ADVANCES IN THE ROLE OF MICRO-NUTRIENTS IN LIVESTOCK PRODUCTION

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SUMMARY

New information on the role of micro-nutrients in livestock production were reviewed. Recent studies on vitamin E in pigs and poultry have confirmed that high supplemental levels can influence immune development and immunocompetence. Although there are inconsistencies between studies on a research basis, one recent large-scale study of commercial broiler operations showed significant production and economic gain from high vitamin E supplementation. The positives effects of vitamin and/or mineral suplementation on a stress-susceptible pig genotype, on poultry performance under heat stress, and on stressed beef cattle entering feedlots, were considered. The emerging use of novel vitamin D3 compounds to solve specific problems in poultry production was briefly discussed. Finally, the effect of vitamins and minerals on carcass composition or quality was shown to be significant across a broad range of livestock species.

INTRODUCTION

Research focus has shifted appreciably in recent years from defining requirements to prevent clinical deficiencies to elucidating productive effects of micro-nutrients in livestock. Within commercial livestock production, and particularly for the intensive industries, there is a growing realization of the effects of micro-nutrients and the necessity to utilize them optimally to maximise production and economic gain. Certainly, and for a variety of reasons, it is apparent that continued and sometimes dramatic alterations in animal genotypes result in substantially different responses of poultry and livestock to micro-nutrients or that certain micro-nutrients can ameliorate the effects of some deleterious genetic traits. Additionally, new ways to target specific response tissues with certain micro-nutrients offer potentially significant biological and economic advantages.

Nutritionists, technical advisors and managers responsible for the commercial production of livestock must re-align their thinking on the role of micro-nutrients from strictly one of nutritional deficiency prevention to one which utilizes their production effects. These effects now extend well beyond simple concepts of improvement in weight gain or feed efficiency.

Accordingly, the present paper considers recent studies which are illustrative of the advances in understanding or establishing the role of micro-nutrients in livestock production.

IMMUNITY

Many vitamins play important roles in development of the immune system or immune response mechanisms, as reviewed recently by Nockels (1990) and Bendich (1992). In particular, vitamins A, E and C and the carotenoids have been shown to protect cells from free radical oxidation, to reduce the detrimental effects of some of the eicosanoids (eg. prostaglandins), and to enhance the humoral and cellular immune response to disease

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challenge (Nockels 1990). A large number of studies have focused on the effects of vitamin E on the immune system, and it is well established, that, a deficiency of this vitamin affects disease resistance by two main mechanisms, namely by reducing the ability of phagocytic cells to kill invading pathogens and by decreasing the humoral immune response to antigenic challenge (Rice and Kennedy 1988).

It is also well known that feeding very high levels of vitamin E to animals can result in significant improvement in immunocompetence (Sheffy and Schulz 1979; Rice and Kennedy 1988). Some of these studies were summarized by Rice and Kennedy (1988) as shown in Table 1. The main feature to note from this work is that the levels of vitamin E supplementation are very high (100 - 450 mg/kg) compared with stated requirements to prevent clinical deficiencies of approximately 10 - 15 mg/kg.

Table 1 Effect of dietary vitamin E (as a-tocopherol) on the immune response of livestock (Rice and Kennedy 1988)

	Level of vitamin E in diet (mg/kg)	Challenge	Effect of the higher dose(s)	Reference†
Chickens	150,300	E.coli	↓ mortality ↑ antibody titres	Heingerling et al. (1974)
Turkeys	100	E.coli	↓ mortality, no change in antibody titre	Julseth (1974)
	300	E.coli	↓ mortality ↑ antibody titre	Julseth (1974)
Hens	150	Brucella abortus vaccine	↑ maternal transfer of antibody to chicks	Jackson et al. (1978)
Hens	450	Brucella abortus	↑ antibody titres in chicks vaccinated at 2 weeks of age	Jackson et al. (1978)
Pigs	110	E.coli vaccine	↑ antibody titre	Ellis and Vorchies (1976)
Lambs	300	Clostridial vaccine	↑ antibody titres	Tengerdy et al. (1983)
Sheep	300	Chlamydia induced pneumonia	↑ weight gain and decreased isolation of organism	Stephens et al. (1979)

† As quoted by Rice and Kennedy (1988)

Following on from these initial studies has been considerable work to identify possible improvements closer to actual commercial production systems. These have focused on pigs and poultry because of the higher demands placed on the immune system under intensive production.

Pigs

With respect to pigs the key area of investigation has been on supplementation of sow diets in an attempt to increase the disease resistance of young piglets. This is logical because the neonates* passively acquired immunoglobulins are derived predominantly from maternal colostrum (Bourne 1976). As reviewed by Pharazyn et al. (1990), some studies have shown an improved humoral immune response in piglets when sow diets were supplemented to levels of 50 - 70 mg/kg of vitamin E compared with diets containing

10 mg/kg. Similarly, high vitamin E levels in sow diets (basal diet contained 13 mg α-tocopherol/kg) increased serum vitamin E concentration of their offspring and increased both the immune response against ovalbumin and phagocytic measures at 7 d of age (Babinazky et al. 1991). Other studies have also shown that immune responses of weaner pigs could be enhanced by high dietary vitamin E levels (Peplowski et al. 1981).

Mahan (1991) examined the effect of increasing dietary vitamin E (0,16,33 or 66 IU DL-α-tocopheryl acetate/kg) on sows and their offspring over three parities. The basal diet provided 8.4 mg of α-tocopherol/kg and 0.38 ppm of selenium. Results showed that supplemental vitamin E levels below 16 IU/kg were inadequate for reproducing sows. There was lower ($P<0.01$) post-natal (0-7d) pig mortality and increased litter size ($P<0.05$) as dietary vitamin E increased. These effects were greater with increasing parity number (Table 2).

Table 2 The effects of dietary vitamin E levels in sow diets on reproductive performance and progency performance (Mahan 1991)

	Vitamin E IU/kg			
Parameter	0	16	33	66
No. pigs/litter at birth	9.85	10.87	11.20	10.04
No. stillborns/litter	0.44	0.29	0.23	0.26
No. of pigs/litter at 7d	7.67	8.43	9.04	9.28
Survival %	78.3	77.6	80.7	92.4

Certainly there are inconsistencies in the responses obtained with vitamin E supplementation on immune function between studies, and no firm conclusion can yet be given regarding economic benefit (Kornegay 1991). This is perhaps to be expected given the complexity of immune function, and the number of factors which are known to influence the response to vitamin E supplementation.

One such factor, type of fatty acid, identified in a recent report (Fritsche et al. 1992), could have direct relevance to the livestock industries and needs consideration in studies which examine the influence of vitamin E on the immune system. In this study, rats were fed diets that contained either corn oil (rich in (n-6) PUFA) or menhaden fish oil (rich in (n-3) PUFA) to which vitamin E was added at three different levels (30, 300 and 900 mg/kg diet). Fish oil depressed serum vitamin E and ameliorated the response to supplemental vitamin E, but the higher levels of vitamin E prevented the fish-oil induced depression in splenocyte vitamin E. Immune responses were greater at higher levels of vitamin E when rats were fed fish oil rather than corn oil. The interaction of fatty acids and immune function, and the role of vitamin E, may become increasingly important as diets for pigs and poultry increase in nutrient density and fat levels increase accordingly.

Poultry

The role of vitamin E in enhancement of the immune response of poultry has been known since the early work of Tengerdy and Brown (1977) in which broiler chickens fed high vitamin E (150 - 300 mg/kg) had significantly reduced mortality following challenge with E. coli. Similarly Nockels (1979) showed that high vitamin E fed to broiler breeders resulted in an enhanced immune response in hatched chickens. Coccidiosis continues to be one of the major diseases in the broiler industry and Colnago et al. (1984) showed that high levels of dietary vitamin E (100 mg/kg) reduced mortality and improved liveweight of chickens dosed with Eimeria tenella.

More recent studies have confirmed these general findings on the role of vitamin E in the immune function of poultry. High doses (>300 mg/kg) of vitamin E were shown to enhance antibody titre levels to Newcastle Disease Virus challenge of growing turkeys (Franchini et al. 1990a) and produce higher interferon levels in broiler chickens (Franchini et al. 1990b), as shown in Table 3.

Table 3 Effect of dietary vitamin E level and vaccination with Newcastle Disease Virus on the titre levels of acid-resistant interferon in broiler chickens (Franchini et al. 1990b)

Dietary vitamin E (mg/kg)	Vaccination	Titre levels†
25	-	0.00[a]‡
325	-	3.00[b]
25	+	4.10[c]
325	+	4.50[c]

† Acid-resistant interferon 24h post-inoculation
‡ Means with different superscripts differ significantly ($P<0.05$)

Rice and Kennedy (1988) proposed that responses to high vitamin E supplementation may be determined by the degree of disease challenge which would influence the level of free radical attack on the immune system. They proposed that the only way to properly evaluate production effects on broiler chickens would be by using large numbers of commercial flocks.

Accordingly Kennedy et al. (1992) presented results of an analysis of productivity of 168 broiler flocks incorporating 3 million birds fed on diets containing either 180 mg/kg or 50 mg/kg vitamin E. They found an improvement ($P<0.01$) in income in the vitamin E-supplemented flocks of 8.4%, achieved by an improved feed efficiency and higher average weight gain per bird. Routine commercial levels of vitamin E supplementation for broier chicken diets have increased significantly over the last 3 - 5 years but not to the high levels (>150 mg/kg) found necessary to achieve enhancement of the immune system and, as found by Kennedy et al. (1992), significant economic gain.

STRESS

Some genotypes of pig have an inherited condition called porcine stress (PS) syndrome, with a predisposition to stress resulting in a rapid and fatal increase in body temperature (reviewed by Hoppe 1990). Susceptibility to PS can be ascertained by Halothane anaesthesia.

The fact that high dietary levels of vitamin E can reduce the effects of stressors on PS susceptible pigs (Duthie and Arthur 1989) is seen as a demonstration of the key role of this vitamin in influencing the effects of stress PS pigs exhibit signs of free radical-induced damage to cell membranes such as increased levels of the lipid peroxidation products conjugated dienes and malonaldehyde (MDA). A loss of cell membrane integrity increases leakage of enzymes such as pruvate kinase (PK) and creatine kinase (CK) from cells into plasma (Duthie and Arthur 1989).

In this regard, and using transportation as a stress initiator, these parameters of free radical-induced cell damage in PS pigs were substantially reduced by increased vitamin E supplementation (235 mg/kg), as shown in Figure 1.

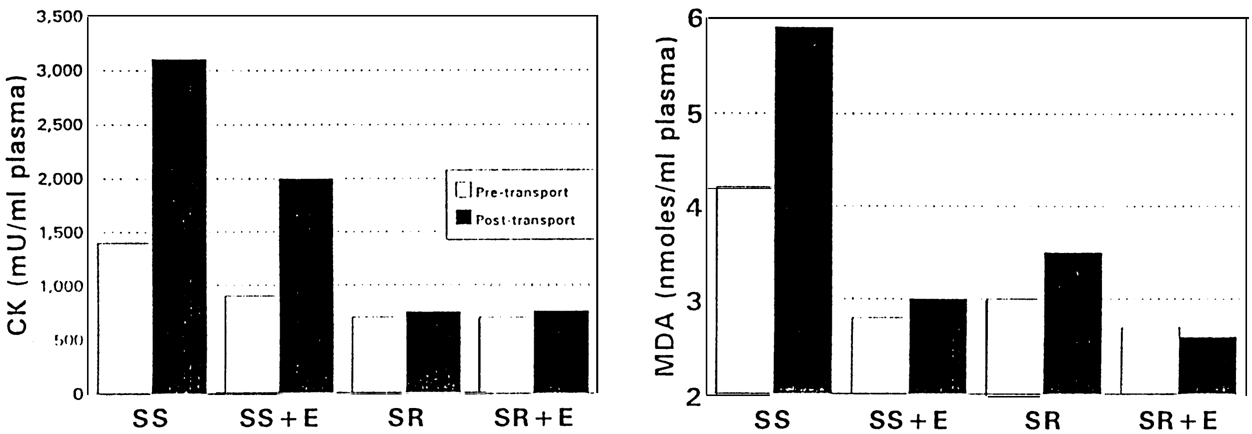

Figure 1 The effect of transportation and vitamin E on creatine kinase (CK) and malonaldehyde (MDA) in PS and normal pigs. SS (Stress Susceptible); SS + E (Stress Susceptible with vitamin E supplementation); SR is stress resistant. (Duthie and Arthur 1989)

Vitamins are known to play a key role in stress responses of other livestock species. Perhaps one of the most commercially important is the effect of vitamin C in poultry production. There is good evidence to suggest that both egg production (Njoku and Nurazota 1989) and broiler growth (Pardue et al. 1985; Njoku 1986) can be improved under conditions of high environmental temperature by supplementation with ascorbic acid. Stress is known to alter ascorbic acid utilisation and/or synthesis in poultry (see Pardue and Thaxton 1986 for review). Njoku (1986) showed linear increases in broiler growth with ascorbic acid supplementation with growing temperatures 35 to 38°C (Table 4). The increased growth and reductions in feed conversion were of such a magnitude that supplementation of approximately 200 mg/kg may be economical under conditions of high environmental temperature.

Table 4 The effect of ascorbic acid supplementation on the performance of broilers (Njoku 1986)

Parameter	Ascorbic Acid (mg/kg feed)			
	0	200	400	600
Weight gain (0-8 weeks)	1666	1962	1834	1778
FCR (g feed/g gain)	2.44	2.08	2.24	2.28

Peebles and Brake (1985) found that supplementation of broiler breeder hens with Vitamin C increased egg production, fertility and hatchability during heat stress (Table 5).

Table 5 Effect of Vitamin C supplementation on the performance of heat-stressed broiler breeder hens (Peebles and Brake 1985)

Parameter	Dietary Vitamin C (g/tonne)		
	0	50	100
Hen-day egg production (%)	50.9[b]	52.8[a]	54.4[a]
Fertility (%)	93.6[b]	97.3[a]	95.3[ab]
Hatchability (%)	88.5[b]	90.8[a]	90.7[a]
Specific gravity of shells	1.0825[b]	1.0832[a]	1.0834[a]

a, b, c. means in a row with different superscripts differ significantly ($P \leq .05$).

Another aspect of vitamin nutrition of poultry which has received considerable attention in hotter regions is supplementation of vitamins and electrolytes via the drinking water. In a detailed study of the effects on broiler performance of vitamin and/or electrolyte supplementation during periods of acute heat stress, considerable beneficial effects were found (Ferket and Qureski 1992). Two periods of acute heat stress (35°C) were imposed from 16 to 21 days and from 39 to 42 days of age during which vitamin and/or electrolytes were administered via the drinking water.

Results on performance of broilers are given in Table 6. Supplementation of the drinking water at these levels significantly improved body weight gain, feed efficiency and the antibody response to sheep red blood cells (SRBC) as an indicator of immune competence.

Table 6 Effect of vitamin supplementation of drinking water on broiler performance during growth which included periods of heat stress (Experiment 1, Ferket and Qureski 1992)

Parameter	Control	Vitamin Mixture
Body weight (gain (g, 1-43d)	1507[a]	1566[b]
Feed: Gain (1-43d)	2.08[a]	1.97[b]
Ig G antibody titre (log 3)†	1.6[a]	2.3[b]

ab means in a row with different superscripts differ significantly ($P<0.05$)
† Antibody response (secondary) to SRBC

Considerable work has also been carried out to find methods of alleviating the initial stress period of feedlot cattle. In particular many recent studies have focused on the role of organic mineral sources. Mineral proteinates are minerals that are chemically bonded to amino acids or small peptides (Vandergrift 1992). Chirase et al. (1992) found that organic forms of zinc and manganese improved the recovery rates of disease-stressed calves. Similarly, Ward et al. (1992) tested either inorganic minerals or organic mineral complexes such as zinc methionine, manganese methionine, copper lysine and cobalt glucoheptonate. They found that trace minerals in the organic complex form stimulated feed intake and growth during the initial stress period of feedlot cattle (Table 7).

Table 7 Effect of mineral source on performance of stressed feedlot cattle (Ward et al. 1992)

Dietary treatment	Feed intake for first 14 d (kg/d)	Bodyweight gain (kg/14 d)	Rumen-soluble zinc on d 30 (mg/l)
Control (C)	3.30	18.57	0.27
C + Oxide minerals†	3.23	17.53	0.38
C + Sulphate minerals	3.05	17.02	0.54
C + Organic minerals	3.37	21.88	0.87

† Minerals supplemented were Zn, 50 ppm; Mn, 30 ppm; Cu, 10 ppm; Co, 0.1 ppm

SKELETAL ABNORMALITIES

Leg disorders in broiler chickens and other livestock, and shell quality problems in laying hens are major economic problems. Recent studies have identified exciting new roles for certain vitamin D_3 compounds in altering the incidence of these problems. Edwards (1990) found a dramatic dose-related reduction in the incidence and severity of tibia1 dyschondroplasia in broiler chickens by feeding 1, 25-dihydroxycholecalciferol (1,25-$(OH)_2D_3$) or 1,24R,25-trihydroxcholecalciferol. No response was obtained by feeding higher levels of vitamin D_3. Results are shown in Figure 2.

Edwards (1990) concluded that rapidly growing broiler chickens may be unable to convert a sufficient amount of vitamin D_3 or 25-OHD_3 to 1,25-$(OH_2)D_3$ to achieve maximum calcium absorption and bone formation. These findings are particularly important because many factors seem to be able to reduce this conversion process. For example Glahn et al. (1991) found that aflatoxins decreased plasma concentration of important D_3 metabolites such as 1,25 $(OH)_2D_3$. In tropical countries a higher incidence of contamination of feed materials with aflatoxins may accordingly increase the incidence of leg disorders. The direct use of vitamin D_3 metabolites in broiler production could have a major economic impact.

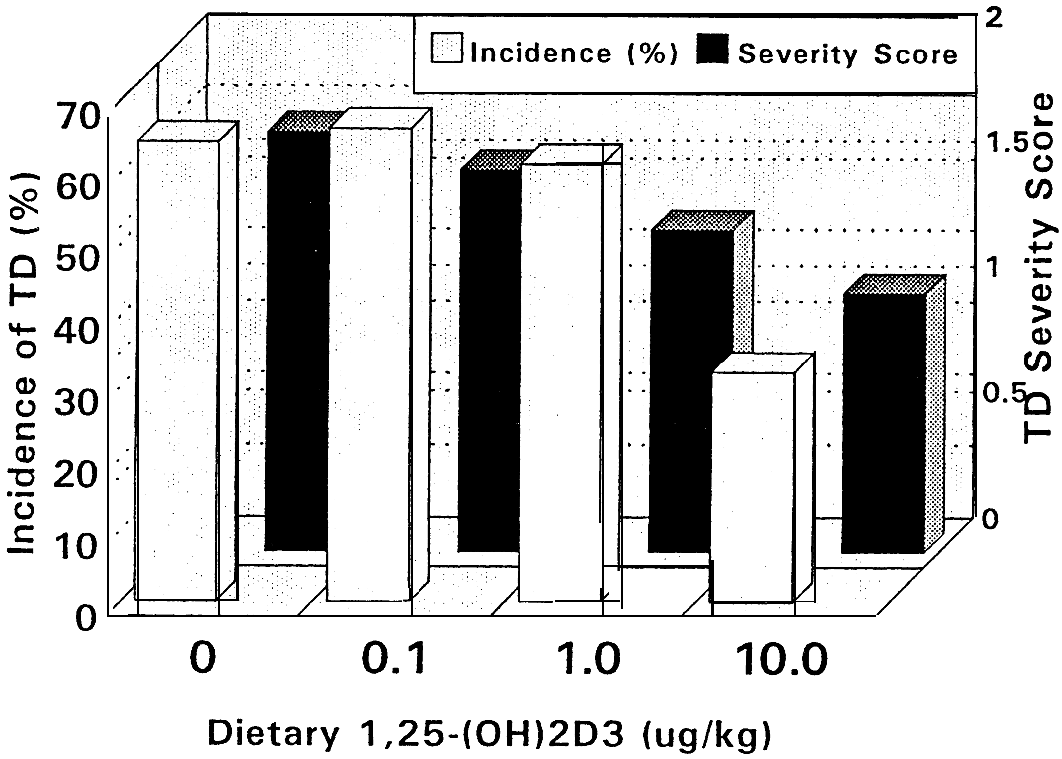

Figure 2 The effect of dietary $1{,}25\,(OH)_2D_3$ supplementation to broiler chickens on the incidence and severity of tibia1 dyschondraplasia (Edwards 1990)

EGG PRODUCTION

Reduced egg shell quality with increasing age of laying hens may be related to decreased biosynthesis of the active vitamin D_3 metabolite $1{,}25(OH)_2D_3$. Results on the supplementation of $1{,}25\,(OH)_2D_3$ to laying hens have been inconsistent and toxicity may result particularly if the diet already contains adequate D_3 (Tsang and Daghir 1990). However, novel synthetic analogs of $1{,}25\,(OH)_2D_3$, designed to carry out specific functions without deleterious side-effects, hold considerable promise of making a significant contribution to this and other problems (De Luca 1990).

Mineral proteinates are receiving considerable interest and some studies have shown beneficial results, as noted previously.

An interesting recent finding that chelated zinc (mineral complexed with organic compound) significantly improved shell quality of laying hens receiving saline drinking water (Moreng et al. 1992) has raised the possibility of using chelated minerals to improve shell quality. Some results from Moreng et at (1992) are shown in Figure 3. The birds were 60 weeks of age either receiving town water (control), saline drinking water (2 g salt/l) with and without 0.2 g zinc methionine/kg of diet.

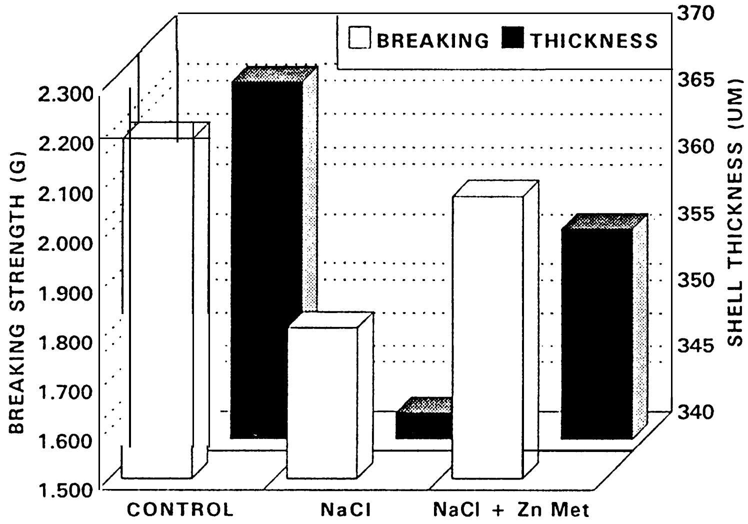

Figure 3 The effect of zinc methionine on shell quality of laying hens receiving saline drinking water (Moreng et al. 1992)

VITAMIN E AS AN ADJUVANT FOR VACCINES

It has been known for some time that vitamin E may increase the immune response to vaccination in sheep (Tengerdy et al. 1983, Afzal et al. 1984).

Similar results were found in young chickens which were challenged with Newcastle Disease Virus in which the vaccine contained various levels of DL-a-tocopherol acetate (see Table 8). However, there was no response when vitamin E was included in a bacterial (E. coli) vaccine.

Table 8 Effect of level of vitamin E in the adjuvant of a vaccine given to young broiler chickens (Franchini et al. 1991)

Treatment	Antibodies† against NDV‡
Control	4.96[C]
10% vitamin E	6.90[A]
20% vitamin E	7.58[A]
30% vitamin E	7.00[A]
40% vitamin E	5.90[B]
50% vitamin E	1.32[D]

† 28 days post-inoculation
‡ Newcastle disease virus

CARCASS QUALITY AND COMPOSITION

There is an increasing interest to utilize vitamins and/or minerals to'influence carcass quality and/or composition. Research in these areas has to date focused on vitamin E and chromium picolinate.

Vitamin E

Lipids associated with the subcellular organelles are very vulnerable to oxidation because of their high contents of polyunsaturated fatty acids (PUFA's). As reviewed by Gray (1990), lipid oxidation is one of the major causes of deterioration in meat quality, particularly during frozen storage.

Studies across a range of animal species have clearly demonstrated an important role for vitamin E in improving meat stability.

Broiler chickens Feeding either 150 ppm vitamin E from only 0 to 3 weeks of age or 100 ppm vitamin E from only 5 to 7 weeks of age significantly improved meat stability at 7 weeks of age of broilers which had been fed a diet containing 60 g soyabean oil/kg (Bartov and Frigg 1992). Results are shown in Table 9.

Table 9 Effect of dietary vitamin E level and the age period of its use on meat stability of broiler chickens at 7 weeks of age (Bartov and Frigg 1992)

Treatment	Vitamin E added (mg/kg)	Age of vitamin E feeding (weeks)	Plasma AT (mg/l)†	TBA value after incubation‡
1	None	0 - 7	6.4	6.71
2	100	0 - 7	25.1	1.15
3	150	0 - 3	8.6	4.30
4	150	0 - 3		
	100	6 - 7	22.9	3.13
5	100	5 - 7	23.2	3.77

† Plasma α-tocopherol
‡ Thiobarbituric and values expressed as mg sodium salt of malonaldehyde bis-bisulphite/kg meat

High levels of vitamin E (30, 90, 180, 360 ppm) fed for 140 days to meat turkeys increased a-tocopherol content of muscle tissue and dramatically improved the stability of the fats in carcases stored for 5 months at -20°C (Franchini et al. 1990b), as shown in Table 10.

Table 10 The effect of dietary vitamin E level on a-tocopherol content of muscle tissue and stability of carcass fat of turkeys (Franchini et al. 1990b)

Vitamin E (ppm)	Muscle Vitamin E (ppm)	Time (h) for complete oxidation
30	13.5	1.55
90	21.0	1.70
180	48.0	4.80
360	107.0	12.00

†Time (hours) required for complete oxidation of tissue lipids (Rancimat Test)

These results on avian species demonstrate the importance of vitamin E nutrition to meat quality. In this regard it is very salient to note the finding by Whitehead (1991) that genetic selection of broiler chickens for leanness altered the metabolism of vitmins A and E. Plasma levels of both vitamins were lower in lean birds and a-tocopherol levels were lower in tissues. This study shows the possible nutritional effects of genetic selection.

Pigs A number of studies have been carried out on improving meat quality from pigs fed high dietary vitamin E (Gray 1990). An example of such work is shown in Table 11.

Table 11 Effect of different dietary vitamin E levels on the quality of pork chops stored for 10 days at 4°C under fluorescent light (Azghar et al. 1991)

Parameter†	Dietary Vitamin E (IU/kg) 10	100	200
TBARS number‡	5.17	2.96	1.93
Hunter "a" value (redness)	7.2	7.9	8.5
Drip loss (%)	21.3	21.2	14.1

† Pork loins initially frozen at -20°C for three months prior to cutting into chops for the storage study.
‡ mg malonaldehyde/kg meat

Beef Cattle In a study by Faustman et al. (1989), Holstein steers were fed for 10 months on corn plus supplement and corn silage. They were given a supplement of 370 mg a -tocopherol acetate per day. The a-tocopherol content of muscle tissue was significantly increased (0.44 versus 0.16 mg/100 g tissue), and there was a significant decrease in the rate of metmyoglobin formation in the meat during 6 d of storage and of lipid oxidation (TBA) in vitamin E-supplemented steers. TBA values of cooked sirloin slices subsequently stored for 2 days at 4°C, and for frozen ground sirloin patties stored at -18°C for 1.5 and 3 months, were significantly lower in beef from supplemented steers than controls.

Similar results were recently found by Mitsumoto et al. (1991). Crossbred beef steers and Holstein steers were either supplemented daily with 1200 mg a-tocopheryl acetate/animal for 38 days (Holsteins) or 67 days (Crossbreds) and longissimus dorsi muscles assayed after slaughter for stability of meat colour and lipid oxidation. Vitamin E supplementation greatly improved the stability of meat colour (lower metmyoglobin concentration) and reduced lipid oxidation (lower TBA values).

There were quite clear relationships between the level of a-tocopherol in the meat and meat colour and stability, as shown in Figure 4 below.

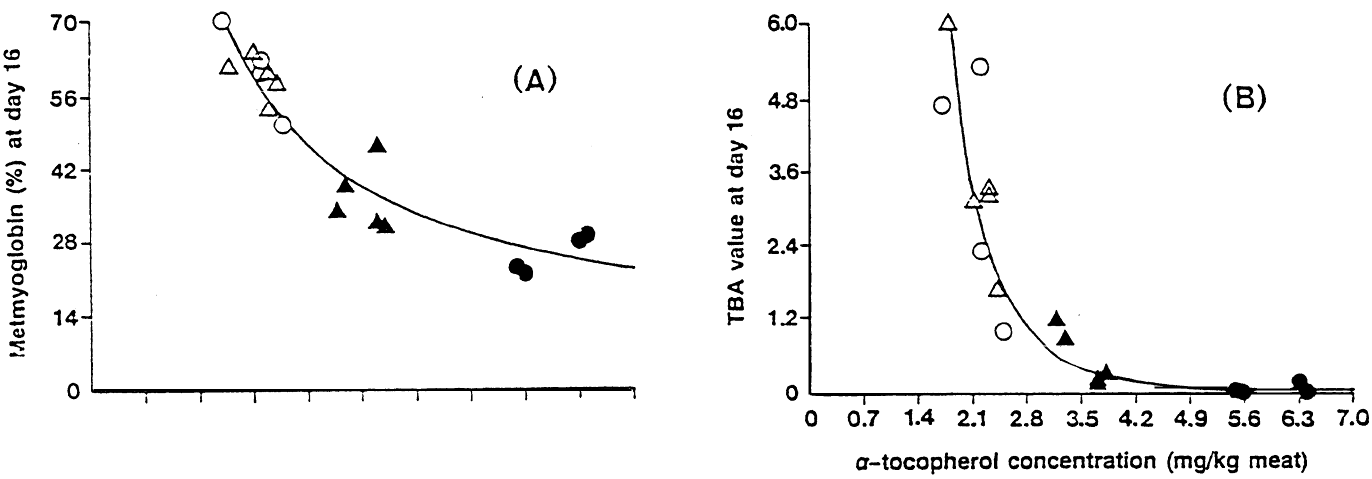

Figure 4 Relatioinships between muscle α-tocopherol concentration and (A) metmyoglobin percentage at day 16 and (B) TBA values at day 16 (Mitsumoto et al. 1991)

Chromium picolinate

Interest in chromium picolinate was generated recently with two studies which showed significant alternations in carcass composition of 'pigs (Page et al. 1991; Page et al. 1992). Page et al. (1991) found that feeding pigs 100 or 200 ppb Chromium (Cr) from chromium picoinate increased loin eye area by 18% and percentage muscling by 7% and decreased tenth rib fat by 21%. There was no effect of feeding similar chromium levels from chromium chloride ($CrCl_3.6H_2O$). Page et al. (1992) investigated the effect of feeding 200 ppb chromium from chromium picolinate to two genetic strains of pigs. Results on carcass composition are shown in Table 12 below.

Table 12 The effect of chromium picolinate (CrP) on carcass composition of two genetic strains of pigs (Page et al. 1992)

	Strain A		Strain B	
Parameter	Control	CrP	Control	CrP
Serum cholesterol	103.0	82.7	106.2	86.6
Loin eye area	32.0	34.8	31.7	38.4
% muscling	50.4	52.6	49.6	54.1
10th rib fat	3.26	2.78	3.42	2.55

This study showed marked alterations in carcass composition of pigs fed chromium picolinate. There was some evidence that certain genotypes would respond markedly to chromium picolinate supplementation (Table 11).

CONCLUSIONS

This paper was not intended as a detailed review of the literature on the role of micro-nutrients in livestock production. However, by focusing on just a few key areas it has illustrated the potential powerful roles of certain micro-nutrients. Considerably more research is being carried out on micro-nutrients as our understanding of the requirements for macro-nutrients becomes clearer.

In the area of immunity the hypothesis put forward by Rice and Kennedy (1988), and its subsequent partial validation (Kennedy et al. 1992), that the only way to properly evaluate effects of high supplemental vitamin E levels would be by large-scale studies under commercial production systems, is particularly important given the complexity of the immune system and the myriad of factors known to affect it.

The effects of vitamins on stressed animals is clearly illustrated in the case of vitamin E for pigs and vitamin C for heat-stressed poultry. Although there is considerable work yet to be done, the use of mineral proteinates in beef cattle entering feedlots shows potential, at least under USA conditions.

In terms of skeletal abnormalities in livestock and egg shell problems in laying hens, recent work on $1,25(OH)_2D_3$ and on synthetic analogues of this metabolite shows considerable promise as a means of alleviating these problems. Again, some studies have found interesting results on the use of mineral proteinates in the reduction of specific egg shell quality problems, but further work is required to gain an understanding of the mode of action.

The role of vitamin E in ensuring carcass quality is now well documented across a broad range of animal species. With the increasing trend away from frozen product to fresh product for meats, this role is particularly important. The emergence of novel mineral compounds such as chromium picolinate to influence carcass composition is interesting but requires further studies to eludicate mode of action.

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