Reprod. Nutr. Dev. 43 (2003) 77–90

DOI: 10.1051/rnd:2003007

Original article

Intestinal function and body growth of broiler chickens on diets based on maize dried at different temperatures and supplemented with a microbial enzyme

Paul A. IJI, Kwazi KHUMALO, Stephen SLIPPERS, Robert M. GOUS*

Discipline of Animal & Poultry Science, University of Natal, Private Bag X01, Scottsville 3209, South Africa

(Received 24 May 2002; accepted 13 December 2002)

Abstract — A study was conducted to evaluate the effects of varying drying temperature (Fresh, 85, 95 or 105 °C) on the nutritive value of maize and response of broiler chickens to diets based on such grain, and supplemented with a microbial enzyme (Avizyme 1500). The chemical composition of the grain was affected by drying temperature. Starch and amylopectin contents were increased while there was a reduction in amylose content. These changes were expected to underlie the response of chicks to the diets. Total feed intake over 28 days was increased ($P < 0.05$) as a result of heat-treating the maize up to 95 °C. The final body weight of chicks on the diet based on fresh maize was improved ($P < 0.05$) by the microbial enzyme supplement (MES). There was no effect of the enzyme supplement on body weight when assessed at earlier ages. Over the entire feeding period, feed conversion efficiency (FCE) declined ($P < 0.001$) with increasing oven temperature, regardless of the supplementation with the microbial enzyme. Body weight was influenced ($P < 0.05$) by the microbial enzyme only when assessed over the entire trial period. The weight of visceral organs, protein content and activities of pancreatic and jejunal digestive enzymes were unaffected by grain heat treatment or MES. The ileal digestibility of calcium was reduced ($P < 0.001$) on diets based on fresh maize and maize that was oven-dried at 105 °C. Heat-treatment also improved ($P < 0.05$) the ileal digestibility of phosphorus in chicks on the diets without MES. There were no effects of grain heat treatment or MES on the ileal digestibility of energy, protein, Ca and amino acids. The results indicate some variations in grain quality as a result of heat treatment but the differences were not significant enough to stimulate major responses to the MES. Further studies should examine samples from commercial drying processes or samples obtained from a closer simulation of commercial conditions, to arrive at more practical conclusions.

body growth / broiler chicks / digestibility / digestive enzymes / drying temperature / grain quality / maize

* Correspondence and reprints
E-mail: Gous@nu.ac.za

1. INTRODUCTION

Maize is one of the premier cereals used in poultry feeding around the world. It is relatively devoid of viscous non-starch polysaccharides, the principal antinutritive factors present in most temperate cereals [1–3]. In spite of this advantage, the nutritive value of maize is known to vary widely, as a result of climatic conditions during growth and harvest as well as post-harvest processing and storage [4–5].

The digestibility of cereal components is greatly influenced by the large starch component, especially the ratio between amylose and amylopectin [6]. Amylopectin is more readily digested than amylose due to its amorphous nature. In research on broiler chickens, Noy and Sklan [7] reported that the terminal ileal digestibility of maize starch rarely exceeds 85%. The undigested starch at the terminal ileum is assumed to be "resistant" to digestion and presents an opportunity for use of microbial enzyme supplements in maize-based diets. Amongst the three types of resistant starch found in cereals, two types are known to be caused by inherent factors during the formation of the grain while a third, referred to as RS3 is created by processing and storage conditions [8]. Retrograde (RS3) starch results from high temperature heating of starch followed by storage at lower temperatures over long periods of time. The starch in high-moisture grains may also anneal after heat processing. It has not been established how much of these processes occurs during routine production and processing of maize. A wet climate during harvesting, however, could warrant the artificial drying of maize in many areas of the world. In parts of Africa, maize is still harvested and sun-dried; a method that has been shown to cause stack-burn and reduction in in vitro digestibility of the grain [9]. The quality of diets based on stack-burnt grains is low, tending to negatively affect AME, body weight gain and feed conversion efficiency (FCE) of poultry raised on them. It may therefore be beneficial to artificially dry maize even in parts of the tropics. There is a need to determine the ideal temperature that would not negatively impact on the quality of maize processed under such conditions.

The aim of the present study was to examine the effects of varying temperature during drying on the nutritive value of maize. The gross response and digestive function of broiler chickens raised on diets based on these grains were also evaluated.

2. MATERIALS AND METHODS

2.1. Maize processing and analysis

The maize tested was obtained from a commercial farmer in the Kwa-Zulu Natal province of South Africa. The material was received at a moisture content of 11.3%, in 50-kg bags. Some of the maize was used as received (fresh). Other batches were obtained through drying in two large draught-ovens at 85, 95 or 105 ºC. Each batch was dried over 24 h to yield varying moisture contents. The grain was then milled and stored in sealed polythene bags at 5 ºC until the diets were prepared.

The proximate analysis of the maize samples, diets and digesta was conducted in accordance with the methods of AOAC [10]. The AMEn and TMEn of the maize samples were determined according to the method of Fisher [11]. The method of Englyst et al. [12] was used in the measurement of starch, amylose and amylopectin. Resistant starch was defined as residual starch after 120 min of digestion with pancreatin and amyloglucosidase.

2.2. Experimental birds and diets

Three hundred and twenty day-old female broiler chicks (Ross) were used for the study. The chicks were randomly allocated to cages (without bottom) on litter in groups of 10 and assigned to one of four main diets (Tab. I). The four diets were based on maize and a commercial soyabean concentrate (Central Soya European Proteins A/S, Denmark). Three maize batches dried at different oven temperatures (85, 95 or 105 ºC) were tested against a batch that had been naturally sun-dried after harvesting. Each of these four diets, in mash form was fed with or without a microbial enzyme supplement, Avizyme 1500 (Finnfeeds International, Malborough, UK) at 1 $g \cdot kg^{-1}$ diet. The experiment was therefore a 4 × 2 factorial design, with 4 replicates for each of the eight general treatments. Poolbrite® (Poolbrite (SA) (Pty) Ltd., Atlantis, S. Africa), a source of acid-insoluble ash was also included in the diets to enable the assessment of nutrient digestibility. The diets were fed for 28 days. Feed and water were supplied ad libitum and light was provided over 23 1/2 h. The room temperature was managed according to the requirements for chicks between hatch and 28 days.

Table I. Composition of the fed diets.

Ingredient	Amount ($g \cdot kg^{-1}$)
Maize	608.9
Soyabean concentrate	200.0
Fishmeal	60.0
Sunflower oil	42.7
Limestone	13.4
Monocalcium phosphate	12.0
Salt	2.56
Plaster sand	25.0
DL-methionine	1.56
L-lysine HCl	1.39
Vitamin/mineral premix[1]	2.5
Poolbrite(r)	30.0
Nutrient composition ($g \cdot kg^{-1}$)	
Gross energy ($MJ \cdot kg^{-1}$)	16.3
Crude protein	212.7
Crude fibre	22.3
Lipid	63.7
Calcium	11.5
Total phosphorus	6.3
Methionine	4.59
Lysine	13.63

Four main diets varied on the basis of maize that was dried at different temperatures and were fed with or without supplemental microbial enzyme, Avizyme 1500 at 1 $g \cdot kg^{-1}$ diet.

[1] Active ingredients ($g \cdot kg^{-1}$): Vitamin B_1 (1.0), B_2 (3.0), B_6 (2.5), E (25), K_3 (1.5), folic acid (1.5), choline (150.0), niacin (35.0), pantothenic acid (7.5), iodine (1.0), manganese (50.0), copper (5.0), zinc (50.0) and iron (20.0). Other active ingredients were vitamin A (6 MIU), D_3 (2 MIU), B_{12} (10 mg), selenium (150.0 mg) and Cobalt (250 mg) (Nutec S.A. (Pty) Ltd., Pietermaritzburg, South Africa).

Feed intake and body weight were measured at the end of each week. At the end of the feeding period, 6 chicks, randomly selected, per cage were killed through asphyxiation with CO_2 and dissected. Samples of ileal digesta were collected and frozen and used to determine nutrient digestibility as described below. The weight of the visceral organs was obtained. The pancreas and a sub-sample of the jejunum were also taken and snap-frozen in liquid nitrogen. These tissues were later processed and used to determine protein content and the activities of digestive enzymes, targeting various nutrients, as described below.

2.3. Evaluation of nutrient digestibility

The concentration of acid-insoluble ash (AIA) in the diet and digesta was measured, in line with the methods described by Annison et al. [13]. The materials were also analysed for gross energy, protein, minerals and amino acids. The digestibility coefficient of the nutrients was then calculated from the equation:

$$1 - [(\text{ileal nutrient}/\text{ileal AIA})/(\text{diet nutrient}/\text{diet AIA})]. \quad [1]$$

2.4. Tissue protein content and enzyme activities

The concentration of protein in the pancreas and jejunal mucosa was measured using the Coomassie dye-binding method described by Bradford [14]. For the jejunum, the homogenate was prepared as described previously by Shirazi-Beechey et al. [15]. Pancreatic homogenate was obtained through a similar process except that distilled water was used, the entire tissue was homogenised and the homogenate was centrifuged at 30 000 *g* for 10 min to obtain a supernatant on which analysis was done [16].

Enzyme assays were conducted on fixed substrate concentrations established in studies on mammals and other species, after standardization for poultry [17]. On jejunal homogenates, biochemical assays were conducted for maltase (EC. 3.2.1.20) and sucrase (EC. 3.2.1.26) and alkaline phosphatase (AP, EC. 3.1.3.1). For the pancreas, assays were conducted for amylase (EC. 3.2.1.1), lipase (EC. 3.1.1.3) and chymotrypsin (EC. 3.4.21.1). The specific activities of the enzymes were measured according to the methods previously described [18–22]. The assays were conducted at a temperature of 39 ºC. For amylase, glucose output was measured by incubating with glucose oxidase (Roche Diagnostics, Indianapolis, USA) rather than with dinitrosalicylic acid (DNS) reagent, previously described by Miller et al. [18]. This modification was to cut down on the number and volume of chemicals required for the determination of the end-products of digestion.

2.5. Data analysis

Data were analysed by both the general linear model (GLM) and regression of Minitab [23]. Initial analysis did not reveal any significance in interactions between the tested factors; therefore the data were analysed to enhance the effects of the individual factors. The data were regressed, using varying levels of temperature or microbial enzyme as independent factors. The differences between the mean values were determined by the use of least significant difference.

3. RESULTS

The chemical composition of the maize batches is shown in Table II. As would be expected, DM content increased with an increase in drying temperature. The CP, lipid and to a lesser extent, P contents followed a similar trend. Higher drying temperatures, however, resulted in a decline in crude fibre content. The amino acid contents of the oven-dried maize were also generally higher than those of the sun-dried maize (Fresh), especially up to 95 ºC of heating. Oven-drying increased the starch and amylopectin contents but reduced the amylose content. Compared to the fresh maize, oven-drying at 105 ºC improved the starch and amylopectin contents by 8 and 5%, respectively while amylose content was reduced by about 12.4%. The level of resistant starch was increased as a result of drying the fresh maize at 85 ºC but decreased at higher drying temperatures. This was the pattern observed for AME_n and TME_n. The ratio of amylose: amylopectin declined with increasing drying temperature.

Feed intake during the entire trial period was increased ($P < 0.05$) as a result of heat-treating the maize up to 95 ºC (Tab. III). Further heating did not have any significant effects on the intake of the diet. There were also no significant effects of microbial enzyme supplement on feed intake at any period of assessment. The 7-day body weight of chicks was reduced ($P < 0.05$) in chicks on the control diet in which maize had been heated at 85 ºC. At 14 days of age, body weight was also reduced ($P < 0.05$) by oven-drying at up to 95 ºC but this was

Table II. Chemical composition of maize batches under varying drying conditions.

A. Dry matter (DM), crude protein (CP), crude fibre and mineral contents ($g \cdot kg^{-1}$ DM)

Maize	DM	CP	Crude Fibre	Lipid	*P*	Mg
Fresh	887.0	77.9	227.5	34.8	1.9	1.1
85 °C	915.0	79.9	23.9	43.4	2.2	1.2
95 °C	924.5	80.4	20.7	40.7	2.1	1.1
105 °C	928.5	80.8	19.7	41.0	1.9	1.1

B. Amino acids ($g \cdot kg^{-1}$ DM)

	Met	Lys	Thr	Ala	Phe	Arg	Leu	Ile	Val
Fresh	1.4	2.4	2.7	5.7	3.5	3.3	9.0	2.4	4.3
85 °C	1.9	2.3	2.8	5.2	3.5	3.3	8.6	2.3	4.4
95 °C	1.5	2.6	3.0	5.6	4.2	3.8	8.8	2.6	4.8
105 °C	1.6	2.4	2.8	5.9	3.8	3.3	9.5	2.4	4.6

C. Starch content and components ($g \cdot kg^{-1}$ DM)

	Starch	Resistant starch	Amylopectin	Amylose	Amylose: Amylopectin
Fresh	699.1	177.2	529.5	169.6	0.32
85 °C	701.8	183.7	546.2	155.6	0.29
95 °C	700.5	167.7	541.8	158.7	0.29
105 °C	704.8	158.9	556.2	148.6	0.27

D. Gross and metabolisable energy ($MJ \cdot kg^{-1}$ DM)

	GE	AME_n	TME_n
Fresh	18.5	15.7	16.1
85 °C	18.6	16.0	16.4
95 °C	18.4	15.7	16.1
105 °C	18.2	15.6	16.0

Sub-samples analysed were taken from 2 kg milled material for each maize batch. Gross energy, AME_n and TME_n contents were determined on roosters.

observed only on diets supplemented with the microbial enzyme. The final body weight of chicks on the diet based on fresh maize was improved ($P < 0.05$) by the microbial enzyme supplement. There was no effect of the enzyme supplement on body weight assessed at earlier ages.

Between hatch and 14 days of age, feed conversion efficiency was reduced ($P < 0.05$) as a result of oven-drying up to

Table III. The effect of maize drying temperature, microbial enzyme supplementation and bird age on feed intake and body weight.

		Feed intake (g/bird)				Body weight (g)			
Maize	Avizyme	0–7d	0–14d	0–21d	0–28d	7d	14d	21d	28d
Fresh	–	99.4	353.4	841.6	1508.9^{b}	113.3^{a}	249.5^{ab}	476.5	770.7^{bc}
	+	89.6	351.4	839.3	1525.3^{b}	112.0^{ab}	263.1^{a}	539.8	851.4^{a}
85 °C	–	86.2	340.2	843.9	1550.5^{b}	101.5^{c}	227.3^{b}	433.9	709.2^{c}
	+	81.3	332.8	854.0	1649.0^{ab}	103.5^{bc}	233.9^{ab}	470.6	766.1^{bc}
95 °C	–	87.3	343.5	852.6	1633.3^{ab}	107.4^{abc}	241.3^{ab}	480.1	777.0^{abc}
	+	84.5	345.1	874.5	1732.3^{a}	105.4^{abc}	231.4^{b}	473.7	791.6^{ab}
105 °C	–	87.6	355.0	936.8	1631.4^{ab}	112.3^{ab}	256.0^{ab}	495.8	764.5^{bc}
	+	92.8	344.0	913.5	1645.6^{ab}	109.3^{ab}	258.5^{ab}	492.4	775.1^{abc}
	SEM	6.77	19.17	46.94	68.76	4.73	15.33	29.32	38.18
Source of variation									
Maize		NS	NS	NS	*	*	*	NS	NS
Enzyme		NS	NS	NS	NS	NS	NS	NS	*

^{a,b}Mean values on the same column not sharing a superscript are significantly different *$P < 0.05$ for the factors shown. NS: not significant. SEM is the standard error of difference between the mean values.

Table IV. The effect of maize drying temperature, microbial enzyme and bird age on feed conversion efficiency.

		Feed conversion efficiency (g weigh·kg^{-1} feed)			
Maize	Avizyme	0–7d	0–14d	0–21d	0–28d
Fresh	–	739.8	574.5^{ab}	517.7^{b}	483.7^{ab}
	+	802.4	633.5^{a}	594.1^{a}	533.6^{a}
85 ºC	–	714.7	549.1^{b}	466.4^{b}	431.9^{b}
	+	782.8	583.1^{ab}	506.6^{b}	440.7^{b}
95 ºC	–	758.7	582.3^{ab}	515.7^{b}	450.6^{b}
	+	765.8	550.0^{b}	493.7^{b}	434.0^{b}
105 ºC	–	831.1	609.9^{ab}	489.8^{b}	444.7^{b}
	+	745.7	637.1^{a}	495.6^{b}	449.0^{b}
	SEM	39.99	28.04	26.32	24.58
Source of variation					
Maize		NS	*	**	***
Enzyme		NS	NS	NS	NS

[a,b] Mean values on the same column not sharing a superscript are significantly different $*P < 0.05$, $**P < 0.01$, $***P < 0.001$ for the factor shown. NS: not significant. SEM is the standard error of difference between the mean values.

Table V. The effect of maize type and microbial enzyme on the weight of visceral organs (g·100 g^{-1} body weight) at 28 days of age.

Maize	Avizyme	Gizzard/ Proventriculus	Small intestine	Liver	Pancreas	Caeca	Spleen
Fresh	–	5.5	7.4	3.1	0.51	0.8	0.15
	+	5.3	6.8	3.2	0.51	0.7	0.18
85 ºC	–	6.0	7.2	3.1	0.48	0.8	0.12
	+	5.8	7.0	3.4	0.0.51	1.0	0.18
95 ºC	–	5.3	6.8	3.5	0.47	0.9	0.11
	+	5.4	7.5	3.5	0.46	0.8	0.15
105 ºC	–	5.4	6.7	3.2	0.43	0.8	0.15
	+	5.6	7.2	3.6	0.52	0.8	0.15
	SEM	0.44	0.59	0.34	0.067	0.17	0.031
Source of variation							
Maize		NS	NS	NS	NS	NS	NS
Enzyme		NS	NS	NS	NS	NS	NS

Table VI. The effect of maize type and microbial enzyme on tissue protein content and the activities of digestive enzymes in the pancreas of chicks at 28 days of age.

Maize	Avizyme	Protein[1]	Amylase[2]	Lipase[3]	Chymotrypsin[4]
Fresh	–	61.3	10.5	0.03	0.5
	+	57.5	8.7	0.02	0.5
85 °C	–	61.2	10.8	0.03	0.5
	+	58.8	10.5	0.03	0.5
95 °C	–	63.1	9.6	0.02	0.5
	+	60.6	10.5	0.03	0.5
105 °C	–	57.8	10.9	0.02	0.6
	+	56.7	10.4	0.02	0.5
	SEM	3.99	1.60	0.005	0.09
Source of variation					
Maize		NS	NS	NS	NS
Enzyme		NS	NS	NS	NS

[1] Concentration in tissue (mg·g^{-1} wet tissue).
[2] Specific activity (ρmole glucose/mg protein/min).
[3] Units/min, in relation to porcine lipase standard.
[4] Specific activity (µmole p-nitroaniline/mg protein/min).

95 °C in chicks on both the control diets and diets supplemented with the microbial enzyme (Tab. IV). Feed conversion efficiency between hatch and 21 days of age was reduced ($P < 0.01$) in chicks fed the control diets based on all heat-treated maize. Over the entire feeding period, FCE declined ($P < 0.001$) with an increasing oven temperature, regardless of the supplementation with the microbial enzyme. There were no significant effects of the microbial enzyme supplement on FCE at any of the periods investigated.

The weight of visceral organs was not affected by grain heat treatment or microbial enzyme supplement (Tab. V). The protein content of pancreatic tissue and activities of pancreatic enzymes were also unaffected by the grain heat treatment or the enzyme supplement (Tab. VI). The protein content of the jejunal mucosa was increased in chicks raised on diets supplemented with the microbial enzyme but this was significant ($P < 0.01$) only on the diet based on maize that was oven-dried at 105 °C (Tab. VII). There were no effects of grain heat treatment or of microbial enzyme supplement on the activities of the jejunal digestive enzymes.

The ileal digestibility of calcium was the lowest ($P < 0.001$) in chicks fed diets based on fresh maize and maize that was oven-dried at 105 °C (Tab. VIII). This response was observed for the control diet in the case of fresh maize while for the maize that was oven-dried at 105 °C, Ca digestibility was lower for the enzyme-supplemented diet. Heat-treatment also improved ($P < 0.05$) the ileal digestibility of phosphorus in chicks fed the control diets. In chicks fed the enzyme-supplemented diets, there was a linear increase ($P < 0.05$) in ileal digestibility of P as a result of oven-drying. There was no effect of heat treatment on ileal

Table VII. The effect of maize drying temperature and microbial enzyme on tissue protein content and activities of digestive enzymes in the jejunum of 28-day old birds.

Maize	Avizyme	Protein[1]	Maltase[2]	Sucrase[2]	Alkaline Phosphatase[3]
Fresh	–	49.6^{ab}	2.0	0.02	1.3
	+	51.7^{ab}	2.2	0.03	1.3
85 °C	–	46.5^{ab}	2.4	0.02	1.5
	+	43.6^{ab}	3.0	0.03	1.9
95 °C	–	47.9^{ab}	2.6	0.03	1.9
	+	56.3^{ab}	2.1	0.04	1.5
105 °C	–	30.0^{b}	3.0	0.03	1.9
	+	63.7^{a}	2.3	0.03	1.3
	SEM	7.38	0.35	0.006	0.27
Source of variation					
Maize		NS	NS	NS	NS
Enzyme		*	NS	NS	NS

^{ab} Mean values on the same column not sharing a superscript are significantly different ($P < 0.05$) for the factor shown. NS: not significant. SEM is the standard error of difference between the mean values.
[1] Concentration in mucosa (mg·g^{-1} wet tissue).
[2] Specific activity (µmole glucose/mg protein/min).
[3] Specific activity (µmole p-nitrophenol/mg protein/min).

Table VIII. The effect of maize type and microbial enzyme on ileal digestibility of energy, protein and phosphorus at 28 days of age.

Maize	Avizyme	Energy	Protein	Calcium	Phosphorus
Fresh	–	0.70	0.76	0.45^{bc}	0.37^{bc}
	+	0.70	0.78	0.40^{c}	0.31^{c}
85 °C	–	0.60	0.74	0.62^{a}	0.55^{a}
	+	0.63	0.76	0.59^{ab}	0.45^{ab}
95 °C	–	0.63	0.77	0.65^{a}	0.52^{ab}
	+	0.64	0.76	0.68^{a}	0.49^{ab}
105 °C	–	0.52	0.71	0.49^{bc}	0.33^{bc}
	+	0.62	0.76	0.60^{ab}	0.49^{ab}
	SEM	0.065	0.039	0.053	0.065
Source of variation					
Maize		NS	NS	***	*
Enzyme		NS	NS	NS	NS

^{ab} Mean values on the same column not sharing a superscript are significantly different *$P < 0.05$, ***$P < 0.001$, for the factor shown. NS: not significant. SEM is the standard error of difference between the mean values.

Table IX. The effect of maize type and microbial enzyme on ileal digestibility of key amino acids.

Maize	Avizyme	Met	Lys	Thr	Ala	Phe	Arg	Leu	Ile	Val
Fresh	–	0.85	0.83	0.67	0.80	0.83	0.80	0.83	0.80	0.98
	+	0.87	0.86	0.71	0.83	0.85	0.84	0.85	0.82	0.98
85 °C	–	0.86	0.87	0.68	0.83	0.85	0.84	0.85	0.83	0.98
	+	0.84	0.84	0.63	0.81	0.83	0.81	0.82	0.80	0.98
95 °C	–	0.87	0.86	0.67	0.81	0.84	0.87	0.84	0.81	0.98
	+	0.87	0.85	0.66	0.81	0.83	0.85	0.83	0.81	0.98
105 °C	–	0.84	0.81	0.58	0.76	0.78	0.74	0.78	0.75	0.97
	+	0.87	0.87	0.73	0.84	0.85	0.88	0.86	0.83	0.98
	SEM	0.049	0.027	0.074	0.035	0.031	0.057	0.032	0.033	0.004
Source of variation										
Maize		NS	NS	NS	NS	NS	NS	NS	NS	NS
Enzyme		NS	NS	NS	NS	NS	NS	NS	NS	NS

digestibility of energy or protein. Microbial enzyme supplementation also did not appear to have any effects on the digestibility of energy, protein, Ca or *P*.

The ileal digestibility of some amino acids is shown in Table IX. There was no variation in digestibility as a result of grain heat treatment or of enzyme supplementation of the diet.

4. DISCUSSION

Although the maize grain was received at relatively low moisture contents, further drying led to a significant reduction in moisture content and concurrent increases in the concentrations of the solid components, especially proteins and lipids. Higher drying temperatures tended to reduce the concentration of lipids, energy and some of the amino acids. There is a strong link between the lipids and energy contents but it is not exactly known if some of these losses were due to volatilisation of components other than moisture. Oven-drying also resulted in an increase in the starch and amylopectin contents of the samples. The reduction in the content of amylose suggests an improvement in grain quality since amylose is more slowly digested than amylopectin and affects the digestion of nutrients other than carbohydrates [24–26].

The effect of oven-drying on feed intake and animal growth response was inconsistent and less conclusive. The increase in total feed intake, for example was not accompanied by an increase in final body weight although body weight at other points of evaluation was improved on diets based on oven-dried maize. There was also no pattern in the effect of the microbial enzyme supplement on the gross biological response of the chicks. These inconsistencies may probably be due to a lack of drastic differences between the samples. The effects of Avizyme are known to be the most pronounced in low-quality maize and sorghum or where there are wide differences between samples [27]. The reduction in amylose, as a measure of improvement in grain quality has been highlighted. The improvement in body weight through microbial enzyme supplement on the diets based on fresh maize may be due to the fact that this batch of grain was the highest in amylose concentration. Although resistant starch content or starch digestibility was not measured in the present study, it is unlikely that there were any major negative effects of oven-drying on the samples. The classical effects of heat treatment of cereals include an increase in amylose content; annealing, and retrograding of starch [26, 28, 29]. The moisture content of the samples used in this study may be too low to cause retrograding of starch through heating. Although the samples were stored at a low temperature prior to use, this was not done immediately after oven-drying. Therefore, the grains would have cooled slowly, which would reduce the chances of annealing.

Organ weights and digestive enzyme activities were unaffected by the grain quality or microbial enzyme supplement. There is a general dearth of research reported on the effects of starch or of microbial enzyme supplements on the development of the GIT in poultry. In a previous study, Mahagna et al. [30] reported a reduction in the activities of pancreatic enzymes in situ and in intestinal digesta as a result of supplementation with a microbial enzyme, with proteolytic and amylolytic activities. In rats on high-amylose maize starch diets, the activities of disaccharidases in the upper jejunum were reduced while there was an increase in such activity in the lower intestine [24]. These effects may be attributed to the variation in the availability of disaccharides at different points of the GIT. Viscous non-starch polysaccharides (NSP) and high-amylose cereals could influence the development of the GIT through the effects of volatile fatty acids produced by microbial fermentation in rats [31–34]. There is considerable fermentation of such carbohydrates, especially NSP in the upper GIT as a result of the slow rate of digestion, a pattern that encourages the migration of microbial populations to the small intestine [35, 36]. Viscous NSP are also able to physically distend the volume of the GIT, consequently increasing the weight of its component parts. The concentration of such NSP is low in maize. The effects of feed factors on pancreatic enzymes are usually regulated by the concentration of the substrates in the intestinal lumen while such factors may directly influence the structure of the intestinal mucosa, the source of membrane-bound enzymes. A few studies on poultry and pigs [36–39] suggest some link between the supply of dietary nutrients and the natural development of the mucosal structure and activities of digestive enzymes. The absence of differences in activities of the digestive enzymes in the present study may be due to similarities in the nature and the concentrations of the dietary nutrients involved.

The change in digestibility of the two mineral elements as a result of heat-treating the maize is unclear. The results appear to contradict those reported by de Schrijver et al. [25] who did not observe any significant effects of high levels of retrograde starch on the faecal digestibility of minerals, including Ca, *P* and Mg. The differences in the results may, however, be due to variation in the site of evaluation. There were no effects of the treatment of microbial enzyme supplement on the digestibility of the other nutrients, including proteins. The enzyme tested exhibits some protease activity. Its failure to improve protein digestion may be due to the close similarities between the samples. In a previous study, Leeson et al. [40] evaluated maize quality over a wider range of moisture content at harvest. The ME value was reduced by 0.05 MJ for each 1% increase in moisture content at harvest. Wider drying temperatures have also been evaluated by Barrier-Guillot et al. [41] with no effects on the chemical composition of the grain although no direct comparisons can be made with regards to the nutritive value due to the age differences in the chickens tested.

5. CONCLUSION

There were definite effects of heat treatment on the chemical composition of maize grain but these did not impart enough variation in the samples to stimulate a response to the microbial enzyme supplement tested. Heat treatment tended to also improve the starch quality of the grain, thereby obviating the need for a microbial enzyme supplement. It may be necessary to test maize with a higher initial moisture content and over a wider range of temperatures or duration of heat treatment, to see how these would affect quality and therefore, nutritive value of the grain in diets for poultry. There is a need to test samples obtained from actual commercial processes or to more closely simulate the commercial conditions in future studies.

ACKNOWLEDGEMENT

Starch content and components were measured at the Department of Agricultural and Environmental Science, Queen's University, Belfast, UK.

REFERENCES

[1] Bedford MR. Mechanism of action and potential environmental benefits from the use of feed enzymes. Anim Feed Sci Technol 1995, 53: 145–155.

[2] Smits CHM, Annison G. Non-starch polysaccharides in broiler nutrition – towards a physiologically valid approach to their determination. World's Poult Sci J 1996, 52: 203–221.

[3] Bach Knudsen KE. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim Feed Sci Technol 1997, 67: 319–338.

[4] Leeson S, Yersin A, Volker L. Nutritive value of the 1992 corn crop. J Appl Poult Res 1993, 2: 208–213.

[5] Collins NE, Moran ET, Stilborn HL. Corn hybrid and bird maturity affect apparent metabolizable energy values. Poult Sci 1998, 77: 42.

[6] McDonald *P*, Edwards RA, Greenhalgh JFD, Morgan CA. Animal nutrition. Longman Scientific and Technical, Harlow, UK. 1995.

[7] Noy Y, Sklan D. Digestion and absorption in the young chick. Poult Sci 1994, 74: 366–373.

[8] Brown I. Complex carbohydrates and resistant starch. Nutr Rev 1996, 54: S115–S119.

[9] Panigrahi S, Bestwick LA, Davis RH, Wood CD. The nutritive value of stackburned yellow maize for livestock: tests in vitro and in broiler chicks. Br J Nutr 1996, 76: 97–108.

[10] Association of Official Analytical Chemists. Official methods of analysis. AOAC, Washington, DC, USA. 1992.

[11] Fisher C. Energy values of compound poultry feeds, Occasional Publication No. 2. Poult Research Centre, Agricultural Research Council, Roslin, UK. 1982.

[12] Englyst HN, Kingman SM, Cummings JH. Classification and measurement of nutritionally important starch fractions. Eur J Clin Nutr 1992, 46: S33–S50.

[13] Annison G, Hughes RJ, Choct M. Effects of enzyme supplementation on the nutritive value of dehulled lupins. Br Poult Sci 1996, 37: 157–172.

[14] Bradford M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem 1976, 72: 248–254.

[15] Shirazi-Beechey SP, Smith MW, Wang Y, James PS. Postnatal development of lamb intestinal digestive enzymes is not regulated by diet. J Physiol 1991, 437: 691–698.

[16] Nitsan Z, Dror Y, Nir I, Shapira I. The effects of force-feeding on enzymes of the liver, kidney, pancreas and digestive tract of chicks. Br J Nutr 1974, 32: 241–247.

[17] Iji PA, Saki A, Tivey DR. Body and intestinal growth of broiler chicks on a commercial starter diet. 2. Development and characteristics of intestinal enzymes. Br Poult Sci 2001, 42: 514–522.

[18] Miller GL, Blum R, Glennon WE, Burton AL. Measurement of carboxymethylcellulase activity. Anal Biochem 1960, 2: 127–132.

[19] Dahlqvist D. Method for assay of intestinal disaccharidases. Anal Biochem 1964, 7: 18–25.

[20] Holdsworth ES. The effect of vitamin D on enzyme activities in the mucosal cells of the chick small intestine. J Membr Biol 1970, 3: 43–53.

[21] Smeltzer MS, Hart ME, Iandolo JJ. Quantitative spectrophotometric assay for Staphylococcal lipase. Appl Environ Microbiol 1992, 58: 2815–2519.

[22] Serviere-Zaragoza E, Navarrete del Toro MA, Garcia-Carreno FL. Protein-hydrolyzing enzymes in the digestive system of the adult Mexican blue abalone, *Haliotis fulgens* (Gastropoda). Aquaculture 1997, 157: 325–336.

[23] Minitab Inc. Minitab Release 12.1. Minitab Inc, State College, PA 16801–3008, USA, 1998.

[24] Goda T, Urakawa T, Watanabe M, Takase S. Effect of high-amylose starch on carbohydrate digestive capability and lipogenesis in epididymal adipose tissue and liver of rats. J Nutr Biochem 1994, 5: 256–260.

[25] De Shrijver R, Vanhoof K, vande Ginste J. Nutrient utilization in rats and pigs fed enzyme resistant starch. Nutr Res 1999, 19: 1349–1361.

[26] Ito T, Saito K, Sugarawa M, Mochida K, Nakakuki T. Effect of raw and heat-moisture-treated high-amylose corn starches on the process of digestion in the rat digestive tract. J Sci Food Agric 1999, 79: 1203–1207.

[27] Bedford MR. Enzymes for cereals which do not pose viscosity problems. In: Proceedings of the 3rd European symposium on feed enzymes, Noordwijkerhout, the Netherlands, 2000. p 8.

[28] Jacobs H, Delcour JA. Hydrothermal modifications of granular starch, with retention of the granular structure – a review. J Agric Food Chem 1998, 46: 2895–2905.

[29] Jacobs H, Eerlingen RC, Spaepen H, Grobet PJ, Delcour JA. Impact of annealing on the susceptibility of wheat, potato and pea starches to hydrolysis with pancreatin. Carbohydr Res 1998, 305: 193–207.

[30] Mahagna M, Nir I, Larbier M, Nitsan Z. Effect of age and exogenous amylase and protease on development of the digestive tract, pancreatic enzyme activities and digestibility of nutrients in young meat-type chicks. Reprod Nutr Dev 1995, 35: 201–212.

[31] Johnson IT, Gee JM, Mahoney RR. Effect of dietary supplements of guar gum and cellulose on intestinal cell proliferation, enzyme levels and sugar transport in the rat. Br J Nutr 1984, 52: 477–487.

[32] Chinery R, Goodlad RA, Wright NA. Soy polysaccharide in an enteral diet: effects on rat intestinal cell proliferation, morphology and metabolic function. Clin Biochem 1992, 11: 277–283.

[33] Pell JD, Gee JM, Wortley GM, Johnson IT. Dietary corn oil and guar gum stimulate intestinal crypt cell proliferation in rats by independent but potentially synergistic mechanisms. J Nutr 1992, 122: 2447–2456.

[34] De Shrijver R, Vanhoof K, vande Ginste J. Effect of enzyme resistant starch on large bowel fermentation in rats and pigs. Nutr Res 1999, 19: 927–936.

[35] Choct M, Hughes RJ, Wang J, Bedford MR, Morgan AJ, Annison G. Increased small intestinal fermentation is partly responsible for the anti-nutritive activity of non-starch polysaccharides in chickens. Br Poult Sci 1996, 37: 609–621.

[36] Jorgensen H, Xinquan Z, Bach-Knudsen KE, Eggum BO. The influence of dietary fibre source and level on development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. Br J Nutr 1996, 75: 379–395.

[37] Baranyiova E, Holman J. Morphological changes in the intestinal wall in fed and fasted chickens in the first week after hatching. Acta Vet Brno 1976, 45: 151–158.

[38] Moran ET. Digestion and absorption of carbohydrates in fowl and events through perinatal development. J Nutr 1985, 115: 665–674.

[39] Tivey DR, Smith MW. Cytochemical analysis of single villus peptidase activities in pig intestine during neonatal development. Histochem J 1989, 21: 9–10.

[40] Leeson S, Summers J, Daynard TB. The effect of kernel maturity at harvest as measured by moisture content, on the metabolizable energy value of corn. Poult Sci 1977, 56: 154–156.

[41] Barrier-Guillot B, Jondreville C, Chagneau AM, Larbier M, Leuillet M. Effect of heat drying temperature on the nutritive value of corn in chickens and pigs. Anim Feed Sci Technol 1993, 41: 149–159.

To access this journal online:
www.edpsciences.org