavier progeny, higher bone ash & lower TD incidence
25OHD$_3$ (HyD®) [2]	mg	-	-	0.069	0.069	Lin et al., 2019, **0.069 mg**, improve survival breeder rate with restricted and ad-libitum intake; Araujo, et al., 2019 0.069 mg
Vitamin E [3] [4]	mg	100	130	100-150	105-160	Siegel et al., 2001, 300 mg, more eggs; Yang et al., 2021, **400 mg**, maternal dietary vit E increased 42d body weight of offspring
Vitamin K_3	mg	6	9	5-7	**6-9**	Fares et al., 2018, **11 mg**, decreased embryonic mortality
Vitamin B_1	mg	3	6	3-3,5	**3.5 - 6**	Industry practice and breeding company recommendation. Olkowski and Classen, 1999, **8 mg**, Increased thiamine metabolism of the offspring
Vitamin B_2	mg	13	20	12-16	13 **- 20**	**Industry practice and breeding company recommendations;** Leeson, 2005, 7 mg, Influence on hatchability, vigor and survival of the chick
Vitamin B_6	mg	6	8	4-6	**5-8**	**Industry practice and breeding company recommendations;** Robel, 1992 and 2002, 6.2 mg higher hatchability (turkey breeders
Vitamin B_{12} [5]	mg	0.035	0.07	0,03-0,04	**0.035-0.07**	**Industry practice and breeding company recommendations**; Panic et al., 1970, 0.02 mg, better hatchability
Niacin	mg	50	70	50-60	**55-70**	Leeson 1991, **132 mg** improved shell quality
D-Pantothenic Acid	mg	20	25	15-25	16-25	**Industry practice and breeding company recommendations** Goeger and Ascott, 1984, **24 mg** increased semen quantity and quality
Folic acid	mg	3	5	2-4	**2.5-5.0**	Robel, 2002, **7.4 mg**, improved hatchability, higher body weight and offspring vitality (turkey breeders)
Biotin	mg	0.375	0.6	0,25-0,40	**0.3-0.6**	**Industry practice and breeding company recommendations**; Robel, 1989, 0.44 mg, better hatchability broiler breeders; Robel, 2002, **0.8 mg**, better hatchability turkey breeders; Daryabari et al., 2014, 0.45 mg, Improved fertility
Vitamin C [6]	mg	-	-	100-150	105-160	Monsi and Onitchi, 1991, **500 mg**, improved semen volume, motile sperm per ejaculate and sperm number per ejaculate; Asensio et al., 2020, 200 mg, improved tail and wing feather score (stress and welfare indicator)
Choline	mg	500	1,600	350-700	370-740	Rama-Rao et al. 2001, **760 mg**

[1] Added per kg air-dry feed; Local limits need to be observed; OVN levels are ranges for consideration, depending on several factors, such as husbandry conditions and health status [2] Add 60 mg/kg CAROPHYLL® Red to improve hatchability. MaxiChick™ (HyD® 1,25% and CAROPHYLL® Red) is a DSM Patent and Trademark. [3] When dietary fat is higher than 3% then add 5 mg/kg feed for each 1% dietary fat [4] Under heat stress conditions increase level up to 200 mg/kg [5] Use upper level as reference for animal protein free diets and when cobalt is supplemented at very low levels or removed [6] Recommended under heat stress condition and to enhance reproductive performance; Use ROVIMIX® STAY-C35 for reducing loss during processing

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Figure 1. Vitamin addition rate per ton feed across growout and breeder phases

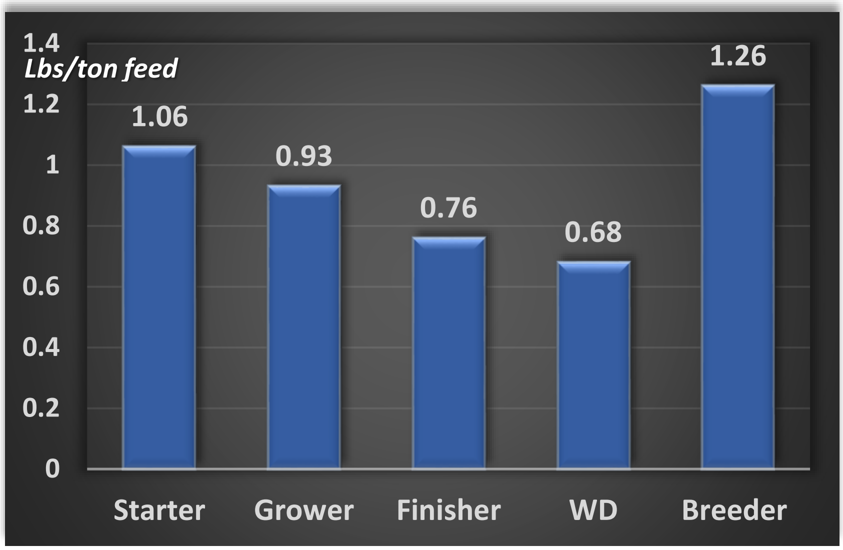

Table 3. Average vitamin inclusion rates across broiler growout phases

Units/ton feed*	Starter	Grower	Finisher	WD	Breeder
A, *MIU*	8.43	7.48	6.35	5.2	9.6
D, *MIU*	3.38	3.10	2.62	2.13	3.9
E, *TIU*	46.32	37.35	31.88	24.84	61.1
K, *G*	2.29	2.13	1.84	1.36	3.1
Niacin, *G*	46.8	43.15	38.07	28.19	49.1
Thiamine, *G*	2.23	1.98	1.7	1.25	2.82
Riboflavin, *G*	7.70	6.91	6.07	4.67	10.1
Pyridox, *G*	3.24	2.44	2.5	1.92	4.3
Pantoth, *G*	12.25	11.52	9.91	7.65	15.7
B12, *MG*	18.65	14.37	14.3	11.4	24.7
Folic, *MG*	1206	1082	902	632	1856
Biotin, *MG*	164.1	118.9	129	91	243

*MIU = million international units; TIU = thousand international units; G = grams; MG = milligrams

Table 4. Comparison of vitamin inclusion rates from 2022 and 1993 (Broiler Starter Feed)

Units/ton feed*	2022 Starter	1993 Starter
A, MIU	8.43	7.48
D, MIU	3.38	3.10
E, TIU	46.32	37.35
K, G	2.29	2.13
Niacin, G	46.8	43.15
Thiamine, G	2.23	1.98
Riboflavin, G	7.70	6.91
Pyridoxine, G	3.24	2.44
Pantoth, G	12.25	11.52
B12, MG	18.65	14.37
Folic, MG	1206	1082
Biotin, MG	164.1	118.9

*MIU = million international units; TIU = thousand international units; G = grams; MG = milligrams

Figure 2. Coefficient of variation in 2022 vitamin inclusion rates across four feeding phases

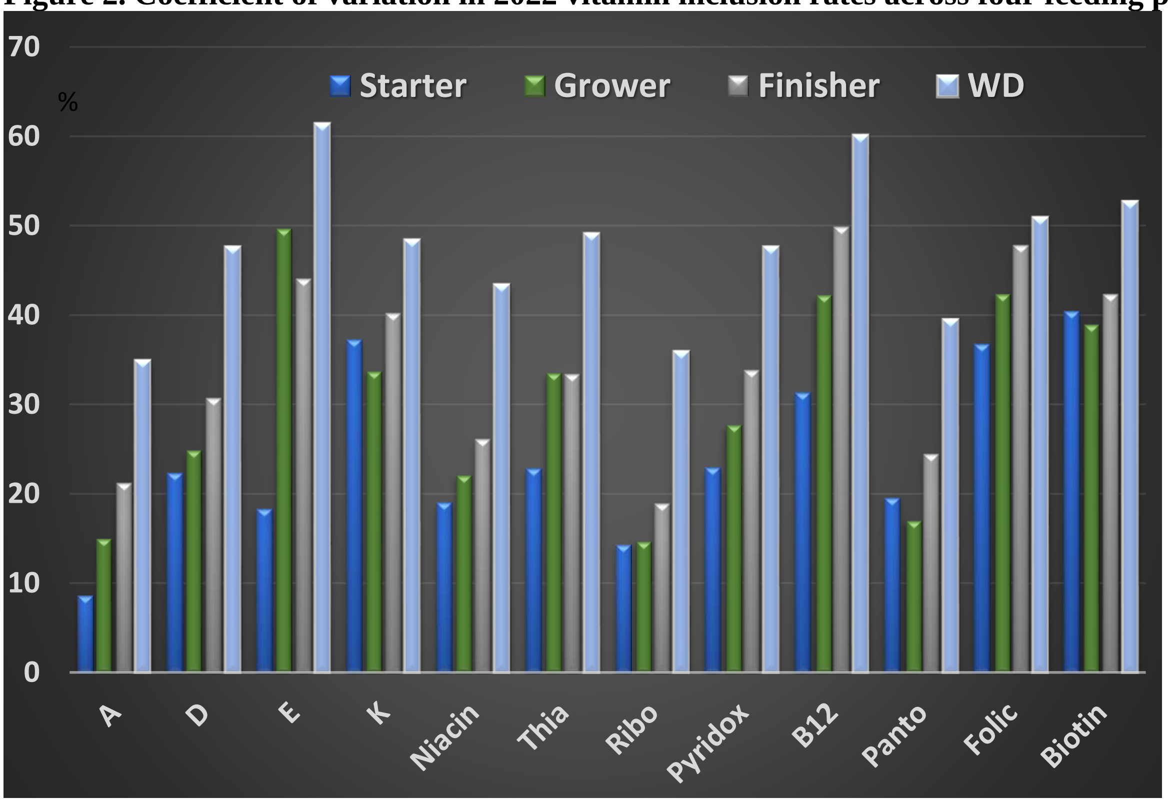

Table 5. Comparison of starter vitamin levels relative to OVN 2022

Units/ton feed*	Hi 25%	Average	Lo 25%	OVN 2022**
A, MIU	9.67	8.43	7.54	12.6-15.7
D, MIU	4.30	3.38	2.66	4.2-5.2
E, TIU	65.8	46.32	31.4	160-210
K, G	3.41	2.29	1.42	3.2-4.2
Niacin, G	57.41	46.8	37.86	64-84
Thiamine, G	2.83	2.23	1.64	3.2-4.2
Riboflavin, G	8.96	7.70	6.66	8.4-10.5
Pyridoxine, G	4.13	3.24	2.34	4.2-6.3
Pantoth, G	15.1	12.25	9.71	16-21
B12, MG	28.69	18.65	11.81	21-42
Folic, MG	1830	1206	795	2,100-2,600
Biotin, MG	9.67	8.43	7.54	12.6-15.7

*MIU = million international units; TIU = thousand international units; G = grams; MG = milligrams
**OVN is Optimal Vitamin Nutrition Guidelines

Table 6. Broiler performance* when fed low 25% commercial, average commercial, and OVN 2016 vitamin levels (Mejia et al., 2014)

	Vitamin Supplementation Level		
	Low25% Commercial	Average Commercial	OVN*** 2016
Body wt, lbs	5.450b	5.595ab	5.827a
Feed intake, lbs	10.798	10.699	11.030
FCR	1.946a	1.889ab	1.834b
Livability	96.9	97.1	94.6
Carcass yield, %	72.08b	72.32ab	73.01a
Breast meat, lbs	1.188b	1.223ab	1.320a
Breast meat, %	22.06b	22.64b	23.47a

*Live performance at 48 days; carcass performance at 49 days
**P<0.05 within row when superscripts were different
***OVN is Optimal Vitamin Nutrition Guidelines