ASA
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feed Formulation

Technical Report Series

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TableOfContents

1. **Feed Processing and Nutrient Enhancement** — 5
John D. Summers

2. **Preventing Mixing Errors and Cross-Contamination of Premixes and Feeds** — 12
David Eisenberg

3. **Formulating with Phytase to Maximize Poultry Performance** — 17
Ulrich Heindl

4. **Ingredient Quality and Performance** — 24
Anthony C. Edwards

5. **Importance of Nutrient Levels and Variability in Feedstuffs** — 30
John D. Summers

6. **Use of True Ileal Digestible Amino Acids in Feed Formulation** — 35
Zhirong Jiang

7. **The Economics of Ingredient Allocation** — 42
Matthew Clark

8. **Formulation of Diets on a Digestible Amino Acid Basis and Factors Affecting Digestibility of Feedstuffs** — 49
Jeff D. Firman

9. **Effects of Processing on Nutrient Content of Soybean Meal** — 54
K. C. Rhee

Feed Processing And Nutrient Enhancement

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While it is true that the main factors influencing the nutritive value of a diet are the ingredients employed and their chemical composition, there are many other factors that can have a marked influence on the feeding value of a diet. Unfortunately since many of these are routine steps in feed manufacturing, often a minimum amount of effort is put into making sure that they are optimized so as to maximize diet efficiency.

Grinding

One of the first steps in feed processing is the grinding of cereals. The main effect of grinding is to improve feed utilization. This is accomplished by increasing the surface area of the grain portion of the diet by a marked reduction in particle size. Eley and Bell (1948) fed fine, medium or coarse mash feeds and observed an increase in feed consumption and less feed wastage with the coarser feed. Reece et al. (1985) reported that feed containing roller milled corn, having larger particle size, resulted in heavier weight broilers than a similar diet containing hammer milled corn, when diets were fed in the form of mash. However, steam pelleting the diets resulted in equal bird performance. A point of interest was the author's statement that the energy involved in grinding corn could be reduced by 14.5 % by the use of the roller mill.

Energy Costs Of Grinding

Deaton et al. (1989) pointed out that the energy required for grinding grain is the second largest energy cost after the pellet mill. Since in many cases layer feeds are not pelleted, grinding is the largest energy cost in producing these rations. The above authors prepared yellow corn by passing it through a hammer or roller mill. Laying diets were formulated, using up to 67% of the corn samples. No difference was noted in hen performance (Table 1) when fed these diets even though particle size averaged 1422 m from the roller mill and 844 m from the hammer mill. If such results are consistent under commercial conditions, significant savings in energy cost may be made by evaluating grinding conditions.

Table 1. Effect of method of grind (hammer versus roller mill) on laying hen performance

	Production 0%	Egg wt (g)	Feed Consumption (g)	71 wk body wt (g)
Hammer Mill	74.7	57.1	96	1594
Roller Mill	73.4	57.1	94.7	1610

Selected and rearranged data from Deaton et al. (1989)

Particle Size

Reece et al. (1986 a,b) looked at particle size of hammer milled corn and concluded that for pelleted diets variability in fineness of grind had very little influence on the nutritive value of the diet, nor on pellet quality (Table 2). However, a marked reduction in the use of energy for grinding resulted from the use of a 6.35 versus a 4.7 mm screen opening, since the grinding rate was 27% higher for the larger screen.

Table 2. Performance of broiler and pellet quality when fed pelleted diets with corn ground with a 4.76 or 6.45 Mm opening screen

Hammer Mill Screen (mm)	Body Weight (g)	Feed/Gain	Pellet Durability* (% intact pellets)
4.76	2097	1.96	91
6.35**	2092	1.96	91

**After tumbling for 40 min. in a durability tester*
***A 27% greater throughput was achieved with the larger screen*
Selected and rearranged data of Reece et al. (1986a).

Nir et al. (1990) also compared the grinding of sorghum by a hammer and roller mill. Their data would suggest that at similar particle size there is no difference in feeding value of hammer or roller milled sorghum.

Whole Grain Feeding

McIntosh et al. (1962) fed Leghorn pullet diets containing whole, ground or pelleted wheat and compared performance at different ages (Table 3). While the whole wheat diet was significantly inferior to the ground and pelleted wheat diets to 5 weeks of age, these differences decreased with age and by the 11-15 week period the whole wheat diet equalled the performance of the ground wheat diet. Such findings are of interest in view of the implementing of whole grain feeding to improve the economics of feeding (Forbes and Shariatmadari, 1994), as well as reports that whole grain feeding may improve the health of the bird by developing a healthier digestive system (Cumming, 1988).

Table 3. Influence of form of wheat on performance of pullets

	Age (wks)					
	0 - 5		6 - 10		11- 15	
Form of Wheat	Wt. gain (g)	Feed intake (g)	Wt. gain (g)	Feed intake (g)	Wt. gain (g)	Feed intake (g)
Whole	309	751	495	1634	327	2021
Ground	363	806	508	1666	331	2082
Pelleted	389	856	495	1683	236	1768

Selected and recalculated data of McIntosh et al. (1962)

Whole Soybeans

White et al. (1967) compared the heat treatment of whole soybeans, either by infra-red heating (temperature in a generator of 1500 to 1800°F; beans treated for 4 to 6 minutes had an exit temperature of 235°F), extrusion (beans preconditioned at 212°F to 18-21% moisture, temperature in extruder reaching 240 to 290V), autoclaving (autoclaved for 30 minutes with 30% of water added at 6 pounds pressure). All these heat treatments significantly improved the feeding value of the raw soybeans (Table 4), as well as reducing pancreas weight to levels similar to that of the control, dehulled, extracted soybean meal. Arnold et al. (1971), heat treated soybeans in a still-air oven. Three samples of beans, harvested with 10.0, 12.5 and 16% moisture were subjected to various temperatures for 5 or 10 minutes. As can be noted in Table 5, a critical quantity of heat is required to deactivate the "toxic factors" and this will vary with the time the beans are exposed to heat and the amount of moisture in the beans.

In a further study Simovic et al. (1972) utilized higher temperatures than used in the above study and utilized an infra red apparatus with a endless wire mesh belt under the heater strips, the speed of which could be controlled. It was found that the time and temperature could be varied over a wide range with performance of birds being similar if the critical quantity of heat applied to the beans was similar. The optimum times for various temperatures are shown in Table 6.

Table 4. Effect of soybean treatment on performance of broiler chickens (7 - 28 days)

Diet*	Av. wt. gain (g)	Feed: gain	28 day pancreas wt. (g)
Control	467^{a}	1.61^{a}	1.90^{a}
Raw flakes	324^{d}	2.35^{d}	3.80^{b}
Autoclaved flakes	428^{b}	1.77^{b}	1.97^{a}
Ground raw beans	356^{c}	2.12^{c}	3.21^{b}
Ground autoclaved beans	447^{ab}	1.58^{ab}	1.88^{a}
Extruded beans	444^{ab}	1.59^{ab}	1.75^{a}
Infra-red cooked beans	429^{b}	1.70^{ab}	1.97^{a}

** Soybean fractions made up 30.8% of the diet.*
Selected data from White et al. (1967)

Table 5. Performance of chicks fed heat-treated soybeans at three different moisture levels (7 - 21 days)

Treatment time (minutes)	Oven temperature °C		Weight gain (g)* (% moisture)	
		10	**12.5**	**16**
	149	70	80	-
	171	72	65	72
10	194	44	62	72
	204	-4	43	68
	149	49	58	-
5	171	76	85	18
	194	75	74	46
	204	72	74	67
Control		73	53	53
Ground raw soybeans		28	17	-

**There were 3 different experiments and thus weights should be compared with the control in each experiment.*
Selected data from Arnold et al. (1971)

Steam Pelleting

The advantages of steam pelleting diets for poultry have been demonstrated on numerous occasions. With steam pelleting, heat, moisture and pressure are involved, all factors which are known to enhance chemical reactions. Thus besides the positive physical effect of pelleting there are also chemical effects

Table 6. Proper time and temperature for processing whole soybeans

Processing treatment		Average wt. gain (g)	Feed: gain	Pancreas size (mg/g body wt.)
Time (min.)	Temp. (°C)			
3.0	204	90.6	2.67	3.33
2.5	232	87.3	2.7	3.18
2.0	260	91.4	2.57	3.1
1.5	260	94.4	2.67	3.16
1.0	316	92.4	2.69	3.07
Raw		13.2	13.1	6.02
Control		75.6	2.98	3.39

Selected and rearranged data of Simovic et al. (1972)

Table 7. Effect of dry and steam-pelleting on the performance of chicks fed wheat bran or corn diets

Diets	Unprocessed[1]	Processed[2]	Unprocessed	Processed
	Average weight (g)		Metabolizable energy for test material (kcal/g)	
Bran				
Mash	164	259	1.46	1.7
Dry-pelleted	288	296	1.48	1.85
Steam-pelleted	303	294	2.05	2.5
Corn				
Mash	231	248	3.45	3.51
Dry-pelleted	258	269	3.58	3.55
Steam-pelleted	314	183	3.61	3.61

[1] The 50% aded test material was regular corn and bran.
[2] The added test materials had been steam pelleted and reground
Selected data of Summers et al. (1967)

which enhance the feeding value of a diet. This is demonstrated in Table 7 where a sample of corn and wheat bran were steam pelleted and then reground to mash. The above ingredients, along with similar samples of regular bran and corn, were mixed 50:50 with a corn, soybean meal basal diet. These diets were then fed as mash, as dry-pellets (pelleted in a small dry pelleting machine), or as regular commercial steam pellets. Since the diets were fed to young White Leghorn cockerels, the pellets were reduced to crumbles for feeding. Dry pelleting the wheat bran (a physical change) resulted in a marked improvement in weight gain, but no change in ME of the bran, while steam pelleting (a physical and chemical change), gave a further increase in weight gain and a marked improvement in the ME value of bran (Table 7). The processed wheat bran further increased the ME value of the bran, especially for the double steam-pelleted treatment. Dry and steam-pelleting the corn diet also gave a response in weight gain, however, with the processed corn diets the mash and dry pelleted diets did not alter weight gain while birds fed the double steam pelleted diet showed a marked reduction in weight gain. Such an effect is obviously due to too much heat being applied to this diet with the possible tying up of lysine. The ME of the test corn was little affected by pelleting treatment.

Diet Enhancement Through Supplements

Supplementary Fat

While it is obvious that subjecting a diet to various physical treatments, as outlined above, will enhance it's nutritive value, there is increased attention being paid to dietary supplements that can improve the availability or utilization of dietary nutrients. One of the most common ingredients added to poultry diets is supplementary fat. There have been many reports published showing the benefits of fat supplementation over and above it's contribution as an energy source. Much of this work has been reviewed in the papers of Mateos and Sell (1981 a,b,c). Of interest is the demonstration by Mateos and Sell (1981 c) that the extra caloric effect of fat, reported by a number of workers, is due in large part to fat slowing down the rate of food passage in the gut, thus allowing enhanced digestive activity resulting in increased nutritive value of the diet. This is demonstrated in Table 8, where it can also be noted that type of carbohydrate (starch versus sucrose) can also influence rate of passage.

Table 8. Influence of carbohydrate source on time of appearance of a chromic oxide marker when fed to leghorn pullets after a 30 minute fast

Appearance of marker (min. after feeding)						
Diets		Starch		Sucrose		
Fat						
0%		155		111	x	133
7%		158		143	x	150
	x	156	x	127		

Selected and rearranged data of Maetos and Sell (1981c)

Other Dietary Supplements

While the use of antibiotics and growth promoters have been in use for many years, in relatively recent years there has been a renewed interest in the use of enzymes, as well as probiotics, to enhance the nutritive value of a diet, through their action on the utilization of nutrients, as well as improved health of a flock. Recently oligosaccharides have been investigated as dietary additions that act through competitive inhibition, to tie up enteric pathogens and also to stimulate or interact on the immune system.

Nutrient Balance

Essential Amino Acids

Another area to look at and one that is receiving increased attention is formulating to more precisely meet nutrient requirements and thus improve nutrient efficiency by enhancing nutrient balance. There is a lot of evidence to suggest that enhanced utilization of essential amino acids occur when there is less non-essential nitrogen in the diet. Any essential amino acid in excess of requirements is, in effect, non essential nitrogen as far as the bird is concerned. This is covered in some detail by the report of Bedford and Summers (1985). Thus in order to enhance essential amino acid utilization and, in turn, reduce diet costs, more attention should be paid to EAA balance and their ratio to non-essential amino acids.

It has been shown by Boomgaardt and Baker (1973) and Morris et al. (1987) that the essential amino acid requirement remains constant as a percent of dietary protein. Obviously this means that they would increase as a percent of the diet as dietary protein levels increased. This demonstrates that there is a reduction in the efficiency of EAA utilization as dietary protein level increases. From the data of Boomgaardt and Baker (1973), it was shown that the lysine requirement to maximize weight gain was approximately 4.7% as a percent of the dietary protein with levels of protein of 14, 18 and 23%, however, as a percent of the diet the requirements were .66, .88 and 1.05% respectively.

Minimum Levels And Balance Of Essential Amino Acids

Parr and Summers (1991) fed chicks a “perfectly” EAA balanced diet (NRC 1984) by formulating a 23% protein, corn, soybean meal diet then reducing the protein level, in a step-wise manner, while at the same time keeping the ratio of corn to soya constant, until the last essential amino acid histidine, just met NRC requirement levels. As dietary protein level was reduced, EAA supplements were made to keep them at minimum requirement levels. For example, methionine was the first EAA to be limiting, then lysine, arginine, etc. Hence, increased quantities of these amino acids were added to the diets as dietary protein level was reduced. The intact protein level, where histidine just met minimum requirements, was around 14% with a crude protein level of around 16%. Weight gain and feed intake of the birds at the minimum histidine level are shown in Table 9.

Table 9. Performance of male broilers (7 to 21 days) fed corn, soya, glucose diets formulated to minimum EAA requirement levels with histidine at minimum requirement level

Treatment	Weight gain (g)	Feed intake	Feed/gain (g)
1. 23% protein control	475	744	1.57
2. All, EAA at minimum levels	512	819	1.6
3. As 2 + 10% additional histidine	494	801	1.62
4. As 2 + NEAA to equal nitrogen in diet 1.	465	731	1.57

Selected data of Parr and Summers (1991)

The minimum EAA diet resulted in greater weight gain than the control and this diet did not respond to additional histidine or NEAA supplementation. Thus it was assumed that the balance of EAA in diet 2 was a reasonable estimate of a “perfectly” balanced EAA diet.

Lipstein et al. (1975) concluded that increased deposition of carcass fat in the growing chicken was the result of the bird increasing it’s feed intake to try and obtain the minimum amounts of omitting EAA required for growth. If this is the case, the inference is that birds consume feed in an attempt to meet their amino acid requirements. Parr and Summers (1991) formulated three diets containing either 2560, 2850 or 3050 kcal of ME/kg using the balanced minimum EAA diet shown in Table 9 (diet 2). Thus the diets varied only in their energy concentration which differed by the amount of glucose monohydrate and cellulose added. In Table 10 it can be noted that weight gain increased as dietary energy increased. However, feed intake was identical. Thus, it would appear that the birds ate to satisfy their protein requirement. In doing so birds fed the high energy diet consumed more energy, were fatter, as shown by carcass fat content, and were thus heavier. While carcass protein, as a percent of dry weight, was reduced with the higher energy diet, based on total carcass protein deposition, the diets resulted in similar body protein deposition. Thus it would appear that with an ideal balanced EAA diet, growing birds will eat to satisfy their protein not their energy requirement.

Table 10. Performance of male broilers fed diets formulated with identical amino acid balance but with three levels of energy (7 - 12 days)

Dietary energy levels (kcal/ME/kg)	Weight gain (g)	Feed intake (g)	Carcass protein		Carcass fat	
			(% dry wt)	Total (g)	% dry wt	Total (g)
1. 2650	505	829	55.1[a]	97.6[a]	34.1b	60.5c
2. 2850	516	832	51.2b	91.9b	39.9[a']bb	71.6b
3. 3050	551	823	50.0b	98.8[a']bb	41.1a	81.1[a']bb
	NS	NS	**	*	**	**

Data from Parr and Summers (1991)

If the above is the case, then in commercial formulation an effort has to be made to get closer to that ideal essential amino acid balance in order to improve the efficiency of EAA utilization and hence increase diet profitability.

Table 11. Male broilers fed whole wheat and cracked corn

Treatment	Weight (g) 49 d	Feed/gain	Abdominal Fat (% 1)	Feed Cost (¢/kg)
Control	2883	1.84	2.52	38.6
Plus wheat	2760	1.93	2.38	35.2
Plus corn	2762	1.98	2.38	

Cereal grains % of total intake

	Wheat	Corn
0 - 7d	0	0
7 - 21d	16.3	12.7
21 - 35d	39.2	34.3
35 - 49d	39.6	42.9

Selected data from Leeson and Caston (1993)

Table 12. Feeding whole or ground barley to broilers from 14 to 35 days

	Whole	Ground
Weight gain (g)	935	975
Feed intake (g of DM)	1890	1885
Feed:gain	2.01	1.94
Gizzard size (% live wt.)	4.54	3.83

Selected and rearranged data from Svikus et al (1997)

Table 13. Influence of moisture level and feed form on broiler performance (0 - 6 wk)

Treatment Moisture*	Gain (g)	Feed:gain (g/g)
Low - mash	2089	0.59
Low pelleted	2225	0.60
High - mash	2043	0.54
High - pelleted	2186	0.57

**Low moisture 91.8%DM; high 85.6*
Selected data from Moritz et al (2001)

Table 14. Influence of moisture type and formula density on broiler performance (3 - 6 wks)

Diets*	Gain (g)	Feed:gain (g:g)	Mortality
Regular	1604	0.6	2.9
Regular + surfactant	1606	0.59	2.7
Higher density	1643	0.63	2.4
Higher + surfactant	1650	0.63	1.6

**All diets had 5% added water*
Selected data from Moritz et al (2001)

Whole Grain Feeding

There has been renewed interest in investigating the use of feeding whole grains, especially in Europe where wheat is the commonly used cereal. Leeson and Caoston (1993) fed whole wheat and cracked corn, free choice, to broilers (Table 11). The main effects noted were a poorer feed:gain ratio and less abdominal fat with the free choice cereals, as well as a significant reduction in feed costs. During the 35 to 49 day period the birds were eating approximately 40% of the free choice cereals. Similar results were found by Svihus et al (1997) when whole or ground barley were fed to broilers (Table 12). As has been reported previously, they noted a marked increase in gizzard size by the feeding of whole as compared to ground barley.

Pellet Quality

With the use of more by products in North America, pellet durability index (PDI), which is a measure of the percent of intact pellets, was deteriorating to almost unacceptable levels. Hence, studies were initiated to investigate this problem. Fairchild and Greer (1999) had reported that by increasing the water content of the feed in a mixer PDI was enhanced with a significant decrease in energy usage by the pellet machine. Moritz *et al.* (2001) showed that the addition of up to 5% water to a feed mix, resulted in improved feed efficiency when fed to broilers to 6 weeks of age (Table 13).

It has been suggested that surfactants facilitate absorption of water into grain and thus should improve feed utilization. However, Moritz et al. (2002), failed to show any positive effect in feed utilization, both with a regular and a higher fat supplemental diet, with the addition of a surfactant to the diet (Table 14).

Feed Processing Procedures

Another feed processing procedure that has been introduced to the feed industry is what is called “friction compaction”. A chamber with a screw auger to pull feed through an insulated jacket at 80 - 85°C, forces the heated mash through a V shaped compression chamber with rollers that help to compact the feed and raise the temperature to around 95°C. Feed leaving the adjustable friction ring has a crumbled texture and is fed directly into the pellets.

Leeson et al. (1998) compared conventional pelleted and compacted feed when fed to broilers. They looked at a corn, soya as well as a corn, soya diet containing by-products. While 21-day weight was superior for the compacted feeds, by 49 days of age there were no differences in performance (Table 15).

Table 15. Effect of compacting feed on performance of male broilers

	Body wt (g)		Feed:gain	
Diet	**21d**	**49d**	**0-21d**	**0-49d**
(Corn/soya)				
Conventional	733	3110	1.42	1.84
Compacted	759	3076	1.41	1.8
(By products)				
Conventional	736	3040	1.43	1.89
Compacted	762	3014	1.46	1.86

Selected data from Leeson et al (1998)

A relatively new type of feed processing was introduced in Europe in the nineties. Customers had been complaining about the low PDI and due to the fact that most poultry operations were not integrated, like in North America, the feed processors were challenged to look into the matter. This was also the time when more by-products were finding their way into poultry rations and also governments were pushing for some control of pathogens in feed. Hence, the goal was to come up with a process where by-products could be utilized, also investigate thermal processing as a means of reducing pathogens, while at the same time, maintaining or increasing plant output.

Expander technology was investigated. An expander is similar to an extruder with a heavy duty screw in a barrel which is equipped with an adjustable annular gap. The annular discharge gap controls the degree of pressure on the mash feed. Material exiting the annular gap is referred to as “expandate”.

Expandate on exiting expands, resulting in moisture to flash evaporate, thus lowering the moisture in the finished feed. An expander is basically used to pretreat feed prior to pelleting and after going through a conditioning chamber. Usually the mash temperature is higher, thus there is more starch gelatinization. However, total energy expenditure is greater. Feed particles are usually more porus, thus better absorption of liquids is gained. The process is reported to improve feed digestibility, as indicated in Table 16.

Table 16. Impact of feed conditioning on live performance of broilers to 42d

	Relative	
Treatment	**Body weight (%)**	**Feed conversion (%)**
Conventional	100	100
Expander 1	404.4	96.2
Expander 2	106.6	94.7
Steam enhancer	101.4	99.2

Selected data from Fancher et al (1996)

Future Diet Formulations

In Table 17 several laying diets have been formulated and compared with the NRC (1994) requirements. Diet 1 is a regular 17% protein, corn, soya diet. It would be slightly deficient in total sulphur amino acids. Diet 2 has all the protein coming from soya and when formulated to just meet the minimum valine level, meets all other EAA minimum levels except for total sulphur amino acids. Diet 3 would be a regular 13% corn, soya laying diet. Not only does it require methionine and lysine supplementation, but it is also deficient in valine. Diet 4 is a 13% protein diet with all the protein coming from full-fat soybeans. It is slightly deficient in methionine and perhaps valine. (For EAA levels, see Table 18.)

Table 17. Composition of diets (kg)

	1	2	3	4	5
Corn	65.0	-	76.07	-	-
Soya (48%)	23.75	27.6	13.5	-	27.6
Starch*	-	60.0	-	3.0	45.0
Full fat soybeans	-	-	-	60.0	-
AV blend	1	-	-	-	7.0
Limestone	8.0	8.15	8.2	8.15	8.15
Calcium phosphate	1.15	1.15	1.15	1.25	1.65
Other	1.10	1.15	1.08	1.0	1.15
Total weight (kg)	100	98.4	100	73.4	90.4
Composition					
Protein (%)	17.1	13.3	13.1	13.2	13.3
Energy (kcal ME/kg)	2850	2870	2880	2880	2867
Calcium (%)	3.34	3.47	3.39	3.59	3.47
Available phosphorus (%)	0.40	0.40	0.38	0.41	0.40

**Starch was used as it has a similar energy level to corn, sorghum and carbohydrate products such as cassava and sugar.*

Most diets are formulated using a grain base and then adding a protein supplement to provide the proper level and balance of protein (amino acids). Soybean meal is the most common protein supplement used in poultry diets and while corn is the cereal commonly used in North America, this is not the case in many other parts of the world. Thus consideration should be given to using soybean products to supply the protein (amino acid) portion of the diet, then dilute it down with local cereals, by-products, high carbohydrate ingredients (cassava, sugar) etc., keeping in mind minimum amino acid requirements and balance, energy concentrations and above all, economics of production.

Table 18. Essential amino acids

			Diets		
		1	2	3	4
	Requirement*	17% protein	13% soya	13% corn	13% full fat
EAA	NRC (% of diet)	protein	soya	soya	
Arginine	0.70	1.10	0.99	0.79	0.78
Histidine	0.17	0.42	0.33	0.31	0.36
Isoleucine	0.65	0.94	0.72	0.73	0.48
Leucine	0.82	1.53	1.02	1.26	0.96
Lysine	0.69	0.89	0.88	0.58	0.78
Methionine	0.30	0.30	0.19	0.25	0.30
+ Cystine	0.58	0.56	0.41	0.43	0.54
Phenylalanine	0.47	0.92	0.69	0.72	0.54
+ Tyrosine	0.83	1.67	1.13	1.39	0.84
Threonine	0.47	0.74	0.55	0.57	0.60
Trypotophan	0.16	0.23	0.19	0.17	0.18
Valine	0.70	0.85	0.69	0.64	0.66

** NRC 1994 for a laying hen with 100g intake per day and 15% protein diet.*

Diets

1. *65.4% corn, 23.75% soya*
2. *All the protein coming from soya (27.6%)*
3. *A 13% protein corn, soya diet (76% corn, 13.5% soya)*
4. *A 13% protein, 60% full fat soybean diet*
5. *A 13% protein diet, 27.6% soya, 7.0% fat*

It is of interest that diet 2, with all the protein coming from soya, has a similar level of soya as diet 1 (Table 17). Thus in many instances this would be a more economical diet to produce and still meet the minimum EAA levels for the laying hen (Table 18). Diet 4 is of interest as it shows that with full-fat soybeans the nutrient requirement of the laying hen can be put in a much smaller “package” (Table 17) than diets 1 and 2, while still meeting the hen’s requirements. Diet 5 has the same EAA levels as diet 3, but with the use of fat, if available, can provide the proper level of nutrients in a smaller “package”

With the significant increase in poultry production around the world, there is going to be an increased use of local ingredients to supply a significant portion of dietary nutrients. For the immediate future this will probably consist mainly of products that contribute to the energy portion of the diet (e.g. Cereals, by-products, fat, etc.) Thus, more emphasis will be placed on maximizing the efficiency of the protein portion of the diet in order to reduce production costs. This may well mean changes in diet formulation and the manner in which the diets are fed.

Preventing Mixing Errors And Cross-Contamination Of Premixes And Feeds

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The basic premise for manufacturing formula feeds is that by "least cost" formulation of many ingredients, and additive feeds may be manufactured that provide optimum nutrition and health to animals, poultry and fish. It is assumed that feed must be mixed so that each serving or at least each day's consumption of feed should provide nutrients and additives at formulated levels.

The "level of scrutiny" is thereby critical, as a cow may consume 10 kilos of feed a day and a shrimp less than 1 gram. Even if the mixing of feeds is validated by analyzing for one or many nutrients or additives as tracers for all other ingredients, mixing may not be adequate if the particle sizes of specific ingredients or additives are not fine enough to provide a uniform dispersion at the "level of scrutiny". An example would be adding a powdered vitamin that clumps on the end wall of a mixer. When it falls off the wall, it will be present in the feed as formulated but it will not be adequately dispersed even if other ingredients are.

With this as a caveat, how can one prevent mixing errors and cross-contamination of premixes and feeds? The answer is by careful design and selection of mixing equipment, conveyers, bucket elevators, holding bins, pelletmills and all other feedmill equipment with which feed is handled. Since most feedmills are designed with components from many vendors with specific expertise, the builder must rely on the knowledge of these suppliers. In the end, however, since equipment wears and changes over time the only way to know the capability of a feedmill and to thereby prevent errors in mixing and/or in cross-contamination of feeds is to study these specific issues.

Determining Mixing Of Premixes And Feeds

Knowing the capability of the feedmill to mix feeds will allow optimization of mixing parameters including: mixing time, batch size, and speed (revolutions per minute). Optimizing manufacturing conditions will: ensure the quality of feed manufactured, increase plant capacity while reducing labor, energy and equipment depreciation costs. The optimum mixing conditions will depend upon the bulk density of the feed, the shape of the feed ingredients and the size of feed particles. It is critical mixers not be overloaded and several studies have suggested it takes longer to mix large particles than it does to mix smaller ones.

Validating The Mixing Process

One must consider at least five issues before studying mixers to determine the adequacy of mixing and to optimize mixer performance.

- Selection of one or more tracers.
- Addition of the tracer to the test feed.
- Sampling the feed.
- Analyzing the samples.
- Interpreting the results.

A. Selection of the tracer

Whatever tracer or tracers are chosen for the mixer test, data from their analysis will be used to evidence the mixing for all other ingredients. If they yield results typical of a complete mix, one will assume all other ingredients are also mixed.

At least the following criteria should be considered in selecting one or more than one tracers for the test.

* The tracer should be contributed to the feed from only one source. If a feed is formulated with both corn and wheat with 12% protein, analyzing for protein is meaningless as even if no mixing

occurred analytical results from a series of samples would yield a low coefficient of variation (CV).

* The tracer should be a microingredient. While it may be reasonable to assume that if a tracer added at 50 grams/tonne is completely mixed then macroingredients added at 1% or more will also be mixed, it is seemingly unreasonable to make the converse assumption. Drugs such as halofuginone (1) are added to feeds at 3ppm or less and selenium is added at 0.3ppm or less. Is it reasonable to assume these are mixed if the mixer study employs salt (sodium chloride) as the tracer with the salt added to the feeds at 2% of the total formula, especially if salt is also contributed to the feed from other ingredients such as fish meal?
* The analytical procedure to determine the tracer must be accurate and reliable with minimum analytical error.
* The analytical procedure should be inexpensive.
* The analytical procedure should provide quick results, ideally "on the spot" so additional batches of feed can be studied with mixing parameters changed based upon initial test results.
* One should be able to interpret the results objectively.

The most commonly used tracers for validating mixing are:

* Salt (sodium chloride)- in the Official ASAE (American Society of Agricultural Engineers) method. Assays cost for chloride or for sodium as low as USD $15/sample with analytical error for chloride as low as 2% or 3% coefficient of variation and for sodium 5%.
* Minerals such as zinc, manganese and cobalt. Determined by atomic absorption spectroscopy. Assay cost as low as $25/sample with analytical error as low as 5% to 7%.
* Amino acids- such as lysine and methionine. Determined by HPLC. Assay cost as low as $50/sample with analytical error as low as 5%.
* Vitamins such as Riboflavin. Determined chemically or by HPLC. Assay cost as low as $60/sample with analytical error as low as 7% to 10%.
* Medicated premixes- such as amprolium. Determined chemically. Assay cost as low as $50/sample with analytical error as low as 10% to 15%.
* Colored iron particles or colored fine iron powder (2). Retrieved magnetically from feed samples, with colored spots developed or with colorimetric readings made from dye dissolved from the colored iron powder. Assay cost as low as $10/sample or much less if performed by feedmill personnel with analytical error as low as 2% to 3%.

B. Addition of the tracer(s) to the test feed

This should be via a premix that can, if necessary, be prepared by mixing the tracer additive in ground corn or another diluent. If the tracer is to be added at 50 grams/tonne, the 50 grams might be mixed in 450 grams of diluent to make a 500-grams/tonne addition.

The location of the tracer premix addition is usually where a "hand add" premix would normally be added. If one is studying the design capability of a mixer as required for paddle mixers that often have difficulty achieving an end-to-end mix, two tracers may be added to a batch one at each end. Alternately, if one wants not only to study mixing capability but also the capability of automated metering equipment to consistently add microingredients to a series of batches of feeds, the tracer may be added via such automated addition equipment with samples then taken not from one batch of feed but from a series of batches.

The tracer is normally added after the mixer is fully loaded. Starting and ending times for the test must be carefully controlled and addition of the tracer must be coordinated with the sampling plan.

C. Sampling the test feed

Ideally, one takes samples from within the mixer. All samples must be "grabs" not composites. If samples are taken from within a mixer, it may be adequate to take as few as three samples- one sample from each end and one from the middle.

Often it is difficult to obtain samples from within a mixer. In such instances, one may take a series of ten or more "grab" samples from the discharge of a batch off a screw conveyer exiting a surge bin. These samples will reflect not only mixer performance but incomplete cleanout of feeds from the mixer and surge bin. Such cross-contamination if it is occurring can be documented by taking samples from the next following batch of feed.

A 500-gram sample for the mixer performance test is adequate though samples from following batches to be tested for cross-contamination should be larger, possibly 2-kilos. Samples must be marked and they should not be homogenized prior to analysis as this will weaken the power of the test. If the samples are homogenized, one will compare results for 500-gram samples whereas if the samples are not mixed one will compare results for the sample analyzed (i.e. 80 grams or less).

D. Analyzing the test feed

This depends upon the tracer(s) one employs. If one uses vitamins, minerals, drugs, salt or amino acids, samples must be boxed tightly and shipped to the applicable laboratory for analysis. If one tests for chlorides via test strips or colored iron particulates or very fine colored iron powder, the tests may be performed at the plant.

E. Interpreting the test results

For the mixer performance test, this should be done by comparing the coefficient of variation (CV) found from the test data with the CV inherent to the method. The method CV is what one expects from repeat analysis of the same homogenous sample and can be as little as 2% for chloride chemical analysis or as high as 20% for many feed drug assays.

Results follow for studies of two mixers where colored iron particulates were employed, one study yielding results evidencing a complete mix and one evidencing a statistically significant mixing error follow.

In both cases red colored iron particles were formulated at 50 grams/tonne with an expected count of 100 particles from analysis of 80 grams of feed. The feed tested in both was broiler mash with a mixer capacity of 3 tonnes and a mixing time of 3 minutes.

Complete Mix and Consistent Metering of Tracer to Four Test Batches of Feed

Sample	Batch 1	Batch 2	Batch 3	Batch 4	Total
1	93	101	109	99	402
2	105	96	98	104	403
3	122	95	103	111	431
4	117	96	113	103	429
5	98	106	106	103	413
6	102	115	95	102	414
7	108	103	116	104	431
8	111	98	100	87	396
9	98	115	116	107	436
10	98	110	88	109	405
Total	1,052	1,035	1,044	1,029	4,160
CV	8.8%	7.7%	9.0%	6.6%	CV theory-10.1%
Chance Probability*	49.5%	74.0%	48.1%	87.5%	

** Likelihood a complete mix would yield a CV equal to or greater than that found in the test.*

Incomplete Mix and Inconsistent Metering of Tracer to Five Test Batches of Feed

Sample	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Total
1	84	76	91	90	85	426
2	68	74	83	90	56	371
3	56	104	105	117	94	473
4	79	122	129	115	60	505
5	52	108	140	122	96	518
6	102	120	106	116	94	538
7	146	95	101	106	50	498
8	126	95	129	140	75	565
9	96	94	96	111	61	458
10	66	95	118	128	56	463
Total	875	980	1,098	1,135	727	4,815
CV	34.9%	16.2%	18.5%	15.5%	18.2%	CV theory-10.2%
Chance Probability*	0.00%	0.32%	0.05%	1.42%	0.01%	

** Likelihood a complete mix would yield a CV equal to or greater than that found in this test.*

The complete mixes yielded CV's consistently less than the 10.1% expected from a complete mix. This was better than one could reasonable expect. The incomplete mix yielded CV's consistently greater than the 10.2% expected.

The Chance Probabilities for the complete mixes were consistently greater than 5%, likelihoods typical of a complete mix. The Chance Probabilities for the incomplete mixes were in 4 or 5 batches less than 1% and would be expected in less than 1 in 100 studies of a complete mix. Since this data was not typical of a complete mix, the mix is judged incomplete.

Correcting A Mixing Problem

Common causes of incomplete mixing that may be easily corrected include overloading the mixer and mixing for too short a time. One should visually inspect the mixer when loaded to be sure ribbons or paddles are visible at least 15 centimeters above the feed. If the mixer is overloaded, one can reduce the batch size and run another mixer test. If the mixer is not overloaded, one may run another test with the mixing time extended by possibly a minute. If results are improved, one should repeat the test to be sure the improvement in consistent.

One may also visually inspect the mixer blades or paddles to be sure they are not severely coated with fat that can distort their ability to mix. One should also inspect the discharge gates to be sure they have no dead spots and to be sure they are not leaking. Ribbons or paddles should also be inspected to be sure they are not worn or broken. Typical life expectancy for ribbons may be 2 to 4 years.

If one cannot improve results by reducing the loading or increasing the mixing time, one can investigate increasing the speed (revolutions per minute) of the mixer or re-engineering the mixer blades or paddles. If all else fails, it may be necessary to replace the mixer.

Cross-contamination Of Feeds And Premixes.

Currently, the greatest concerns over cross-contamination of feeds relate to "carryover' of ruminant by-product formulated in non-ruminant feeds to ruminant feeds where it could spread mad cow disease and "carryover' of medicated feeds into non-medicated feeds. Medicated feed carryover is a concern where trace levels of the drug in feeds can lead to tissue residues in meat, poultry and fish and condemnations or import refusals by the European Union, Japan and other countries with demanding import standards.

One way to prevent cross-contamination from causing problems is to not use ruminant by-products or drugs in feeds or to make feeds for only one species at the feedmill. This may be effective but it can also be costly. An alternate approach is to study the capability of the feedmill and to develop procedures to control cross-contamination at levels sufficiently low they will cause no problems.

Determining Cross-contamination Of Feeds And Premixes

Analytical methodology for determining trace level contamination of ruminant by-products or of most drugs into withdrawal feeds is limited and in many cases not precise or accurate. Most medicated feed assays yield accurate results at formulated levels but do not yield meaningful results in feeds at 1% or less of the formulated level. Since drug assays of meat, poultry or fish tissue may have far lower levels of detection than in feeds, this creates a situation where one may find tissue residues but be unable to determine whether the drug was present in the feed or not.

One solution is to employ simple easy to detect tracers, one example being colored iron particulates and to interpret tracer results as being indicative of the drug. It has also been found that fine powders will "carryover" more in feeds than granulated products. Electrostatic and van der Waals forces may also cause a tracer to behave differently than a drug. The validity of using colored iron tracers as indicators for a medicated feed was addressed by studying cross-contamination at the premix level rather than at the feed level, utilizing a medication with a good assay with a low level of detection.

This study compared counts for particulate iron particles, colorimetric readings for very fine colored iron particles and chemical assays for the drug amprolium. The study was performed at a premix plant where the drug was formulated at 2.5% into the initial batch of premix and each of the two iron based tracers were formulated at 1.1-kilos per tonne.

Sample	Weight	Red Iron Particulates		Blue Iron Powder
		Count	Color Absorbance	Color Absorbance
Amprolium 2.5%-Mixer	4 grams	121	0.280	0.415
Average of Samples from Mixer, Conveyer, Elevator, Cooler and Packer	4 grams	100	0.229	0.305
Batch #1-Following- Mixer	200 grams	21	0.062	0.091
Conveyer- five samples	200 grams	395	0.590	0.675
Elevator- five samples	200 grams	144	0.381	0.380
Batch #2- Following-Mixer	200 grams	0.4	Nil	Nil
Conveyer- five samples	200 grams	47.4	0.105	0.143
Elevator- five samples	200 grams	37	0.083	0.081

These values could be used to calculate estimated levels of amprolium in the various samples and could be compared with chemical assay results for the drug.

Sample	Amprolium Chemical Assay	Estimated Amprolium Red Tracer Count	Color	Estimated Amprolium Blue Tracer Color
Amprolium 2.5%- Mixer	2.02%	2.75%	2.25%	2.73%
Packer Pellets-	1.79%	2.09%	2.25%	1.70%
Batch #1-Following				
Mixer- first sample-	370ppm	90ppm	120ppm	140ppm
Batch #1- Following-				
Conveyer- first sample-	4,170ppm	4,470ppm	4,380ppm	2,360ppm
Elevator- first sample-	730ppm	790ppm	760ppm	590ppm
Batch #2- Following				
Mixer- first sample-	150ppm	Nil	Nil	Nil
Conveyer- first sample-	660ppm	470ppm	340ppm	340ppm
Conveyer- second sample-	170ppm	130ppm	Nil	Nil

This data suggested the percentage of cross-contamination of the drug into non-medicated premixes could be estimated with reasonable accuracy and precision from the red tracer counts and colorimetric readings and also from the colorimetric readings from the fine blue colored iron powder.

The level of detection for the drug was 50 ppm or 0.2% of the formulated level. The level of detection for the red iron particle counts, the colorimetric readings from the red tracer and the colorimetric readings from the blue iron powder were all about 0.02% the formulated level. The tracer results were thus about 10 times more “sensitive” than the chemical assay results. In this study, the amprolium and the two tracers appeared to cross-contaminate similarly.

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Footnotes

1. *halofuginone is sold commercially as StenorolTM manufactured by Intervet Canada Ltd, 250 Water Street Whitby, Ontario, Canada LIN 9T5.*
2. *colored iron particulates and fine colored iron powder are sold commercially as Microtracers (tm) manufactured by Micro-Tracers, Inc. San Francisco, Ca. 94124 USA.*

Formulating With Phytase To Maximize Poultry Perfomance

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Introduction

Phosphorus is a mineral that is essential to growth and development. Cereal grains and oil seeds contain substantial quantities of phosphorus, however up to 80% of the phosphorus is present as phytic acid. This poses a problem to monogastric animals because they do not produce sufficient amounts of intrinsic phytases necessary to hydrolyze the phytic acid complex. Because monogastric diets are mainly comprised of feedstuffs that have low phosphorus availabilities, phosphorus supplementation from inorganic sources is necessary in order to obtain optimal animal performance.

The low availability of phosphorus in plant ingredients poses problems both economically and environmentally. Economically, phosphorus is usually the third most expensive component in a monogastric diet after energy and protein. Environmentally, a large amount of consumed phosphorus is excreted in the feces and urine due to its high unavailability.

The beneficial effects of dietary supplementation of phytase were observed in layers, broilers, ducks, goose and pigs. Phytase supplementation in layers improved feed consumption, egg production and egg weights in birds fed low levels of available phosphorus compared to an unsupplemented treatment.

Until recently, phytic acid was considered primarily as a factor limiting phosphorus availability from plant-derived feedstuffs. Today, however, there is evidence that the deleterious effects of phytic acid go much beyond just limiting phosphorus availability. In its native stage, phytic acid is also complexed with various cations (Ca, Fe, Zn, Cu) protein and amino acids but also lipids and starch. Supplemental phytase has been shown to have the capacity to counter these anti-nutritional effects on protein and energy utilization.

Phytases are a group of enzymes that hydrolyze phytate to release phosphorus and other nutrients from the phytate complex. Phytases are widely found in different plant tissues or microorganisms. However, the activity of these phytases is highly variable and is influenced by several factors such as the pH value, temperature, moisture and substrate concentration or formulation technology used to stabilize the enzyme. In order to evaluate the efficacy of different phytase products, *in vitro* evaluations can give only an indication on the real effect of the enzyme in the intestinal tract of the animal. For a commercial evaluation of the value of a phytase product, the release of phosphorus and other nutrient has to be compared *in vivo* in the animal.

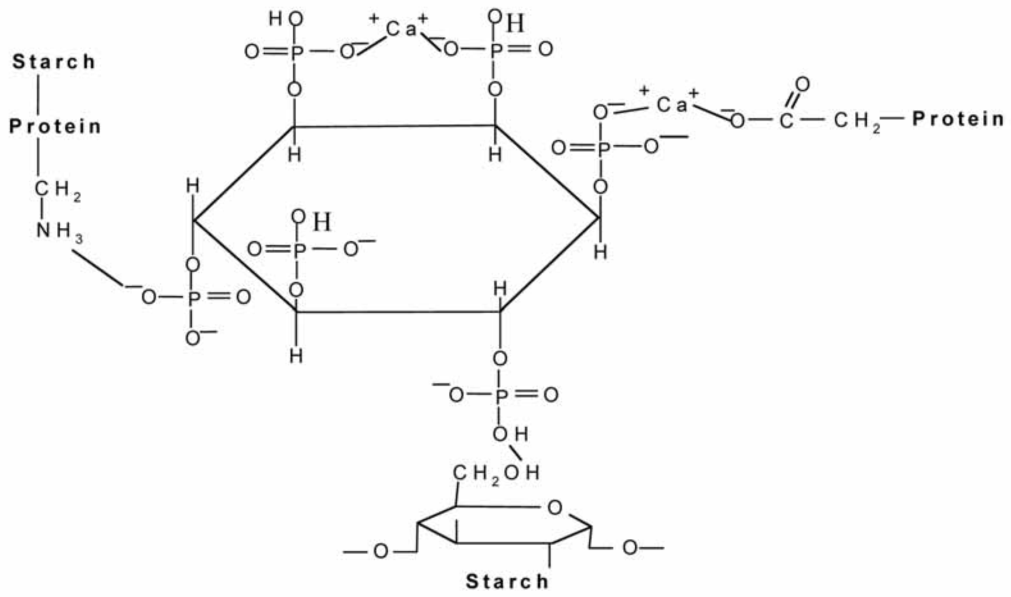
Phytic Acid: An Anti-nutritional Factor

In plant seeds about two-thirds of the phosphorus is stored as phytate (myo inositol hexakisphosphate). Phytates are binding mineral cations like Ca-Mg, K-Mg, Fe or Zn and form a poorly soluble complex. The main role of phytic acid in plant seeds is the storage of phosphorus, which is utilized during seed germination. Apart from minerals, phytic acid is also able to form complexes with proteins and amino acids. The amino group present on the side chain of amino acids is thought to be one of the main functional groups involved in protein-phytate interactions. Therefore, a significant proportion of amino acids that are frequently supplemented to poultry diets may complex with phytate. Such complexes decrease the digestibility of proteins and of supplemented amino acids. Figure 1 shows the possible interactions between phytic acid and different nutrients like phosphorus, calcium, trace elements and proteins.

The Use Of Phytase In Layer Diets

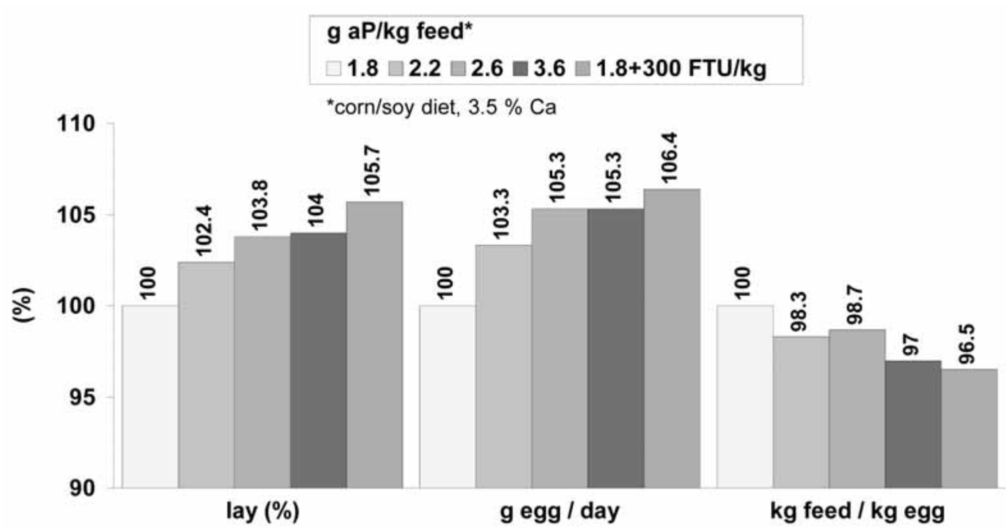
A correct determination of the efficacy of supplemented phytase in layer diets requires test diets, which are sufficiently low in phosphorus, so than an improvement in the phosphorus availability due to added phytase will be reflected in an improvement of performance criteria like laying percentage, egg weight, feed conversion ration or egg shell quality.

Figure 1. Possible interactions of phytic acid with minerals, protein and starch



An extensive layer trial was conducted by Vahl et al. in 1993 to demonstrate the effectiveness or microbial phytase in diets low in available phosphorus compared to a supplementation with inorganic phosphorus. A basal diet containing an available phophorus content of only 1.8g/ kg feed was supplemented with incremental levels of inorganic phosphorus (MCP) resulting in 2.2, 2.6 or 3.6 g of available phosphorus per kg of feed. The diet containing only 1.8 g of available phosphorus was supplemented with 300 units of microbial phytase (Natuphos). Performance parameters like laying percentage, gram egg per day, feed per hen and day, as well as feed per egg were determined over a period of 21 to 40 weeks of age. The results of the experiment are shown in Figure 2. Performance of the negative control containing only 1.8 g of available phosphorus was set 100% and all changes in performance either as a result of inorganic phophorus addition or phytase supplementation were expressed relative to the negative control. Laying percentage, gram egg per day as well as kg feed per kg egg were improved with addition of inorganic phosphorus to the negative control proving that the phosphorus level in the negative control was deficient for the laying birds. Available phosphorus levels higher than 2.6 g per kg of feed did not further improve layer performance. The supplementation

Figure 2. Effect of inorganic phosphorus and phytase on layer performance



of the diet deficient in available phosphorus with 300 units of phytase improved performance to a level even higher than the highest addition of inorganic phosphorus proving the 300 units of phytase can easily compensate for 0.8 available phosphorus. This conclusion can be made as the added phytase compensated for the difference between the negative control (1.8 g available phosphorus) and the treatment containing 2.6 g available phosphorus. A further increase in the available phosphorus level to 3.6 g per kg feed could not improve performance. Therefore other nutrients than only *(other than)* phosphorus are responsible for the additional performance effects in the phytase treatment.

Phytase is not only known to release phosphorus from the phytate complex, but also releases amino acids, protein and energy. Using digestibility measurements, these effects have been quantitied for phytase (valid for Natuphos only) and a matrix value sytem has been developed. This matrix value system allows to include phytase into least cost formulation. A layer experiment has been conducted at the University of the Philippines Los Banos in 2000 to evaluate the effect of microbial phytase in layers using the matrix value system for feed formulation. A commerial layer diet was used as the reference group. This commercial diet was reformulated using the matix value system developed for microbial phytase (Natuphos). The reformulated diet was supplemented with 300 phytase units. Table 1 shows the diet composition, the nutrient contents as well as the diets cost. Feed cost using the matrix values and microbial phytase were reduced significantly by US$6.

Performance was monitored from week 24 to week 35 and the results are summarized in Table 2. The results of this practical experiment show that phytase can improve the utilization of other nutrients besides phosphorus. The supplementation of a diet formulated with the matrix values developed for phytase (Natuphos only) kept performance at the same level as in a commercial layer feed, and at the same time, reducing feed cost by US$6.

Table 1. Composition, nutrient content and cost of layer feed

Ingrediets	Reference diet	Reformulated diet
Corn, 5	51.72	53.40
Soybean meal, %	25.11	24.32
Rice bran, %	10.00	10.72
Coconut oil, %	2.00	1.00
Biofos, %	1.49	1.01
Limestone powder, %	4.96	4.82
Limestone grits, %	4.00	4.00
Salt, %	0.30	0.30
Premix, %	0.20	0.20
Coline Chloride, %	0.10	0.10
Metheonine, %	0.08	0.08
Anti-mold, %	0.03	0.03
Anti-oxidant, %	0.01	0.01
Phytase	-	0.01
ME, kcal/kg	2800.00	2768.31
Crude protein, %	17.5	17.37
Calcium, %	3.61	3.48
Available phosphorus, %	0.44	0.34
Lysine, %	0.94	0.93
Methionine, %	0.38	0.37
Feed cost per t, USD	200	194

Table 2. Performance of layers fed either a commercial diet or a diets with reduced nutrient specificating supplemented with microbial phytase

Parameter	Commercial diet	Reduced nutrient specifications supplemented with phytase
Laying percentage	87.67	88.36
Egg weight, g	53.72	53.71
Feed Intake,g	105.39	104.18
FCR,g/g	2.24	2.19
Eggshell thickness	0.34	0.33

The Use Of Phytase In Duck Diets

The effectiveness of microbial phytase in laying hens has been demonstrated in a large number of experiments whereas the number of trial with ducks is less. The following example shows that phytase is a very effective tool in ducks too.

Table 3. Composition (%) and nutrient content of the diets

Treatment	Positive Control	Negative Control			
Phytase	**-**	**-**	**300 FTU**	**400 FTU**	**500 FTU**
Corn	49.4	49.6	49.6	49.6	49.6
Wheat bran	9.4	9.6	9.6	9.6	9.6
Soybean meal	27.1	25.1	25.1	25.1	25.1
Rapeseed meal	1.7	4.11	4.11	4.11	4.11
Fish meal	2.5	2.5	2.5	2.5	2.5
Premix	1	1	1	1	1
Dl methionine	0.05	0.05	0.05	0.05	0.05
Limestone	6.85	7.34	7.34	7.34	7.34
DCP	1.7	0.4	0.4	0.4	0.4
Salt	0.3	0.3	0.3	0.3	0.3
Phytase*	0	0	0.006	0.008	0.01
ME, kcal/kg	2650	2650	2650	2650	2650
Protein, %	19	19	19	19	19
Calcium, %	3.0	2.9	2.9	2.9	2.9
Phosphorus total, %	0.65	0.45	0.45	0.45	0.45
Lysine, %	0.92	0.92	0.92	0.92	0.92
Methionine, %0.34	0.34	0.34	0.34	0.34	
Meth + Cys, %	0.65	0.65	0.65	0.65	0.65

*Natuphos , BASF-AG, Germany

A total of 1200 Chinese Shaoxin ducks were housed in floor pens from 26 weeks of age up to 36 weeks of age. The dietary treatments included a positive control with a nutrient content representing a practical commercial situation and a negative control with a reduced specification for total phosphorus from 0.65% (positive control) down to 0.45%

(negative control). This phosphorus reduced diet was supplemented with incremental levels of phytase (300, 400 or 500 units/kg diet). The diets consisted mainly of corn, soybean meal, wheat bran and fishmeal. Details of the diet composition as well as the nutrient contents are shown in Table 3.

To evaluate the effects of a reduction of inorganic phosphorus and supplementation with microbial phytase, the parameters feed intake, egg production percentage, egg weight and feed conversion efficacy were determined. All data are summarized in Table 4. Neither reduction of phosphorus content of the diets nor the addition of microbial phytase effected feed intake of the laying ducks during the 10 week trial. Egg weight was not influenced by the treatments, with a tendency of lower egg weights in the group containing the low phosphorus content supplemented with 500 ulits/kg diet.

Egg production in the positive control group was 78.5% and was reduced to 74.5% in the negative control with lower phosphorus content. This indicates that the phosphorus supply was below the requirement of the ducks at this stage of production. Addition of phytase significantly increased egg production compared to the negative control at all dosages and also compared to the positive control group at addition rates of 400 units and 500 units/kg. Notice that the highest level of phytase supplementation (500 units) resulted in egg production which was 11 and 15 percentage points higher than the positive and negative control treatments respectively.

Feed conversion in the positive control was 3.49 kg/kg . Reduction of phosphorus content (negative control) tended to impair feed conversion ratio (3.58). Addition of 300 units of phytase/kg diet improved feed conversion compared to the negative control (3.39 vs.3.58). Compared to the positive control the addition of 400 units tended to improve feed conversion and 500 units resulted in a significant improvement in feed conversion, to 3.16.

Table 4. Feed intake and performance of laying ducks

Treatment	Positive Control	Negative Control				SEM	P
Phytase	**-**	**-**	**300 units**	**400 units**	**500 units**		
Feed Intake g/d	176.6	173.6	169.1	171.4	172.4	2.999	0.523
Egg Weight g	62.07	62.50	61.82	61.95	61.22	0.268	0.073
Egg Production %	78.6^{c}	74.5^{d}	80.7^{bc}	82.8^{b}	89.5^{a}	1.156	0.0001
FCR kg/kg	3.49^{ab}	3.58^{a}	3.39^{b}	3.25^{bc}	3.16^{c}	0.085	0.034

^{abc} *P<0.05*

The economic impact of replacing inorganic phosphorus (DCP) by supplementation with microbial phytase was evaluated by comparing costs of the commercial duck diet (positive control) with the diet reduced in DCP and supplemented with 500 units of phytase/kg. The treatment containing 500 units/kg was selected for this comparison because this level of phytase has shown the greatest beneficial effects with respect to laying performance and feed conversion ratio. Reduction of phosphorus content in the phytase supplemented group resulted in a replacement of 13 kg of DCP by only 100 g of microbial phytase. Other changes in the feed formula to make up the free space in the diet as a result of the replacement of 13 kg of DCP by 100 g of phytase had a further impact on the cost of the different feed formulas. The cost evaluation for all diet ingredients as influenced by the inclusion of phytase are shown in Table 5.

Table 5. Economic impact of phytase addition to a laying duck diet

	Positive control	Negative Control + 500FTU	Impact on costs (in USD)*
Corn %	49.4	49.6	-0.23
Wheat Bran %	9.4	9.6	-0.22
Soybean Meal %	27.1	25.1	+5.06
Rapeseed Meal %	1.7	4.11	-2.61
Limestone %	6.85	7.34	-0.06
DCP %	1.7	0.4	+2.61
Phytase %	0	0.01	-2.05
Net Savings (USD/t feed)			+2.62

** - increase in costs + savings*

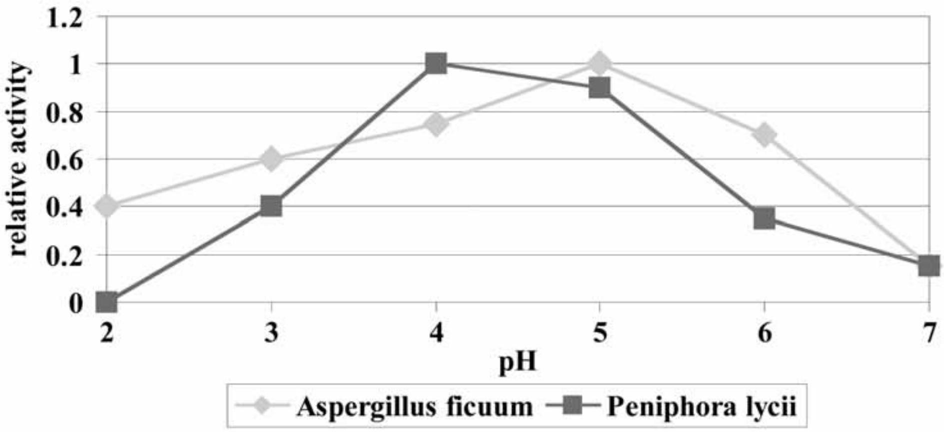
Adding extra corn, wheat bran and rapeseed meal to the diet adds cost whereas the reduced inclusion level of soybean meal saves costs. Reducing DCP affected not only the phosphorus level but also the calcium level of the diet. Therefore additional limestone has been added back to the diet to reach a calcium level which meets the requirement of the ducks. Overall this calculation shows that reduction of phosphorus level and supplementation with 500 units of phytase resulted in net cost savings of 2.6 USD per tonne feed in comparison with a commercial laying duck diet. Calculations, which take the higher egg production of the 500 units of phytase treatment into account, would result in even greater profits for phytase use.

The Efficiency Of Different Phytase Sources

Intensive research tests have shown that the fungus *Aspergillus ficuum* produces the highest phytase activity compare to other fungi. Phytase from *Aspergillus ficuum* is a so called 3-phytase as it starts its initial hydrolysis of phytate on the 3 position of the phytate ring. Recently a new phytase product has been introduced to the market, which is a phytase from *Peniphora lycii*. This phytase starts the hydrolization of the phytate ring on position number 6 instead of position 3. Consequently it can be assumed that the properties and the mode of action of both enzymes are quite different. In order to evaluate the efficacy of different phytase products in vitro evaluations can give only an indication on the real effect of the enzyme in the intestinal tract of the animal.

Besides the temperature optimum, the pH profile of an enzymes is the most important parameter to evaluate the efficiency of an enzyme under certain conditions. Figure 3 shows the relative phytase activity of two phytases. Pig or broiler feed normally has a pH value of around 6. In the stomach, the pH is reduced to a value between 2 and 3 by the secretion of HCl. At a low pH of about 3 *Aspergillus ficcuum* phytase has a 20 percentage points (0.6 vs.0.4) higher relative activity than *Peniphora lycii* phytase. At a higher pH of 6, which is relevant for the small intestine of pigs and the crop of poultry, *Aspergillus ficcum* again shows a higher activity than *Peniphora lycii* phytase.

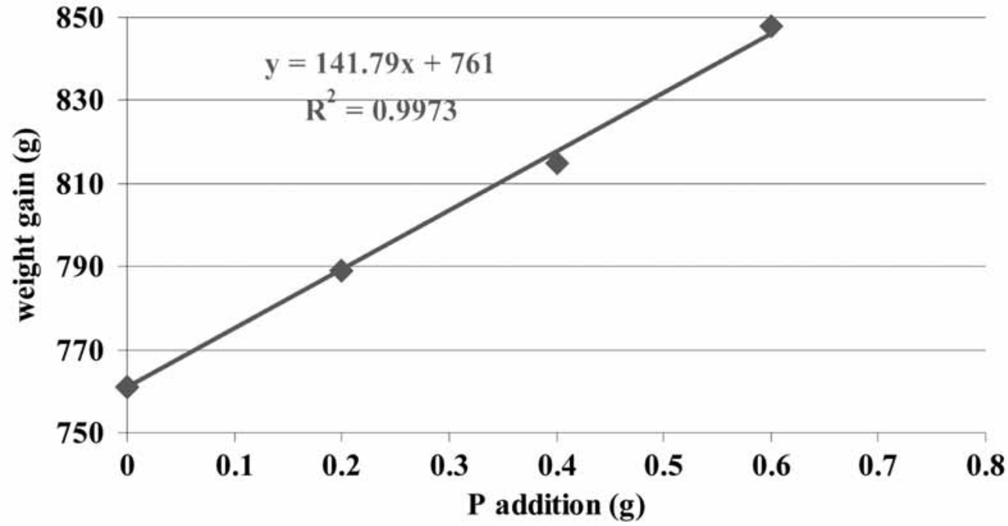
Figure 3. pH profile of Aspergillus ficcum and Peniphora lycii phytase



Although the parameter described above is of interest to characterize phytases, finally phytase has to work in the animal's digestive tract and has to be bio-effective in releasing nutrients. In the case of phytase, phosphorus is the target nutrient. The bio-efficacy of phytase compared to a standard phosphorus source can be measured in an animal trial measuring performance or bone parameters. A basic diet deficient in phosphorus is supplemented with graded amounts of monocalcium phosphate to establish a dose response curve and to calculate the response per unit of monocalcium phosphate added (see Figure 4). Likewise, the basal phosphorus deficient diet is supplemented with graded levels of the phytase sources (see Figure 5). A dose response curve can than be determined and the release of phosphorus compared to monocalcium phosphate can be calculated. A scientifically unacceptable approach to compare the efficacy of different phytases is to take a positive control with an adequate phosphorus level, reduce this phosphorus level by a set amount and measure the response on the addition of different phytases. This trial design can not determine the true release of phosphorus, as the adequacy of the phosphorus level relative to the needs of the animals is unknown. If diets are only marginally deficient in phosphorus the release of small amounts of phosphorus can restore the phosphorus adequacy and therefore differences in the efficacy of different products never will be detected.

In order to determine the bio-efficacy of the two phytase sources, a phosphorus deficient feed was used as a control diet. This phosphorus deficient diet (0.20 % of available phosphorus) was either supplemented with different amounts of phosphorus from MCP (0.2, 0.4 or 0.6 g phosphorus addition) or with increasing levels of each phytase (100, 200 or 300 phytase units/kg). Figure 4 shows the

Figure 4. Effect of inorganic phosphorus (MCP) in weight gain of broilers

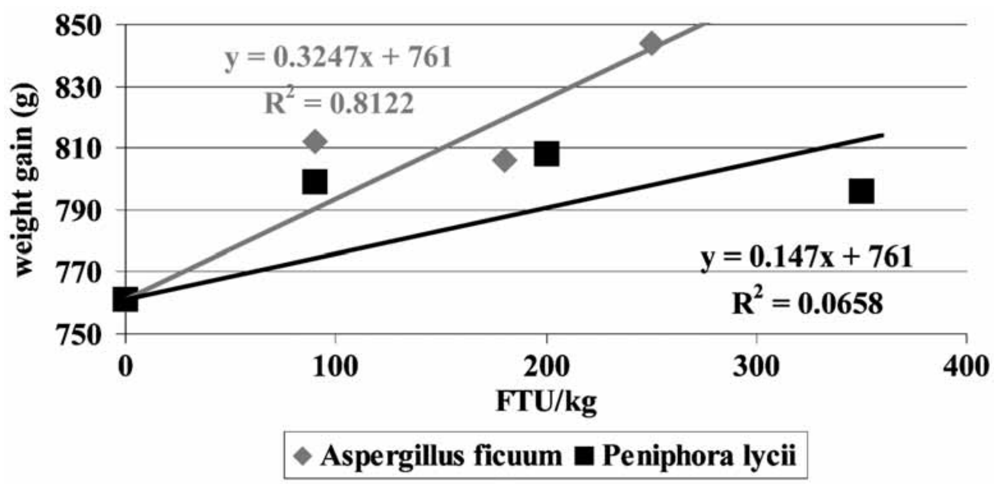


effect of increasing supplementation of inorganic phosphorus from MCP on weight gain of broilers. The regression equations shows that weight gain increased by 141.79 g with the addition of 1 g of available phosphorus from monocalcium phosphate. The correlation between weight gain and phosphorus addition was very close with a correlation coefficient of more than 99%.

In Figure 5, the effect of the supplementation with the three levels phytase from *Aspergillus ficuum* and *Peniphora lycii* on weight gain is shown together with the regression equations and the correlation coefficients. The best response in weight gain on phytase addition could be measured for *Aspergillu ficuum* phytase. Weight gain increased by 0.3247 g per phytase unit. When *Peniphora lycii* phytase was added to the phosphorus deficient basal diet, weight gain increased only by 0.1470 g per phytase unit.

The comparison of the response curves for the *Aspergillus ficuum* and *Peniphora lycii* supplementation show that more than double of the *Peniphora lycii* phytase has to be used to achieve the same weight gain as with *Aspergillus ficuum* phytase.

Figure 5. Effect of phytase supplementation on weight gain of broilers



Conclusion

Phytase has been studied extensively in laying hens, breeders and ducks to allow reliable conclusions about the release of phosphorus from phytic acid. It has been calculated from long term production trials as well as from direct measurements in the gastrointestinal tract that 300 units of phytase (only valid for Natuphos phytase from BASF) are equivalent to 1 g of phosphorus from MCP or 1.14 g of phosphorus from DCP. This replacement of inorganic phosphorus has a significant impact on the feed and production cost. The effects of phytase on the utilization of protein and energy are furthercontributing to the economical benefit of using phytase. These effects of microbial phytase on the utilization of protein, amino acids and energy have been quantified and summarized in a matrix value system. Using this matrix value system phytase can be used as a feed ingredient in least cost formulation reflecting the release of nutrients from the phytic acid complex. Practical performance trials have shown that microbial phytase is a very efficient tool to improve the profitability of feed and animal production as documented in the above described layer and duck trials.

For a complete evaluation of the value of phytase not only the effects on animal performance and feed cost but also the efficacy of different products have to be taken into consideration.

With respect to the efficiency of different phyases, the data presented above clearly prove that phytase derived from *Aspergillus ficuum* is more effective in hydrolizing phytic acid than phytase derived from *Peniphora lycii*. Broiler tests using formulated dry phytase products demonstrated that phytase produced with *Aspergillus ficuum* is 100% more effective than phytase produced with *Peniphora lycii*.

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Ingredient Quality And Performance

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In all livestock operations, the production performance depends very heavily on just how well the diet provided meets the nutritional requirements of the animals. There are many aspects of feed quality, feed manufacturing practice and feeding management that interact to secure success in this area but fundamental to the equation is the control of ingredient quality.

The whole effort of feed formulation becomes futile if the nutrient composition and integrity of raw materials is not as assumed in the computer matrix.

The stockfeed industry has long been frustrated by the time delay in wet chemistry analysis of feedstuffs with much of the received material being consumed before results are available. Bioassay of materials is not a practical method of routine raw materials assessment/grading on a day-to-day basis. Near infrared reflectance (NIR) has emerged as a "real time" method of evaluation but this too has its limitations.

The classical textbook tabulation of nutrient requirements of various animal species has been shown to be too insensitive to accommodate the needs of modern intensive livestock operations. The differentiation of requirements by age, sex, genetics, environmental conditions, different production systems, different market requirements, and dynamic market economics, has proven too complicated to the simple fixed nutrient requirements table approach. Most intensive livestock industries have developed simulation models which allow the definition of optimum nutrient supply levels for each specific production situation. The efficiency of the practical application of these recommendations however still depends on the accuracy of the descriptions we apply to the feedstuffs employed.

Ingredient quality has many aspects, some of which are discussed below,

Variation In Basic Proximate Analysis
[protein, fat, fibre, NFE (carbohydrates), minerals]

a) Protein
The protein content of grain is often discounted as being secondary to that of the protein meals. Yet in most diets the grain component supplies approximately one third to one half of the dietary protein. In the Australian context wheat is the dominant feed grain and each percentage unit of protein has a value of approximately A$4/tonne so it is important to specify this accurately. This is not only important from an economic stand point but also from an amino acid supply standpoint since protein increases generally involve a changing mix of proteins eg. a constant level of metabolic proteins (albumin and globulins of high essential amino acid content) and variable levels of the storage protein (gliadins and glutelins of low essential amino acid content). Hence the proportion of essential amino acids in the protein declines with rising protein control. These can be largely predicted from regression equations based on protein. Total and digestible amino acid levels in feedstuffs can be measured by NIR technologies but despite some very positive research (Jackson et al. 1996, Kempen and Boden 1998, Leeson 1997) commercial adoption has been limited due to concern with the errors involved with some feedstuffs. As more robust calibration sets are developed this technique will no doubt emerge as the most rapid and cost effective means of monitoring amino acid content in feedstuffs.

b) Fat/Oil
Variation in the fat content of feedstuffs (natural levels or residual levels following processing) and their fatty acid profiles profoundly influences the energy value, hence to achieve precise formulation, fat levels and composition need to be consistent or at least closely monitored.

c) Fibre And Other Carbohydrates
The available carbohydrate (starch and sugars) component of feedstuffs contributes positively to the energy value of the material while the crude fibre acts as a diluent and the non-starch polysaccharide fractions interfere with nutrient utilization. Since the negative effects of NSP's and oligiosaccharides can to some extent be countered with specific enzyme supplementation, the relative proportions of starch and fibre remains the major influence on the energy available to poultry from cereal grains (Black, 2001).

In a summary of feed grains in Australia Van Barneveld (1999) revealed a wide range in energy values (eg. DE/kg DM for pigs of 13.3 - 17.0 for wheat, 11.7 - 16.0 for barley, and AME for broilers of 10.4 - 15.9 for wheat, 10.4 -13.8 for barley and 8.6 - 16.6 for triticale). Most of the variance was explained by gross chemical composition. Prominent was the influence of total cellulose or faecal DE and total arabinoxylans on ileal DE.

d) Minerals
The trace mineral content of feedstuffs is notoriously variable and it is for this reason that the traditional approach to meeting trace mineral requirements has been to largely ignore their contribution and meet the known requirement by supplementation via the vitamin/mineral premix. However, with the mineral depletion of high performance breeding stock over time even when fed "adequate" diets by NRC standards (Mahan and Newton, 1995) and concern re the bioavailability of inorganic supplements (Close, 2000) there is now more interest in the base mineral contributions from feedstuffs, to make organic mineral supplementation more cost effective.

Anti-Nutritional Factors (ANF's)
Many feedstuffs contain inherent ANF's such as trypsin inhibitors, lectins, gossypol, amylase inhibitors, tannins, phytate, alkaloids, saponins, conglycinin, vicine, convicine, glucosinolates, arabinoxylans, B-glucans, oligosacchrides, etc. These all have the potential to cause nutritional disorders and impair performance. Their influence needs to be either deactivated by heat treatment, mineral binding, enzymic hydrolysis, etc and where this is not possible their levels need to be quantitated to allow appropriate formulation limits to be applied.

Weather Damage
Field crops such as cereal and grain legumes can be subject to weather damage in the growing phase (rain, flooding, hail, and frost). This can create shot and sprung, leached and pinched grain that can be markedly compromised in its feed value. In the initial stages of sprouting the hydrolysis of starch to sugars by endogenous enzymes in the sprung grain can actually enhance its feed value by improving the digestibility of starch. However, as the process proceeds to shooting, the nutrient content of the seed is consumed by the developing shoots and roots creating a drop in nutritional value.

Table 1. Site of energy digestion in pigs fed normal and frosted cereal grains

Parameter (MJ/kg as fed)	Wheat	Barley	Triticale
Normal grain			
Starch (g/kg)	60	55	59
Bulk density (kg/hl)	80.0	70.0	70.0
Ileal diet digestible energy	12.12	10.44	11.63
Faecal diet digestible energy	13.89	12.54	13.14
Ileal DE:Faecal DE	0.87	0.83	0.88
Frosted grain			
Starch (g/kg)	47	45	28
Bulk density (kg/hl)	61.6	38.5	44.4
Ileal diet digestible energy	9.93	5.81	7.88
Faecal diet digestible energy	13.87	10.64	12.57
Ileal DE:Faecal DE	0.72	0.55	0.63

In the case of frosted grain the seed development is often arrested at an immature stage leading to pinched, grain with reduced starch content and elevated NSP levels. Table 1 (from Van Barneveld and Edwards, 2001) demonstrates the drop in starch and bulk density in various grains due to frosting and the compromise to faecal and more dramatically ileal digestibility energy in pigs. Due to the absences of any significant hindgut activity in poultry the energy values for broilers, layers or ducks would parallel those for the ileal responses in pigs.

Moulds And Mycotoxins
These are a constant hazard in tropical climates. Feeds that are not intended for immediate use should be protected with an effective mould inhibitor. Materials of uncertain history should be considered as potentially hazardous and subjected to routine mycotoxin analysis. Any positive analysis should raise an alarm, as there are no safe levels of mycotoxins. The variable nature of their production

means that even the detection of minor levels could signal the presence of far greater problems due to sampling errors. Further to this it has been shown that many of the mycotoxins have synergistic activity in that small amounts of several mycotoxins each below the recognised threshold of toxic effects when activity alone, can result in severe performance depression when operating in combinations (Smith et al., 2000).

Contaminants

Much of the grain used in Asia is imported from other regions. Often it will have been treated with preserving compounds. It is therefore important that they be monitored for potentially hazardous residues such as organochlorides or organophosphates as well as illegal compounds such as DDT or even appropriate compounds at excessive rates.

Oxidative Degradation

The tropical climate is very conducive to oxidative degradation. Once this process initiates the climate will tend to accelerate its development. High fat components such as oils, full fat soya, rice-bran, meatmeal, fishmeal, as well as finished feeds are all vulnerable. Oxidative fats are known to reduce growth and feed efficiency via various mechanisms such as impaired gastrointestinal structure, liver damage, reduced immuno-incompetence, vitamin destruction, and lowered hematorcrits (Shermer et al., 1995).

Consequently antioxidant treatments of feeds not intended for immediate use is recommended. The use of Vitamin E as a natural antioxidant is both expensive and hazardous as a Vitamin E deficiency can quickly compound into an immuno-inadequate situation as well as other direct illnesses (eg encephalomalacia, transudative diathesis).

Putrifaction And Processing Of Animal Proteins

Camden et al (2000) conducted a survey of 20 meatmeal samples in New Zealand and recorded a range in AME from 5.75 to 12.33 MJ/kg DM, and a range of a true digestibility of essential amino acids from 26.7 to 88.8%. The AME and total amino acid value are indicative of the raw materials processed and hence the primary analysis of the meals (protein, fat and ash) while the amino acid digestibility variation is reflective of the processing conditions in different plants.

Biogenic amines form from the degradation of amino acids to their corresponding amines, usually due to bacterial spoilage. This can occur either prior to processing or in subsequent storage of the meal. Birds fed high levels of biogenic amines develop symptoms such as enlarged proventriculus, gizzard lining erosion, undigested food in the excreta and pathological changes in the gut mucosa, kidneys and liver. Den Brinken et al (1997) conducted a survey of 81 Australian meatmeal samples and found a wide range of putrescine, cadaverine and histamine up to a total of 558 mg/kg. Meatmeals and fishmeals traded in Asia can often spend a long time in storage so it is important that they be screened for oxidative or microbial damage.

Consequences Of Ingredient Quality Shortfalls

Where ingredient quality shortfalls are detected prior to feed manufacture the cost of the shortfall can be calculated by the cost of any remedial action eg. reformulation, supplementation, rejection and organisation of alternative supply, treatment or insurance strategy (eg. mycotoxin binder). These exercises tend to be far less expensive than the situation where the quality shortfall is undetected and is unwittingly incorporated into the feed and goes on to compromise livestock production or the market value of the produce.

These compromises come in many forms and have varying effects on profitability.

Some examples are discussed below,

Energy

Where metabolisable energy values are reduced due to shifts in the proportions of starch, fats, fibre and mineral content, or reduced digestibility of specific components due to NSP levels, inadequate processing, heat denaturation, etc. the primary effect is a compromise on feed conversion efficiency as the birds increase their intake to compensate. However, the flow-on effects can be more far reaching eg. increased faecal volume, wet droppings, protein:energy imbalance, reduced essential fatty acids depressing growth or egg size, etc.

Conversely where there is an energy overshoot due to elevated fat levels, intake may drop leading to a protein and mineral shortfall, compromising muscle growth, rate of lay, egg size, shell strength, and maybe inducing fatty liver problems.

The growing cycle of broilers is so tight that there is no time for compensatory growth if the birds suffer a setback due to inappropriate nutrition. The cost of the episode will be reflected in extended growing time, reduced average sale weight, increased variability and increased mortality. In layers any interruption to the laying curve can prove difficult to restore and hence a short-term interruption can result in extended depression of performance

In breeders, even if rate of lay is not affected subtle compromises to fertility, hatchability, egg size or shell integrity can prove very expensive. Due to the extended production cycle of layers and breeders and the need for persistence in lay and maximum egg quality, the issue of consistent feed quality is more critical in these birds.

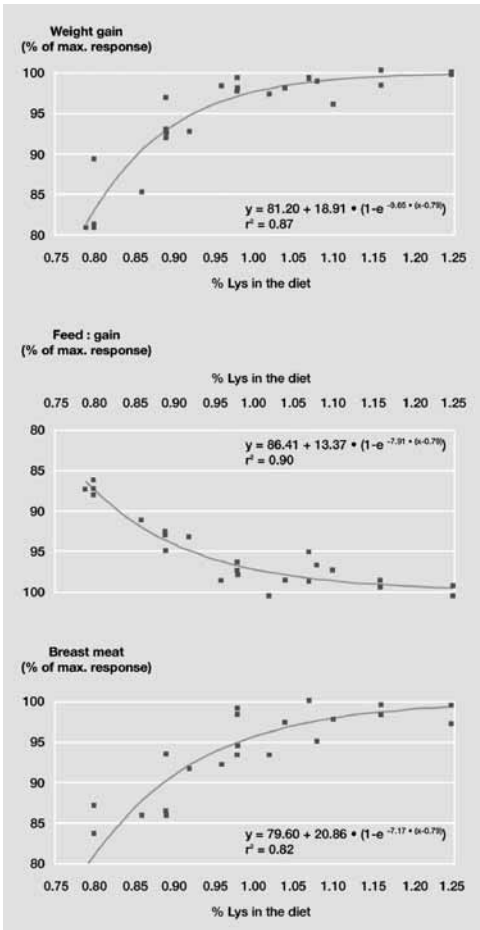
Protein

Amino acid responses in poultry have been extensively studied and generally involve curvilinear responses with increasing specific amino acid inputs up to a plateau. The economic optimisation of these curves varies with the parameter under study. For example the optimum lysine level in the diet for maximum growth, maximum efficiency, breast meat yield, rate of lay, egg size, etc may all be different. As the dietary adequacy falls back from the target due to shortfalls in total amino acid content, lower digestibility or bioavailability then assumed, antogonism/interference from phytate, NSP, amino acid imbalance, etc then each of the parameters will be progressively eroded, with increasing economic compromise.

Hoehler (2000) in a review of several publications demonstrated the nature of the responses to lysine and the descending sensitivity of breast meat yield, FCR and weight gain. (Figure 1) The commercial cost of these shortfalls in performance far exceeds the cost of adjusting the diet to restore lysine levels, if the compromise was identified prior to feed manufacture.

Attempts to optimise responses to amino acids will prove futile where there is no control over the amino acid contributions from specific raw materials.

Figure 1. Relative response in weight gain, feed to gain ratio and breast meat yield (% of live weight) to graded dietary lysine levels in broiler chickens from 20 - 40 days of age. (Hoelher, 2000)



Contaminants And Toxins

Toxic components in feeds such as mycotoxins, alkaloids, mineral excesses, and contra-indicated medications can have a profound and immediate effect on performance and profitability. However, of even greater concern is the risk of carcass or egg condemnation due to bruising or chemical residues (eg. antibiotics, dioxins, heavy metals, other hazardous chemical residues, etc.).

Bacterial contamination of feedstuffs also presents public health risks and any episode of food poisoning can seriously erode consumer confidence and depress sales volumes and prices for extended periods.

Quality Control In The Feedmill

This subject has been reviewed extensively in previous ASA Bulletins (Beggs, 1995 Mc Ellkiney, 1996 and Leslie, 1997) and the importance of this function cannot be over emphasised.

Quality control embraces the procedures in the feed milling process from ingredient receival to finished feed delivery, and the final result is dependent on all areas being managed satisfactorily. If control is lost early in the process due to poor or variable feed ingredient quality then subsequent efforts can prove futile no matter how diligently applied.

Various strategies have evolved to accommodate variability in raw materials. Some mills choose to increase the specification of the diet to ensure that minimum specifications are met but this can prove expensive. If data is available on the variance of individual ingredients then it is more appropriate to maintain normal dietary specs but reduce the nutrient levels of each ingredient by say 0.5 - 1.0 std. deviation. This then focuses the economic pressure in the least cost formulations on the more variable components, with little compromise to the consistent products, and with the same confidence of achieving the final diet specification.

Conclusion

In commercial poultry production it is essential to achieve consistent and uniform growth in growing birds and persistence in lay for layers and breeders. This requires that every batch of feed is right up to the mark in terms of quality and its ability to meet the nutrient requirements of the stock. Fundamental to this is control of the nutrient content and quality of ingredients employed. This alone will not ensure success as there are many downstream process of milling, mixing, pelleting, delivery, feeding out, bird health and shed management, etc that influence the final outcome but none of these downstream events can correct for initial shortfalls in ingredient quality.

When it comes to product quality, consistency from batch to batch, tight coefficients of variation on content and digestibility, high biological value, freedom from contaminants and mycotoxins, 48% US Soybeanmeal sets the standard.

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Importance Of Nutrient Levels And Variability In Feedstuffs

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Formulating to meet a specific set of nutrient requirements, in an attempt to ensure maximum performance of a particular class of poultry, is the aim of the poultry nutritionist. However, there are many factors to consider when formulating diets, and in feeding poultry, which would counter the belief of many producers, that purchasing a diet, calculated to meet the nutrient requirements of the birds in question, is a guarantee for a high performance flock.

Economic Considerations

The economics of production must always be a prime consideration and this is not always easy to evaluate as the most economical diets can be the most costly when considered on a per unit basis. People have tried to overcome this by looking at feed to gain or feed to product ratio. However, this approach does not consider feed costs, with the result that there is a move to look at cost to produce a unit of poultry meat or eggs, as the proper approach to evaluating diet performance. While such an approach goes some distance in the proper economic evaluation of a diet, with today's markets there is increasing pressure to look at yield of specific carcass parts when calculating the net worth of a diet.

Diet Evaluation

The greatest single cost of any poultry diet is providing nutrients to meet the energy needs of the bird. Since the requirement for energy far exceeds the requirement for any other dietary nutrient, the energy level of the diet is the main factor influencing feed intake. For this reason, most other dietary nutrients are required in relation to the energy level of the diet. This being the case, it is important that a fairly precise estimate of the energy content of a diet be made, if intake of other nutrients are going to meet calculated nutrient requirements of the animal.

While energy values of feed ingredients and diets can be measured by classical methods, with relatively good precision, such assays are time consuming and costly. Even the more rapid bio-assays for metabolizable energy developed by Farrell and Sibbald can take close to a week and are still costly.

Since cereal grains make up the majority of the dietary ingredients in most poultry diets, and account for a large portion of the energy, it is important to have reasonable, reliable estimates of their energy values. A similar situation exists for vegetable protein supplements, as they often make up the majority of the supplemental protein and thus they also make a significant contribution to the energy content of a diet.

There has been increased interest in using near infrared reflectance (NIRA) for evaluating the energy content of feedstuffs. NIRA is fast, requires no chemical reagents and is inexpensive after the initial capital costs for equipment. No sample preparation is necessary, other than grinding, and after calibrations are developed, little skill is required in producing reliable energy values. An example of the type of precision to expect is shown in Table 1, for ingredients, diets and several fat products.

Since fish and meat meals make up a relatively small fraction of the dietary energy, chemical methods are often used to give some measure of their energy value. For fish meals, protein levels correlate relatively well with ME values. However, this does not work well with meat meals due to their higher mineral content. Thus, ash values are a better estimator of the ME of meat meals.

Quality Control

Ingredients must be continually monitored to ensure consistency of nutrient profile and presence of contaminants. The frequency of assays will depend on class of ingredient, history of supplier and perhaps season of the year.

Table 1. NIRA predictions of vivo AME_n of ingredients and calculated AMEn of commercial diets

Ingredient	In vivo AME_n	NIRA AME_n
Corn	3380	3370
Soybean Meal	2340	2320
Wheat	3270	3230
Barley	2720	2670

Diets	Calculated AME_n	NIRA AME_n
Broiler Starter	3200	3320
Layer	2700	2900
Breeder	2870	2920

Valdes and Leeson, 1992

NIRA prediction of AMEn of fats and oils

	Determined AME_n	NIRA prediction
Canola Oil	9450	9450
Poultry/tallow	9510	9230
Poultry/soapstock	7800	8140
Tallow/soy/safflower	9600	9420

Valdes and Leeson, 1994

Table 2. Influence of autoclaving raw extracted soybean meal on protein solubility, urease activity and chick performance

Autoclaving time (min)	Weight gain (g/chick)	Protein solubility (%)	Urease activity (pH change)
0	342[d]	92.2	2.40
5	429[c]	87.7	2.04
10	481[b]	79.1	0.23
15	496[a]	74.9	0.00
20	450[bc]	71.8	0.00

Data from Araba and Dale, 1990

Table 3. Range in proximate composition for wheat by product samples (87% moisture)

Range	Protein (%)	Fat (%)	Crude Fiber (%)	NDF (%)	TMEn (kcal/kg)
Low	12.4	2.1	0.9	6.8	1663
High	23.8	6.9	13.2	41.2	3178
Average	15.3	3.3	6.4	27.5	2422

Selected data from Dale, 1996

For example, if fish meal is used extensively, and represents a significant proportion of dietary amino acids, then some check on protein quality should be made periodically and frequent screening for gizzard erosion factors carried out.

Some of the testing that is carried out is as follows.

a. bulk density - mainly for cereals
b. rapid NIRA (for ME, amino acids, minerals)
c. urease testing of soybean meal
d. protein solubility
e. gizzard erosion factor
f. tannins (sorghum)
g. gossypol (cottonseed meal)
h. fats - ME assay, moisture, iodine number
i. mineral solubility (limestone)

As reported by Araba and Dale (1990) in Table 2, soybean meal should be assayed for both trypsin inhibitor and protein solubility. Protein solubility values in excess of 85% or less than 70% indicate under or over processing of soybean meal respectively.

In a recent report of Lilburn (1996), a good review is given with regard to the variability in quality encountered with various fat, corn and protein supplements and the effect such differences can have on nutrient availability.

Ingredient Variability

Variability in feed ingredients can be quite marked when considering milling by-products. A good example of this is the report of Dale (1996) where he studied the ME of wheat by-products. Of 15 samples from various countries tested, the range in composition varied markedly (Table 3).

True metabolizable energy along with proximate analysis were conducted on the samples in an attempt to develop prediction equations for estimating energy values. Only crude fiber gave a significant correlation with TMEn.

eg. 1. TMEn (kcal/kg) = 3157-166(%CF)
R2=.67 (87% DM)

2. TMEn (kcal/kg) = 3497-39 (%NDF)
R2=.77 (87% DM)

From a search of the literature, 42 AMEn values from studies where CF was reported, were used to develop a prediction equation, as follows:

3. AMEn=3086-165(%CF)
   $R2=.77(87\%DM)$

Combining both data sets (57 observations):

*4. MEn=3182-161(%CF)
   $R2=.73(87\%DM)$

* Assuming TME and AME values equal

Equation 1, (TMEn values) obtained with adult cockerels, yielded higher values than did equation 3, which was derived from AMEn assays with young chicks.

It is not clear whether the variation is due to differences in methodology, age of the test animals or both. However, the negative factor associated with CF, (-165 for chicks versus 116 for adults) suggest that adult chickens might digest wheat by-products more efficiently. Thus equation 1 should be used for pullets and hens and equation 3 for young chicks and broilers.

The above demonstrates the marked variability that can be encountered by using average or book values for various ingredients which may vary widely depending on source and nomenclature. Developing prediction equations as shown above, and updating them with current analytical values, should provide a better estimate of the energy of ingredients then the use of published book values.

Table 4. ME of corn and wheat milled to different grinds and fed as mash or steamed crumbles to adult cockerels or chicks (MJ/kg DM)

Grind		Mash		Crumbles	
		Chicks	Cockerels	Chicks	Cockerels
		1		1	
Corn	Fine	15.30		15.52	
	Medium	15.32		15.50	
	Coarse	15.31		15.39	
	X	15.29[a]	15.32[a]	15.96[b]	14.98[c]
Wheat	Fine	13.63		13.84	
	Medium	13.54		14.27	
	Coarse	13.58		14.44	
	X	13.43[a]	13.71[b]	14.07[c]	14.28[c]

1 Average for chicks and cockerels
Selected and rearranged data of Farrell et al., 1983

Improving Nutrient Value

Grinding

Cereal grains are ground before being mixed in a diet to improve nutrient utilization as well as to ensure thorough mixing. There has been recent interest in investigating the energy input into grinding. It would appear that a marked saving in energy inputs can be achieved with a coarser grind, without any decrease in nutritive value of the cereal. This essentially confirms the earlier work of Farrell et al. (1983).

In Table 4 is shown the ME determinations of corn and wheat with different degrees of grinding and fed as mash or steamed crumble to chicks or cockerels. There were no significant differences in the energy value of the corn, depending on fineness of grind, or mash versus pellets. However, pelleting improved the energy content of wheat for both chicks and cockerels while the corn energy value was reduced for the adult birds.

Processing

There has been an increased interest in feed and ingredient processing during recent years in enhancing of processing can be divided into two categories;

a. Thermal
b. Non-thermal

Thermal can be divided into,

Dry heat:
- roasting
- popping
- micronizing

Wet heat:
- pelleting
- expanding
- extruding
- compacting
- steam flaking

Examples of non-thermal processing would include roller or hammermill grinding, blending or mixing of ingredients and feeding of whole cereals.

Steam Pelleting

The advantages of steam pelleting diets for poultry have been demonstrated on numerous occasions. With steam pelleting, heat, moisture and pressure are involved, all factors which are known to enhance chemical reactions. Thus besides a positive physical effect of pelleting there are also chemical effects which enhance the feeding value of a diet. This is demonstrated in Table 5 where a sample of corn and wheat bran were steam pelleted and then reground to mash. The above ingredients, along with similar samples of regular bran and corn, were mixed 50:50 with a corn, soybean meal basal diet. These diets were then fed as mash, as dry-pellets (pelleted in a small dry pelleting machine), or as regular commercial steam pellets. Since the diets were fed to young White Leghorn cockerels the pellets were reduced to crumbles for feeding. Dry pelleting the wheat bran (a physical change) resulted in a marked improvement in weight gain, but no change in ME of the bran, while steam pelleting (a physical and chemical change), gave a further increase in weight gain and a marked improvement in the ME value of bran (Table 5). The processed wheat bran further increased the ME value of the bran, especially for the double steam-pelleted treatment. Dry and steam-pelleting the corn diet also gave a response in weight gain, however, with the processed corn diets the mash and dry pelleted diets did not alter weight gain while birds fed the double steam pelleted diet showed a marked reduction in weight gain. Such an effect is obviously due to too much heat being applied to this diet with the possible tying up of lysine. The ME of the test corn was little affected by pelleting treatment.

Table 5. Effect of dry and steam-pelleting on the performance of chicks fed wheat bran or corn diets

Diets	Unprocessed[1]	Processed[2]	Unprocessed	Processed
	Average weight (g)		Metabolizable energy for test material (kcal/g)	
Bran				
Mash	164	259	1.46	1.70
Dry-pelleted	288	296	1.48	1.85
Steam-pelleted	303	294	2.05	2.50
Corn				
Mash	231	248	3.45	3.51
Dry-pelleted	258	269	3.58	3.55
Steam-pelleted	314	183	3.61	3.61

[1] The 50% aded test material was regular corn and bran.
[2] The added test materials had been steam pelleted and reground.
Selected data of Summers et al. (1967)

Steam pelleting has also been shown to increase the available phosphorus in a diet. This is especially true for diets high in organic phosphorus. As can be seen in Table 6, steam pelleting a diet containing wheat bran was as effective as adding additional inorganic phosphorus to the diet.

Table 6. Effect of steam pelleting on phosphorus utilization

Treatment	Av. wt (g)	Bone ash (%)
Mash		
Basal*	157	30.2
Basal + .28% In. P	172	40.4
Steam crumbles		
Basal	205	38.8
Basal + .28% in. P	206	42.5

**Basal contained corn, soya, pus 25% of wheat bran calculated to contain .18% Av. P*
Selected data from Summers et al., 1967

Work has been undertaken recently in evaluating the effects of further feed processing procedures. A good review of this work can be found in the report of Behnke (1996). Examples of some of the results reported are shown in Table 7.

Table 7. A comparison of steam pelleted and expanded - pelleted diets

Pelleted durability index		
Pelleted	55.4	
Expanded-pelleted	80.3	
Live performance of broilers		
	Av. wt (lbs)	Feed:gain
Pelleted	4.55	4.66
Expanded-pelleted	1.74	1.73

From Behnke, 1996

In general, it can be concluded that thermal processing;
a. decreases feed wastage
b. improves performance due to less ingredient separation and picking over of diet
c. less energy expended in eating
d. improves palatability
e. increases feed intake

Diet Variability

Many of the further thermal processes which are designed to improve pellet quality, result in less variability in nutritive value as well as physical form of the diet, thus enhancing diet performance, as well as increasing pellet output.

Enzyme supplementation has also been reported to significantly reduce the variability between wheat and barley samples as well as improving their nutritive value.

Conclusions

There is no question but that marked variability can occur in nutrient levels in various feedstuffs thus resulting in similar variability in diet quality. Realizing that such is the case, the nutritionist must take care not to blindly use "book values" for ingredients varying widely in source of origin and processing and handling procedures.

It is essential that the quality of ingredients from various suppliers be monitored as consistency of product is important in ensuring consistency in diet quality.

While it is essential that chemical analyses and biological assays be conducted on ingredients, from time to time, one of the best measures of diet quality the nutritionist has available to him is to monitor the performance of the flocks fed. Increased feed consumption, with similar product output, suggests that energy content of the diet is low. While a reduction in weight gain, along with a decrease in feed:gain ratio, suggests that protein level or quality could be a problem.

More attention to ingredient supply and flock performance and less concern about ingredient costs usually results in reduced cost per unit of product produced.

There are a number of ways to enhance diet quality in spite of ingredient variability. This is an area that the nutritionist must spend more time pursuing as ingredient costs continue to escalate.

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Use Of True Ileal Digestible Amino Acids In Feed Formulation

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Introduction

The task of commercial nutritionists is to meet the nutrient requirements of animals through judiciously selecting and mixing several ingredients, in a most economical, ethical, and environmentally friendly way.

The nutrient requirements of an animal vary depending not only on its biological parameters such as genetic potentials, sex, and growth and reproductive stages, but also on performance parameters that are examined. For example, it is known that a higher dietary methionine content is needed to maximize breast meat yield than body weight for broiler chickens. Although variable and complicated, the nutrient requirements of an animal under given conditions have been extensively investigated and relatively well documented (see, for example, NRC, 1994).

A much greater challenge for a commercial nutritionist, however, is to meet the nutrient requirements of an animal through feed formulation. The problem is with the assessment of true feeding value of feed ingredients. It is a fact that all nutrients in a feed ingredient are not available for utilization by the animal. On the other hand, only those nutrients that can be digested, absorbed, and metabolized (utilized) by the animal for maintenance, growth, and/or reproduction, represent the true feeding value of that ingredient. This portion of nutrients are called available nutrients, and in the case of amino acids (AA), the available AA. Amino acid availability varies not only among different types of feed ingredients, but also among different sources and loads of the same ingredient. Because of this variation in AA availability among various ingredients, the total AA content of a feed or an ingredient is, in a sense, of little relevance to meeting the AA requirements of an animal. When formulating feeds using total AA, nutritionists have to rely on subjective techniques such as using a large safety margin and/or using minimum/maximum limitations to exclude or restrict the use of some ingredients that are known to have low or variable AA digestibility coefficients.

Ideally, nutritionists should be able to evaluate feed ingredients and to formulate feeds using available AA. Amino acid availability is a function of digestion, absorption, and utilization. It can be determined by the growth assay. For example, Batterham (1992) used the slope ratio technique to measure AA availability in pigs. This technique offers a more precise estimation of the true feeding value of a feed than other methods. This technique, however, is very expensive and time consuming. So far, only a few ingredients have been evaluated by this method. It is at present impossible to formulate feeds based on available AA.

The true ileal digestible AA offer a compromise between the more or less irrelevant total AA and the trouble of measuring available AA. The aim of this presentation is firstly to evaluate the feed formulation technique using either total or digestible AA, and secondly, to discuss how to use digestible AA in commercial feed formulation. Before evaluating the formulation technique, it is worthwhile to review the concept and measurement of true ileal digestible AA.

True Ileal Digestibility: Concept, Measurement, And Database

The term "true ileal digestibility" of amino acids comprehends three basic concepts in animal nutrition. When a feed/ingredient is consumed, the first tax imposed is represented by that is not digested and is excreted in the feces. This effect is measured by apparent digestibility:

$$\text{Apparent Digestibility \%} = (\text{Ingested AA} - \text{Excreted AA}) \times 100 / \text{Ingested AA}$$

There are at least two factors that affect the effectiveness of using the apparent digestibility for the estimation of AA absorption. Firstly, AA are absorbed only in the small intestine, and microbial activities in the hind gut or ceaca change the profile and the amount of amino acids passing through the hind gut or ceaca. This leads to erroneous estimation of AA absorption. To correct this error, AA excretion should be measured at the end of ileum. To measure ileal digestibility, the animals must be surgically modified. In chickens, the caeca are removed (caecetomized), and in pigs, the large intestine is by-passed using the ileo-rectal shunt. This correction yields the ileal digestibility.

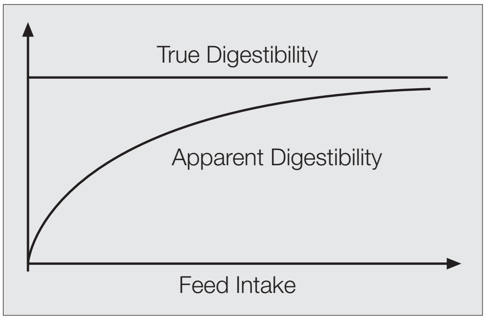
Ileal Digestibility % = (Ingested AA - Excreted AA @ end of ileum) x 100 / Ingested AA

The second factor contributing to the inaccuracy of AA apparent digestibility is the fact that all AA reaching the end of ileum are not of the feed origin. The secretion of digestive enzymes and mucus, and the turn-over of gut wall cells contribute to the AA pool at the end of the ileum. These AA are called endogenous AA. Without correction of these endogenous AA, the apparent AA digestibility would be affected by the amount of feed or ingredient used in the digestibility assay. The so-called "True Ileal Digestibility" is thus obtained by correcting the apparent ileal digestibility with the endogenous AA. True Ileal Digestibility of AA is not affected by feed intake (see Figure 1).

True Ileal Digestibility % =
(Ingested AA - (Excreted AA - Endogenous AA @ end of ileum) x 100 / Ingested AA

For the determination of true ileal digestibility, the method developed by Sibbald (1976) for True Metabolizable Energy (TME) and later extended for AA digestibility by Likuski and Dorrell (1978) was adapted by various groups (Rhone Poulenc Animal Nutrition, 1993; NRC, 1994). Basically, caecectomised cockerels are fasted for 24 to 48 hours before being fed the test materials. During this preliminary period, they are only fed 50 g/bird of glucose through the drinking water to minimize the catabolism of amino acids for energy purpose. Following the fasting, the birds are force fed 50 g of the test feedstuff. Excreta are collected for 48 hours after the force feeding. The excreta are pooled and freeze dried. After separation of uric acid from the excreta, the nitrogen and amino acid content of excreta is determined. The endogenous AA excretion is estimated by feeding a nitrogen-free diet (Rhone Poulenc Animal Nutrition, 1993).

Figure 1. Effect of quantity of ingested feed on true and apparent AA digestibility coefficients



A large number of data have been generated using this technique during the past 15 years, and the results agree reasonably well among different laboratories. The primary sources of digestibility data include Sibbald (1986), Parsons (1990a), and Rhone Poulenc Animal Nutrition (1993).

Advantages Of Using True Digestible Amino Acids

The true ileal digestible amino acids can be used by nutritionists in at least two ways to improve their feed formulation as well as the bottom line of economical returns. Compared to total AA, digestible AA allows nutritionists to more objectively evaluate and select feed ingredients. Furthermore, the use of digestible AA enables nutritionists to formulate feeds using a wider range of feed ingredients, to better match the nutrient requirements of the animal, and to lower feed cost.

Using Digestible AA To Evaluate Feed Ingredients

Some important information can be obtained by simply examining the digestibility data. Table 1 listed the mean and coefficient of variation (CV) of the digestibility coefficients of three most important AA for some major ingredients used in poultry feeds (Rhone Poulenc Animal Nutrition, 1993). In general, methionine (Met) has the highest digestibility, followed by lysine (Lys), while Cystine (Cys) is the least digestible. In terms of mean digestibility, major cereals (corn, wheat, barley) have quite consistent and high values (>80%) for all three AA examined. The digestibility of oilseed meals differ greatly among different types with the lowest values observed for cottonseed meal and the highest for high protein soybean meal. The variety of the oilseed affects AA digestibility. The double-zero rapeseed (canola) meal has significantly higher AA digestibilities than the single-zero rapeseed meal. Processing technique also affects AA digestibility. The high protein soybean meal (46-48%) has higher AA digestibilities than the 44% meal, most likely due to a reduction in crude fiber content. The AA digestibilities of animal meals differ greatly among different types of meals, being highest for fish meal, followed by meat and bone meal, and lowest for hydrolyzed feather meal.

The other set of numbers deserving attention is the CV values listed in Table 1. The CV values indicate how consistent of the AA digestibility of different sources or loads of an ingredient. The lower the CV value is, the more consistent a feed ingredient is in its AA digestibility, and the higher the true feeding value. Again, major cereals have relatively lower CV values (<6%) in AA digestibility. Oilseed meals show a low to medium CV in AA digestibility, with cottenseed meal shows the highest variation, followed by single-zero rapeseed meal and sunflower meal, and the soybean meal the lowest CV among oilseed meals. Fish meal has acceptable CV, while meat and bone meal and particularly feather meal are quite variable in AA digestibility. As a result, when these animal by-products are used in feed production, special attention should be paid to evaluate their AA digestibility.

Table 1. Mean and coefficient of variation (CV, %) of AA true digestibility coefficients (%)

	Lysine		Methionine		Cystine	
	Mean	CV	Mean	CV	Mean	CV
Grain						
Wheat	82.9	2.6	89.1	1.6	87.8	4.3
Corn (maize)	82.4	6.2	92.6	2.1	81.5	5.3
Oilseed meals						
Cottenseed	59.6	9.5	78.1	2.7	52.1	15.1
Rapeseed -0-	68.0	4.6	86.8	2.7	60.1	7.9
Rapeseed -00-	79.9	4.0	90.9	2.9	81.9	4.4
Sunflower	86.3	6.2	93.6	1.3	79.1	8.0
Soybean 44	86.8	2.9	88.7	3.4	78.7	2.6
Soybean 46 / 48	89.4	1.9	91.1	2.8	84.0	6.8
Animal meals						
Fish	84.8	2.4	89.8	0.8	79.1	6.7
Feather	61.9	9.8	66.8	16.8	53.4	12.8
Meat and bone	78.2	8.2	83.8	6.1	54.7	21.0

The use of digestible AA also enables nutritionists to evaluate feed ingredients more objectively and precisely than using total AA. Take sorghum as an example. Table 2 listed total AA and true digestibility of two sorghum samples, one with less than 0.5% tanins while the other has more than 0.5% (Rhone Poulenc Animal Nutrition, 1993). The two had the same total AA contents. Therefore, if evaluated using total AA, the two sample would have the same feeding values. But the low tanin sorghum sample has AA digestibilities of 80 to 92%, while the high tanin sorghum has AA digestibilities of 64 to 79%. Apparently the low tanin sorghum offers a much higher feeding value than the high tanin sorghum does. This difference is only becoming apparent when using digestible AA.

Table 2. True digestibility coefficients of sorghum grains differing in tanin contents

Nutrient	Content %	True Digestibility Coefficients, %	
		Tanin < 0.5%	Tanin > 0.5%
Protein	9.5	92	64
Lysine	0.23	92	79
Methionine	0.15	92	74
Cystine	0.19	80	67

In addition, nutritionists can use the digestible AA data to assign shadow prices to alternative ingredients so that the shadow prices more closely reflect the true feeding values. As shown in Table 3, for instance, the shadow price of rapeseed meal would be 72 and 66% of that of soy 48 if evaluated using crude protein and total lysine contents, respectively. Based on digestible lysine, however, the feeding value and thus the shadow price of rapeseed meal should only be 51% of that of soy 48 due to a much lower lysine digestibility in rapeseed meal. Therefore, using crude protein and/or total AA content would over-estimate the feeding value and shadow price of rapeseed meal.

Table 3. Estimating the shadow price of rapeseed meal based on protein, total, or digestible AA

	Soya 48 (%)	Rapeseed (%)	Relative Feeding Value (%)	Shadow Price (US$/t)
Crude Protein	49.0	35.5	72	254
Total Lysine	3.07	2.03	66	231
Lys. Digestibility	89	68		
Digest. Lys	2.73	1.38	51	177

Adapted from Rhone Poulenc Animal Nutrition, 1993. Assuming price of soya 48 to be US$350/tone.

Formulating Feed Using Digestible Vs Total Amino Acids

Most commercial feeds formulated on total AA basis have a large safety margin, say 5 to 10%, in order to minimise the variation in nutrient content and animal performance. As a result, the impact of formulating using either digestible or total AA on animal performance is easier to be demonstrated with AA deficient diets, or with poorly digested ingredients.

As lysine is the most variable AA in terms of digestibility, a broiler experiment was done using lysine deficient diets (Uzu, 1985). Two sets of broiler feeds were formulated to contain 0.75% lysine based on either total or digestible lysine. The test was carried out using broilers from 21 to 42 days of age. Soybean meal, sunflower meal or rapeseed meal was used as the main source of protein and synthetic lysine was used to equalise the lysine content when formulating on digestible AA.

Table 4. Effects of formulating on total vs digestible lysine on broiler performance (21-42 days)

Meal Type	Total lysine : 0.75%			Digest. lysine: 0.75%	
	Weight gain, g	FCR	Digest. Lys. %	Weight gain, g	FCR
Soybean	837 (100)	2.18 (100)	0.70	863 (100)	2.11 (100)
Sunflower	761 (91)	2.30 (106)	0.64	871 (101)	2.06 (98)
Rapeseed	602 (72)	2.36 (108)	0.60	769 (89)	2.12 (100)

Note: those in brackets are relative values using values with soybean meal as 100%.

With feed formulated on total lysine, growth and feed efficiency of broilers were greatly reduced when soybean meal was replaced by sunflower or rapeseed meals (Table 4). On digestible AA basis, replacement of soybean meal by sunflower meal did not reduce performance. Replacement of soybean meal by rapeseed meal reduced weight gain but did not affect feed efficiency. However, the reduction in weight gain was lower (11% versus 28%) with the digestible AA formulation than with the total AA formulation.

With practical diets, such an effect of formulating technique on performance can be observed more easily with poorly digested ingredients. Two separate broiler studies have recently been published.

Table 5. Chick performance fed cottonseed or soybean meal-containing diets formulated on total or digestible AA (Fernandez et al., 1995)

Formulation Method	Cottenseed Meal, %	Weight Gain g	Weight Gain (% Control)	FCR	FCR (% Control)
Control	0	271^a	(100)	1.52^a	(100)
Total AA	5	270^a	(100)	1.52^a	(100)
	10	271^a	(100)	1.49^a	(98)
	15	267^a	(99)	1.54^a	(101)
	20	252^b	(93)	1.63^b	(107)
Digestible AA	5	270^a	(100)	1.51^a	(99)
	10	275^a	(101)	1.51^a	(99)
	15	275^a	(101)	1.51^a	(99)
	20	272^a	(100)	1.52^a	(99)

$^{a, b}$ Values within a column without similar letters differ significantly at P<0.05.

Fernandez et al. (1995) recently compared the two formulation techniques using cottonseed meal. The adverse effect of gossypol in cottenseed meal was minimised by the addition of FeSO4 (1:1 Fe to free gossypol). As shown in Table 5, with total AA formulation, the growth and feed conversion efficiency were reduced when cottenseed meal was included at 15% and particularly at 20% level. Using digestible AA, cottonseed meal could be used up to 20% in broiler diets without affecting the performance. For inclusion levels higher than 20%, however, adverse effects on growth and feed efficiency were observed despite formulating feeds on digestible AA.

Table 6. Performance of male broilers (1 to 42 days) fed three diets differing in total and digestible amino acids (Rostagno et al., 1995)

	Diet A (high Dig.)		Diet B (low Dig.)		Diet C (B + Lys & Met)	
Calculated analysis, %	Starter	Grower	Starter	Grower	Starter	Grower
Crude protein	22.8	20.7	22.1	20.2	22.1	20.2
Total lysine	1.12	1.00	1.12	1.00	1.17	1.05
Dig. lysine	1.02	0.90	0.97	0.85	1.02	0.90
Total Met+Cys	0.90	0.80	0.90	0.80	0.94	0.84
Dig. Met+Cys	0.81	0.71	0.77	0.67	0.81	0.71
Performance 1-42 days of age						
Weight gain, g	2333 ^{a}		2241 ^{b}		2330 ^{a}	
Feed/gain	1.786 ^{a}		1.848 ^{b}		1.799 ^{a}	
Carcass, %	72.4 ^{a}		72.4 ^{a}		72.6 ^{a}	
Breast, %	30.1 ^{a}		29.0 ^{c}		29.6 ^{b}	
Feed Cost Analysis						
US$/kg bird	0.383		0.375		0.370	
US$/kg carcass	0.529		0.518		0.510	
US$/kg Breast	1.759		1.785		1.722	

$^{a-c}$ Values within a row without similar letters differ significantly at P<0.05.

Rostagno et al (1995) fed three sets of diets to male broilers for 6 weeks. The Control (Diet A) was corn-soya based with high AA digestibility. Diet B was formulated to contain the same levels of total AA as those of Diet A but included by-products such as rice bran, meat & bone meal, poultry by-products, and feather meal. Diet B thus had lower digestible AA. Diet C was similar to Diet B but supplemented with synthetic lysine and methionine to the same levels of digestible lysine and methionine of Diet A (Table 6).

As shown in Table 6, formulating on total AA using low digestible ingredients (Diet B) significantly reduced weight gain, feed conversion efficiency, and breast meat yield. Supplementing Diet B with synthetic lysine and methionine (Diet C) improved the live performance to the same level as achieved with Diet A, although breast yield was still slightly lower. In terms of cost ratios, Diet A resulted in the highest feed costs per kg live weight or per kg carcass weight, and Diet B the highest feed cost per kg breast meat. Diet C generated the lowest feed costs for all three parameters examined. These results demonstrated that the performance of poultry could be maintained and the profitability of poultry production improved by including low digestible ingredients such as cereal and animal by-products, if the diets are formulated based on digestible rather than total AA.

The same effects of formulating on digestible AA on performance were also demonstrated in laying hens by Bougon and Joly (1990).

In summary, the use of true digestible instead of total AA enables nutritionists to evaluate and select feed ingredients more objectively, to use a wider range of ingredients such as by-products in feed formulation, to formulate feeds that meet the nutrient requirements of animals better, and to improve the profitability of poultry operation. In addition, when formulating diets based on digestible AA, the crude protein content of diets could often be reduced by using synthetic amino acids without affecting the performance. This reduction in dietary crude protein may lead to a decrease in nitrogen excretion, which in turn, will improve the welfare of the animal (better litter and air quality) and reduce nitrogen-related pollution problem.

The Application Of True Digestible AA In Feed Formulation

There are three questions that have to be addressed before using digestible AA to formulate feeds. Firstly, the additivity of digestibility coefficients of various ingredients has to be demonstrated. Furthermore, a database of digestible AA contents of all ingredients that are used in the feed formulation has to be established. Finally, the nutrient requirements of animals have to be expressed in digestible amino acids.

Additivity Of AA Digestibility Coefficients

The additivity of the digestibility coefficients can be demonstrated by comparing the determined AA digestibilities of practical feeds to those calculated based on coefficients of individual ingredients.

Table 7. Calculated and determined digestibility coefficients of practical poultry feeds

	Number	Determined		Calculated	
		Average	Std	Average	Std
Lysine	15	84.4	2.8	86.7	2.4
Methionine	15	92.7	2.1	93.8	1.5
Cystine	15	80.9	5.8	80.2	3.1
Methionine + cystine	15	87.1	3.1	88.0	2.1
Threonine	15	85.3	2.6	85.5	2.0
Tryptophan	6	87.4	3.6	83.7	1.5
Arginine	15	89.7	2.5	92.4	1.4

A number of feeds were tested in Rhône-Poulenc laboratory, based on ingredients currently used in the feed industry at usual inclusion rates (Rhone Poulenc Animal Nutrition, 1993). As shown in Table 7, there was in general an agreement between the determined and calculated digestibility coefficients, although the determined coefficients were often slightly lower than those calculated, with a larger variability.

Establishing Ingredient Database Of Digestible AA

It would be cost prohibitive to build an ingredient database on digestible amino acids from scratch. Instead, the digestibility coefficients published by major laboratories could be used to convert the database of total AA to digestible AA. As mentioned before, the three major sources of this information are Sibbald (1986), Parsons (1990a), and Rhone Poulenc Animal Nutrition (1993), and the results agree reasonably well among these major sources. The work on true digestible energy and AA in Sibbald's laboratory had been discontinued. Parsons at University of Illinois, Rhone Poulenc Animal Nutrition in France, and a few other labs, are still actively involved in determining true AA digestibility of ingredients. Therefore, the digestibility of any new and specialty ingredients can be determined when needed.

Establishing Nutrient Requirements In Digestible AA

This is a challenging area because the AA requirements of animals are reported in most cases (e.g., NRC, 1994) in total instead of digestible AA. So far, two approaches have been reported to solve this problem, i.e., direct determination and indirect estimation.

The digestible AA requirements of an animal can be directly determined by growth assay using diets containing graded levels of the digestible AA to be examined. Rhone Poulenc Animal Nutrition (Dalibard and Paillard, 1995) had carried out several such tests to determine the digestible lysine and digestible sulphur AA requirements of broiler chickens during various growing periods. In one of such tests, for example, the requirements of broilers for digestible sulphur AA were found to be 0.81% and 0.77%, for body weight gain and for feed conversion efficiency, respectively, during the first three weeks of age. Han and Baker (1994) reported the digestible lysine requirement of male and female broiler chickens during the period of three to six weeks of age.

Alternatively, the digestible AA requirements can be estimated indirectly by applying the AA digestibility coefficients to the total AA requirements reported in various sources. Parsons (1990b) re-evaluated 28 published studies on the lysine and sulphur AA requirements of broilers, turkeys, and laying hens. Firstly, using the AA digestibility coefficients, he calculated the digestible AA contents of the basal feed ingredients used in the requirement studies. Then he added the calculated digestible AA to the amount of supplemental crystalline AA (assumed to be 100% available) to derive the digestible AA requirements. He found that the results were consistent for the 28 studies reviewed. The digestible AA requirements were 8 to 10% lower than the determined total AA requirements. Similar efforts have also been taken by Rhone Poulenc Animal Nutrition (1993). The digestible AA requirements of various animal species were estimated by applying the digestibility coefficients of feed ingredients to total AA requirements.

Table 8. Comparison of digestible AA requirements estimated from growth test or derived from digestibility coefficients

	From Growth Test		From Digest. coefficients
Lysine	Weight Gain	Feed/gain	
1-21 days	1.25	1.03	0.99
8-28 days	0.97	0.89	0.96
20-41 days	0.89	0.92	0.90
22-49 days	0.73	0.79	0.88
Sulphur Amino Acids			
1-21 days	0.81	0.77	0.80
8-28 days	0.77	0.78	0.76
21-35 days	0.66	0.74	0.73
22-49 days	0.64	0.67	0.71

The two methods generated quite close results (Table 8), indicating that both approaches can be used to establish digestible AA requirements.

Conclusion

The concept and methodology of true ileal digestible amino acids has gained wide acceptance in academics as well as in industry. A number of laboratories world-wide have generated and continue to generate a large number of data which are available to the feed industry. The AA digestibility data allow nutritionists to more accurately and objectively evaluate the true feeding value of feed ingredients. Formulating diets using digestible AA enables nutritionists to improve the precision of formulation, to use with confidence of poorly digestible ingredients, to lower feed cost while maintaining animal performance. This will increase the competitiveness and the profitability of the operation.

To switch from total to digestible amino acid formulation, the digestibility coefficients data published by major laboratories (Sibbald, 1986; Parsons, 1990a; Rhone Poulenc Animal Nutrition, 1993) can be used to convert the database. The database of Rhone Poulenc Animal Nutrition is constantly expanded by new feed ingredients coming from various countries. The digestible AA requirements of animals could
be readily estimated by applying the digestibility coefficients to total amino acid requirements.

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The Economics Of Ingredient Allocation

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Introduction

Ingredient Allocation is a term used to describe a method of formulation or ingredient evaluation that is based on multiple formulation. This paper seeks to describe the principles of multiple product formulation and then will show two exercises. The first will be to show how multiple formulations can be used to save ingredient cost, and then to demonstrate the comparison of two ingredients against each other on a n economic and technical basis.

Single Product Optimization

In order to understand the workings of Multiple Product Optimization (MPO), we should first look at the basic Single Product Optimization (SPO). Both techniques use the same method of calculation, Linear Programming or LP, to achieve an optimal solution. There are some basic functions common to all SPO systems:

Ingredient Data	The ingredient database contains all the nutrient data for the ingredients in the feedmill and also those that the feedmill may wish to evaluate. One of the roles of the nutritionist is to search for alternative ingredients even though they may not be currently available.
Price Data	The ingredients should all have prices. Operationally these may be the stock or replacement prices. Test ingredients may use guide prices or even very high prices to prevent them from being used. These high prices are used to generate shadow prices.
Formula Specifications	Formula specifications contain two components; the nutrient specifications and the ingredient specifications. These take the form of minimum and maximum limits in both sections.

Examples of these are given in the Tables 1, 2 and 3.

Given these three data, the LP can be used to calculate a solution. The solution, if feasible, is a combination of ingredients that meets the nutrient limits at the lowest or “least cost”. We have to use the term “least cost” with some caution as it can imply that the feed is too cheap, however, it should be remembered that the selection of the ingredients and their limits makes a major contribution to the quality of the feed. The term “optimize” is preferred as this implies that the feed will have the best cost for a required situation and desired quality. Table 4 shows the ingredient solution resulting from optimizing the feed specified in Table 3.

The first three columns are ingredient name, percent of mix and ingredient cost per kg (from the ingredient file). The next two columns are information generated by the LP relating to ingredient price. In Table 4, the price of corn changes from 6.30 to less than 6.18 (the Low Range Price) then the formula will change. If the price exceeds 7.79 (the high range price) then the formula will change. This applies only if the other ingredient prices do not change. Thus the ranging prices give an indication of the price stability of the feed.

Originally when LP was applied to feed formulation problems, this was very useful information as an experienced formulator could spot potential problems. It would also enable the nutritionist to make judgments from print outs of solutions. The application of this was to be able to make accurate changes to the specification or prices before calculating the feed again. This was important as feeds could take several minutes to re-optimize so changes had to be selected with care. Now that both the programs and particularly the computer hardware are faster, the ranging values are not so important

Table 1. Ingredient data for soybean meal 44 and 48

Nutrient		Soybean Meal 48	Soybean Meal 43	
Crude Protein	%	48.0000	43.0000	11.6%
ME Poultry	Kcals/Kg	2525.0000	2350.0000	7.4%
ME Swine	Kcals/Kg	3380.0000	3245.0000	1.04%
Moisture	%	12.2500	12.2500	
Fat	%	1.0000	1.0000	
Crude Fiber	%	3.5000	7.0000	
Ash	%	6.3000	6.3500	
Ca	%	0.2900	0.3800	
Phos	%	0.6600	0.5800	
AP	%	0.2310	0.2030	
Na	%	0.0100	0.0300	
Cl	%	0.0200	0.0300	
Salt	%	0.0300	0.0600	
Non Phyt P	%	35.0000	35.0000	
Linoleic Acid	%	0.5500	0.5500	
Lysine	%	3.0000	2.6000	15.4%
Methionine	%	0.6600	0.6300	4.8%
Met & Cys	%	1.3700	1.3000	5.4%
Threonine	%	1.8700	1.7600	6.3%
Try	%	0.6300	0.6055	5.0%
Arg	%	3.5000	3.0500	

Energy values based on NRC, Amino Acid values from Novus International.

Table 2. Sample prices for ingredients (baht per kg)

Ingredient No.	Name	Price
1101	Thai Corn	6.3000
1401	Broken Rice 8.5	8.0000
2302	Tapioca Starch	4.8000
2403	Ricebran 12/12/	5.5000
2502	Distillers Gr &	9999.0000
3111	Soybean Meal 48	14.0000
3113	Soybean Meal 44	12.0000
3121	Extruded Full F	15.0000
3911	Corn Gluten Meal	17.0000
4113	Chilean Fishmeal	19.0000
4131	Fishmeal Thai 6	17.0000
4133	Fishmeal Thai 5	15.8000
4211	Meat and Bone 5	14.0000
4212	Meat and Bone M	14.0000-0
4214	Meat and Bone M	13.0000
4441	Sweet Whey	28.0000
4911	DL Methionine	170.0000
4912	L-Lysine 99%	120.0000
4913	Alimet 88%	140.0000
5113	Fat Pak 100	50.0000
5213	Crude Palm Oil	16.0000
6111	Salt	2.0000
6122	Limestone	1.0000
6146	Mono Dical 16/2	12.0000
6147	D.C.P. 22/18	9.0000
8211	Fermacto	55.0000
9501	Broiler Premix	20.0000
9505	Pig Premix	50.0000

Table 3. Broiler starter specification

Ing No.	Name	Minimum	Maximum
1101	Thai Corn		
1401	Broken Rice 8.5%		
2403	Ricebran 12/12/12		5.0000
3111	Soybean Meal 48% Sol		100.0000
3113	Soybean Meal 44% Sol		100.0000
3911	Corn Gluten Meal 62%		
4131	Fishmeal Thai 60%	5.0000	8.0000
4133	Fishmeal Thai 55%		10.0000
4211	Meat and Bone 55% DD		3.0000
4212	Meat and Bone Meal 4		
4214	Meat and Bone 52% DD		3.0000
4215	Meat and Bone 50% Fe		
4912	L-Lysine 99%		0.3000
4913	Alimet 88%		
5213	Crude Palm Oil	1.0000	3.5000
6111	Salt		
6122	Limestone		
6146	Mono Dical 16/20		
9501	Broiler Premix	0.6000	0.6000

Nut. No.	Name	Minimum	Maximum
1	Weight	1.0000	1.0000
2	Crude Protein	21.5000	23.0000
6	ME Poultry	3200.0000	
16	Dry Matter		
17	Fat	3.0000	
18	Crude Fiber		6.0000
22	Calcium	0.9500	1.0500
23	Total Phos		
24	Available Phos	0.4200	
25	Sodium	0.1800	
26	Chloride		
27	Salt	0.3800	0.4500
31	Lysine	1.2500	
37	Methionine	0.5300	
43	Met & Cys	0.8600	
49	Threonine	0.6000	
55	Tryptophan	0.2200	

to the user. It is much simpler to use a parametric analysis where the feed is tested over a pre-set range of prices to see the impact on ingredient composition and feed cost.

The restriction cost indicates the cost of imposing an ingredient limit. For example, rice bran has an ingredient cost of –0.120. This means that each 1 percent of increase in the maximum limit of rice bran will save 0.120 Baht per Kg. The units in which these restrictions costs are expressed will vary between systems, so reference to your user manual may be needed before making any deductions regarding the restriction price. As with ranging price there are some limitations to the value of the data. The cost of restriction is only valid and linear up until the next break point (that is where the

Table 4. Broiler starter ingredient solution

Ing Name	Pet of Mix	Cost KG	Low Range	High Range	Rest/KG	Min	Max
Soybean Meal 44% Sol	16.445	12.00	10.97	12.43			100.000
Fishmeal Thai 60%	9.000	17.00		17.55		5.000	10.000
Ricebran 12/12/12	5.000	5.50		5.62	-0.120		5.000
Meat and Bone 55% DD	3.000	14.00		15.45	-1.448		3.000
Meat and Bone 52% DD	3.000	13.00		15.18	-2.179		3.000
Crude Palm Oil	2.676	16.00	10.70	17.18		1.000	3.500
Broiler Premix	0.600	20.00	1.81		20.000	0.600	0.600
Alimet 88%	0.106	140.00		203.50			
L-Lysine 99%	0.060	120.00	102.18	204.61			0.300
Salt	0.021	2.00		5435.8			

cost/unit changes as the inclusion changes). We cannot assume that the relationship of –0.12 Baht per Kg holds true over a wide range. So again the best approach is to run a parametric analysis on the formula to see the reaction of feed cost to rice bran inclusion over a wide range.

The last two columns show the minimum and maximum limits of each ingredient. Note that the usage of these is slightly different between ingredients. Some ingredients such as fat will have minimum values as well as maximum due to physical constraints on production, others such as rice bran will have maximum constraints. These constraints are very subjective, and depend on the experience of the nutritionist, QC department and production staff.

Table 5. Rejected ingredient data

Ing Name	Pet of Mix	Cost KG	Low Range	High Range	Rest/KG	Min	Max
Rice Bran 8.5			8.00	6.54			
Soybean Meal 48%		14.00	13.35				100.000
Corn Gluten Meal		17.00	16.25				
Fishmeal Thai 5		15.80	15.25				7.000
Meat and Bone			14.00				
Limestone			1.00				
Mono Dical 16/2		12.00					

Table 5 shows the data on rejected ingredients. Some of these have been rejected due to availability such as Meat and Bone Meal 45%. Others, such as Soybean Meal 48% have been rejected on price. The Low Range Price then shows the price at which the ingredient can be accepted into this formula. This price is often referred to as the Shadow Price or Entry Price.

Again this is useful information, but it has limitations of which we have to be aware. Firstly, the shadow prices will vary between formulas. Indeed where prices are competitive, some formulas may use an ingredient whereas others will reject it. The other limitation is that while this indicates the threshold price, the quantity of the ingredient may not be sufficient to warrant purchasing it.

With all of this price and restriction cost data there is the other advantage that as soon as a price of one ingredient changes significantly, the comparable price information will also change. Thus the shadow prices would have to be re-evaluated, which would be very time consuming. Unfortunately, in a large feedmill, the amount of time required may be prohibitive which underscores the need for multiple formulation where the operation is fully integrated and considerably faster.

Similar data is also generated for the Nutrient Data as shown in Table 6. The minimum and maximum nutrient values have all been met and where the nutrients are restricted, there is a restriction cost. The unit of restriction here is per 100 kgs feed per unit of change. As with ingredient data, it is better to use the parametric analysis to take a closer look at these constraints as wider ranges of nutrient can be examined dynamically.

It should be remembered that any "tightening" of a limit will lead to an increase in cost of the feed. Tightening means either lowering an active maximum constraint or increasing an active minimum constraint. The same principle applies to MPO where applying tighter limits will increase the cost of the overall solution.

Before running MPO, all the formulas should be optimized and feasible. Some MPO systems will highlight any formulas in the set that are infeasible, but correcting them at this stage can be time consuming, so it is best done first.

In the MPO examples that follow, we will be running the sample feeds listed in Table 7. Table 8 shows the ingredients that will ideally be needed to manufacture these feeds.

Multiple Product Optimization

The original use for MPO was to restrict the usage of ingredients that were not available at the full amount required. As an example, we might limit the amount of 4124 Meat and Bone Meal 52% to 100 tons. We can see the effects in Table 9a, b, c and 10. Table 9a shows the usage of ingredients from the MPO solution to the SPO solution without restriction.

As well as the minimum and maximum ingredient limits there is a column showing the Penalty (Table 9b). This is the restriction cost of limiting the usage of 4214 Meat and Bone 52% DD. The unit is in per ton of restriction. This however only applies at the particular quantity shown above. At other levels of restriction, the effect may be less.

As we allow more Meat and Bone Meal to be used, the penalty decreases. This is partly explained by the difference in value in different formulas. As mentioned earlier, the ranging data will be different for each feed, and this response reflects a summary of those ranging values. A contributing factor is that as an ingredient becomes more scarce, it acquires more value. This is a well-known economic effect, shown here in practice.

Table 6. Rejected ingredient data

Nutrient	Min	Actual	Max	Restriction Cost
Crude Protein	21.5000	21.5000	23.0000	8.2315
ME Poultry	3200.000	3200.000		2.2973
ME Swine		3285.735		
Moisture		11.7268		
Fat	3.0000		6.8593	
Crude Fiber		3.8156	6.0000	
Ash		5.9016		
Calcium	0.9500	1.0417	1.0500	
Total Phos		0.8155		
Available Phos	0.4200	0.5714		
Sodium	0.1800	0.1800		12.882
Chloride		0.2219		
Salt	0.3800	0.4019	0.4500	
Linoleic Acid		2.2162		
Xantophyll		13.2796		
Lysine	1.2500	1.2500		147.859
Methionine	0.5300	0.5643		
Met & Cys	0.8600	0.8600		162.577
Threonine	0.6000	0.8841		
Tryptophan	0.2200	0.2422		
Arginine		1.3774		
Glycine		1.4228		
Histidine		0.5179		
Isoleucine		0.9271		
Phenylalanine		0.9806		
Phe & Tyr		1.7094		
Valine		0.8314		

Table 7. Forecast feed production

Code	Feed	Tonnage
104	Layer Feed ISA Brown	500.00
203	Broiler Starter	1200.00
204	Broiler Grower	3600.00
301	Pig Pre Starter	450.00
302	Pig Starter	650.00
303	Pig Grower	900.00
306	Pig Gestation	700.00
307	Pig Lactation	250.00
308	Pig Lactation Hi Energy	200.00
801	Duck Starter RP	500.00
802	Duck Grower RP	800.00

Table 8. Forecast ingredient usage

Code	Feed	Tonnage			
1101	Thai Corn	5232901.00	5232.9	32967280.00	40.19
3113	Soybean Meal 44% Sol	1491600.00	1491.6	17899200.00	21.82
2403	Ricebran 12/12/12	1197450.00	1197.4	6585975.00	8.03
4131	Fishmeal Thai 60%	482700.00	482.70	8205900.00	10.00
1401	Broken Rice 8.5%	408459.00	408.46	3267672.00	3.98
4214	Meat and Bone 52% DD	236250.00	236.25	3071250.00	3.74
2302	Tapioca Starch	157500.00	157.50	756000.06	0.92
6122	Limestone	120110.00	120.11	120110.00	0.15
5213	Crude Palm Oil	111515.00	111.51	1784240.00	2.17
4113	Chilean Fishmeal 67/	105000.00	105.00	1995000.00	2.43
4441	Sweet Whey	45000.00	45.00	1260000.00	1.54
4211	Meat and Bone 55% DD	44800.00	44.80	627200.00	0.76
4133	Fishmeal Thai 55%	41500.00	41.50	655700.00	0.80
9501	Broiler Premix	20700.00	20.70	414000.00	0.50
6111	Salt	18520.00	18.52	37040.00	0.05
6146	Mono Dical 16/20	12175.00	12.18	146100.00	0.18
4913	Alimet 88%	7076.00	7.08	990640.00	1.21
4912	L-Lysine 99%	6719.00	6.72	806279.94	0.98
8211	Fermacto	5275.00	5.28	290125.00	0.35
3911	Corn Gluten Meal 62%	2500.00	2.50	42500.00	0.05
9505	Pig Premix	2250.00	2.25	112500.00	0.14
	Totals	9750000.00	9750.0	82034712.00	100.00
Weighted Average Feed Cost / Tonne $			8413.82		

Table 9b. Summary of ingredient restrictions

Plant		Ingredient	Min	Max	Penalty
THAI	3113	Soybean Meal 44% Sol		10000.0000	
THAI	4113	Chilean Fishmeal 67/		10000.0000	
THAI	4131	Fishmeal Thai 60%		10000.0000	
THAI	4211	Meat and Bone 55% DD		10000.0000	
THAI	4214	Meat and Bone 52% D		100.0000	1540.83

Table 9c. Summary of ingredient restriction variation

Plant		Ingredient	Min	Max	Penalty
THAI	4214	Meat and Bone 52% D		100.0000	1540.83
THAI	4214	Meat and Bone 52% D		120.0000	1506.35
THAI	4214	Meat and Bone 52% D		140.0000	1506.36
THAI	4214	Meat and Bone 52% D		160.0000	1460.11
THAI	4214	Meat and Bone 52% D		180.0000	1460.11
THAI	4214	Meat and Bone 52% D		200.0000	1034.96
THAI	4214	Meat and Bone 52% D		200.0000	510.04

The concept of value is important. It is not the offer price of the ingredient, but the true value of the ingredient to the feedmill. For example in Table 9b, we can conclude that the value of 160 tonnes of meat and bone meal is 14,000 (its costs) +1460.11 (its penalty) = 15,460.11. Thus if we can successfully bid lower than the value of 15,460.11 we have secured a profit to the feedmill. If we were able to buy it at 15,000, then the profit on each tonne bought would be 460.11 baht.

This is the first instance where we highlight the important concept that ingredient price and quantity are closely interlinked. In fact they are inseparable when calculating the value of a commodity.

Table 10 shows the effect of the restriction on the formula price. It is important to note that the effect of restriction is not equally shared across all formulas. We can see that the layer feeds and duck feeds are unaffected by the restriction whereas there is a varying effect in the others. The feed cost of broiler grower in particular is increased by 51.15 baht. Again, this points to the different value of commodities in different feeds. This is going to affect the pricing of some of the feeds, so the nutritionist may wish to limit the swing in the usage of MBM in the broiler grower to balance out the cost increase. Another consideration that is not often practiced is to strategically sell less of the feed that suffers the most from the ingredient restriction. This will increase the allocation of ingredients for other feeds.

Table 10. Effect of MBM restriction on formula price

104	ISA BROWN 19-40,	05-26-1998	500.00	1000.00	7415.84	7415.84	
203	Broiler Starter	05-26-1998	1200.00	1000.00	9136.48	9137.26	0.78
204	Broiler Grower	05-26-1998	3600.00	1000.00	8475.88	8527.03	51.15
301	Pig Pre Starter	05-26-1998	450.00	1000.00	11942.6	11970.6	28.06
302	Pig Starter	05-26-1998	650.00	1000.00	8424.30	8420.54	-3.76
303	Pig Grower	05-26-1998	900.00	1000.00	7763.78	7763.82	0.04
306	Pig Gestation	05-26-1998	700.00	1000.00	6890.85	6890.85	
307	Pig Lactation	05-26-1998	250.00	1000.00	7698.58	7711.16	12.58
308	Pig Lactation Hi	05-26-1998	200.00	1000.00	7933.84	7940.40	6.56
801	Duck Starter RP	05-26-1998	500.00	1000.00	8683.88	8683.88	
802	Duck Grower RP	05-26-1998	800.00	1000.00	7919.01	7919.01	

The effect of limiting MBM in this case is to raise the average feed price from 8413.78 to 8434.27 baht per ton or an increase in cost per ton of 20.49. This does indicate that it is preferable to buy the ingredients needed. It also suggests that MPO is going to increase the cost of the feed. It should be remembered that MPO will give the cheapest solution to a particular problem.

The solution above contains an example of a very common hidden cost. In the base formulas, the use of meat and bone meal has been manually restricted by putting maxima in the formula specifications that are lower than the maxima that would be technically acceptable. All of the feeds have maximum of 3% where 5% might be used. Table 10 shows the effect of raising the limits in each formula specification and then using the MPO to allocate the ingredient to the most economic formulas.

We can see in this case that the re-allocation has saved 3.91 baht per ton or 38,000 baht on a single commodity. This is analogous to the costs incurred when manual formulation is practiced in case of optimization. In order for these savings to be valid, then technical limits need to be observed closely, but the above changes would be quite acceptable. It is useful to occasionally review limits (if MPO is an option) to make sure that maxima designed to restrict total usage rather than formula usage has not accumulated in the database.

Ingredient Allocation is a critical tool in pricing ingredients. A good example of this is the comparison of 43% SBM to 48% SBM. There are several methods used such as pro-fat pricing comparison of protein values, but these do not take into account the overall contribution of the SBM 48% to a full range of nutrients needed in the feed including ME, Protein, amino acids and density. When we compare values of the two ingredients using MPO additional factors such as available tonnage and product mix can be taken into account.

It is useful to review the single formula shadow prices of SBM 48% in these formulas from SPO. These data show the variable value of SBM 48% in different feeds. This is one reason for the effect of different product mixes on comparative value. Table 12 lists the shadow prices of SBM 48% in different feeds. This is one reason for the effect of different product mixes on comparative value. Table 12 lists the shadow prices of SBM 48% when compared to SBM 43% at 12 baht per kg. There is a range of values from 12.50 up to 13.80 baht per kg so the shadow price is by no means constant. If the enterprise concentrated on making these duck feeds then the value of SBM 48% would be relatively low when compared to a broiler producer.

Table 13 shows the quantities demanded at different levels of SBM 48 price with the same acceptance ranges indicated by the shadow prices of 12.50 to 13.80 baht per kg, however there is no single point at which we can say that SBM 48 is definitively economic. At 12.80 baht per kg, it is the preferred source in terms of volume.

The data from this table is graphed in Figure 1 to show the demand curve of this set of formulations for the different types of soybean meal. This highlights that there is no distinctive formula that would give a relative price in order to decide which of the soybean meals to purchase. If we were to base the price comparison on protein the relative price of SBM 48 would be 13.39 baht. On a lysine basis, the competitive price of SBM 48 would be 13.85 and on an energy basis it would be 12.50.

Table 11. Effect of MBM restriction on formula price

Feed		MBM Max	MBM Actual	MBM Max	MBM Actual
104	ISA BROWN 19-40	3.00	3.00	5.00	5.00
203	Broiler Starter	3.00	3.00	4.00	2.50
204	Broiler Grower	3.00	3.00	5.00	2.90
301	Pig Pre starter	3.00	3.00	4.50	4.10
302	Pig Starter	3.00	2.50	4.00	1.50
303	Pig Grower	3.00	0.10	4.00	0.10
306	Pig Gestation	3.00		4.00	
307	Pig Lactation	3.00	1.20	4.00	
308	Pig Lactation Hi	3.00	2.30	4.00	
801	Duck Starter RP	3.00	3.00	4.50	4.50
802	Duck Grower RP	3.00	3.00	4.50	3.10
Tonnes Used			236.65	236.65	
Average Cost per Ton Feed			8413.80	8409.88	
Total saving on 9750 tons of feed = 38,080 Baht (3.91 baht per ton)					

Table 12. Shadow prices of SBM 48 v. 43 @ 12 Baht per kg

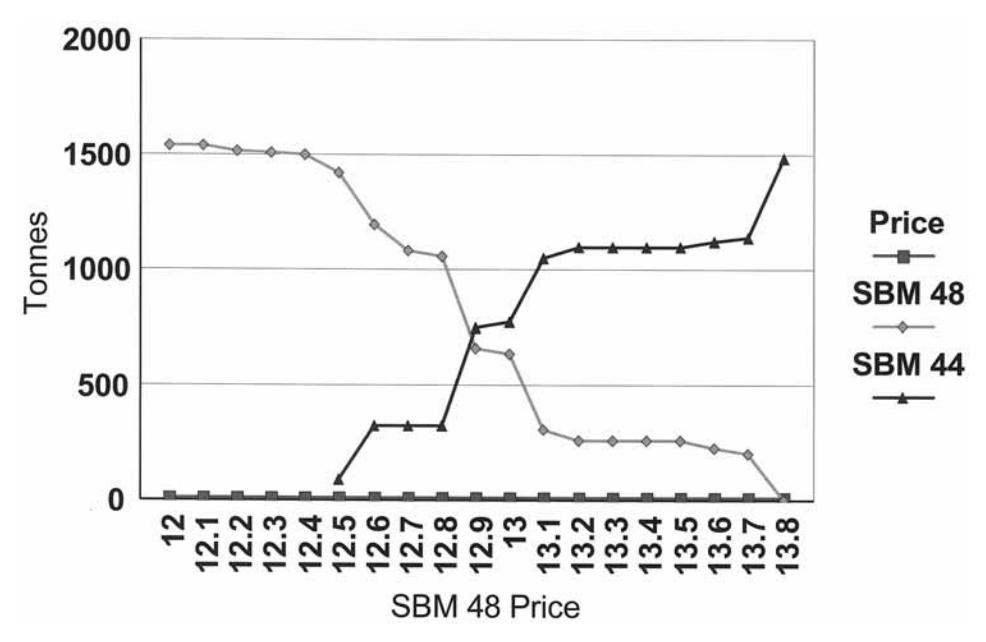
Feed		Shadow Price
104	ISA Brown 19-40,	12.95
203	Broiler Starter	13.79
204	Broiler Grower	13.00
301	Pig Pre starter	12.58
302	Pig Starter	13.73
303	Pig Grower	13.04
306	Pig Gestation	12.84
307	Pig Lactation	13.73
308	Pig Lactation Hi	13.80
801	Duck Starter RP	12.50
802	Duck Grower RP	12.50

Table 13. Usage of SBM 48% (tons) at different price levels.

SBM 48 Price	SBM 48 Quantity	SBM 43 Quantity
12.0	1541.9	0.0
12.1	1541.9	0.0
12.2	1518.8	0.0
12.3	1513.3	0.0
12.4	1504.3	0.0
12.5	1420.3	96.0
12.6	1199.6	327.9
12.7	1085.2	327.9
12.8	1063.6	327.9
12.9	669.2	752.8
13.0	637.2	780.4
13.1	313.2	1049.4
13.2	262.5	1102.8
13.3	262.5	1102.8
13.4	258.5	1102.8
13.5	258.5	1102.8
13.6	228.5	1122.9
13.7	206.4	1143.7
13.8	0.0	1491.6

We can also use the allocation technique to equalize the total prices of the formulations when either SBM 43 or SBM 48 is available. The base price of the formulation is 8,413 baht per tonne when SBM 43 is used and the price of SBM 48 required to equal this over the whole product range is 12.99 baht. It should be stressed that the ingredients being compared here are assumed to have equal amino acid digestibilities. It is important that the evaluations of this type also take account of the origin of the meal and its processing conditions.

Figure 1. SBM 48 and SBM 44 Usage V. SBM 48 price



Conclusion

Ingredient Allocation is a useful exercise in not only producing economic feeds, but also for accurate comparison of feed ingredients. The advantage in normal feed formulation is that MPO can give the best answer to situations when ingredients are in short supply when compared to manual allocation of scarce raw materials. Ingredient Allocation is a better tool for ingredient pricing when compared to less dynamic studies on shadow prices. The presentation of the MPO problem in state of the art formulation programs is such that rapid economic tests can be made to identify the profitable ingredients taking into account the product types and tonnage in the feedmill. In addition, the MPO systems allow the buyer or nutritionist to determine threshold quantities as well as prices for competitive purchases.

Formulation Of Diets On A Digestible Amino Acid Basis And Factors Affecting Digestibility Of Feedstuffs

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Introduction

Over the past several decades, the poultry industry has moved from formulation of diets based on a crude protein basis to a least-cost and total amino acid (AA) basis, in part due to the introduction of affordable computing power. More recently, the industry has begun to switch to newer concepts that may prove cost effective. These include digestible formulation, precision feeding, ideal proteins, modeling. All concepts that have been presented to the poultry industry and have been adopted world wide to some extent. As we look at the industry, we see the entire gambit of methods to provide a nutritional regimen to poultry. In some parts of the world, nutritionists will still use the old Pearson Square as a diet formulation tool and most will formulate on a crude protein basis. In the undergraduate Monogastric Nutrition class I teach, we use the hand calculation method at the beginning of the semester to give them an appreciation for the professional computer formulation package they will use during the rest of the class to formulate far more complex rations based on total amino acids, digestible amino acids and ideal protein ratios. While the industry in the U.S. and much of the world has made the switch to computer formulation, the switch to what may be referred to as more advanced formulation methods has been a bit spottier. A solid percentage of the birds now being fed are using digestible amino acid formulation. We'll look at some of the arguments for making the switch to more advanced formulation methods, show several ways to make the switch and look at factors that affect digestibility and how to maintain a database on feed ingredients.

Digestible Formulation Saves Money

Very few nutritionists would tell anyone that they do a poor job with their diets and that they need help desperately. In fact, most folks are doing an adequate job in terms of bird performance. The real reason to look at newer formulation methods is strictly an issue of money. Providing maximum growth for birds is generally fairly easy, just overfeed all of the nutrients that are required and you will probably come close to maximal growth. But at what cost? When we factor the economic side into the equation we find that overfeeding can be expensive. Thus, least cost diet formulation. Unfortunately, least cost diets are not necessarily the most cost effective diets. A cheap diet that reduces bird performance is not very cheap. We should be looking at least cost per pound of gain or even better least cost per pound of salable meat. To achieve optimal cost efficiency, we need to feed as close to the true requirement as possible to get the performance we seek without overfeeding nutrients, what folks in the U.S. are now terming precision feeding. One of the main ways to feed to the true requirements is by using digestible values for AA. A number of people over the years have questioned this or stated that it wasn't terribly valuable and that what we are currently doing is fine both from a bird standpoint and an economic standpoint. In turn, I have then asked how many of those folks feed birds based on gross energy values or total phosphorus levels in the diet? I'm sure that at some point in the past we did that as well, but no one does it now because we all agree that use of some measure of availability for energy and phosphorus improves accuracy of the formulation and will save us money. A similar argument holds for digestible AA formulations and could be argued to be the next logical step in poultry nutrition.

But is it worth it? Switching to a different method of formulation will take some time to get set up and some work continuously to keep digestible nutrient levels updated. Some of the other aspects of precision feeding will also increase the management costs as well. Let's look at digestible formulation first and see how money can be saved. Digestible formulation is really about two things. First, feeding the correct requirement and second, proper pricing of ingredients based on the available nutrients. For example, if we compare a soybean meal sample with a meat meal sample on a total AA basis, we may find that lysine content of both products is about 3.00%. If we look at these same products on a digestible lysine basis, we will note that the soybean meal is generally higher in digestibility, in some cases as much as 10%. If our soy sample is 92% versus 82% digestible lysine, the actual lysine content of each product available for bird use is 2.76% versus 2.46%, a substantial difference. While we are looking only at a simplistic view of a single amino acid, the point is that the value of the product should be based on its usable content rather than its total content with respect to AA. Once again, we wouldn't think of using gross energy values when data is available for metabolizable energy. If used correctly it thus appears that digestible AA formulation will save some money. When checking with US industry nutritionists, it appears that $1-2/ton (USD) are saved

Digestible Formulation Results In More Accurate Requirements

Digestible amino acids result in the requirement being expressed on a more accurate basis. We have shown this in our research trials when using higher levels of by-product additions formulated on a digestible versus total amino acid basis. However, let me provide a simplistic calculation to make the point. Let's say we wish to provide 1.00% total lysine or 0.90% digestible lysine to meet a requirement for our birds from a feed ingredient that contains 3.00% lysine that is 90% digestible or contains 2.70% digestible lysine (such as soybean meal). To meet this lysine requirement, we can feed 33.3% soybean meal (3.00 x .333 = 1.00% total or .90% digestible). We could also feed a by-product (such as meat meal) at the same level which also happens to contain 3.00% lysine. The problem occurs if the digestibility of lysine is lower, say 80% or 2.40 digestible lysine versus 2.70%. On a total lysine basis, we are meeting the requirement (3.00 x .333 = 1.00%) with either ingredient. However, with the lower digestibility ingredient we are only providing 2.40 x .333 = .80% digestible lysine whereas the higher digestibility of lysine in the first ingredient met the requirement. This is taken into account when formulating on a digestible basis, but not when formulating on a total basis. The result: lower lysine levels as the amount of by-product is increased. This is not a problem if formulating on a digestible basis, although the higher digestibility ingredients may be included at higher rates when formulating on a digestible basis.

Digestible Formulation Allows For Reduced Protein And Increased Energy Without Fat Additions

One of our nutrition professors asked me one time why we feed such low energy rations to growing turkeys in the early stages of growth. If you formulate turkey rations you know this is due to the high protein contents of the starter rations which necessitates high levels of high protein, low energy feeds. The only solution to this is the addition of substantial quantities of fat to the ration. The same is true when formulating broiler rations, less fat may be needed to maintain the energy content of the diet which can now be provided by grains rather than fat.

Table 1. Comparison of two formulations based on total amino acid content and the effect on digestible amino acid values (turkeys)

	Corn-soybean diet		By-product addition diet	
	Total Basis	Digestible Basis	Total Basis	Digestible Basis
Lysine	1.72%	1.52%	1.72%	1.45%
Methionine	0.55%	0.52%	0.55%	0.44%
Threonine	1.05%	0.86%	1.05%	0.84%

Digestible Formulation Allows For More Precise Determination Of Amino Acid Requirements

When a researcher attempts to determine the requirement for an expensive nutrient such as the amino acids, precision is important. Formulation on a digestible basis is more precise in terms of amino acid delivery across the intestinal lumen. As an example, two turkey diets are shown below (Table 1). Both diets have similar total amino acid contents, but when compared on a digestible basis they differ by .07% on lysine, .08% on methionine and .02% on threonine. We see this also when we attempt to do titrations of an amino acid such as lysine. Generally, what is done is that a reduced protein diet is formulated and crystalline amino acids are added back. If we were determining the requirement for lysine, we might add lysine back in small increments until we found the level of lysine that would support optimal growth. The problem comes in when we then utilize this requirement data for a regular diet formulation. Let's say we added back 0.30% lysine to our basal ration to get to the lysine requirement. This 0.30% lysine was added as crystalline lysine which is considered to be 100% digestible. When we formulate a standard ration, this is replaced with ingredients such as soybean meal or meat and bone meal which are not 100% digestible. If we did this on a total lysine basis rather than digestible, we have just inadvertently come up with the wrong requirement.

Digestible Formulation Is Useful Even If You Just Feed Corn And Soybean Meal

A number of people think that they don't need to formulate on a digestible basis because they primarily feed corn and soybean meal. While I would certainly agree that it is more important if one feeds a complex diet, corn-soybean meal diets alone do not change my opinion. Just the precision argument noted above is reason enough to make the switch. The other question I always come back to is why don't we put more ingredients into our matrix to cheapen the ration? Certainly corn-soy alone may provide an adequate ration, but the benefits of least cost ration balancing mostly disappear if there are no feedstuff choices for the computer to balance with.

Time To Make The Switch?

All in all it appears that the benefits of digestible formulation are significant. The downside is that you will need to set things up on your computer to do this and may need to do some routine feedstuff assays to get digestible values. The potential savings are quite real however and many companies have made the change. Let's next look at what's involved in making the change both from the standpoint of the computer changes needed, databases to utilize, assays that can be done and what factors affect digestibility of feedstuffs.

Data Needed For Making The Switch

There are basically two parts to the data needed to make the switch. These include a database of the feedstuffs that will be commonly used and digestible requirement data. Let's look first at the feedstuffs data needed and input into the computer.

Feedstuffs Database

There are a number of locations to access feedstuff digestibility values and there are several things that should be looked at in regards to this. One of these is the methodology with which the data was collected, the number of samples that have been tested and if the data was then used for requirement determination. In other words, if I am using data from cecectomized roosters for the digestibility values, is the requirement that has been determined based on this same type of data? A number of sources are available for the database needs. These will include your amino acid manufacturers, some published literature and in some cases computerized databases. I have included some of our data using the cecectomized rooster model for a starting point (Table 2).

Collection Methods

There are a variety of methods for collecting digestibility values, but all of the in vivo methods revolve around some form of feeding the animal and collection of excreta. In the U.S., a common method is to utilize cecectomized roosters (roosters with the ceca surgically removed). The rooster is removed from feed to clear the gut, force fed a known quantity of feed and its excreta collected for a period of time. Another bird is either left off feed or fed a non-nitrogenous feedstuff and excreta collected for adjustment to account for endogenous loss or loss that occurs regardless of the feed being fed. Other methods involve feeding with a undigestible marker that allows quantitation of feed in the gut and collection of feces from the small intestine after killing the bird. This tends to be more expensive

Table 2. Percent Digestibility of Common Feedstuffs in Roosters

Feedstuff	Arg	Ser	His	Ile	Leu	Lys	Met	Cys	Phe	Tyr	Thre	Trp	Val	Asp	Glu	Pro	Ala	Avg
Barley, steam rolled1	87.9	83.4	79.0	76.9	77.5	67.5	76.2	74.2	85.7	83.2	74.9	91.7	78.3	81.8	84.2	79.3	73.1	79.69
Blood meal1	92.5	94.1	88.4	86.2	91.3	92.5	93.3	84.3	92.2	94.7	91.7	96.3	89.6	90.4	89.1	90.5	92.7	91.16
Corn gluten meal	99.97	100.0	98.4	99.5	99.5	99.5	99.5	98.6	99.2	99.2	100.0	98.0	99.6	99.7	99.8	99.5	99.7	99.5
Corn gluten feed w/bran	81.5	66.8	64.8	73.1	81.5	57.4	76.1	55.3	75.0	81.5	54.9	45.0	59.0	68.0	75.7	69.5	76.1	70.5
Corn grain	99.3	100.0	95.9	100.0	99.2	86.2	98.3	100.0	98.2	99.1	96.6	83.3	99.8	96.3	98.2	100.0	97.9	97.2
Fish meal, Menhaden	92.8	93.0	90.5	96.7	95.5	93.0	94.2	92.3	93.7	96.3	96.6	100.0	95.1	88.6	96.4	92.5	90.2	92.4
Oats1	100.0	82.8	89.5	91.2	93.9	89.4	91.9	80.7	95.2	89.6	83.5	78.0	85.8	90.8	92.8	86.0	79.8	88.3
Poultry by-product meal[1]	93.2	85.7	80.8	90.6	91.1	90.9	92.1	77.8	90.4	93.9	86.6	95.0	88.1	73.3	87.6	80.9	86.5	87.3
Feather meal	84.2	76.4	84.2	82.3	76.8	73.3	77.5	58.8	79.6	79.8	72.9	77.0	77.5	58.0	71.8	63.1	72.3	73.6
Sorghum, grain (milo)	98.0	99.2	89.6	99.5	97.8	92.4	95.7	99.2	97.8	100.0	100.0	99.0	95.9	96.0	97.8	95.2	96.2	97.1
Wheat bran	87.9	85.8	86.1	74.3	80.2	74.8	75.6	80.5	78.0	79.5	84.2	86.4	70.4	76.4	86.3	89.0	56.8	78.6
Wheat middlings	90.0	85.3	77.7	82.9	83.6	82.4	81.0	82.1	84.9	86.5	76.7	86.8	79.5	83.1	90.9	85.9	73.1	83.3
Wheat shorts1	99.5	93.7	90.2	92.0	92.8	94.1	88.1	89.2	93.6	94.1	93.7	91.0	87.9	89.4	95.5	92.8	79.9	91.6
Wheat, soft white1	96.9	92.0	90.0	94.8	95.1	92.6	93.3	98.7	96.1	98.2	93.8	96.5	91.9	94.2	96.1	98.2	84.7	94.3

and time consuming. Either method will provide a reasonable representation of what portion of the amino acids are being absorbed by the bird.

Factors Affecting Feedstuff Digestibility

A number of factors can affect the digestibility of feedstuffs both from the bird standpoint, diet standpoint and the from the feedstuff standpoint. Looking first at the bird, variation may occur due to ages, gender, species or strain, environmental temperature, gut length, gut conditions and level of feed intake. While there is little hard and fast data on these affects, it appears the very young bird does not digest feed as well as after several weeks of life and probably the older bird may depress digestibility somewhat as well. Dietary factors can also affect feedstuff digestibility. We have shown that high levels of dietary fat can improve digestibility of feeds with lower digestibility coefficients. High levels of dietary fiber can reduce digestibility of feeds as well. There is little data on interactions of different feedstuffs in the gut either. While these factors have been shown to occur, for the most part they are of little practical significance. Feedstuff digestibility may also occur with less differential in the grains and well controlled processed feeds such as U.S. soybean meal. More problems occur when one looks at feeds such as by-product meals where there may be differential inputs of fat, ash (from bone), whole carcass, etc. as well as different cooking conditions due to these changes. This can result in overcooking in some cases and leads to changes in digestibility values. One group of research samples of a meat product changed digestibilities each day of product output. Similar effects can be had in processed grain products where different levels of hull may be left in the product causing changes in fiber levels and thus potential changes in digestibilities of the product. The bottom line here is that one should attempt to get solid suppliers that provide a similar and consistent product.

Computer Input

There are several ways to input data into the computer. First, one can split things up based on new nutrients versus new ingredients. Using new nutrients is probably the method of choice if there are experienced operators doing the formulation. Basically, one adds new nutrients on to the database for each ingredient such that we now have lysine (or total lysine) and diglysine (or digestible lysine). If doing this from scratch, one would be best served by putting each amino acid and its digestible counterpart following for ease of comparison. Having taught computer formulation to novices (undergraduate students) for many years, we tend towards the other method which is to make separate feedstuffs for use of digestible values or corn (corn on total AA basis) versus digcorn (corn on a digestible AA basis). I have found there are fewer errors with this method as there is no question that they have chosen an ingredient based on digestible values.

The next data input question is how the digestibility values are calculated and entered. Two basic methods can be used: 1) Do the calculation first followed by input into the database. Basically, this involves taking the level of the total AA such as lysine multiplied by the digestibility coefficient in percent (%). So if lysine is 1.00% total basis multiplied by a digestibility coefficient of 85% the digestible lysine is .85%. In some cases, the coefficients are not expressed as percent and must be converted. 2) The other method is to input an equation into the database with the digestibility coefficient multiplied by the total AA such that the computer does the calculation. Again, the second method may be preferred by the experienced user, whereas the less experienced may do the calculations by hand or on a spreadsheet to keep things simpler.

Requirement Data

While there appears to be a good number of sources of data for digestibility coefficients, there is less data available on requirements for broilers and while data for layers is coming soon, I found nothing published in journals as yet. There are several ways to get values on a digestible basis. Before good data was out, many people used the NRC requirements multiplied by some averaged digestibility value (85-90%). Another way to come up with requirement data is to do what I refer to as *back calculation*. With this method, we will use a diet formulation based on a company's current total AA requirements and back calculate to determine the currently fed digestible requirements. This is easily done by using the method above to get the digestible AA into the database and adding new nutrients to the formulation (digestible lysine for instance). One then formulates on a total basis and then looks at the values obtained on a digestible basis to see what current requirements are being fed based on a digestible AA basis. These values are then used for the digestible requirements. The advantages of this are twofold. First, one will basically feed the same AA levels as are currently being fed and that one is comfortable with. Second, this allows us to compare the currently fed digestible requirements with the book values found through research on digestible values. Below are values for broilers from the group at Illinois based on their Illinois Ideal Protein Ratio (Tables 3 and 4). The ideal protein is the exact ratio of amino acids needed to provide optimal performance without excess and is based on lysine at 100% with all other AA in a ratio to lysine. Theoretically, as the requirement for lysine changes (for example from strain x to strain y), all other AA will change related to that.

Table 3. Predicted Requirements for Lysine, SAA, and Threonine at 8 Growth Periods

Period Day	Dig Lys % of diet	Dig SAA % of diet	Dig Thr % of diet
0 to 7	1.15	0.83	0.75
7 to 14	1.1	0.78	0.72
14 to 21	1.04	0.71	0.68
21 to 28	0.98	0.7	0.65
28 to 35	0.93	0.66	0.61
35 to 42	0.87	0.62	0.58
42 to 49	0.82	0.57	0.54
49 to 56	0.76	0.53	0.51

Table 4. Illinois Ideal Chick Protein

Amino Acid	%	Amino Acid	%
Lysine	100	Threonine	67
Arginine	105	Leucine	111
Histidine	37	Isoleucine	67
Methionine	36	Valine	77
Cystine	36	Tryptophan	16
Phenylalanine	55	Glycine + Serine	65
Tyrosine	50	Proline	44

A variety of factors potentially affect the requirements of the AA including gender, strain, age, temperature, energy content of the feed, etc. These factors have not been well researched to date.

Future Formulation Technologies

While making the switch to digestible formulation is the first step in moving towards more precise feeding, there are other steps that one can take in that direction. One of the next steps is formulation on an AA basis, where the protein constraint is totally removed. This requires excellent information on the digestible AA requirements such that the order of limitation is known to one AA beyond what is being provided as crystalline in the diet. This allows the protein to be as low as possible with intact protein providing the first limiting AA after the crystallines. Another area of interest is the lysine (in an ideal protein relationship) to energy ratio. This will help balance energy needs and AA needs more precisely as well as allowing for calorie cost formulation to be more effective. Ultimately, we will model all of the data and the computer will help with a great deal of the decision making needed in the future.

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Effects Of Processing On Nutrient Content Of Soybean Meal

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Introduction

Formulation of balanced diets is fundamental to economical animal production, and this process depends on the knowledge of nutrient requirements of the animal and the nutritional attributes of nutrient sources. The task of correctly assessing the protein nutritive value is rather challenging. The specific protein requirements must be established for each animal species of interest, with due considerations of the breeds, sex, age, weight, intended use, and other particulars of the animal. Also, amino acid contents of the protein source and their availability to animals require careful assessment.

Considerations In Proteins For Feeds

The fact that proteins differ greatly in nutritive value was first demonstrated grossly by comparing the performance of animals fed diets containing approximately the same amount of protein. It has been known that the less-than-desirable performance of an animal on a low-quality protein diet can be compensated for, to a large extent, by increasing the amount of the same low-quality protein. It has also been established that the nutritional quality of proteins is usually related to the amount and availability of amino acids in them, since the supplementation of diets containing low-quality proteins with appropriate amino acids improves their nutritive values.

Dietary requirements for protein are actually requirements for the amino acids contained in the dietary protein. These amino acids are used by animals to fulfill a series of functions. For example, amino acids, as proteins, are primary constituents of structural and protective tissues, such as skin, hair, feathers, bone matrix and ligaments as well as of the soft tissues, including organs and muscles. Also, the digested/absorbed amino acids and small peptides serve a variety of metabolic functions and as precursors of many important non-protein body constituents. An adequate intake of dietary amino acids is required because body proteins are in a dynamic state, with synthesis and degradation occurring continuously. If dietary protein (amino acids) is inadequate, there is a reduction or cessation of growth or productivity and a withdrawal of protein from less vital body tissues to maintain the functions of more vital tissues.

There are 18-21 amino acids that are physiologically essential for proper body functions and maintenance. Nutritionally, these amino acids are divided into essential and nonessential amino acids. Essential amino acids are those that the animal cannot synthesize at all or rapidly enough to meet metabolic requirements. They include arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. Nonessential amino acids are those that can be synthesized by the body in enough quantities from other amino acids, and include alanine, aspartic acid, cysteine, glutamic acid, glycine, proline, serine, and tyrosine. The essential amino acids must be supplied by the diet. If the diet does not provide adequate quantities of nonessential amino acids, the animal must synthesize them from essential amino acids. Thus, stating dietary requirements for both protein and amino acids is an appropriate way to ensure that all amino acids (both essential and nonessential) needed physiologically are provided for from diets.

Protein and amino acid requirements vary considerably according to the animal species, breeds, body size, growth rate, sex, reproductive state, etc. Genetic differences in amino acid requirements may occur because of differences in efficiency of digestion, nutrient absorption and metabolism of absorbed nutrients (NRC, 1975). Such factors, as dietary energy, bulk density and ambient temperature, that affect feed consumption also will affect quantitative intake of protein and amino acids which will consequently influence the dietary concentration of these nutrients needed to provide adequate nutrition (NRC, 1987).

Each amino acid can be metabolized independently of others, but relationships exist between certain amino acids, some with beneficial effects and some with antagonism. Shortfalls for cystine requirement can be met by methionine because two moles of methionine can be used to synthesize one mole of cystine, but the requirement for methionine can only be met by methionine. The need for tyrosine can be satisfied by phenylalanine because tyrosine is the initial degradation product of phenylalanine. Serine can be converted to glycine on a mole-to-mole basis, and this reaction is reversible. The essential amino acids are related to one another to support the need for production and maintenance. Requirement for any one essential amino acid represents the combined need for maintenance and production. Each essential amino acid is unique in its catabolism, and an inadequacy of any one of them (the first limiting) usually necessitates some catabolism of the others. The animal's response to amino acid deficiency can vary with the essential amino acid, the extent of its inadequacy and the existing relationships among the remaining essential amino acids. For example, animals performed better on diets with less-than-adequate amount of methionine/cystine, leucine, lysine, or arginine than on diets with inadequate quantities of all essential amino acids. On the other hand, animals lost additional weights when the amount of one of the following essential amino acids was reduced in diets: phenylalanine, tyrosine, tryptophan, isoleucine, valine or threonine.

Antagonisms exist between certain amino acids: leucine-isoleucine-valine, arginine-lysine, and threonine-tryptophan (D'Mello and Lewis, 1970), with the most practical importance on leucine-isoleucine antagonism. Certain feed combinations (i.e., corn plus corn gluten meal) can lead to practical diets with exceptionally high leucine levels while isoleucine is marginally adequate. Amino acid toxicity requires a particularly high level of one amino acid relative to all other amino acids. Such an occurrence is unlikely under practical circumstances because most of feedstuffs do not have such a large difference in amino acid contents. However, formulation error may lead to amino acid toxicity; excessive methionine is toxic (Ueda et al., 1981; Edmonds and Baker, 1987).

In general, the recommended requirements of proteins and amino acids are intended to support maximum growth and production. However, achieving maximum growth and production may not always ensure maximum economic returns, particularly when prices of protein sources are high. If a slightly decreased performance can be tolerated, dietary concentrations of amino acids may accordingly be reduced somewhat to maximize economic returns.

Prediction Of Protein Nutritive Values

It is well known that the nutritive value of a protein ingredient depends on the composition and availability of amino acids that vary greatly among ingredients. Many factors can influence the composition and availability of amino acids in grains and protein supplements. It is therefore desirable to know the amino acid composition of the actual ingredient to be used in the diet and their availability to animals for accurate and economical feed formulation. However, in general, it is not feasible to analyze all samples of feed ingredients for amino acid availability prior to their use in a particular feed formulation. Therefore, a series of indirect methods have been proposed and used to predict the nutritive value of protein ingredients that can be used in formulating the diets.

Kjeldahl nitrogen determination has been used as a quick and preliminary method to estimate the protein nutritive value of various ingredients. Although the method often overestimates the true protein content and does not give any information on the composition and availability of amino acids, it does provide gross crude protein content of the test material. Under many practical situations, the gross crude protein content data may provide sufficient information to formulate acceptable diets. Needless to say, this information becomes far more powerful and useful when used along with amino acid composition data.

Biological value (BV), defined as the percentage of ingested nitrogen retained in the body, has long been the choice for estimating the nutritive value of proteins. When combined with digestibility (D) data, BV reflects fairly well the nutritive value of the protein. These values are obtained by measuring the fecal and urinary nitrogen of an animal fed a test protein diet and then correcting for the amounts excreted when a nitrogen-free diet was fed.

$$D = \{ [I - (F - F_0)] / I \} \times 100$$

$$BV = \{ [I - (F - F_0) - (U - U_0)] / [I - (F - F_0)] \} \times 100$$

where, I is the nitrogen intake of test protein; F, fecal nitrogen; F_0, fecal nitrogen on a nitrogen-free diet; U, urinary nitrogen; and U_0, urinary nitrogen on nitrogen-free diet.

The overall nutritive value of a protein should then be obtained by BV x D, which is identical with Net Protein Utilization described below.

Determination of Net Protein Utilization (NPU) also provides an estimate of nitrogen retention by measuring the difference between the body nitrogen contents of animals fed no protein and those fed a test protein. This value, divided by the amount of protein consumed, is NPU, which is defined as the percentage of the dietary protein retained.

$$NPU = \{ [I - (F - F_0) - (U - U_0)] / I \} \times 100$$

In chemical score, sometimes called amino acid score, the content of each essential amino acid in the protein (A_x) is expressed first as a ratio of total essential amino acids (E_x) in the diet. These ratios are then expressed as percentages of the ratios between each amino acid in egg (A_e) and the total essential amino acids of egg (E_e). The chemical score (A_xE_e/A_eE_x) is the lowest of all these percentages. Chemical score can also be determined by another method. The content of each amino acid (A_x) in a test protein is expressed as a percentage of the same amino acid in the same amount of egg (A_e). The amino acid showing the lowest percentage is called the limiting amino acid and this percentage is the chemical score (A_x/A_e). The results obtained by these two methods are almost identical and have a rather high correlation ® = 0.86) with Biological Values when egg protein was used as the standard.

Qualitative differences in protein quality can be demonstrated by many methods. The Protein Efficiency Ratio (PER), defined as the weight gain per gram of protein eaten, has been the most widely used method because of its relatively simple procedure. In practice, corrected PER is calculated on the basis of an assumed PER of the standardized casein of 2.50 to normalize inter-laboratory variations.

Processing Effects On Soybean Meal Quality

Soybeans are rich in protein with well-balanced amino acid profile. However, soybeans contain several antinutritional factors that adversely affect protein nutrition unless they are properly controlled. Traditionally, soybeans are processed into defatted meals before they are used as ingredients to formulate diets, particularly for swine and poultry. During the past several years, however, increasing amounts of full-fat soybean meals have also been used as animal feeds. Several steps involved in manufacturing these products can have either positive or negative effect on the quality of the meal protein depending on the conditions used in the processing.

The single most important parameter that affects the soybean meal protein quality is the heat applied at different stages of processing. Proper processing conditions (moisture content, heating time and temperature) inactivate antinutritional factors (i.e., trypsin inhibitors, hemagglutinins, lectins, etc.) in soybean meal, which results in much improved growth when fed to monogastric animals (Araba, 1990a). The heat treatment must be controlled carefully because overheating can result in deterioration of protein quality by destroying heat-sensitive amino acids (methionine, lysine and cystine) and by causing Maillard reaction. Urease assays have generally been used by the feed industry in monitoring soybean meal quality because it is easier to determine urease activity than trypsin inhibitors and urease is more heat resistant than trypsin inhibitors. The U.S. feed industry has long used a maximum urease rise of 0.3 pH units as the standard for processing soybean meal for all types of poultry feeds. Damage to the soy protein from overheating is more serious when dietary lysine concentrations are marginal, and the heat damage can be monitored by measuring the solubility of the protein in potassium hydroxide solution either by the Kjeldahl or by the dye-binding method (Araba and Dale, 1990b; Kratzer et al., 1990).

In the classical soybean processing of conditioning, flaking and then extraction followed by desolventizing and toasting, a number of heat treatment steps are involved. Under the current commercial practice, the conditioning step has little effect on protein quality. The conditioning temperature (approximately 71°C, 11% moisture) is not high enough to denature the protein or inactivate urease and trypsin inhibitors. Flaking itself has no effect on protein quality either; however, more heat is required in the desolventizer/toaster to inactivate urease and trypsin inhibitors in thicker flakes, which will also denature more proteins. It is therefore very important to maintain uniform flake thickness of 0.25-0.3 mm to produce meals with desirable quality. After oil extraction, the meal has about 35% hexane hold-up, which is removed by directly injecting live steam. The desolventized meal with approximately 16-24% moisture is then toasted or cooked at 105-110°C for 15-30 minutes to bring the urease activity down to 0.2 pH units. A considerable amount of heat is required to bring the moisture level down to a safe cool storage level of about 12%. The protein solubility of the resulting product normally ranges between 80-85%, with reduced available lysine content of as much as 40% due to protein denaturation caused by excessive heat treatment.

Many soy processors currently use expanders to improve the efficiency of solvent extraction. Soybeans are dried to 10% moisture, cracked, dehulled, conditioned to about 11% moisture at 55-82°C, flaked to 0.3-0.5 mm thickness, expander processed with steam to exit temperatures of about 105-120°C to form collets, and cooled to 60°C for extraction. Due to the improved solvent percolation and drainage, resulting from the high porosity of the collets, the extracted collets have only about 20% hexane hold-up, 43% less than the flake. These collets can be desolventized and toasted using a considerably smaller amount of steam than flake, leaving less moisture in the meal from collets, about 13.5% (Watkins, 1998). This level of moisture is high enough to effectively inactivate the urease to 0.3 pH units and easy to dry the product with cooling alone to the desired storage moisture level with minimum protein denaturation (protein solubility of about 90-92%) and consequently with minimum loss of protein nutritive value. A complete study on the availability of amino acids will be necessary to fully understand the implications. However, poultry and swine feeding trials at Texas A&M University and others indicate that the product (SoyMAX®) provides higher rates of amino acid digestibility and higher energy values that produce better feed conversion rates and higher body weight gains (Wright, 1998). When combined with other factors, such as increased plant capacity and slightly more oil yield, the expander process becomes an attractive option. It almost doubles the plant capacity, saves energy, saves equipment cost, and produces finished meals with high protein solubility and improved nutritive value over the classical flake method.

Dry extruders are used to prepare full-fat soybean meals. While this process is very effective in inactivating various antinutritional factors, the excessively high operating temperature (somewhere around 150°C) is detrimental to protein nutrition even at the relatively low moisture level used in the process. However, the recently developed double-expander process has been reported to produce full-fat soybean meals (Super Soy) with high lysine availability and low trypsin inhibitor activity.

Other processes used to produce full-fat soybean meals include cooking/autoclaving, micronizing, and roasting. Cooking is a relatively simple and straightforward method. The raw beans are soaked and then boiled at least 30-120 minutes, dried and fed to animals as whole, ground or rolled. Autoclaving is another cooking procedure under steam pressure. These processes are however inefficient and not flexible.

Micronizing is a process of cooking soybeans with the heat generated by vibrating molecules under the influence of infrared rays. Some European countries have used this method primarily to produce human food due to its high investment and operational costs.

Roasting is a process of dry heating soybeans at 110-170°C, depending on the type of equipment used and the desired nutritive value of the full-fat soybean meal. The various types of roasting range from salt bed or heated ceramic tile roasting to common grain dryers and conventional rotary drum type roasters to fluidized bed and hot air roasters. Various types of rotary drum type roasters are popular for full-fat soybean meal processing because of the low investment cost, portability and simplicity of operation. This type roasters are direct fired, and the quality, uniformity, degree of cooking, and color of products can vary greatly. The fluidized bed system utilizes superheated and pressurized air to roast the beans under controlled temperature and residence time. This method is highly efficient, versatile, dependable, uniform, clean, simple and cost effective in roasting full-fat soybean meals.

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Notes