Response of broiler chickens to processed soy protein product when offered at different inclusion levels in mash or crumbled prestarter diets

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Primary Audience: Poultry Nutritionists, Researchers, Feed manufacturers

SUMMARY

This study investigated the effects of varying levels (0, 50, and 100 g/kg) of a processed soy protein product (PSP), fed to chicks in mash or crumbled form up to 10 d posthatch on the gross performance, carcass quality, nutrient digestibility and digestive enzyme activities in broiler chickens. A total of 324 Ross 308 male day-old broiler chicks were used in 6 replicates per group, with 9 birds per replicate. Between hatch and 24 d, birds fed crumbled diets had higher ($P < 0.05$) body weight gain and feed intake than those fed mash diets, with the exception of those fed control mash diet. There was no significant effect of feed form, PSP levels in diets or their interactions on the ileal digestibility of nutrients. However, the total tract digestibility of crude protein and gross energy decreased ($P < 0.05$) with increasing PSP inclusion level. Increasing levels of PSP in diets increased ($P < 0.001$) tissue protein content at 24 d of age. Also, sucrase activity of broiler chickens fed on crumbled diets was significantly ($P < 0.009$) higher than was observed in mash-fed birds. Feed form is an important factor when processed soy protein is supplemented in prestarter diet and may improve growth and development of digestive functions later in the life of the birds.

Key words: Body weight, broiler chicks, early nutrition, feed forms, prestarter diets, soy protein

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DESCRIPTION OF PROBLEM

The benefits of early nutrition, i.e., the nutrition provided to newly hatched chicks within the first 10 d of age [1] have become a subject of interest to poultry nutrition researchers and the poultry industry. This may be as a result of observed negative effects imposed on development and growth of broiler chickens by delayed access to feed and water posthatch. The early posthatch or starter period of broiler chickens now represents a much larger proportion of the growing cycle, accounting for at least 20% of the total production cycle of broilers [2], which stresses the importance of early access to feed in order to take full advantage of the broiler's growth potential [3]. Hence, providing birds with pre-starter/starter diets containing readily available nutrients within the first few days (1 to 10 d) posthatch seems to be one option to mitigate the effects of delayed access, and to maximize the growth performance of newly hatched chicks.

The prestarter diet is the special diet provided to broilers in the first few days posthatch. The

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essence of a prestarter diet is to provide newly hatched chicks with feed as early as possible after hatch that is able to enhance intestinal development so that nutritional and digestive functions can commence in the early life of the chicks. Formulating prestarter diets requires inclusion of highly digestible nutrients in the diets for use by broiler chicks. To meet the nutrient requirements for prestarter diets, ingredients rich in such nutrients need to be provided.

Therefore, the use of high-quality feed ingredients that are rich in digestible nutrients, especially amino acids, is very important in this phase of broiler chick life for faster organ development and growth performance of the chicks. It has been previously indicated that amino acid needs were most critical during the bird's early life for optimization of breast meat yield later in life, and supported by a follow-up finding that feeding more amino acids early in a bird's life is economically advantageous because feed intake is low and potential growth improvements are high [4,5]. More so, Longo et al. [6] reported that the inclusion of highly digestible ingredients might enhance feed intake, nutrient digestibility, and growth performance early in life.

Broiler chickens for the first few days posthatch are typically fed diets either as mash or, more frequently, broken pellet (crumbles). The effects of feeding crumbles or pellets on growth performance of broilers have been studied [7–9]. Under commercial conditions, broilers are frequently fed crumbled diets from the starter to grower phase, and then fed pellets to slaughter. However, few studies have been conducted to compare growth performance of broilers fed mash or crumbles at the early phase, followed by pellets from the grower phase to slaughter [10].

However, while the use, and effects of amino acid-rich feed ingredients in prestarter diets [11] and varying feed forms for early phase feeding in broiler chickens is not new, how these 2 may interact on performance that can be sustained to market age is less known. A processed soy protein with high-quality amino acids and low antinutritional content used in different feed forms may improve growth and development of broiler chickens. The objective of this study was to determine the response of broiler chickens to early supplementation of a high-quality soy protein in different feed forms at later age in terms of growth performance, carcass quality, nutrient digestibility and digestive enzyme activities.

MATERIALS AND METHODS

This experiment was approved by the Animal Ethics Committee of the University of New England (Approval number AEC15–043). Health and animal husbandry practices complied with the Code of Practice for the Use of Animals for Scientific Purposes issued by the Australian Bureau of Animal Health [12].

Experimental Design and Bird Management

This experiment was set up to investigate the effects of varying levels of processed soy protein product (**PSP**) [13] in 2 forms of prestarter diets fed up to 10 d posthatch on the gross performance, carcass quality, nutrient digestibility, and digestive enzyme activities in broiler chickens. The test product, PSP (a highly processed soy protein concentrate), (Table 1), was supplemented in replacement for soybean meal. A total of 324 Ross 308 male day-old broiler chicks [14], (initial weight, 34.48 ± 0.40 g) randomly distributed in a 3 × 2 factorial arrangement were provided with a control diet or a diet containing either 50 (low) or 100 g/kg (high) of PSP in the diet, in either mash or crumbled form for 10 d. The diets were of identical nutrient profiles and formulated to meet the breeder's specifications of nutrient requirements (Table 2). Each dietary group was replicated 6 times, with 9 birds per replicate. After 10 d, birds were provided similar pelleted commercial-type grower (11 to 24 d) and finisher (25 to 35 d) diets for the rest of the feeding trial (Table 3).

Titanium dioxide (**TiO_2**), an indigestible marker, was added to the starter and grower diets at a rate of 5 g/kg diet for the purpose of assessing nutrient digestibility. Feed and water were supplied ad libitum. Chickens were reared in multi-tiered brooder cages (600 × 420 × 23 cm), placed in a climate-controlled room. The room temperature was gradually decreased from 33°C on d 1 to 24 ± 1°C at 35 d. Lighting was provided following Ross 308 management specification. On 8 to 10 d, excreta samples were collected in plastic containers daily and frozen immediately at –20°C until samples were ana-

Table 1. Nutrient composition of the processed soy protein (PSP) tested in the study.

Nutrient (g/kg)	
Dry matter	930.0
ME poultry (kcal/kg)	2284
Crude protein	556.0
Crude fat	25.0
Starch	30.0
Amino acids (g/kg)	
Arginine	38.9
Lysine	32.2
Methionine	7.5
Cysteine	7.8
Methionine + cysteine	15.3
Tryptophan	7.5
Glycine	23.7
Histidine	14.2
Leucine	41.4
Isoleucine	25.6
Phenylalanine	27.5
Threonine	21.7
Tyrosine	19.5
Valine	26.7
Serine	28.6
Alanine	24.6
Aspartic acid	62.2
Glutamic acid	99.4
Proline	9.6
Minerals (g/kg)	
Calcium	2.50
Sodium	0.40
Total phosphorus	8.00
Chloride	0.625
Magnesium	3.5
Iron (mg/kg)	200.0
Manganese (mg/kg)	50.0
Zinc (mg/kg)	60.0

lyzed for nutrient contents. On d 10, 24, and 35, the birds and feed were weighed to measure the body weight gain (**BWG**), feed intake (**FI**) and feed conversion ratio (**FCR**; feed intake/weight gain).

$$Digestibility\ coefficient = 1 - \frac{Digesta\ nutrient\left(\frac{g}{kg}DM\right)/Digesta\ TiO2\left(\frac{g}{kg}DM\right)}{Diet\ nutrient\left(\frac{g}{kg}DM\right)/Diet\ TiO2\left(\frac{g}{kg}DM\right)}$$

On 10 d, one bird of average group weight was selected from each replicate, while 2 birds were similarly selected on 24 d and were killed by cervical dislocation. The abdominal cavity of the birds was opened and the internal organs were removed and weighed. On both days, the whole pancreas and a part of the proximal jejunum were collected for the measurement of digestive enzyme activities. Also, ileal digesta was collected in plastic containers on d 24 and frozen at –20°C until samples were analyzed for nutrient contents. The collected excreta and ileal digesta samples were later freeze-dried [15] and ground, using a small coffee grinder. The ground samples were stored at 4°C in airtight plastic containers until analyzed for Ti, minerals, crude protein, gross energy and amino acids. Carcass weight and the weight of breast meat, (without bone), thighs, drumsticks and wings were taken from sampled birds and recorded at d 35. The relative part weight was calculated as mass per unit live BW (g/kg of live BW).

Ileal and Total Tract Digestibility of Nutrients

The Ti and other mineral contents of the ileal digesta excreta and feed samples were determined according to the method described by Morgan et al. [16], using the inductively coupled plasma-optical emission spectrometry (ICP-OES) [17]. The concentrations of Ti and of nutrients in the ileal digesta, feed, and excreta samples were used to calculate the ileal and total tract digestibility of nutrients. The nitrogen content of the samples was determined according to Dumas' combustion technique following the method described by Sweeney [18] using LECO® TruSpec Carbon and Nitrogen Analyser [19].

The gross energy (**GE**) value of the samples was obtained digitally from a calorimeter [20]. The ileal digesta and feed samples were analyzed for amino acids (AA) at the Australian Proteome Analysis Facility located at Macquarie University, Sydney [21]. The digestibility coefficient of nutrients was calculated using the following equation:

Tissue Protein and Digestive Enzyme Activities

To evaluate the activity of digestive enzymes and protein concentration, the jejunal tissue was processed according to the method described by Susbilla et al. [22]. The pancreas was pro-

Table 2. Ingredient and nutrient composition of the starter diets used in the study.

	PSP levels (g/kg)					
Starter	Mash			Crumbled		
	0	50	100	0	50	100
Ingredients (g/kg)						
Corn	305.2	400	436.5	305.2	400	436.5
Wheat	254	164.5	139.5	254	164.5	139.5
Soybean meal	305.2	253.0	190.5	305.2	253.0	190.5
Canola meal	20	25	27.5	20	25	27.5
Meat meal	41.8	35.0	35.0	41.8	35.0	35.0
Canola oil	29.9	27.6	25.0	29.9	27. 6	25.0
PSP	-	50	100	-	50	100
Limestone	9.6	11.0	9.0	0.96	1.10	0.9
Dicalcium Phosphate[1]	11.1	11.1	14.8	11.1	11.1	14.8
Salt	1.3	1.4	1.3	1.3	1.4	1.3
Sodium bicarbonate[2]	1.8	2.0	2.0	1.8	2.0	2.0
TiO_2	5.0	5.0	5.0	5.0	5.0	5.0
Vit and mineral premix[3]	3.9	3.7	3.5	3.9	3.7	3.5
Choline chloride	0.8	1.2	1.6	0.8	1.2	1.6
L-lysine HCl	3.5	3.2	3.0	3.5	3.2	3.0
DL-methionine	3.8	3.7	3.6	3.8	3.7	3.6
L-threonine	1.9	1.6	1.3	1.9	1.6	1.3
Avizyme 1300[4]	0.5	0.5	0.5	0.5	0.5	0.5
Ronozyme Hi-Phos[5]	0.5	0.5	0.5	0.5	0.5	0.5
Nutrient composition						
ME (kcal/kg)	2997.52	2997.52	2997.52	2997.52	2997.52	2997.52
Crude protein	231.4	230.0	230.0	231.4	230.0	230.0
Dig. lysine	13.2	13.2	13.1	13.2	13.2	13.1
Dig. methionine	6.8	6.7	6.6	6.8	6.7	6.6
Dig. arginine	13.9	13.9	13.8	13.9	13.9	13.8
Dig. methionine + cysteine	9.5	9.5	9.5	9.5	9.5	9.5
Dig. threonine	8.3	8.3	8.3	8.3	8.3	8.3
Calcium	10.5	10.5	10.5	10.5	10.5	10.5
Available phosphorus	5	5	6	5	5	6
Sodium	1.6	1.6	1.6	1.6	1.6	1.6
Choline	1.6	1.6	1.6	1.6	1.6	1.6

[1]Dicalcium phosphate; [2]Sodium bicarbonate, [3]Vitamin and mineral premix (supplied activity per ton of feed): Cu (sulphate), 8 g; Fe (sulphate), 60 g; I (iodide), 1.0 g; Se (selenate), 0.3 g; Mn (Manganese), 80 g; Zn (sulphate and oxide), 60 g; Mo (Molybdenum), 1 g; Cobalt (Co), 0.3 g; Vitamin A (retinol), 12 MIU; Vitamin D3 (cholecalciferol), 3.5 MIU; Vitamin E (tocopherol acetate), 40 g, Vitamin K3 (menadione), 2 g; Thiamine (Vitamin B1), 2 g; Riboflavin (B2), 6 g; Niacin (B3), 50 g; Pantothenic Acid (B5), 11 g; Pyridoxine Hydrochloride (B6), 5 g; Folate (Vitamin B9), 1.5 g; Biotin (vitamin H), 100 mg; Cyanocobalamin (Vitamin B12), 20 mg; Antioxidant, 25 g. [4]Xylanase+amylase+protease; [5]Phytase.

cessed in a similar way, except that the entire organ homogenised. The homogenate was then centrifuged at 30,000 $\times$ *g* [23] for about 15 minutes at 4°C. Subsamples of supernatant were then taken in duplicate of 1.5 mL into Eppendorf tubes and stored in a freezer (–20°C) until assayed for enzyme activities.

The specific activities of jejunal maltase and sucrase were assessed by incubation with fixed substrate concentrations as standardized for poultry by Iji et al. [24], while aminopeptidase activity was assessed as described by Caviedes-Vidal and Karasov [25]. The pancreatic trypsin and chymotrypsin activities were assessed using methods described by Erlanger et al. [26] and modified by Caviedes-Vidal and Karasov [25]. The concentration of protein in both the jejunal and pancreatic tissue homogenate was measured using the Comassie dye-binding procedure described by Bradford [27].

Table 3. Ingredient and nutrient composition of the grower and finisher diets used in the study.

Ingredients (g/kg)	Grower	Finisher
Corn	420	474.2
Wheat	150	150
Soybean meal	274.4	189.3
Canola meal	21.7	60
Meat and bone meal	40	50
Canola oil	47.1	51.4
Limestone	7.3	4.8
Dicalcium phosphate	8.7	3.3
Salt	1.5	1.2
Sodium bicarbonate	1.7	1.9
TiO_2	5.0	-
Vit and mineral premix[1]	4.0	4.0
Choline chloride	0.1	1.1
L-lysine HCl	3.1	2.8
DL-methionine	3.4	2.8
L-threonine	11.0	2.2
Avizyme 1300[2]	0.5	0.5
Ronozyme Hi-Phos[3]	0.5	0.5
Nutrient composition		
ME (kcal/kg)	3097.83	3198.15
Crude protein	215	195
Dig. lysine	11.9	10.6
Dig. methionine	6.2	5.5
Dig arginine	12.5	11.1
Dig. methionine + cysteine	8.7	8.0
Dig. threonine	17.0	7.8
Calcium	9.0	7.8
Available phosphorus	4.5	3.9
Sodium	1.6	1.6
Choline	1.6	1.5

[1]Composition as in Table 2;
[2]xylanase+amylase+protease; [3]Phytase.

Data Analysis

Statistical analyses were performed using Minitab® 17 [28]. The data were subjected to general linear model and tested for significance between the treatment means by Fisher's multiple range test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Gross Performance

On d 10, the gross responses of broiler chickens were affected by feed form and PSP level ($P < 0.05$), while the interaction between both factors did not have any effect ($P > 0.05$) on the gross response of the birds at this age (Table 4). Generally, feed intake, BWG and FCR were better ($P < 0.05$) in the birds fed crumbled diet, compared to their mash-fed counterparts. Again, BWG in the control mash diet group was significantly ($P < 0.05$) higher than in the group fed 100 g PSP/kg in mash diet. Birds fed the control mash diet had better ($P < 0.05$) FCR than those fed 50 or 100 g PSP/kg in mash diet to d 10.

Between hatch and 24 d, birds fed crumbled diets had higher ($P < 0.05$) feed intake than those fed mash diets, with the exception of those fed control mash diet (Table 5). Similarly, crumble-fed birds had higher ($P < 0.04$) BWG than those on mash. Feed conversion ratio was not affected by either of the 2 factors or their interaction.

There was no significant ($P > 0.05$) effect of feed forms, PSP levels and their interactions on gross responses of the birds from one to 35 d (Table 6). The levels of inclusion of PSP levels did not have any effect ($P > 0.05$) on BWG of broilers. There was no significant ($P > 0.05$) effect of feed form, PSP inclusion level and their interactions on FCR.

The results of the study showed that feeding broilers with crumbled diets with or without PSP supplementation during the first 10 d improved the feed intake for up to 24 d, after which this response weakened. This response seems to indicate that the inclusion of PSP in the prestarter diets for broiler chicks may be more effective in crumbled diets than in mash diets. However, the observed improvement may also be related to feed form, since both mash and crumbled diets were supplemented with equal levels of PSP. Feed refusal, which is part of voluntary consumption and feed wastage may have also contributed to the observed differences in feed intake, even though such wastage has once been reported to be higher in crumbled (11.6 g/d) than in mash (10.9 g/d) diets [29]. At this early stage, feed particle size of mash diets may be too small, making it difficult to consume enough per time. While there were no interactive effects between PSP inclusion levels and feed forms on BWG, the crumbled diets improved the birds' BWG, to 24 d more than did mash. Birds are known to have a preference for larger feed particles and tend to choose feed size according to variations in their oral cavities [30]. This may have resulted in the increased feed intake also observed in the same group of birds on crumbled diets. Again,

Table 4. Effect of levels of PSP and feed forms on response of broiler chickens from hatch to 10 d of age.

Feed form	PSP level (g/kg)	Feed intake	BWG	FCR
Mash	0	263.20	230.83	1.14
	50	260.60	212.73	1.23
	100	257.50	205.62	1.25
Crumbled	0	295.81	284.75	1.04
	50	287.52	277.00	1.04
	100	294.05	273.02	1.08
SEM		3.50	6.11	0.016
Main effects				
Mash		260.43[b]	216.40[b]	1.21[a]
Crumbled		292.46[a]	278.25[a]	1.05[b]
	0	279.50	257.79	1.09[b]
	50	274.05	244.86	1.13[a]
	100	275.77	239.32	1.17[a]
Source of variation (P-value)				
Feed form		0.000	0.000	0.000
PSP level (g/kg)		0.628	0.056	0.002
Feed form × PSP level (g/kg)		0.702	0.648	0.059

Mean values in the same column not sharing a superscript are significantly different ($P < 0.05$); SEM = Standard error of mean.

Table 5. Effect of levels of PSP and feed forms on response of broiler chickens from hatch to 24 d of age.

Feed form	PSP level (g/kg)	Feed intake	BWG	FCR
Mash	0	1365.3	1166.2	1.17
	50	1307.1	1095.5	1.20
	100	1334.6	1134.1	1.17
Crumbled	0	1448.0	1249.0	1.16
	50	1401.4	1254.2	1.11
	100	1456.0	1232.9	1.17
SEM		16.40	14.90	0.010
Main effects				
Mash		1335.6[b]	1131.9[b]	1.18
Crumbled		1435.1[a]	1245.4[a]	1.15
	0	1406.7	1207.6	1.17
	50	1354.2	1174.9	1.15
	100	1395.3	1183.5	1.17
Source of variation (P-value)				
Feed form		0.002	0.000	0.739
PSP level (g/kg)		0.315	0.503	0.146
Feed forms × PSP level (g/kg)		0.857	0.387	0.195

Mean values in the same column not sharing a superscript are significantly different ($P < 0.05$); SEM = Standard error of mean.

the benefits of supplementing the diets at early stage with PSP may have been lost to the inability of the birds fed mash diet to consume enough feed, due to the generally smaller feed particles. However, there seemed to be some degree of compensatory growth in birds fed mash so that by d 35 all birds had statistically similar BWG, even though there was a difference of about 3.80% between the heaviest birds on crumbled and those on mash.

In an earlier study [1], mash or crumbled feed followed by pellets resulted in similar performance in later periods. Birds on crumbled diets were more efficient in feed conversion, all through the production cycle in the current study. Earlier in the life of the birds, the rate of feed conversion was better in birds fed the diets not containing PSP. This improved conversion efficiency was not observed during the grower phase. The initial improvement in feed

Table 6. Effect of levels of PSP and feed forms on growth performance of broiler chickens at 35 d of age.

Feed form	PSP level (g/kg)	Feed intake	BWG	FCR
Mash	0	3396	2110	1.61
	50	3298	2051	1.61
	100	3353	2143	1.57
Crumbled	0	3363	2084	1.63
	50	3236	2095	1.55
	100	3367	2226	1.52
SEM		123	28	0.059
Main effects				
Mash		3349	2101	1.60
Crumbled		3322	2135	1.56
	0	3379	2097	1.62
	50	3267	2073	1.58
	100	3360	2184	1.54
Source of variation (P-value)				
Feed form		0.791	0.606	0.521
PSP level (g/kg)		0.600	0.377	0.445
Feed form × PSP level (g/kg)		0.954	0.796	0.770

SEM = Standard error of mean.

conversion at the early phase may have been caused mainly by differences in FI in the early period of growth.

Visceral Organ Weight

The relative organ weight of liver ($P < 0.05$), gizzard plus proventriculus ($P < 0.001$), small intestine and pancreas ($P < 0.001$) at 10 d was lower in birds fed crumbled diets than in birds on mash (Table 7). There was no significant ($P > 0.05$) effect of PSP levels on relative organ weights at 10 d. The interactions between feed form and PSP level were significant with respect to the relative weight of gizzard plus proventriculus ($P < 0.05$), small intestine ($P < 0.001$) and pancreas ($P < 0.05$). No such interactions were observed for the other visceral organs.

However, by the end of the grower phase (d 24), feed form was the only factor that had a significant ($P < 0.05$) effect on relative weight of visceral organs, with the gizzard plus proventriculus being heavier in birds fed mash diet (Table 8). Inclusion level of PSP and the interactions between feed form and PSP level did not have any effect on visceral organs at d 24.

In the present study, feeding mash diets with or without PSP supplementation improved the development of the digestive organs of birds than in birds fed crumbled diets. The gizzard plus proventriculus, small intestine and pancreas were heavier at 10 d of age in birds fed mash diets, with an interaction effect between the feed form and PSP level in the 2 latter organs. However, only the feed form effect was maintained in gizzard/proventriculus up to d 24. It may be that the mash diets are retained longer in the gizzard plus proventriculus, allowing for a longer time of activity and mechanical stimulation in it, than the crumbled diets. The heavier weights of the gizzard/proventriculus and pancreas suggest a greater activity of the gizzard and pancreas in the birds fed mash diets. The interaction that was observed during early growth would suggest the involvement of the PSP inclusion too. This is in agreement with Serrano et al. [29] and Engberg et al. [31], who had also reported that birds fed mash diets in an experiment involving varying sources of soybean meal and different feed forms had heavier gizzards than those on crumbled diets.

It has been postulated that a well-developed gizzard may increase nutrient digestibility [32], which is expected to improve performance, but that was not the case in the present study, as the results show lower performance in birds fed mash diets. An increase in the weight of pancreas is essential to secretion of enzymes and this may have been potentially induced by the mash diets used in this study. Since the small intestine is the site of terminal digestion and absorption

Table 7. Effect of levels of PSP and feed forms on relative organ weights (g/100 g body weight) of 10-d old broiler chickens.

Feed form	PSP level (g/kg)	Heart	Liver	G + P	SI	Bursa	Spleen	Pancreas
Mash	0	0.78	3.7	6.0[a]	8.6[a]	0.18	0.08	0.54[a]
	50	0.83	4.0	5.8[a]	8.9[a]	0.17	0.08	0.57[a]
	100	0.83	3.8	5.8[a]	8.1[a,b]	0.19	0.07	0.54[a]
Crumbled	0	0.91	3.5	5.8[b]	6.9[c]	0.17	0.07	0.39[b]
	50	0.84	3.6	5.0[b]	7.3[b,c]	0.16	0.08	0.42[b]
	100	0.85	3.6	5.1[b]	7.2[b,c]	0.18	0.07	0.49[a,b]
SEM		0.021	0.07	0.11	0.18	0.007	0.002	0.019
Main effects								
Mash		0.82	3.83[a]	5.8[a]	8.5[a]	0.18	0.08	0.55[a]
Crumbled		0.87	3.54[b]	5.0[b]	7.1[b]	0.17	0.07	0.43[b]
	0	0.85	3.6	5.5	7.7	0.17	0.07	0.47
	50	0.83	3.8	5.4	8.1	0.17	0.08	0.50
	100	0.84	3.7	5.4	7.6	0.19	0.07	0.52
Source of variation (P-value)								
Feed form		0.224	0.042	0.001	0.001	0.361	0.499	0.001
PSP level (g/kg)		0.966	0.638	0.749	0.365	0.578	0.379	0.466
Feed form × PSP level (g/kg)		0.420	0.733	0.003	0.001	0.984	0.651	0.010

Mean values in the same column not sharing a superscript are significantly different ($P < 0.05$); G + P = gizzard plus proventriculus; SI = small intestine; SEM = Standard error of mean.

Table 8. Effect of levels of PSP and feed forms on relative organ weights (g/100 g body weight) of 24-d old broiler chickens.

Feed form	PSP level (g/kg)	Heart	Liver	G + P	SI	Bursa	Spleen	Pancreas
Mash	0	0.72	2.7	2.7	4.9	0.21	0.09	0.23
	50	0.77	2.7	3.0	4.5	0.20	0.08	0.22
	100	0.74	2.8	2.9	4.9	0.20	0.08	0.23
Crumbled	0	0.72	2.7	2.4	4.4	0.20	0.08	0.21
	50	0.73	2.6	2.5	4.6	0.16	0.08	0.21
	100	0.73	2.7	2.7	4.4	0.15	0.08	0.20
SEM		0.020	0.04	0.08	0.10	0.009	0.003	0.007
Main effects								
Mash		0.74	2.8	2.8[a]	4.8	0.20	0.08	0.23
Crumbled		0.73	2.7	2.5[b]	4.5	0.17	0.08	0.21
	0	0.72	2.7	2.5	4.7	0.20	0.08	0.22
	50	0.75	2.7	2.7	4.5	0.18	0.08	0.21
	100	0.74	2.8	2.8	4.6	0.17	0.08	0.22
Source of variation (P-value)								
Feed form		0.592	0.299	0.038	0.134	0.101	0.793	0.175
PSP level (g/kg)		0.702	0.672	0.370	0.860	0.448	0.971	0.873
Feed form × PSP level (g/kg)		0.846	0.980	0.753	0.398	0.856	0.693	0.784

Mean values in the same column not sharing a superscript are significantly different ($P < 0.05$); G + P = gizzard plus proventriculus; SI = small intestine; SEM = Standard error of mean

of most nutrients [33], it was expected that a heavier small intestine would lead to improvement in digestion and absorption, resulting in better performance. This was not the case in the present study, and the reason for this response is unclear, but this finding could have possibly be confounded by weighing intestine with contents.

Carcass Parts Yield

There was no significant ($P > 0.05$) effect of feed form, PSP inclusion level, or their interactions on the carcass traits of broiler chickens on d 35 (Table 9). This finding agrees with Longo et al. [6] and Ullah et al. [34], who did not observe any improvement in carcass composition

Table 9. Effect of levels of PSP and feed forms on dressing percentage and weight of carcass parts of broiler chickens at 35 d of age.

Feed form	PSP level (g/kg)	Dressing %	Breast (g/kg)	Thighs (g/kg)	Drumsticks (g/kg)	Wings (g/kg)
Mash	0	75.2	196.1	124.2	118.6	102.7
	50	74.3	198.0	123.2	112.6	104.0
	100	75.2	202.6	127.4	115.4	107.0
Crumbled	0	74.8	203.1	128.4	114.0	104.0
	50	74.0	194.0	126.5	114.7	102.8
	100	76.2	212.2	128.1	114.7	105.0
SEM		0.29	2.42	0.084	0.085	1.27
Main effects						
Mash		74.89	198.8	125.0	115.6	105.0
Crumbled		75.11	203.1	127.7	114.5	104.5
	0	75.00	200.0	126.3	116.2	10.34
	50	74.12	195.8	124.8	113.6	10.34
	100	75.70	207.4	127.8	115.0	10.56
Source of variation (P-value)						
Feed form		0.856	0.143	0.109	0.488	0.809
PSP level (g/kg)		0.090	0.371	0.364	0.484	0.735
Feed form × PSP level (g/kg)		0.551	0.485	0.669	0.258	0.874

SEM = Standard error of mean.

Table 10. Ileal digestibility of gross energy, crude protein and minerals at 24 d of age in response to different levels of PSP and feed forms.

Feed form	PSP level (g/kg)	Crude protein	Gross energy	P	K
Mash	0	0.73	0.66	0.12	0.86
	50	0.74	0.67	0.12	0.83
	100	0.72	0.66	0.06	0.86
Crumbled	0	0.71	0.65	0.11	0.84
	50	0.73	0.66	0.12	0.87
	100	0.72	0.64	0.14	0.84
SEM		0.006	0.007	0.016	0.005
Main effects					
Mash		0.73	0.66	0.10	0.85
Crumbled		0.72	0.65	0.13	0.85
	0	0.72	0.65	0.12	0.85
	50	0.73	0.67	0.12	0.85
	100	0.72	0.65	0.10	0.85
Source of variation (P-value)					
Feed form		0.474	0.544	0.936	0.846
PSP level (g/kg)		0.584	0.573	0.470	0.999
Feed form × PSP level (g/kg)		0.981	0.964	0.408	0.109

P = Phosphorus; K = Potassium, SEM = Standard error of mean.

when birds were fed high levels of protein and digestible amino acid (lysine), respectively in prestarter diets.

Ileal and Total Tract Digestibility of Nutrients

There was no significant effect of feed form, PSP inclusion level in diets or their interactions on the ileal digestibility of protein, gross energy, and the 2 minerals analyzed in broiler chickens at 24 d of age (Table 10).

The total tract digestibility of crude protein, gross energy, and sulphur was higher ($P < 0.05$) in birds fed mash diets (Table 11). Crude protein and gross energy digestibility decreased ($P < 0.05$) with increasing PSP inclusion level, with coefficients of digestibility higher in birds on diets without PSP inclusion. Birds fed diets with 50 or 100 g PSP/kg inclusion were similar in total tract digestibility of minerals but lower ($P < 0.05$) than in birds fed diets without PSP.

Table 11. Total tract digestibility of gross energy, crude protein and minerals of 24-d old broiler chicks fed different levels of PSP and feed forms.

Feed form	PSP level (g/kg)	Crude protein	Gross energy	Ca	P	Na	Cu	S
Mash	0	0.67[a]	0.77[a]	0.53	0.57	0.80	0.43[b]	0.58[a]
	50	0.66[a]	0.77[a]	0.52	0.53	0.71	0.37[b]	0.55[a]
	100	0.50[c]	0.65[d]	0.44	0.43	0.68	0.14[c]	0.44[b]
Crumbled	0	0.62[a,b]	0.74[a,b]	0.36	0.46	0.60	0.16[c]	0.42[b,c]
	50	0.51[c]	0.67[c,d]	0.19	0.34	0.43	0.10[c]	0.28[d]
	100	0.58[b]	0.71[b,c]	0.24	0.35	0.46	0.57[a]	0.35[c,d]
SEM		0.015	0.010	0.026	0.018	0.025	0.035	0.021
Main effects								
Mash		0.60[a]	0.73[a]	0.50[a]	0.20[a]	0.73[a]	0.31	0.53[a]
Crumbled		0.57[b]	0.70[b]	0.26[b]	0.04[b]	0.50[b]	0.28	0.35[b]
	0	0.65[a]	0.75[a]	0.45[a]	0.22[a]	0.70[a]	0.36[a]	0.50[a]
	50	0.59[b]	0.72[b]	0.35[b]	0.09[b]	0.57[b]	0.30[a,b]	0.42[b]
	100	0.53[c]	0.68[c]	0.34[b]	0.06[b]	0.57[b]	0.23[b]	0.40[b]
Source of variation (P-value)								
Feed form		0.036	0.018	0.001	0.001	0.001	0.343	0.001
PSP level (g/kg)		0.001	0.001	0.014	0.001	0.001	0.045	0.003
Feed form × PSP level (g/kg)		0.001	0.001	0.086	0.175	0.447	0.001	0.015

Mean values in the same column not sharing a superscript are significantly different ($P < 0.05$); Ca = Calcium; P = Phosphorus; Na = Sodium; Cu = Copper; S = Sulphur; SEM = Standard error of mean.

The interactions between feed form and PSP inclusion level affected total tract digestibility of crude protein ($P < 0.01$), gross energy ($P < 0.01$), copper ($P < 0.01$) and sulphur ($P < 0.05$).

The ileal digestibility of amino acids in broiler chickens fed different levels of PSP in either mash or crumbled diets at d 24 of age was not affected ($P > 0.05$) by feed form, PSP inclusion level or their interaction (data not shown). Generally, the highest coefficients of digestibility were observed in some key essential amino acids across all treatments when birds were fed a mash diet with 50 g PSP/kg inclusion.

In the present study, feed form, PSP inclusion level and their interactions did not have any effect on ileal digestibility of the nutrients assessed after 24 d of age. However, the total tract digestibility of protein, energy, and sulphur was improved by feeding birds mash diet containing 50 g PSP/kg within the first 10 d compared to birds fed crumbled diet with the same level of PSP inclusion. Considering main effects, supplementing 50 g PSP/kg in the diets seemed to reduce the total tract digestibility of nutrients in the mash fed birds. In crumble-fed birds, digestibility was improved when PSP was included at 100 g/kg. The reason for this pattern is not clear but it may be that the supplement needed to be provided in diet at a higher amount than 50 g/kg in order to enhance digestibility of nutrients. The differences in digestibility between the ileal and total tract may be due to site of measurement and contents of samples used for the assessment.

Amino acid digestibility was statistically similar across all experimental treatments. Most of the amino acids with highest coefficients of digestibility (methionine, threonine, arginine, and lysine) are essential in broiler chicken nutrition, and may be beneficial when highly digested. The reason for this may be the high content of digestible essential amino acids in PSP, which was made available with increasing supplementation of PSP. Generally, it seems that feeding mash diets or supplementing 50 g PSP/kg in diet at the prestarter stage would potentially improve amino acid digestibility. It may also be possible that supplementing PSP at this level over a longer period than tested in this study may effect a better digestibility of amino acids.

Tissue Protein Content and Digestive Enzyme Activities

At d 10, there was no significant effect of PSP inclusion level, feed form or their interactions on tissue protein contents and activi-

Table 12. Tissue protein and digestive enzyme activities in the jejunum and pancreas of broiler chickens fed different levels of PSP and feed forms at 10 d of age.

		Jejunum				Pancreas		
Feed form	PSP level (g/kg)	Prot[1]	Mal[2]	Suc[3]	AMP[4]	Prot[1]	Chy[5]	Tryp[6]
Mash	0	39.6	0.94	0.16	56.8	8.3	2.14	2.23
	50	31.76	0.84	0.14	50.8	8.8	2.64	2.74
	100	35.1	0.78	0.17	61.4	7.5	2.00	3.69
Crumbled	0	37.4	0.76	0.17	55.2	7.5	2.34	2.70
	50	40.0	0.85	0.13	51.4	8.6	2.58	2.82
	100	37.1	0.80	0.23	56.6	8.5	2.66	3.04
SEM		1.12	0.023	0.012	1.75	0.32	0.142	0.22
Main effects								
Mash		35.5	0.85	0.18	56.33	8.2	2.24	2.89
Crumbled		38.1	0.80	0.16	54.38	8.2	2.52	2.84
	0	38.6	0.85	0.16	56.0	7.9	2.24	2.45
	50	35.8	0.84	0.13	51.1	8.7	2.61	2.78
	100	36.1	0.79	0.20	59.0	8.0	2.30	3.37
Source of variation (P-value)								
Feed form		0.242	0.300	0.479	0.589	0.976	0.336	0.927
PSP level (g/kg)		0.528	0.470	0.160	0.204	0.573	0.530	0.258
Feed form × PSP level (g/kg)		0.146	0.132	0.636	0.837	0.606	0.537	0.604

SEM = Standard error of mean; [1]Protein (mg/g tissue), [2]Maltase (μmol/mg protein), [3]Sucrase (μmol/mg protein), [4]Aminopeptidase-N (μmol/mg protein), [5]Chymotrypsin (μmol/mg protein), [6]Trypsin (μmol/mg protein).

Table 13. Tissue protein and digestive enzyme activities in the jejunum and pancreas of broiler chickens fed different levels of PSP and feed forms at 24 d of age.

		Jejunum				Pancreas		
Feed form	PSP level (g/kg)	Prot[1]	Mal[2]	Suc[3]	AMP[4]	Prot[1]	Chy[5]	Tryp[6]
Mash	0	131.0	0.25	0.02	16.1	21.6	2.13	1.43
	50	113.7	0.23	0.03	21.0	20.9	1.60	1.83
	100	147.6	0.25	0.05	20.0	22.1	1.60	1.85
Crumbled	0	107.7	0.27	0.05	19. 0	20.0	2.03	2.22
	50	97.3	0.25	0.04	21.2	20.0	2.38	1.56
	100	154.0	0.24	0.05	20.3	20.7	2.11	1.62
SEM		4.89	0.005	0.003	0.60	0.52	0.119	0.098
Main effects								
Mash		130.8	0.24	0.03[b]	19.0	21.5	1.80	1.70
Crumbled		119.7	0.25	0.05[a]	20.2	20.2	2.18	1.80
	0	119.4[b]	0.26	0.04	17.7	20.7	2.08	1.82
	50	105.5[b]	0.24	0.04	21.0	20.4	2.00	1.70
	100	150.9[a]	0.25	0.05	20.1	21.4	1.85	1.74
Source of variation (P-value)								
Feed form		0.095	0.401	0.009	0.262	0.244	0.096	0.604
PSP level (g/kg)		0.001	0.503	0.246	0.059	0.738	0.713	0.866
Feed form × PSP level (g/kg)		0.196	0.460	0.075	0.477	0.975	0.326	0.055

Mean values within the same column not sharing a superscript are significantly different ($P < 0.05$); [1]Protein (mg/g tissue), [2]maltase (μmol/mg protein), [3]sucrase (μmol/mg protein), [4]aminopeptidase-N (μmol/mg protein); [5]chymotrypsin (μmol/mg protein), [6]trypsin (μmol/mg protein).

ties of enzymes assayed in the jejunum or pancreas (Table 12). Increasing the level of inclusion of PSP in diets increased ($P < 0.001$) the protein content at 24 d of age (Table 13), with the birds on the diet with 100 g PSP/kg inclusion having higher tissue protein content than the rest. Also, the jejunal sucrase activity of broiler chickens fed on crumbled diets was significantly ($P < 0.009$) higher than was observed in mash-fed birds.

During the grower phase, increased PSP inclusion improved jejunal tissue protein content while sucrase activity was more pronounced in broiler chickens fed on crumbled diet. These findings may be an indication of an improvement in digestive function as a result of inclusion of PSP, with the activities mostly higher when the supplementation is in crumbled diets. These generally improved activities of digestive enzymes in birds fed crumbled diets with increased levels of PSP may be linked to the observed better gross responses observed in birds on crumbled diets during the early phase of production.

CONCLUSIONS AND APPLICATIONS

1. This study was conducted to evaluate the effect of inclusion of high-quality soy product in mash or crumbled prestarter diets for broiler chicks. Supplementing starter diets with the product improved feed intake and body weight gain, although this was dependent on feed form, especially in later life.
2. The test product appears to be more effective in improving feed intake and weight gain when fed in crumbled diets, and further tests should be conducted, to identify the mechanisms behind this response. The use of processed soy protein in prestarter diets in this study did not significantly improve meat yield in later life but shows the potential to do so, which needs further investigation.
3. Tissue protein content and digestive enzyme activities were influenced by the application of the product both in mash and crumbled diets, while ileal nutrient digestibility was not affected by feed form and level of the test product in diets.
4. It is important to consider feed form while using the test product in prestarter diets for broiler chicks as this seems to influence growth and digestive functions later in life.

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