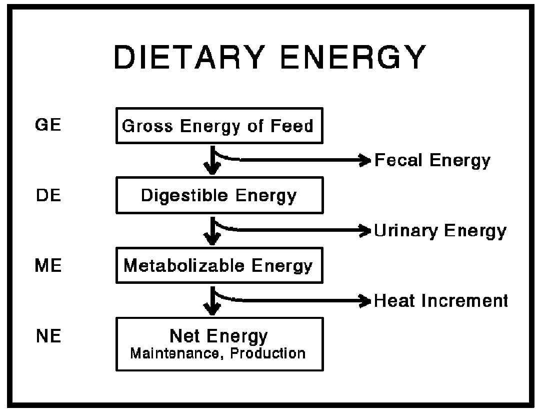
ENERGY METABOLISM & VITAMINS

ENERGY SYSTEMS

1. **Various Systems**

A. Partition of dietary energy: [Adapted from Wiseman & Cole, 1985. In: Cole & Haresign (Ed.)]



B. "TDN:"

1) TDN = Apparent digestible CP +
Apparent digestible CF +
Apparent digestible NFE +
2.25 x Apparent digestible EE

2) Usefulness?

a) Based on many assumptions & approximations, and perhaps, many errors associated with each one of those assumptions or approximations?
b) Using the same weight for protein and carbohydrates.
c) To use the "calorie" system, must be converted to ME or DE.

C. DE, ME & TDN systems - The heat loss is ignored.

D. NE system - Considers a heat loss, but it may vary with a source of energy & also with purposes:

1) ME utilization for energy gain & maintenance - e.g., 27% for wheat middlings, 69% for corn & 75% for soybean oil.
2) Efficiency of utilization of major nutrients for different purposes (ARC, 1981):

Item	Maintenance	Fat production
Carbohydrate	100	100
Fat	95	112
Protein	78	81

☞ The bottom line?

1) The NE system - Theoretically the best measure of available energy for maintenance & production . . . But, practical to use?
2) Also, from "GE to NE," progressively the function of animals rather than the feed ingredient or diet?

2. **Choosing the System**

A. The system should be: 1) Precise, 2) simple to apply, and 3) easily estimated!
B. TDN - As indicated before:

1) Various assumptions/estimates are involved in its calculation, thus not "exact," vs DE & ME, which can be measured directly.
2) Must be converted to DE or ME when switching to the "calorie" system.
☞ Thus, the DE, ME or NE system is preferred by many!

C. DE or ME vs NE:

1) In evaluating feedstuffs:

a) Again, from "**GE** → DE → ME → **NE**" estimations, values are influenced more by animals, i.e., not the value of a feedstuff or diet *per se*.
b) "NE values" may be too sensitive for a practical use, i.e., may have to use different values according to age, sex, etc.

2) Estimation of NE:

a) Direct determination - Very complex since it requires a measurement of total energy exchange by the calorimetry.
b) Based on the prediction equations using N, EE, CF & NFE in both feed & feces - May not be precise!

3) Practical diets for nonruminant species (e.g., grain-protein supplement-based diets) - Usually less variations in relative contributions of energy from protein, CH_2O and fat to the total digested energy, thus the relationships among various systems would be relatively similar?

☞ Thus, DE or ME values are commonly used for nonruminant species!

D. Relationships between DE and ME:

1) Some estimated relationships between ME & DE:

a) ME/DE = 0.957, 0.949, 0.947, 0.977, 0.963, 0.982, 0.970, 0.967, 0.972, etc. with an average of "**0.965**."
b) The most commonly used/quoted assumption - "ME consists of 96% of DE!"

2) But, the quantity & quality of dietary protein can affect this relationship, ∴ adjustment factor(s) must be used:

   a) There are many equations to estimate ME values from DE!
   b) Most commonly used?

      ME = DE x [96 - (0.202 x % CP)] (Asplund and Harris, 1969; NRC, 1988).

3) DE or ME to use?

   a) The loss of energy as combustible gases in pigs - Generally ignored because losses are negligible & difficult to measure (NRC, 1988).
   b)) The variation in the relationship between DE & ME - More of a function of the animal rather than feed or ingredient itself?
   c) "Determined" DE values for most ingredients are available?

   ☞ Thus, preferable to use DE values? (See Chiba , 2000. In: Theodorou & France.)

ENERGY REQUIREMENT

1. **Energy Requirement (e.g., Growing Pigs)**

   ◦ The sum of requirements for maintenance, protein retention, fat retention and cold thermogenesis:

     $DE = \sum(DE_m + DE_{pr} + DE_f + DEH_c)$ (NRC, 1988).

A. Energy requirement for maintenance:

   1) Influenced by environmental temperatures, activity, group size, stress, body composition, etc.
   2) Can be estimated from: [Close & Fowler (1985) in Cole & Heresign]

      a) Measurements from fasting metabolism.
      b) Linear regressions relating energy retention (ER) to ME intake & calculating ME_m where ER = 0.
      c) The relationships between ME intake and protein & fat accretion rates, and determining ME_m as the intercept of the multiple regression analysis.

   3) Live weights and maintenance requirements:

a) e.g., Estimates based on two separate equations: [ARC, 1981; Close & Fowler (1985) in Cole & Haresign]

	ME, MJ/day	
Weight, kg	$ME_m=0.719W^{0.63}$	$ME_m=0.458W^{0.75}$
5	1.98	1.53
10	3.07	2.58
20	4.75	4.33
30	6.13	5.87
40	7.35	7.28
50	8.45	8.61
60	9.48	9.87
70	10.45	11.08
80	11.37	12.25
90	12.24	13.38

b) The most commonly used estimate is ≈ **110 kcal/kg $BW^{.75}$**.

B. Energy requirements for protein and fat retention:

1) Chemical composition of growing pigs (% of body weight): [Kotarbinska, 1969. (Cited by ARC, 1981)]

Weight, kg	Protein	Fat	Water
2.5	15.6	5.0	77.3
8.5	16.7	6.1	75.3
20.7	16.2	9.6	71.0
30.2	16.4	12.4	67.8
60.6	16.6	20.5	59.9
90.4	15.9	26.3	55.1

2) Considerable variations among reported estimates on the cost of protein or fat retention - One example (Tess et al., 1984. J. Anim. Sci. 58:111):

a) Protein - 7.1 to 14.6 Mcal DE/kg with an average of 12.6 Mcal DE/kg protein.
b) Fat - 9.5 to 16.3 Mcal DE/kg with an average of 12.5 Mcal DE/kg fat.

C. "Below" critical temperatures & energy requirement:

1) Equation to estimate the cold thermogenesis:

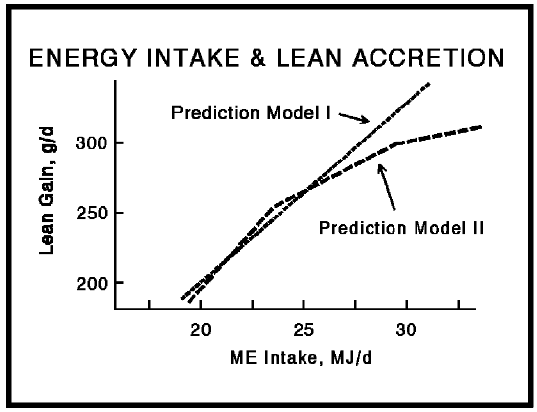
DEH_c (kcal DE/day) = 0.326W + 23.65 (T_c - T) [where W = weight in kg and T (ambient temperature) & T_c (critical temperature) in °C.]

2) According to one estimate, need additional 25 g (80 kcal ME) of feed/day to compensate for each 1°C below T_c in 25- to 60-kg pigs.

D. Energy requirements: (e.g, NRC, 1988)

Body wt., kg	DE, kcal/d	ME, kcal/d
1-5	850	805
5-10	1,560	1,490
10-20	3,220	3,090
20-50	6,460	6,200
50-110	10,570	10,185

E. Energy intake & growth rate of lean tissues: [ARC, 1981; Close & Fowler, 1985. In: Cole & Haresign (Ed.)]



1) Presented only two regression lines covering a range of most ME intakes.
2) Assuming that N intake is not limiting!
3) Considerable variations in responses.
4) Young pigs tend to show a linear response, whereas a response tends to be curvilinear with older/larger pigs & higher energy intakes.

2. **Energy Requirements (e.g., Breeding Swine**)

A. During pregnancy:

1) Should be gaining ≈ 25 kg (. . . more like 10 to 15 kg in net weight?) during gestation for the first 4-5 parities, plus ≈ 20 kg for placenta & products of conception, thus a total of ≈ 45 kg?!
2) Estimation of energy requirements (similar to growing swine):

a) Estimate the maintenance requirement.
b) Consider the rate and efficiency of both uterine (all ♀) & net maternal tissue accretions (gilts & young sows).

3) Maintenance, maternal & conceptus gains:

a) DE_m - 96 to 167 Mcal DE with an average of 110 kcal DE/kg $BW^{.75}$/day.
b) Maternal protein and fat gains (assuming maternal gains = 25% fat & 15% protein)
   - ≈ 12.5 Mcal DE/kg of gain with 40% efficiency, thus, 5 Mcal DE/kg of maternal gains.
c) Conceptus gain - Assuming 1% fat & 9% protein with 10% efficiency, thus, 1.3 Mcal DE/kg!

d) Intrauterine deposition[a]: (Noblet et al., 1990. J. Anim. Sci. 68:562)

	Weight, kg	DM, g	Protein, g	Energy, Mcal
Fetus	13.8 (61)	2444 (73)	1368 (68)	11.1 (72)
Placenta	4.3 (19)	387 (12)	272 (13)	1.9 (12)
Fluids	2.1 (9)	173 (5)	108 (5)	0.7 (5)
Uterus	2.3 (10)	350 (10)	276 (14)	1.7 (11)
Total	22.1 (100)	3365 (100)	2153 (100)	15.6 (100)

[a]Determined at d 110 of pregnancy & determinations are based on 12 fetuses; ( ) = %; Uterus = empty uterus.

B. During lactation - Need energy for maintenance & milk production.

1) DE_m = 110 kcal/$BW^{0.75}$/day.
2) Milk production - 2 Mcal DE/kg milk (assuming GE content of milk = 1.3 Mcal/kg & efficiency of utilization = 65%.)

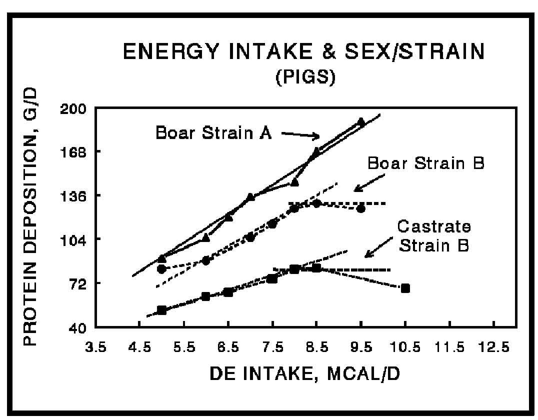
C. Requirements for sows:

Weight, kg:	
Weight at breeding time	140
Pre-farrowing	185
Post-farrowing	165
Gestation:	
Mean gestation wt, kg	162.5
Energy requirement, Mcal DE/d:	
Maintenance (110 x $Wt^{.75}$)	5.00
Maternal gain (25 kg x 5 Mcal/kg ÷ 114)	1.10
Conceptus gain (20 kg x 1.3 Mcal/kg ÷ 114)	.23
Total	**6.33**
Lactation:	
Milk yield, kg/d	6.25
Energy requirement, Mcal DE/d:	
Maintenance (110 x post-farrowing $wt^{.75}$)	5.1
Milk production [(1.3 Mcal/kg ÷ .65) x 6.25]	12.5
Total	**17.6**

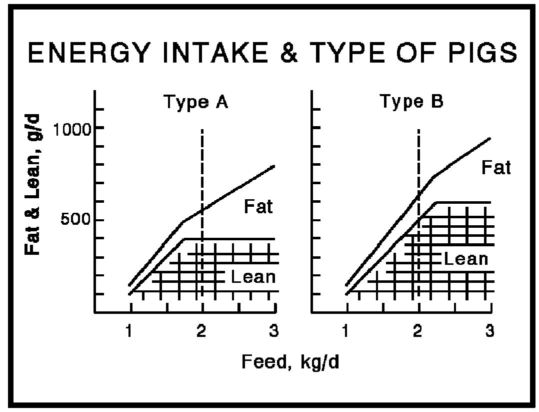
GROWING ANIMALS AND ENERGY (e.g., PIGS)

1. **Energy Intake & Body Component Deposition**

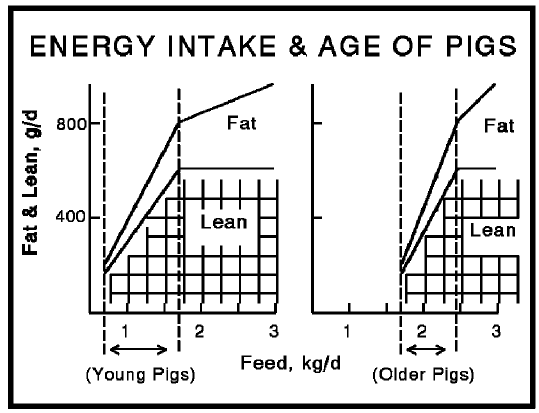
A. Effects of energy intake & sex/strain of pigs on protein deposition - Adapted & redrawn from Campbell and Taverner, 1988. J. Anim. Sci. 66:676.



B. Effects of energy intake and type of pigs on lean/fatty tissue growth - Whittemore, 1985. In: Haresign & Cole.



C. Effects of energy intake and age on lean/fatty tissue growth - Whittemore, 1985. In: Haresign & Cole.



☞ The bottom line?

1) No response in lean growth to additional energy once pigs consumed adequate energy for a maximum protein accretion! The potential for lean growth is determined by age, sex, breeds, strains, use of repartitioning agents, etc.
2) Excess energy consumed can be partitioned into fat deposition, thus increasing fat to lean ratio.

2. **Restricting Energy Intake or Limit-Feeding**

A. Finisher pigs tend to consume energy in excess of that needed for maximum protein or lean deposition.
B. Thus, energy intake can be restricted (usually ↓ by 10-15%) without adversely affecting performance.
C. A limit feeding is very popular in many countries possibly because:

1) Pigs are sold on carcass basis (discounts for fat carcasses).
2) Availability & cost of feed ingredients.

3) Possibly, lower labor costs.

D. Energy intake and pig performance[a]: (Haydon et al., 1989. J. Anim. Sci. 67:1916)

Item	Ad libitum	85%	70%
20-50 kg:			
ADG, kg	.798	.686	.573
Gain:feed	.402	.402	.373
Avg. backfat, cm	2.14	1.78	1.51
Loin muscle, cm^2	23.97	25.61	24.09
Lean cut, %	65.12	66.11	68.32
50-80 kg:			
ADG, kg	1.015	.856	.668
Gain:feed	.297	.308	.286
Avg. backfat, cm	3.23	3.21	2.97
Loin muscle, cm^2	29.40	28.02	31.36
Lean cut, %	60.45	61.58	63.24
80-110 kg:			
ADG, kg	.773	.693	.546
Gain:feed	.205	.219	.208
Avg. backfat, cm	4.00	3.22	2.78
Loin muscle, cm^2	34.31	34.73	40.28
Lean cut, %	58.31	60.71	61.53
Overall:			
ADG, kg	.848	.745	.586
ADFI, kg	2.99	2.50	2.11
Gain:feed	.281	.295	.273

[a]Nutrient levels were adjusted to achieve similar daily intakes.

◦ Summary:

a) Reduced carcass fat by 15% ↓ in energy intake.
b) A greater reduction of fat with 30% ↓ in energy intake.
c) Energy restrictions extended the feeding period, and did not improve feed efficiency.

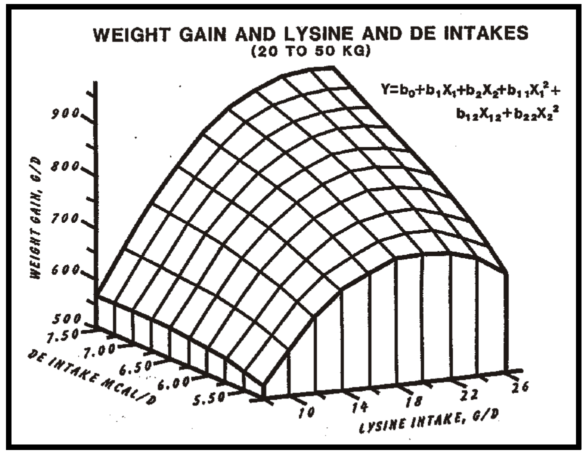
☞ The bottom line?

1) Carcass quality can be improved, but a limit-feeding ↑ days to market because of ↓ weight gain, thus need some incentive programs (premiums) to produce leaner pigs!
2) Presently, no practical means or feeding methods to ensure an adequate individual daily feed intake (i.e., in the group housing/feeding situation).
3) Probably, will not be accepted in the US (at least not in the near future) because:

a) Most pigs are sold on a live weight basis.
b) Feed ingredients are abundant and cheap.
c) Pigs have been selected based on ad libitum feeding.

3. **Interaction of Energy and Amino Acids**

A. Effects of amino acid & energy intakes on weight gain - Chiba et al., 1991. J. Anim. Sci. 69:708)



B. The bottom line?

1) When AA intake is inadequate:

a) ↑ AA intake results in a concomitant ↑ in protein deposition to a point.
b) ↑ energy intake has little beneficial effects on protein metabolism, and excess energy may be used for fat deposition!

2) When energy intake is limited:

a) ↑ energy supply ↑ protein deposition to a point, and excess energy may be used for fat deposition!
b) ↑ AA intake has little beneficial effects on protein metabolism, and some AA may be utilized for energetic purposes.

☞ Thus, for optimum growth and utilization of nutrients, must supply energy and AA in the correct proportion!

BREEDING ANIMALS AND ENERGY (e.g., SWINE)

1. **Energy Intake During Gestation**

A. Effect of additional feed during the late gestation on reproductive performance[a]: [Cromwell et al., 1989. J. Anim. Sci. 67(1):3]

Item	Contr.	+ 1.36 kg/d
Gestation wt gain, kg	39.0	48.7
Weight change during lactation (from d 110 to d 21), kg	- 16.4	- 21.3
Total pigs born	10.42	10.77
Pigs born alive	9.71	10.05
No. of pigs at 21 d	8.06	8.35
Birth wt, kg	1.44	1.48
Weight at 21 d, kg	5.20	5.37
Return to estrus, d	5.81	5.70

[a]Involving 1,080 litters at 8 Exp. Stations (S-145); Additional feed offered during the last 23 d of gestation.

B. The bottom line?

1) Additional feed in the late gestation can improve reproductive performance of sows.
2) Benefits (0.3 more pig/litter at weaning & 2.6 kg more total litter weaning wt) can offset additional feed costs.

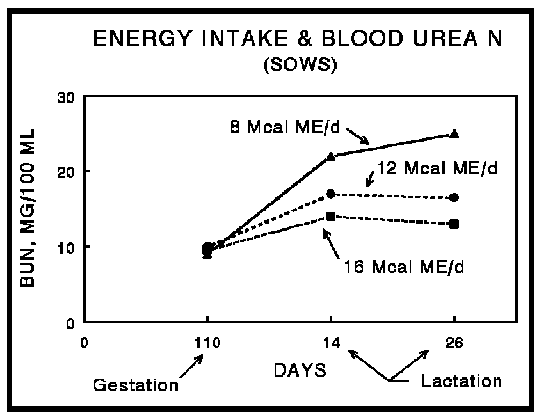
2. Energy Intake During Lactation

A. Effect of energy intake during lactation on reproductive performance: (Reese et al., 1982. J. Anim. Sci. 55:590) [Provided 8, 12 or 16 Mcal ME/d during lactation.]

1) Sow & pig performance:

Item	8 Mcal/d	12 Mcal/d	16 Mcal/d
Sow wt change (lact.), kg	- 25.7	- 13.3	- 3.3
Sow BF change (lact.), mm	- 8.4	- 4.6	- 1.8
Return to estrus (≤ 7 d), %	65.2	91.3	95.7
Avg. pig weaning wt, kg	6.6	6.7	7.0

2) Energy intake & changes in blood urea N - Figure on the right.
3)) An inadequate energy intake may increase the rate of protein catabolism (tissues and dietary sources) to support lactation.
4) An adequate energy intake is important in minimizing weight and backfat losses of lactating sows.
5) An excessive wt loss is likely to have adverse effects on early return to estrus & others.



B. Effects of a source of energy during lactation:

1) Effect of tallow or cornstarch on reproductive performance (restricted to 8 Mcal ME/d): (Nelssen et al., 1985. J. Anim. Sci. 60:171)

Item	Tallow	Cornstarch
Lactation wt change, kg	- 27.5	- 24.3
Lact. backfat change, mm	- 10.0	- 9.6
Return to estrus (%):		
≤ 7 d	68.2	56.5
≤ 14 d	79.5	73.9
Pig wt at d 28, kg	6.7	6.5
No. of pigs at d 28	8.5	8.9

☞ No effect of a source of energy on reproductive performance!

2) Other research:

a) Addition of 2.5% sucrose - No effect. (NCR-89, 1990. J. Anim. Sci. 68:3498.)
b) Addition of fructose - No effect. (Campbell et al., 1990. J. Anim. Sci. 68:1378.)

☞ The bottom line? - "*For optimum reproductive performance, ensuring an adequate energy intake during lactation is more important than the source of energy!*"

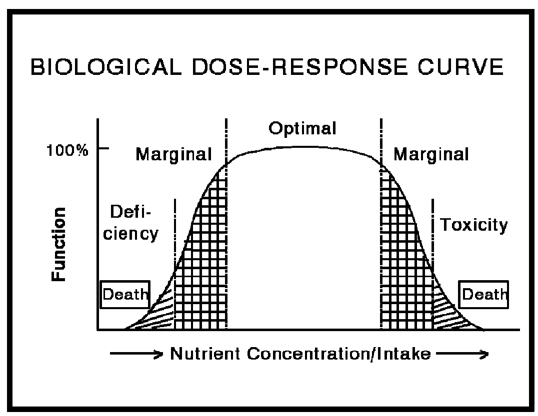
VITAMINS IN GENERAL

1. **Introduction**

A. Nutritional requirements: (Braude, 1978. Proc. Annu. Int. Mineral Conf. pp 39-49)

". . . Should reexamine the whole concept of requirements for a certain nutrients.
*In the past, we have been mainly concerned with crude quantitative aspects - **how much**?*
*Subsequently, also with the crude qualitative aspects - **of what** and **in what form**?*
*Now we have to add, perhaps, the most awkward question - **for what**?*
And this brings us to the basic disciplines of biochemistry and physiology."

B. Intake of an essential nutrient: (Adapted & redrawn from Mertz, 1981. Science 213:1332)



2 **Definition of Vitamin**

A. Wagner and Folkers [1964. Cited by Sullivan (Pers. Comm.)] - An organic compound, which:

1) Is a component of natural food, but distinct from carbohydrates, fats, proteins, minerals & water.
2) Present in food in a minute amount.
3) Is essential for a development of normal tissues, health, growth and maintenance.
4) Can result in a specific disease or syndrome when absent from the diet or not properly absorbed or utilized.
5) Cannot be synthesized by the animals and must be obtained exclusively from the diet.

B. Later by Folkers [1969. Cited by Sullivan (Pers. Comm.)]:

1) An organic substance of nutritional nature present in low concentration as a component of enzymes, and
2) It catalyzes reactions and may be derived externally or by intrinsic biosynthesis.

3. **Deviation from the Classic Definition**

A. Ascorbic acid - Synthesized from glucose by most species often in sufficient amounts to meet their needs.
B. Vitamin D - Produced from precursors in the skin by ultraviolet light, and also its active form can be considered as a hormone.
C. Niacin - Can be produced from Trp.
D. Choline - Can be produced by amination & subsequent methylation of Ser.

4. **Vitamin Needs**

A. In the early 1900s:

1) Many nutritionists simultaneously began to realize that a diet could not be adequately defined in terms of CH_2O, fat, protein and salt.
2) They believed that other organic compounds had to be present to support "normal" growth & health of the animal.

B. Efforts by many investigators led to a discovery of various vitamins.

5. **Vitamin Deficiency**

A. Borderline deficiency:

1) Animals do not perform well, ∴ costly, but they exhibit no known symptoms associated with vitamin deficiencies.
2) May be deficient in vitamin(s), but extremely difficult to detect.

B. Multiple deficiency:

1) Usually don't see a single vitamin deficiency in practical situations.
2) Symptoms are combination of deficiency signs of various vitamins, or may be entirely different.
3) Conditions such as unthriftness, reduced appetite & poor growth are common to "malnutrition" in general.

6. **Vitamin Needs - Becoming More Critical in Recent Years - Possible Reasons?**

A. Wide genetic differences in the type of animals being produced - Can alter vitamin needs.
B. Selection, cross breeding & other practices to produce more meatier and(or) faster-growing animals.
C. Increased use of confinement facilities & slotted floors/cages:

   1) ↓ the opportunity for coprophagy.
   2) Changes in environment may ↑ stress, disease levels, etc.

D. New plant varieties, new methods of handling/processing of ingredients & feeds - greater variations in vitamin levels & availability.
E. For swine, there is a trend for earlier weaning, which may ↑ vitamin requirements.
F. Increased use of grain-soy type diets - ↓ use of vitamin-rich ingredients.
G. Increased use of antimicrobial agents - ↓ biosynthesis of many vitamins.

7. **Supplementation**

A. Metabolic needs are similar among various species, but dietary needs for the vitamin may differ widely. (1° due to differences in their ability to synthesize vitamins.)
B. Swine, poultry & other nonruminant animals:

   1) Depend on their diets to a greater extent compared to ruminants.
   2) Intestinal synthesis of B vitamins:

      a) Although considerable, not extensive as ruminants.
      b) Also, synthesis occurs at the lower tract, ∴ absorption rate may be low & may have no/little benefits to the animal!

   3) Those species habitually practice coprophagy such as rats & rabbits, contributions of intestinal synthesis of B vitamins can be significant!

C. Horses:

   1) General:

      a) Lack of information on the type & level of vitamins needed for horses fed well-balanced diets.
      b) Most likely to be deficient in vitamins A & E (& D for those housed in the confinement). But, their vitamin requirements can be met with a high-quality sun-cured hay, so . . . ?
      c) For mature horses, vitamin K and B vitamins are less likely to be deficient vs other nonruminants. But, the absorption rate of vitamins synthesized in the cecum/large intestine has not been well established!

2) Supplementation? - Considering the ↑ use of a total confinement & uncertainty regarding absorption rates, may need to supplement vitamins!

D. Vitamin supplementation? e.g., Vitamin contents of corn-SBM & vitamin requirements for grower pigs (. . . based on the 1988 NRC).

Vitamin, unit/kg	Corn	SBM	Corn-SBM	Reqt.[a] 20-50 kg
Vitamin A, IU	200	-	161	1300
Vitamin D, IU	-	-	-	150
Vitamin E, IU	21	3	17	11
Vitamin K, mg	-	-	-	.5
Vitamin C, mg	-	-	-	?
Riboflavin, mg	1.1	3.0	1.4	2.5
Panto. acid, mg	5.1	16.5	6.9	8.0
Niacin, mg	-	28.0	4.8	10.0
Vitamin B_{12}, μg	-	-	-	10.0
Choline, mg	500	2600	850	300
Pyridoxine, mg	6.2	6.0	4.0	1.0
Thiamine, mg	3.7	6.0	4.0	1.0
Folacin, mg	.3	.6	.4	.3
Biotin, mg	.07	.30	.11	.05

[a]Requirements for 20-50 kg pigs (NRC, 1988).

8. **Important Vitamins in Energy Metabolism**

A. Thiamin (B_1).
B. Riboflavin (B_2).
C. Niacin.
D. Pantothenic acid.
E. Biotin.

THIAMIN (VITAMIN B_1)

1. **General**

A. Considered to be the oldest vitamin:

1) The first of "water-soluble" vitamins to be discovered from so called a "growth factor."
2) The deficiency disease, beriberi, is probably the earliest documented disorder. (Recorded in China as early as 2,600 B.C.).

B. Beriberi in general: [Please see Maynard et al. (1979), McDowell (1989) & others]

1). The major health problem observed in the Far East for a long time, and the problem persisted until fairly recently - e.g., Even as recently as 1940's, the mortality rate from beriberi in Philippine was 132/100,000 (1947).
2) Usually both cardiac and nervous functions are disturbed:

a) Signs include edema (ankles), puffiness of face, anorexia, digestive disturbances, heart enlargement, tachycardia, lassitude & muscle weakness, loss of knee & ankle reflex, etc.
b) Beriberi patients are unable to rise from a squatting position, indicating the neurological damages.

3) In the early 1880s:

a) A physician in the Japanese Navy substituted some of polished rice with other foods, and was able to ↓ the incidence of beriberi.
b) Incorrectly thought that added protein was responsible for preventing beriberi.

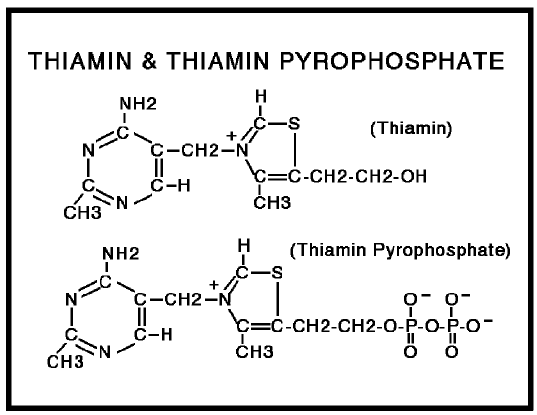
4) In the 1890s:

a) Eijkman discovered polyneuritis in chickens, and symptoms were similar to beriberi.
b) Rice bran was effective in curing & preventing beriberi, and also it had similar effects on polyneuritis.
c) Incorrectly assumed that polished rice produced a toxin.

5) Casmir Funk (1910s):

a) Obtained a potent anti-beriberi substance from rice bran (discovery of thiamin).
b) A substance had characteristics of amine, thus coined the term "vitamin(e)" (vital amine). (Found later that many vitamins are not amines!)

2. **Structure** - Thiamin and thiamin pyrophosphate (TPP; Martin et al., 1983)



3. **Functions**

A. Along with riboflavin and niacin, plays important roles in the citric acid cycle.
B. TPP is responsible for decarboxylation:

1) Pyruvate → acetyl-CoA + CO_2
2) α-Ketoglutaric acid → succinyl-CoA + CO_2

C. TPP is also involved in transketolase reaction (pentose pathway/synthesis of ribose).
D. In nervous tissues - Little is known, but:

1) Involved in the synthesis of acetylcholine - Transmission of neural impulses.
2) Involved in a passive transport of Na (excitable membranes) - Transmission of impulses.

4. **Deficiency**

A. Poultry - Signs include loss of appetite & weight, weakness in leg/muscular, bradycardia (from 300 to 90-100/min), edema, diarrhea, vomiting, . . . & death.

B. Swine - Signs include loss of appetite & weight, weakness, premature birth, high mortality, slow pulse, heart failure, edema, hemorrhages, diarrhea, vomiting . . . & sudden death.

C. Fish:

1) Signs include poor appetite, muscle atrophy, convulsions, instability & loss of equilibrium, edema & poor growth.
2) Thiaminase - Found in tissues of most fish, and can destroy thiamin:

a) Can split the vitamin into two component ring structures in non-living tissues.
b) Thiaminase in unheated fish or fish viscera can destroy the vitamin prior to ingestion - e.g., Channel catfish can develop a deficiency by feeding diets containing 40% unheated fish viscera for 10 wk.

5. **Requirements and Sources**

A. Thiamin (Vitamin B_1) requirements:

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	0.8-1.0
Laying	0.60-0.88
Broilers	1.80
Turkeys, all classes	2.0
Swine (NRC, 1998):	
3-120 kg	1.0-1.5
Adults	1.0
Horses (NRC, 1989):	
Horses &ponies (DM)	3.0-5.0
Also via	Microbial synthesis?
Fish (NRC, 1993):	
Channel catfish & rainbow trout	1.0
Pacific salmon	No dietary requirement?
Common carp	.5
Tilapia	Not tested

☞ Usually, can be met by natural ingredients!

B. Sources:

1) Cereal grains (seed coats & germs) & their by-products, oil extraction residues - relatively rich sources (≈ 3-12 mg/kg).
2) Brewer's yeast is the richest known natural source (95.2 mg/kg).

C. Thiamin in pork:

1) For some unknown reason, pigs' tissue contains high levels of thiamin vs other species (several times higher).
2) Thus, pork is an excellent source of thiamin (0.87 mg/3 oz of broiled chop vs RDA of 1-2 mg/day).

D. Factors affecting the requirement:

1) Heat processing - Cooking, pelleting, etc. (Thiamin is relatively heat-stable, but it's not stable in a moist-heat!)
2) Presence of thiaminases - e.g., Moldy grains/feeds (microbes can produce thiaminases).

RIBOFLAVIN (VITAMIN B_2)

1. **General** [Please see Maynard et al. (1979), McDowell (1989) & others]

A. "Water-soluble" factor or factors promoted growth & prevented beriberi.
B. Heating destroyed anti-beriberi effect more rapidly than growth-promoting effect.
C. Water-soluble fractions consisted of two essential factors:

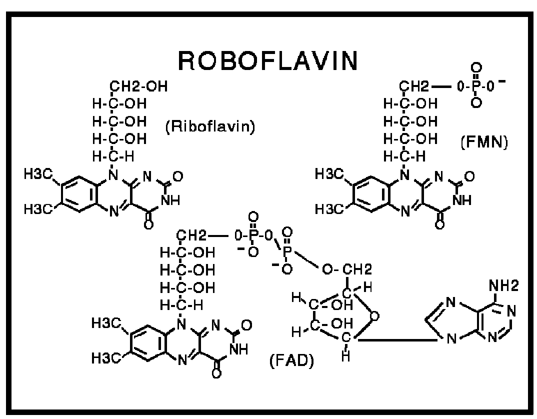
1) Less heat stable factor - Thiamin.
2) Heat stable factor - Riboflavin.

D. Warburg & Christian (1932) - Isolated an oxidative enzyme from yeast, which showed "yellow" color with green fluorescence (∴ "Old Yellow Enzyme!"), and able to split it into a protein- & nonprotein (pigment)-fraction.

☞ Perhaps, this was the first identification of a "prosthetic" group of the enzyme!?

E. Kuhn (1933) - Isolated a yellow pigment from egg white that had oxidative properties, and suggested the name "flavin" for this growth factor:

1) e.g., Ovoflavin - isolated from eggs, lactoflavin - isolated from milk, hepatoflavin - isolated from liver, & uroflavin - isolated from urine.
2) Crystalline compounds contained a ribose, thus the name, "riboflavin!"

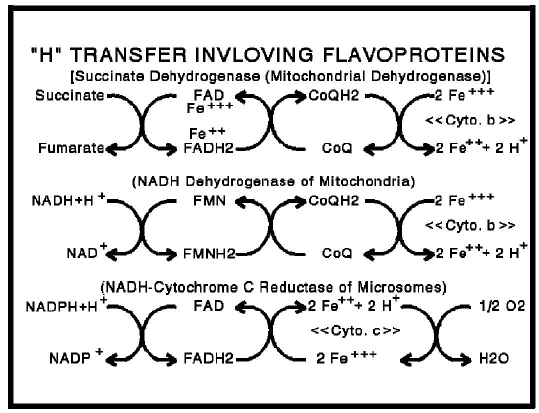


2. **Structure** - Adapted & redrawn from Martin et al. (1983).

3. **Functions**

A. A component of FMN and FAD - A prosthetic group for active enzymes, flavoproteins. (Most flavoproteins contain FAD.)
B Involved in a transfer of electrons in biological oxidation-reduction reactions.
C. About 40 flavoprotein enzymes participate in the electron transfer:

a) Some examples - "Hydrogen transfer involving flavoproteins:" (Adapted & redrawn from McDowell, 1989)



b) Aerobic dehydrogenases (no metal) - D- & L-AA oxidase, glucose oxidase, etc.
c) Oxidases (Cu, Fe or Mo) - Cuproflavoprotein in butyryl-CoA-dehydrogenase, xanthin oxidase, etc.
d) Anaerobic dehydrogenases - acyl-CoA dehydrogenases & electron-transferring flavoprotein, succinic dehydrogenase, fumaric reductase, etc.
e) Others - Choline dehydrogenase, α-glycerophosphate dehydrogenase, L-lactate dehydrogenase, D-lactate cytochrome reductase, etc.

4. **Deficiency**

A. Poultry - A characteristic sign, curled-toe paralysis, is a reflection of degenerative changes in myelin sheaths in sciatic & brachial nerves; other signs include retarded growth, diarrhea, high mortality, reduced hatchability, reduced egg production, etc.
B. Swine - Signs include anorexia, slow growth, rough hair coat, dermatitis, unsteady gait, scours, reproductive & digestive tracts disorders, vomiting, cataracts, light sensitivity, etc.
C. Fish - Signs include cloudy lens, hemorrhagic eyes & other organs, photophobia, dim vision, incoordination, abnormal pigmentation of iris, striated constriction of abdominal wall, dark coloration, poor appetite, anemia, poor growth, etc.

5. **Requirements and Sources**

A. Riboflavin requirements:

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	1.7-3.6
Laying hens	2.1-3.1
Broilers	3.0-3.6
Turkeys	2.5-4.0

- Cont. -

- Cont. -

Swine (NRC, 1998):	
3-120 kg	2.0-4.0
Adults	3.75
Horses (NRC, 1978):	2.0
Fish (NRC, 1993):	
Channel catfish	9.0
Rainbow trout	4
Pacific salmon & common carp	7
Tilapia	6

☞ One of the vitamins most likely to be deficient in nonruminant species, and also in humans!

B. Sources:

1) Cereal grains, their by-products & soybean meal are rather low (e.g., corn, 1.4 mg & SBM, 3.2 mg/kg DM) - Corn-soy diets are borderline to deficient, thus must be supplemented!
2) Green, leafy vegetables, yeast & forages are good sources - e.g., Sun cured alfalfa leaves contain 23.1 mg/kg.

☞ For humans, milk, eggs, liver, heart & muscle are rich sources!

C. Factors affecting the requirement:

1) Heating will destroy some vitamin (little more stable than thiamin though).
2) A free-form (produced by microbes or by chemical synthesis) is sensitive to light.
3) Divalent heavy metals (Cu, Fe, Mn, Zn, Cd) bind the vitamin & make it unavailable.

NIACIN

1. **General** [Please see Maynard et al. (1979), McDowell (1989) & others]

A. Niacin has been known to organic chemists since 1867, a long before its importance as an essential nutrient was discovered.
B. Funk (1911-1913) isolated niacin from yeast & rice polishing.
C. The interest in niacin was lost because of its ineffectiveness in curing beriberi.
D. Warburg et al. (1935) reported that niacin functioned as part of a hydrogen transport system.
E. Third vitamin to be discovered from the "vitamin B complex," i.e., thiamin first, riboflavin second & then niacin.

2. **Pellagra in General**

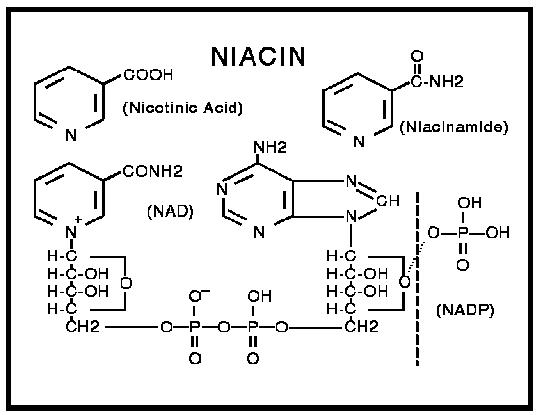
A. A niacin deficiency in humans - Means a rough skin (dermatitis).
B. Not a clear cut deficiency of niacin, but may also involve Trp, thiamin, riboflavin and pyridoxine.
C. A condition common in the corn-eating population - Appeared in Europe in the 1730s when corn from the New World became the major staple foodstuff.
D. Most cases occurred in a low-income group.

☞ Diets associated with the disease were referred to as three **M's** - **M**eal (corn), **M**eat (back fat) and **M**olasses. (+ **poverty**!)

E. In the US (especially in the south), it's common for 20,000 deaths/year from pellagra around the turn of the century.
F. Clinical signs & mortality from pellagra are referred to as the **four D's**:

☞ **D**ermatitis of the area exposed to sun, **D**iarrhea, **D**ementia [a mental disorder - depression & schizophrenia (indifference, withdrawal, hallucination, illusion of persecution and omnipotence)], and **D**eath.

3. **Structure** (Adapted & redrawn from McDowell, 1989)



4. **Functions**

A. Component of 2 important coenzymes, NAD (formally called DPN) & NADP (formally called TPN), which are involved in biological oxidation-reduction systems.
B. Important reactions catalyzed by NAD & NADP:

1) CH_2O metabolism - Glycolysis (anaerobic & aerobic oxidation of glucose) & citric acid cycle.
2) Lipid metabolism - Glycerol synthesis and breakdown, fatty acid oxidation and synthesis & steroid synthesis.
3) Protein metabolism - Degradation and synthesis of amino acids & oxidation of carbon chains via citric acid cycle.
4) Others - Photosynthesis & rhodopsin synthesis.

5. **Deficiency**

A. Poultry - Black tongue (inflammation of the tongue, mouth cavity, & esophagus), ↓ appetite & growth or weight loss, reduced egg production and hatchability, etc.

B. Swine - Poor appetite & weight gain, dermatitis, hair loss, diarrhea, inflammation & necrosis of the GI tracts, etc.
C. Fish - Loss of appetite, lesions in colon, jerky or difficult motion, weakness, edema of stomach & colon, muscle spasms, poor growth, anemia, fin lesions, etc.

6. **Requirements and Sources**

A. Niacin requirements:

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	10.3-27.0
Laying hens	8.3-12.5
Broilers	25-35
Turkeys	40-60
Swine (NRC, 1998): (Available)	
3-120 kg	7-20
Adult	10
Horses (1978):	Microbial synthesis
Fish (NRC, 1993):	
Channel catfish	14
Rainbow trout	10
Pacific salmon	Required, but not determined
Common carp	28
Tilapia	Not tested

- Usually, diets are supplemented!

B. Sources:

1) Grains (corn, sorghum, wheat & oats) are low in niacin, and it exits 1° as a bound form (85 to 90%) & not available to animals.
2) Soybean meal (31 mg/kg DM) - 100% available based on a chick assay.
3) Wheat bran (268 mg) & brewer's yeast (482 mg/kg DM) are good sources.

7. **Trp & Niacin Requirement**

A. Animals can synthesize niacin from Trp, but there are wide variations in their ability to synthesize this vitamin.
B. Trp levels in the diet may affect niacin requirements: (e.g. in pigs)

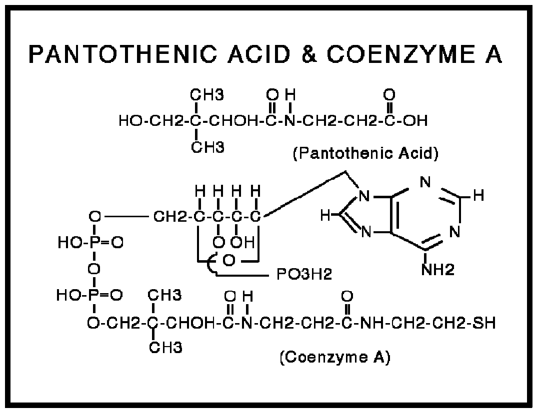
1) ≈ 50 mg Trp → ≈ 1 mg niacin - i.e., Every 0.01% Trp above the requirement (or 100 mg/kg), pigs can synthesize 2 mg niacin/kg of diet.
2) Thus, for high-protein diets, probably no need for niacin supplementation.

PANTOTHENIC ACID

1. **Introduction** [Please see Maynard et al. (1979), McDowell (1989) & others]

   A. Isolated during the 1930s from the vitamin B_2 complex along with pyridoxine.
   B. Previously called a chick anti-dermatitis factor.
   C. The name pantothenic acid was derived from the Greek word "*Pantos*," meaning found everywhere.
   D. Found in two enzymes, coenzyme A and acyl carrier protein, which are involved in many reactions in CH_2O, fat & protein metabolism.

2. **Structure** (Adapted & redrawn from McDowell, 1989)



   A. Found in feeds in both bound (as coenzyme A) & free forms.
   B. A free form is unstable & easily degraded by heat, acids & bases.

3. **Functions**

   A A constituent of coenzyme A and acyl carrier protein.
   B The most important function of coenzyme A is probably its role as a carrier of carboxylic acids.
   C. Some biochemical reactions involving pantothenic acid: (McDowell, 1989)

Enzyme	Derivative	Reactant	Product	Site
Pyruvate dehydrogenase	CoA	Pyruvate	Acetyl CoA	Mitochondria
α-ketoglutarate dehydrogenase		CoA	α-ketoglutarate	Succinyl CoA
Mitochondria				
Fatty acid oxidase	CoA	Palmitate	Acetyl CoA	Mitochondria
Fatty acid synthetase	Acyl carrier protein	Acetyl CoA, malonyl CoA	Palmitate	Microsomes
Propionyl CoA carboxylase	CoA	Propionyl CoA, CO_2	Methylmalonyl CoA	Microsomes
Acyl CoA synthetase	Phospho-pantetheine	Succinyl CoA, GDP + Pi	Succinate, GTP + CoA	Mitochondria

4. **Deficiency**

   A. Poultry - Signs include severe dermatitis, broken feathers (become brittle & fall-off), perosis, poor growth, reduced egg production & hatchability, mortality, etc.
   B. Swine - Signs include anorexia, poor growth, diarrhea, rough hair coat, brown exudates around eyes, anemia, "goose stepping" (resulting from sciatic nerve damages), etc.

C. Fish - Signs include clubbed gills, prostration, loss of appetite, necrosis & scarring, cellular atrophy, gill exudate, sluggishness, poor growth, anemia, etc.

5. **Requirements and Sources**

A. Pantothenic acid requirements:

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	9.4-10.0
Laying hens	1.7-2.5
Broilers	10.0
Swine (NRC, 1998):	
3-120kg	7-12
Adults	12
Horses (NRC, 1978):	Microbial synthesis
Fish (NRC, 1993):	
Channel catfish	15
Rainbow trout	20
Pacific salmon	20
Common carp	30
Tilapia	Not tested

B. Sources:

1) Corn (6.6 mg) & SBM (18.2 mg/kg DM) based diets tend to be deficient in pantothenic acid, ∴ diets are usually supplemented.
2) Milling by-products such as rice bran (25.2 mg) & wheat bran (33.5 mg/kg DM) are good sources.

BIOTIN

1. **General** [Please see Maynard et al. (1979), McDowell (1989) & others]

A. Different lines of investigations led to the discovery of biotin:

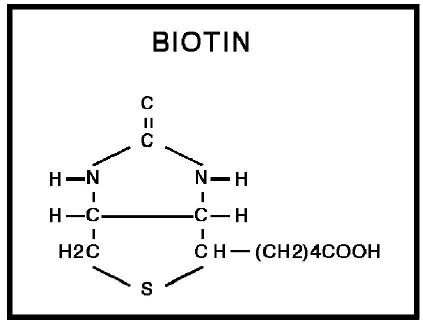
1) Coenzyme R - Required for legume nodule bacteria.
2) Biotin - Isolated from egg yolk, which was necessary for yeast growth.
3) Factor H or vitamin H - A factor present in certain foods (especially in the liver & kidney) that protected egg-white injury (dermatitis).

B. Szent-György et al. (1940) found that all three were the same substance.

C. Generally believed for many years that supplemental biotin is not necessary for swine & poultry because biotin is widely distributed in nature/feedstuffs & it is synthesized by many different microorganisms in the GI tract.

D. But in the mid 1970s, several field cases of deficiency signs were observed, and animals responded to a supplemental biotin, which led to re-evaluation of the role of biotin in animal diets.

2. **Structure** (Adapted & redrawn from Martin et al., 1983)



3. **Functions**

◦ Serves as a prosthetic group for a number of enzymes (carboxylases, transcarboxylases & decarboxylases), and biotin moiety functions as a mobile carboxyl carrier.

A. Carbohydrate metabolism:

1) Carboxylation of pyruvic acid to oxaloacetic acid.
2) Conversion of malic acid to pyruvic acid.
3) Interconversion of succinic acid and propionic acid.
4) Conversion of oxalosuccinic acid to α-ketoglutaric acid, etc.

B. Protein metabolism:

1) Protein synthesis.
2) Amino acid deamination.
3) Purine synthesis & nucleic acid metabolism, etc.

C. Lipid metabolism:

1) Conversion of acetyl-CoA to malonyl-CoA (the first reaction in FA synthesis).
2) Essential FA metabolism, etc.

4. **Deficiency**

A. Poultry - Signs include reduced performance, broken feathers, dermatitis, leg & beak deformities, increased embryonic mortality & reduced viability after hatching, etc.
B. Swine - Signs include reduced performance, loss of hair, dermatitis (dry & rough), brownish exudate, ulceration of skin, inflammation of the mouth mucosa, cracking of soles & top of hooves, etc.
C. Fish - Signs include loss of appetite, lesions in colon, coloration, muscle atrophy, spastic convulsion, fragmentation of erythrocytes, skin lesions, poor growth, etc.

5. **Requirements and Sources**

A. Requirements:

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	0.09-0.15
Laying hens	0.08-0.13
Broilers	0.12-0.15
Turkeys	0.10-0.25
Swine (NRC, 1998):	
3-120 kg	0.05-0.08
Adults	0.20
Horses (NRC, 1978)	Microbal synthesis?
Fish (NRC, 1993):	
Channel catfish	Required, but not determined
Rainbow trout	.15
Pacific salmon	Required, but not determined
Common carp	1.0
Tilapia	Not tested

B. Sources:

1) Exists in both bound (unavailable) & free forms - e.g., > ½ of biotin in various feedstuffs is in the bound form & biologically unavailable.
2) Contents in cereal grains are influenced by variety, season, yield, storage conditions, etc.
3) Corn (.07 mg/kg) and SBM (.32 mg/kg DM) are highly available sources, but the availability in wheat, barley & milo is very low.

C. Avidin (antivitamin):

1) Present in raw eggs, which is denatured by moist heat.
2) Secreted by mucosa of oviduct of the hen into egg white, and combines with biotin in "1:1 ratio" (the bound biotin is not available).
3) Dietary avidin < biotin - Cures/prevent deficiency symptoms.

6. **Biotin Supplementation (e.g., Swine Diets)**

A. In general, no improvement in performance of growing pigs with biotin supplementation.
B. In sows, inconsistent responses:

1) Observed improved hoof hardness/strength, improved skin & hair coat condition, reduced hoof cracks & footpad lesions in some investigations.
2) Also observed improved reproductive performance (litter size, weaning wt, days to return to estrus, etc.) in some studies.

C. Recent data:

A. Biotin and reproductive performance of sows: (Watkins et al., 1991. J. Anim. Sci. 69:201)

Item	Basal	+ Biotin
Foot score	7.16	6.48
Hair score	1.68	1.58
Soundness score	2.38	2.23
Rebreeding interval, d	4.98	5.25
No. of pigs born	11.41	10.66
% born alive	78.8	81.9
Pig birth wt, kg	1.58	1.45
No. of pigs at 21 d	7.42	7.56
% alive at 21 d	89.0	85.8
Pig 21-d wt, kg[a]	5.15	4.73

[a]Biotin effect, $P < 0.03$.

B. Biotin and foot lesions: (Lewis et al., 1991. J. Anim. Sci. 69:207)

Item	0	330 µg/kg	*P*
Kentucky:			
No. of lesions[a]	2.59	2.40	0.59
Overall lesion score[b]	1.20	1.07	0.24
Minnesota & Nebraska:			
No. of horn crack[a]	3.04	3.19	0.68
Severity of horn cracks[c]	0.91	0.98	0.51
No. of heal cracks[a]	2.86	3.03	0.58
Severity of heal cracks[c]	1.19	1.14	0.72
No. sidewall cracks[a]	3.57	4.57	0.08[d]
Severity of sidewall cracks[c]	1.27	1.44	0.19
No. of bruises[a]	0.87	1.40	0.01
Severity of bruises[c]	0.52	0.93	0.01

[a]Total No. of lesions for all four feet; [b]Based on overall condition of the feet where 0 represents no lesions & 5 represents many lesions; [c]Based on the system where each lesion was give severity score ranging from 1 (a very small lesion) to 5 (a very large severe lesion); [d]Station x treatment, $P < .05$.

◦ Biotin has no effect on cracks & bruises on the feet of sows.