DOI: 10.1079/WPS20035

Nutritional factors affecting excreta/litter moisture and quality

M. FRANCESCH and J. BRUFAU

IRTA, Department of Animal Nutrition, Centre Mas Bové, Apartat 415, 43280 Reus, Spain, e-mail: maria.francesch@irta.es

The control of excreta/litter moisture and quality is a priority in the modern poultry industry, to avoid environmental and animal welfare problems and to reduce productivity losses. Control implies the reduction of their amounts and moisture content. Several factors can affect them, some related to management and housing, others related to diseases and finally, dietary factors. The paper reviews some nutritional aspects that could interfere with the moisture and quality of poultry excreta/litter, focusing on dietary factors affecting water consumption, water excretion and the amount and composition of excreta: dietary protein level, electrolyte balance, ionophores, cereals causing viscosity problems or containing high levels of non-digestible fibre fractions, unusual ingredients or by-products and finally some feed technological treatments.

Keywords: excreta; litter; electrolyte balance; ionophores; cereals; legumes; by-products; feed processing

Introduction

With further intensification and high performance goals to be achieved in the modern poultry production, the control of excreta/litter quality may avoid environmental and animal welfare problems and may increase economic profits in the commercial poultry industry. The control of excreta/litter quality implies the reduction of their amounts and moisture content. Many environmental and management problems could be associated with a high moisture content in excreta or litter such us increase of relative humidity; increased weight and volume of manure which increase their management, storage and removal costs; more fly development; increase of the rate of loss of ammonia into the environment. Moreover, many welfare and productivity constraints would be associated with high litter or excreta moisture, increase of dirty eggs, foot-pat dermatitis and breast burns, respiratory diseases, increased survival of viruses, etc.

This paper was first presented at the 14th European Symposium on Poultry Nutrition, Lillehammer, Norway, August 10-14, 2003

Received for publication August 20, 2003
Accepted for publication September 26, 2003

Several factors can affect the excreta/litter moisture content; some of them are related to management and housing (amount and type of litter, temperature, ventilation, heating, drinking system, density), other factors are related to diseases caused by various infections (coccidiosis, *Escherichia coli*, *Campylobacter*, *spirochaetes*), finally there are dietary factors which may affect water consumption and excretion. The excreta composition, which can affect their water retention capacity limiting the evaporative water losses, may also alter the litter characteristics.

This paper reviews some nutritional aspects that could modify the moisture and quality of poultry excreta/litter, focusing on dietary factors affecting water consumption, water excretion and the amount and composition of excreta: dietary protein level, electrolyte balance, ionophores, ingredients causing viscosity problems or containing high levels of non-digestible fibre fractions, some unusual ingredients or by-products and finally some feed technological treatments.

Dietary protein level

Excessive dietary protein supply in birds must be catabolised and excreted via the kidneys in the form of uric acid, this implies higher water consumption. On average and after Larbier and Leclercq (1992), the increase of 1 percentage point in protein level increases water consumption by 3%. Marks and Pesti (1984), feeding birds with diets changing protein content from 17% to 26% by increasing soybean at the expense of maize, observed a permanent increase of water consumption and higher water/feed ratios. Alleman and Leclercq (1997) studied the combined effect of temperature and dietary protein on water consumption, by testing two diets (16 and 20% of crude protein) at two temperatures (22° and 32°C). From 23 to 44 days and at 22°C, water intake increased linearly with age whereas at 32°C water intake remained constant. The increase of protein level raised water consumption at both temperatures. The water/feed ratio at 22°C was 1.69 (16% CP) and 1.93 (20% CP); at 32°C the ratios were 2.84 and 3.07, respectively. Ferguson *et al.* (1998) pointed out that it was possible to decrease litter moisture by 6%, litter nitrogen by 16.5% and equilibrium NH3 gas concentration by 31%, by reducing CP during the period of 22 to 43 d from 21.5% with 1.15 % lysine to 19.6% CP and 1.13% lysine but the improvement of litter quality was at the expense of increased feed intake and slight impairment of feed to gain ratio. No differences in litter quality parameters were observed between 16.5 and 19.5% of CP, but an important impairment of performance was noted at 16.5% of CP. However, the detrimental effect of dietary protein level on water consumption could be confounded with the protein source factor. In the three studies mentioned, the increase of dietary protein level was reached by the increase of soybean meal. Wheeler and James (1950) reported that soybean meal resulted in greater water intake than equal amounts of animal protein. Soybean meal, the main protein source in poultry diets, contains other components that can be responsible for a higher water excretion, such as fibre with high water retention capacity, fermentable sugars and potassium.

Electrolyte balance

Sodium, chloride and potassium are essential for all animals to maintain osmotic pressure regulation, acid-base balance and fluid balance in body tissues (Henry, 1995). Under practical conditions the acid-base status of birds is determined primarily by the amounts of sodium and potassium in the diet in addition to chloride (DEB, dietary electrolyte balance=Na^++K^+-Cl^-). Excessive intake of sodium and/or potassium in relation to chloride leads to alkalosis and an excessive intake of chloride results in an acidosis. Mongin (1981) reported that optimal chick growth performance when feeding purified diets was achieved using an electrolyte balance (Na^++K^+-Cl^-) of 250 mEq/kg with a relation (K+Cl)/Na > 1. Recently, Oviedo-Rondón *et al.* (2001) and Murakami *et al.* (2001) established with modern broiler strains and practical diets, an optimal DEB for the starter phase between 246 and 315 mEq/kg and for the grower one between 249 and 257 mEq/kg. Studying the influence of the DEB on water intake and litter moisture under warm and humid ambient, Borges *et al.* (2003) calculated an ideal predicted DEB of 236 mEq/kg for weight gain and 207 mEq/kg for feed conversion from 0 to 42. Water intake increased linearly with the dietary DEB increase and the increase of water intake was also reflected in a progressive increase in litter moisture. By the fourth week, litter moisture rose from 29.8% to 51.4% with 360 DEB, rendering management difficult. The authors concluded that under the conditions of the experiment and for growth and feed efficiency purposes, the most adequate DEB was 240 mEq/kg, although the high water intake and litter moisture were observed from the fourth week. In addition, birds fed diets with DEB higher than 240 had the lowest rectal temperatures and the smallest body heat variation from morning to afternoon, indicating a protective heat stress at that DEB level.

It would be difficult to demonstrate the detrimental effect of increasing dietary DEB on water consumption and excreta moisture, without taking into account the separate effects of the ions involved. The excess of Na^+ and K^+ promotes increases in litter moisture and water intake, whereas the increase of chloride anions seems unrelated to the humidity of droppings (Oviedo-Rondón *et al.*, 2001). The sodium requirement to achieve maximum growth rate has been estimated to be from 0.20% to 0.28% for young chickens and from 0.15% to 0.20% for growing chickens (NRC, 1994; Murakami *et al.*, 1997; Oviedo-Rondón *et al.*, 2001). The effect of dietary sodium level on water intake and excrete moisture is well documented and there is a wide agreement between authors that excess of sodium in chicken diets increases excreta moisture (see summary in *Table 1*). In the majority of reports the increase of excreta moisture is linearly dependent on the increase

Table 1 Some published studies on the effects of ions on increasing water consumption and excreta/litter moisture.

Ion	Supplemental level	Water intake	Excreta/litter moisture	Author
Sodium	0.1, 0.15, 0.2, 0.35%	Linear	-	1
	0.12, 0.16, 0.20, 0.24, 0.28%	-	>0.24%	2
	0.15, 0.30, 0.45%	No effect	-	3
	0.20, 0.39, 0.59, 0.78%	No affect	>0.39%	4
	From 0.15 to 0.30% (Δ 0.05%)	-	>0.25% (litter)	5
	0.16, 0.5, 1.0, 1.5%	-	Linear	6
	0.16, 0.55, 0.94, 1.33, 1.72, 2.11%	Linear	Linear	7
	From 0.10 to 0.35% (Δ 0.05%)	-	Linear (litter)	8-9
Potassium	0.5, 1.0%	Increase	-	3
	0.23, 0.5, 0.75, 1.0, 1.5, 2.0%	Linear	Linear	7
Chloride	From 0.10 to 0.35% (Δ 0.05%)	-	No effect (litter)	8
Electrolyte balance	125, 165, 205 mEq/kg	-	205 increase	10

1. Nan *et al.* (1979); 2. Damron and Harms (1981); 3. Fleet and Saylor (1983); 4. Damron *et al.* (1986); 5. Murakami *et al.* (1997); 6. Smith et al. (2000a); 7. Smith *et al.* (2000b). 8. Oviedo-Rondón *et al.* (2001); 9. Murakami *et al.* (2001); 10. Karunajeewa and Barr (1988).

of added sodium (Fleet and Saylor, 1983; Murakami *et al.*, 1997; Oviedo-Rondón *et al.*, 2001). In layers, Smith *et al.* (2000b) also found that increasing dietary sodium from 0.16 to 2.11% gave a linear increase of the excreta moisture; a 0.9% increase for each 0.1% of sodium. The same group (Smith *et al.*, 2000a) observed that the increase of dietary sodium concentration from 0.16% to 1.5% gave a linear increase of excreta moisture and for each 10% increase in excreta moisture dirty egg numbers increased by 0.52%. Others authors did not find impairment with sodium addition below 0.24-0.25% (Damron and Harms, 1981; Damron *et al.*, 1986; Murakami *et al.*, 1997). Water consumption has been less frequently measured than excreta moisture, but some reports indicated also a linear increase of water consumption with the increase of sodium supplementation (Damron *et al.*, 1986). Smith *et al.*, (2000b) measured in layers a 2.9-fold increase on water consumption and a 6.7-fold increase on water-feed to ratio with the rise of sodium supplementation from 0.16 to 2.11%.

It is a current practice in the poultry industry to use sodium bicarbonate (SBC) as a source of supply of sodium in broiler and turkey diets, to maintain electrolyte balance, improve heat stress tolerance, and dry litter. In layer diets, sodium bicarbonate is used to improve eggshell quality, particularly in older hens and during heat stress, but its use is not fully supported by scientific evidence. At high temperatures, broilers showed disturbance in the acid-base balance and under thermal stress birds regulated heat loss through the evaporation of water from their lungs, increasing respiratory rate, which leads to a respiratory alkalosis (Teeter and Belay, 1996). In this situation, the supplementation of feed or drinking water with SBC has shown some beneficial response (Balnave and Gorman, 1993). But under practical conditions, the other supposed advantage of SBC in broilers feeds is the reduction of NaCl to avoid wet litter problems. Merrill (1993) reported that in Western Europe, 0.2% of sodium bicarbonate plus 0.15% of added NaCl is regularly used for this purpose, where in this context there is no enough scientific evidence. Damron and Harms (1981), Damron *et al.* (1986), Murakami *et al.* (1997) and Smith *et al.* (2000b) did not find differences in excreta moisture between the addition of the same quantity of sodium from sodium chloride or sodium bicarbonate. On the other hand, Hooge *et al.* (1999) found differences between sodium sources comparing the effect of adding 0.054 % of extra sodium from sodium bicarbonate, chloride or sulphate on top of a maize-soybean or maize-soybean-meat diets containing 0.20% of sodium. Birds were challenged with coccidia and diets included Monensin. They found that water excretion expressed as a percentage of intake and litter moisture were significantly increased by extra NaCl compared with the control, SBC resulted in an intermediate and significant increase as well, and sodium sulphate had no effect.

Potassium is readily absorbed from the upper small intestine and is excreted from the body primarily through the urine. The functions of potassium in the body include osmotic pressure regulation, maintenance of water and acid-base balance, nerve impulse conduction, muscle contraction and enzymatic reactions balance (Miller, 1995). The increases of dietary potassium level has also been associated, like sodium, with an increase of water consumption and excreta moisture. After Smith *et al.* (2000b), each 0.1% increase of potassium increased the moisture content of excreta by 1.2% in layers fed potassium levels from 0.23 to 2.0% and the increase was similar to that observed for sodium (0.9%). Carré *et al.* (1994) measured water and feed consumption and water excretion of 5-week-old turkeys fed with 27 feeds, to establish functions for prediction of water excretion and consumption from feed parameters. The highest correlations ($r = 0.71$ and $r = 0.77$ for water excretion and consumption, respectively) were observed with the RAV (real applied viscosity) and the most efficient regressions were that combining RAV with dietary potassium content (ranged from 0.59 to 1.06%). Potassium appeared in the regressions as a modulator of slopes attributed to viscosity, turkeys fed low potassium diets were more sensitive to variations in viscosity than turkeys fed high potassium diets. The effect of feed viscosity on water intake and excreta moisture will be commented on later. Some prediction equations to estimate water intake and excreta moisture from the dietary ion concentrations are shown in *Table 2*.

Table 2 Some linear estimates of changing the dietary ions concentration (%) on water intake and excreta moisture.

Mineral	Dependent variable	Estimate	Author
			Smith *et al.* (2000b). Layers
X=sodium:	Excreta moisture (g/kg)	y=693.7 + 9.04x	
	Water intake (g/d)	y=130.7 + 13.67x	
X=potassium:	Excreta moisture (g/kg)	y=570.7 + 11.95x	
	Water intake (g/d)	y=174.2 + 9.19 x	
X=phosphorus	Excreta moisture (g/kg)	y=723.5 + 5.59x	
	Water intake (g/d)	y=192.1 + 7.43x	
			Carré *et al.* (1994). Turkeys
X_1=potassium	Water intake/feed intake	$Y=(3.4x_1^2 - 6.36x_1 + 3.14)x_2 + 1.16x_1 + 0.63$	
X_2= viscosity(1)	Water excretion/feed intake	$Y=(2.78x_1^2 - 5.16x_1 + 2.50)x_2 + 0.66x_1 + 0.23$	

(1)Real applied viscosity (g^{-1}.ml)

Ionophores

Ionophores are used as coccidiostats in poultry to prevent development of coccidia in the gastro-intestinal tract. Their mode of action is related to high diffusion rates of the complexes across lipid barriers together with high cation selectivity, making membranes permeable to Na^+ and K^+ ions, allowing excess water enter into the cell and affecting mitochondrial activity. The ionophore coccidiostats interact with nutrients in the diet, especially with the electrolytes sodium, potassium and chloride. The selectivity of ionophores for ions is variable, whereas monensin and narasin have preference for transporting sodium over potassium; salinomycin and lasalocid are more selective for potassium than sodium (Pressman, 1976). Due to their interaction with the electrolyte balance, ionophores have often been suspected of stimulating water consumption and causing litter moisture problems in broilers, and of changing nutrients requirements in poultry; but scientific data are not conclusive. It seems that the use of monensin did not change the sodium requirements (Damron and Harms, 1981) and the use of either monensin or lasalocid did not alter the balance of electrolytes required for optimum growth (Karunajeewa and Barr, 1988). Regarding water consumption and wet litter problems, some reports have shown a significant effect of lasalocid on these parameters. Wheelhouse *et al.* (1985) reported a significant increase of water consumption for lasalocid over monensin groups, but not over non-medicated or salinomycin groups in females during seven weeks, whereas in males differences were not statistically different. Lasalocid at 110 or 124 mg/kg increased water consumption, water: feed and water: body weight in comparison with amprolium, salinomycin, monensin and non-medicated groups trough the first 21 d (Damron, 1994). In 42-day study (Ouart *et al.*, 1995), lasalocid at 100 and 124 mg/kg also increased water intake by 9% at 21 and 42 days and litter moisture by 6% at day 21 in comparison with halofuginone, salinomycin, monensin and non-medicated control. Other studies were not able to find a higher water consumption or higher litter moisture with the use of lasalocid over that of controls (Patel *et al.*, 1980; Salsbury, 1984; Wheelhouse *et al.*, 1985; Macy *et al.*, 1990). Some trials showed a reverse effect of monensin, reducing water consumption over that of non- medicated birds (Frigg and Broz, 1983; Fleet and Saylor, 1983). Radu and Van Dijk (1987) found that broilers given diets with maduramicin drank more water than the non-medicated birds (by 5.7%), which in turn, drank more than birds fed salinomycin (by 6%). With wheat-based diets, Karunajeewa and Barr (1990) found significantly higher litter moisture in maduramicin groups than in salinomycin groups (48.5% vs. 38.7%).

Cereals causing viscosity problems

The use of cereals rich in soluble non-starch polysaccharides (sNSP) like rye, barley, triticale and often wheat have been currently associated with litter problems related to the increase in amount of excreta or to the excreta stickiness and wateriness. Roberts *et al.* (1998) compared the effect of different cereals, sorghum, barley, wheat and triticale, on excreta moisture content in laying hens and they found that barley diets caused the wettest (77.5% vs. 74.5% on average). The antinutritive effect of sNSP (β-glucans and arabinoxylans) is manifested by growth depression, reduced nutrient digestibility (especially fat), physiological and morphological changes in the digestive system, increased digesta viscosity and by modifying intestinal microflora (Choct, 2000). The effect of sNSP on digesta viscosity could be probably the first direct cause of increased water consumption and faecal moisture in birds fed barley, rye, wheat or triticale. As mentioned before, and according to the results of Carré *et al.* (1994), water consumption and excretion in relation to feed intake and excreta score in turkeys were highly correlated with feed viscosity (r=0.78, 0.71 and 0.89, respectively). Also Carré *et al.* (2002) found positive correlations between viscosity-related parameters and excreta water/feed intake ratio in birds fed different wheat varieties. Increase of feed viscosity lowers water absorption and thus increases water losses through the excreta. The regular use of non-starch polysaccharides degrading enzymes in diets containing cereals high in sNSP helps to alleviate the problem. According to Bedford and Morgan, (1996), enzymes are probably used in practice more for their effect on reducing wet litter than for any other reason. The same author (Bedford, 1995) measured the whole excreta production of birds fed an enzyme supplemented barley diet and it was reduced by more than 25% at 3 weeks and 22% at 6 weeks of age compared with controls. *Table 3* shows a summary of some published studies on the effects of enzyme supplementation on digesta viscosity, water intake and quality of excreta/litter. The majority of data is from barley diets and the trends showing a clear effect of enzyme addition towards reduction of the sticky droppings, digesta viscosity, higher dry matter of excreta and lower water consumption, when it was measured. *Figure 1* clearly showed that as the amount of barley increased, water consumption and the incidence of sticky droppings also increased, whereas with enzyme addition no effect of barley inclusion was observed (Francesch *et al.*, 1989).

Although the negative effect of sNSP is much stronger in young birds than in older ones (Almirall *et al.*, 1995), enzyme addition has shown some beneficial effect on reducing excreta viscosity and number of dirty eggs. Choct (1999) compared the effect of different enzymes on wet droppings in four strains of layers fed a barley diet. There was a significant interaction between diet (different enzymes) and hybrid with regard to excreta moisture. In general, enzyme reduced excreta moisture but the reduction was dependent on the strain.

Fibrous ingredients and by-products

A cereal by-product that can cause problems with droppings is rice bran. Martin and Farrell (1998) found higher moisture content in ileal content of birds fed a diet containing

Table 3 Some published studies on the effects of enzyme supplementation on reduction of digesta viscosity, water intake, sticky droppings and excreta/litter moisture.

Cereal	Bird[1]	Digesta viscosity	Water intake	Sticky droppings	Excreta moisture Enzyme +	Excreta moisture Enzyme –	Author
Barley	BC	-	-	-	77.3%	81.0%	1
Barley	BC	-	-	-	74.6%	77.7%	2
Barley	BC	-	10%-19%	21%-32%	72.5% 69.5%	74.3% 71.1%	3
Barley	BC	-	6.9%-9.8%	88%-97%	43.3- 40.6%	47.8%[3]	4
Barley	T	-	-	-	23%	27.0%[3]	5
Barley	BC	-	-	50%	-	-	6
Barley	BC	-	-	41%-64%	75.6%	77.4%	7
Barley	BC	42%-74%	-	-	55.9%	59.4%	8
Barley	L	-	6.4%	-	78.6%	80.2%	9
Barley	BC	85%-90%	-	-	81.4%	83.3%[2]	10
Barley	BC	30%	-	73%	81.8 % 76.6%	85.3%[2] 82.5%	11
Wheat	BC	65%	0%[4]	0%	71.0%	73.3%	12-13
Barley		73%	21%	31%	68.2%	73.5%	
Rye		90%	12%	17%	73.5%	75.7%	
Rye	BC	-	21%[4]	-	-	-	14

[1]BC=broiler chicken, L=layer, T=turkey. [2]Ileal digesta moisture. [3]Litter moisture. [4]Water/feed

1. Hesselman *et al.* (1982); 2. Broz and Frigg (1986); 3. Francesch *et al.* (1989); 4. Elwinger and Teglöf (1991); 5. Ferket (1992); 6. Brufau *et al.* (1993); 7. Francesch *et al.* (1994); 8. Fuente *et al.* (1995); 9. Francesch *et al.* (1995); 10. Almirall *et al.* (1995); 11. Svihus *et al.* (1997); 12-13. Francesch *et al.* (1999a, 1999b); 14. Mathlouthi *et al.* (2002)

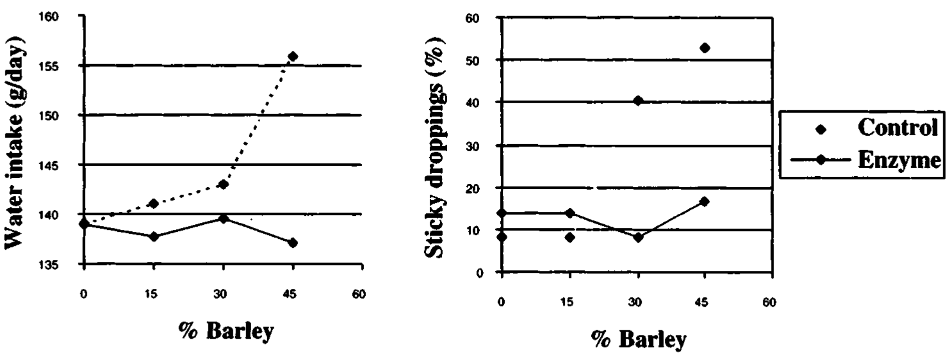

Figure 1 Effects of barley inclusion on water intake and incidence of sticky droppings in broilers chickens (Francesch *et al.*, 1989).

40% of rice bran replacing sorghum (84.6% vs. 81.7%). The same group observed that viscosity as well as dry matter of ileal digesta decreased with the use of 20 and 40% of rice bran in the diet (Farrell and Martin, 1998); they did not find any beneficial effect of using NSP degrading enzymes and authors concluded that soluble NSP were not a significant factor in altering the nutritive value of rice bran. Rice bran has a considerable amount of pentosans and the major proportion of this type of NSP is in insoluble form. Moreover, the structures of these pentosans are different from that present in wheat or rye (Annison *et al.*, 1995). The inclusion of isolated rice bran arabinoxylans in a broiler diet had no effect on performance and nutrient digestibility. Other fibrous by-product ingredients that can increase the quantity of voided excreta and their water content are palm kernel meal, brewer's dried grains and maize offal (Onifade and Babatunde, 1998). Broilers fed the control diet voided less wet excreta than those fed the by-products. With all three products, wet and dry excreta weights increase as the amount of ingredients rose (from 10 to 20%) and excreta water content was highest with maize offal followed by palm kernel meal and the lowest was dried brewer's grains. The dietary energy dilution in laying hens by using sugar beet pulp has also produced an increase of water consumption, by 21% with 7.5% and by 56% with 15% of sugar beep pulp (Almirall *et al.*, 1997). Water to feed ratio was also increased in a similar magnitude in both mash and pelleted diets. Tapioca can cause droppings problems in poultry if included at high levels (30%) possible due to the presence of indigestible starches, presence of toxins (Pattison, 1987). Moreover, the potassium level in tapioca could be considerable high, depending on the quality.

Legumes

As a consequence of the recent ban of the use of meat and bone meals in poultry feeds, the levels of soybean meal increased, especially in turkey diets demanding high protein content. In France, Perez *et al.* (2002) reported an increase of problems related to an over-excretion of water in turkeys and laying hens, probable due to an increase of dietary potassium provided by soybean meal, naturally high in potassium (over 2%). Moreover, the increased use of high levels of vegetable protein ingredients in poultry diets implies also an increase of the quantity of indigestible carbohydrates in the gut, which lead to poor nutrient digestion and absorption (Classen and Bedford, 1999) and increased occurrence of unspecific digestion disturbances, which can affect water consumption and increase litter problems. Approximately 40% of soybean meal is poorly digested carbohydrate, principally cell wall components. Soybean meal contains a high level of NSP (about 22%) and considerable amount of low molecular weight sugars (about 14%) of which 44% are α-galacto-oligosaccharides (Bach Knudsen, 1997). The oligosaccharides present in soybean meal cause faeces to have hydroscopic properties, resulting in higher litter moisture (Bedford, 1995).

Sweet lupins have been shown to cause wet droppings in layers as well as in broiler chickens (Farrell *et al.*, 1999), attributable to their higher concentration of soluble NSP. Lupin kernel contains around 35% of total NSP, consisting predominantly of pectic polysaccharides rhamnogalacturonans, of which 15% are in soluble form (Evans *et al.*, 1993). Recently, Hughes *et al.* (2000) have also shown that the inclusion of lupin kernel isolate in the diet depressed AME and bird performance, and increased ileal viscosity and excreta moisture, in a dose-dependent manner. The use of an enzyme combination with pectinase, α-galactosidase, xylanase and β-glucanase activities resulted in a small improvement in dietary AME and had a beneficial effect on excreta moisture, only at the low level of lupin kernel.

Feed technological treatments

Some feed technological treatments, such as pelleting conditions, extrusion, and grinding can affect water consumption of birds fed barley or wheat. Samarasinghe *et al.* (2000) reported an increase in the water/feed ratio (by 3.6%) by the increase of pelleting temperature of a barley diet from 60 to 90°C; the increase in water intake followed the same pattern of increase of feed viscosity with the temperature. Silversides and Bedford

(1999) found a dramatic increase of digesta viscosity of birds fed on wheat-based diets with the increase of conditioning temperature before pelleting from 70 to 95°C; digesta viscosity increased from 4.12 to 11.14 cps. The increase of intestinal viscosity with higher processing temperatures is likely due to the increase of NSP solubility as well as the destruction of endogenous enzymes. The extrusion of barley before pelleting the diet also increased feed viscosity from 1.59 to 3.79 cP, due to an increase of soluble fibre and a decrease of insoluble fibre and a starch gelatinisation (Vukic Vranjes and Wenk, 1995). Barley extrusion increased dietary water binding capacity. Extruded barley depressed feed utilisation and dietary AME and increased water consumption during the first weeks.

In relation to the majority of ingredients used in poultry diets, Carré *et al.* (1995) tried to predict the sticking level and the visual score of the excreta of turkeys from the characteristics of feeds. The best equation obtained included real applied viscosity, with a positive coefficient, and water retention of cells walls with a negative coefficient. The water retention was depending on those of the raw materials and on outlet pelleting temperature. Among the ingredients tested the highest water retention of cells walls were found for alfalfa, soybean meal, full-fat extruded soybean meal and tapioca. Carré and Melcion (1995) pointed out the possibility to control water intake and excretion in turkeys taking into account in the formulation the potential applied viscosity values and potassium together with the monitoring of outlet temperature of pelleting.

Finally, feed particle size and pellet form can also affect water excretion. Carré *et al.* (1995) found a higher water excretion in relation to feed intake in birds fed pelleted than in mash diets containing guar gum or pectin. The same group (Carré *et al.*, 2002), feeding birds with pelleted diets containing different wheat varieties, have observed that water excretion (calculated as indices independent of food intake) was negatively related to the proportion of coarse particles measured after grinding wheat through a 3 mm screen. The authors explained this negative correlation by an increase of transit time induced by coarse particles allowing more water reabsorption.

Acknowledgement

The author is grateful to Dr Jiri Broz for his critical comments on the manuscript.

References

ALLEMAN, F. and LECLERCQ, B. (1997) Effect of dietary protein and environmental temperature on growth performance and water consumption of male broiler chickens. *British Poultry Science* **38**: 607-610.

ALMIRALL, M., FRANCESCH, M., PÉREZ-VENDRELL, A.M., BRUFAU, J. and ESTEVE-GARCIA, E. (1995) The differences in intestinal viscosity produced by barley and β-glucanase alter digesta enzyme activities and ileal nutrient digestibilities more in broilers than in cocks. *Journal of Nutrition* **125**: 947-955.

ALMIRALL, M., COS, R., ESTEVE-GARCIA, E. and BRUFAU, J. (1997) Effect of inclusion of sugar beet pulp, pelleting and season on laying hen performance. *British Poultry Science* **38**: 530-536.

ANNISON, G., MOUGHAN, P.J. and THOMAS, D.V. (1995) Nutritive activity of soluble rice bran arabinoxylans in broiler diets. *British Poultry Science* **36**: 479-488.

BACH KNUDSEN, K.E. (1997) Carbohydrate and lignin contents of plant materials used in animal feeding. *Animal Feed Science and Technology* **67**: 319-338.

BALNAVE, D. and GORMAN, I. (1993) A role for sodium bicarbonate supplements for growing broilers at high temperatures. *World's Poultry Science Journal* **49**: 236-241.

BEDFORD, M.R. (1995) Mechanism of action and potential environmental benefits from the use of feed enzymes. *Animal Feed Science and Technology* **53**: 145-155.

BEDFORD, M.R. and MORGAN, A.J. (1996) The use of enzymes in poultry diets. *World's Poultry Science Journal* **52**: 61-67.

BORGES, S.A., FISCHER DA SILVA, A.V., ARIKI, J., HOOGE, D.M. and CUMMINGS, K.R. (2003) Dietary electrolyte balance for broilers chickens under moderately high ambient temperatures and relatively humidities. *Poultry Science* **82**: 301-308.

BROZ, J. and FRIGG, M. (1986) Effects of beta-glucanase on the feeding value of broiler diets based on barley or oats. *Archiv für Geflügelkunde* **50**: 41-47.

BRUFAU, J., FRANCESCH, M., PÉREZ-VENDRELL, A.M. and ESTEVE-GARCIA, E. (1993) Effects of post-harvest storage on nutritive value of barley in broilers. In: *Enzymes in Animal Nutrition*, Kartause Ittingen, Thurgau, Switzerland, pp: 125-128.

CARRÉ, B., GÓMEZ, J., MELCION, J.P. and GIBOULOT, B. (1994) La viscosité des aliments destinés à l'aviculture. Utilisation pour prédire la consommation et l'excretion d'eau. *INRA - Production Animale* **7**: 369-379.

CARRÉ, B., FLORES, M.-P. and GOMEZ, J. (1995) Effects of pelleting, lactose level, polyethylene glycol 4000, and guar gum compared on growth performances, energy values, and losses of lactose, lactic acid, and water in chickens. *Poultry Science* **74**: 1810-1819.

CARRÉ, B. and MELCION, J.P. (1995) Effects of feed viscosity on water excretion in meat-turkey poults. In: *Recent Advances in animal Nutrition in Australia*, Armidale, Australia, pp: 1-6.

CARRÉ, B., MONREDON, F.D., MELCION, J.P. and GÓMEZ, J. (1995) Qualité de la litière en aviculture. Aliments et caractéristiques physiques des excretas. *INRA - Production Animale* **8**: 331-334.

CARRÉ, B., IDI, A., MAISONNIER, S., MELCION, J.-P., OURY, F.-X., GOMEZ, J. and PLUCHARD, P. (2002) Relationships between digestibilities of food components and characteristics of wheats (*Triticum aestivud*) introduced as the only cereal source in a broiler chicken diet. *British Poultry Science* **43**: 404-415.

CHOCT, M. (1999) Effects of commercial enzymes on wet droppings in four strains of layers fed a barley-based diet. In: *Australian Poultry Science Symposium*, pp: 89-93.

CHOCT, M. (2000) Enzyme supplementation on poultry diets based on viscous cereals. In: M. Bedford and G.G. Partridge (eds.) *Enzymes in farm animal nutrition*, CAB International, Wallingford, pp: 145-160.

CLASSEN, H.L. and BEDFORD, M. (1999) The use of enzymes to improved the nutritive value of poultry feeds. In: J. Wiseman and P.C. Garnsworthy (eds.) *Recent developments in poultry nutrition 2*. Nottingham University Press, UK.

DAMRON, B.L. (1994) The relationship of maximum or intermediate coccidiostat levels to broiler chick water intake. *Poultry Science* **73**: 33-36.

DAMRON, B.L. and HARMS, R.H. (1981) Broiler performance as affected by sodium source, level and monensin. *Nutrition Reports International* **24**: 731-740.

DAMRON, B. L., JOHNSON, W.L. and KELLY, L.S. (1986) Utilization of sodium from sodium bicarbonate by broilers chickens. *Poultry Science* **65**: 782-785.

ELWINGER, K. and TEGLÖF, B. (1991) Performance of broiler chickens as influenced by a dietary enzyme complex with and without antibiotic supplementation. *Archiv für Geflügelkunde* **55**: 69-73.

EVANS, A.J., CHEUNG, P.C.-K. and CHEETHAM, N.W.H. (1993) The carbohydrate composition of cotyledons and hulls of cultivars of lupinus angustifolius from western Australia. *Australian Journal of Agricultural Research* **50**: 189-194.

FARRELL, D.J. and MARTIN, E.A. (1998) Strategies to improve the nutritive value of rice bran in poultry diets. I. The addition of food enzymes to target the non-starch polysaccharide fractions in diets of chickens and ducks gave no response. *British Poultry Science* **39**: 549-554.

FARRELL, D.J., PEREZ-MALDONADO, R. A. and MANNION, P.F. (1999) Optimum inclusion of field peas, faba beans, chick peas and sweet lupins in poultry diets. I. Broiler experiments. *British Poultry Science* **40**: 674-680.

FERGUSON, N.S., GATES, R.S., TARABA, J.L., CANTOR, A.H., PESCATORE, A.J., FORD, M.J. and BURNHAM, D.J. (1998) The effect of dietary crude protein on growth, ammonia concentration, and litter composition in broilers. *Poultry Science* **77**: 1481-1487.

FERKET, P.R. (1992) Use of barley in growing turkey diets. In: *Minnesota Nutrition Conference*. p 251-259.

FLEET, J.C. and SAYLOR, W.W. (1983) Interaction of dietary electrolytes and coccidiostats in broilers chickens. *Poultry Science* **62**: 1422-1423.

FRANCESCH, M., PÉREZ-VENDRELL, A., ALMIRALL, M., ROURA, E. and BRUFAU, J. (1989) Beta-glucanase supplementation in barley based diets for broilers. Effects on dry matter content of excreta, water consumption, sticky droppings and carcass yield. In: *7th European Symposium on Poultry Nutrition, Lloret de Mar*, Spain, pp: 309-313.

FRANCESCH, M., PÉREZ-VENDRELL, A., ESTEVE-GARCIA, E. and BRUFAU, J. (1994) Effects of cultivar, pelleting and enzyme addition on nutritive value of barley in poultry diets. *British Poultry Science* **35**: 259-272.

FRANCESCH, M., PÉREZ-VENDRELL, A., ESTEVE-GARCIA, E. and BRUFAU, J. (1995) Enzyme supplentation of a barley and sunflower-based diet on laying hen performance. *Journal of Applied Poultry Research* **4**: 32-40.

FRANCESCH, M., PÉREZ-MOYA, S., BADIOLA, I. and BRUFAU, J. (1999a) Effects of cereal and feed enzyme on digesta viscosity and bacterial counts in broiler chickens. In: *12th European Symposium on Poultry Nutrition, The Netherlands*, pp: 242-245.

FRANCESCH, M., PÉREZ-MOYA, S., BADIOLA, I. and BRUFAU, J. (1999b) Effects of cereal and feed enzyme on water consumption, dietary metabolisable energy and nutrient digestibility in broilers chickens. In: *12th European Symposium on Poultry Nutrition*, The Netherlands, pp: 258.

FRIGG, M. and BROZ, J. (1983) Effect of various doses of lasalocid and monensin in combination with increasing potassium levels on performance and water consumption of broilers chickens. *Archiv für Geflügelkunde* **47**: 153-158.

FUENTE, J.M., PÉREZ DE AYALA, P. and VILLAMIDE, M.J. (1995) Effect of dietary enzyme on metabolisable energy of diets with increasing levels of barley fed to broilers at different ages. *Animal Feed Science and Technology* **56**: 45-53.

HESSELMAN, K., ELWINGER, K. and THOMKE, S. (1982) Influence of increasing levels of β-glucanase on the productive value of barley diets for broilers chickens. *Animal Feed Science and Technology* **7**: 351-358.

HENRY, P.R. (1995) Sodium and chloride bioavailability. In: C.B. Ammerman, D.H. Baker and A.J. Lewis (eds.) *Bioavailability of nutrients for animals*. Academic Press, San Diego, California, US, pp: 337-348.

HOOGE, D.M., CUMMINGS, K.R. and MCNAUGHTON, J.L. (1999) Evaluation of sodium bicarbonate, chloride, or sulphate with coccidiostats in corn-soy or corn-soy-meat diets for broilers chickens. *Poultry Science* **78**: 1300-1306.

HUGHES, R.J., CHOCT, M., KOCHER, A. and VAN BARNEVELD, R.J. (2000) Effect of food enzymes on AME and composition of digesta from broiler chickens fed on diets containing non-starch polysaccharides isolated from lupin kernel. *British Poultry Science* **41**: 318-323.

KARUNAJEEWA, H. and BARR, D.A. (1988) Influence of dietary electrolyte balance, source of added potassium and anticoccidial agents on the performance of male broilers. *British Poultry Science* **29**: 137-147.

KARUNAJEEWA, H. and BARR, D.A. (1990) Effects of maduramicin, salinomycin and dietary level of wheat on the performance of broilers chickens. *Applied Agricultural Research* **5**: 227-234.

LARBIER, M. and LECLERCQ, B. (1992) Consommation d'aliment et d'eau. In: INRA (ed.) *Nutrition et alimentation des volailles*. INRA, Paris, France, pp: 17-25.

MACY, L.B., DELEE, J.A., WALDROUP, P.W., IZAT, A.L., GWYTHER, M.J. and EOFF, H.J. (1990) Effects of feeding lasalocid on performance of broilers in moderate and hot temperature regimens. *Poultry Science* **69**: 1265-1270.

MARKS, H.L. and PESTI, G.M. (1984) The roles of protein level and diet form in water consumption and abdominal fat depot deposition of broilers. *Poultry Science* **63**: 1617-1625.

MARTIN, E.A. and FARRELL, D.J. (1998) Strategies to improve the nutritive value of rice bran in poultry diets. II. Changes in oil digestibility, metabolisable energy and attempts to increase the digestibility of the oil fraction in the diets of chickens and ducklings. *British Poultry Science* **39**: 555-559.

MATHLOUTHI, N., LALLES, J.P., LEPERCP, P., JUSTE, C. and LARBIER, M. (2002) Xylanase and beta-glucanase supplementation improve conjugated bile acid fraction in intestinal contents and increase villus size of small intestine wall in broiler chickens fed a rye-based diet. *Journal of Animal Sciences* **80**: 2773-2779.

MERRILL, D. (1993) Survey on Sodium Bicarbonate use in the Western European Animal feed market. SRI International for Church & Dwight Company, Inc, Princeton, NJ.

MILLER, E.R. (1995) Potassium bioavailability. In: C.B. Ammerman, D.H. Baker and A.J. Lewis (eds.) *Bioavailability of nutrients for animals*. Academic Press, San Diego, California, US, pp: 295-301.

MONGIN, P. (1981) Recent advances in dietary anion-cations balance: Applications in poultry. *Procedings Nutrition Society* **40**: 285-294.

MURAKAMI, A.E., SALEH, E.A., ENGLAND, J.A., DICKEY, D.A., WATKINS, S.E. and WALDROUP, P.W. (1997) Effect of level and source of sodium on performance of male broilers to 56 days. *Journal of Applied Poultry Research* **6**: 128-136.

MURAKAMI, A.E., OVIEDO-RONDÓN, E.O., MARTINS, E.N., PEREIRA, M.S. and SCAPINELLO, C. (2001) Sodium and chloride requirements of growing broiler chickens (twenty-one to forty-two days of age) fed corn-soybean diets. *Poultry Science* **80**: 289-294.

NAN, C.W., MANNING, B., PATEL, M.B. and MCGINNIS, J. (1979) Observations of the effect of different dietary sodium levels and coccidiostats (monensin and lasalocid) on growth, feed efficiency, water intake, and mortality in broilers. *Poultry Science* **58**: 1088.

NRC (1994) Nutrient requirements of poultry. 10th Ed. ed. national Academy Press, Washington, DC.

ONIFADE, A.A. and BABATUNDE, G.M. (1998) Comparison of the utilisation of palm kernel meal, brewers' dried grains and maize offal by broiler chicks. *British Poultry Science* **39**: 245-250.

OUART, M.D., DAMRON, B.L. and CHRISTMAS, R.B. (1995) Effect of coccidiostats on performance, water intake, and litter moisture of broilers. *Journal of Applied Poultry Research* **4**: 374-378.

OVIEDO-RONDÓN, E.O., MURAKAMI, A.E., FURLAN, A.C., MOREIRA, I. and MACARI, M. (2001) Sodium and chloride requirements of young broiler chickens fed corn-soybean diets (one to twenty-one days of age). *Poultry Science* **80**: 592-598.

PATEL, M.B., NAN, C.W., BISHAWI, K.O. and MCGINNIS, J. (1980) Effect of different levels and combinations of lasalocid and monensin on broiler performance, water consumption and prevention of coccidiosis. *Poultry Science* **59**: 1649.

PATTISON, M. (1987) Problems of diarrhoea and wet litter in meat poultry. In: W. Haresign and D.J.A. Cole (eds.) *Recent advances in animal nutrition*. Butterworths, London. pp: 27-37.

PEREZ, J.M., BORIES, G., AUMAITRE, A., BARRIER-GUILLOT, B., DELAVEAU, A., GUEGUEN, L., LARBIER, M. and SAUVANT, D. (2002) Conséquences en élevage et pour le consommateur du remplacement des farines et des graisses animales. *INRA Production Animale* **15**: 87-96.

PRESSMAN, B.C. (1976) Biological application of ionophores. Annual Review of Biochemistry **45**: 501.

RADU, J. and VAN DIJK, C. (1987) Feed and water consumption and performance of male and female broilers fed salinomycin and maduramicin followed by a withdrawal ration. *Poultry Science* **66**: 1878-1881.

ROBERTS, J.R., BALL, W. and LEARY, A. (1998) Effects of different cereal grains on egg and egg shell quality in laying hens. In: *Australian Poultry Science Symposium*. pp: 199.

SALSBURY, R.L. (1984) Feed and water intake by broiler chicks as affected by ionophore, sodium and chlorine concentration in feed. *Poultry Science* **63**, Suppl. 1: 174.

SAMARASINGHE, K., MESSIKOMMER, R. and WENK, C. (2000) Activity of supplemental enzymes and their effect on nutrient utilization and growth performance of chickens as affected by pelleting temperature. *Archives of Animal Nutrition* **53**: 45-48.

SILVERSIDES, F.G. and BEDFORD, M.R. (1999) Effect of pelleting temperature on the recovery and efficacy of a xylanase enzyme in wheat-based diets. *Poultry Science* **78**: 1184-1190.

SMITH, A., ROSE, S.P., WELLS, R.G. and PIRGOZLIEV, V. (2000a) The effect of changing the excreta moisture of caged laying hens on the excreta and microbial contamination of their egg shells. *British Poultry Science* **41**: 168-173.

SMITH, A., ROSE, S.P., WELLS, R.G. and PIRGOZLIEV, V. (2000b) Effect of excess dietary sodium, potassium, calcium and phosphorus on excreta moisture of laying hens. *British Poultry Science* **41**: 598-607.

SVIHUS, S., NEWMAN, R.K. and NEWMAN, C.W. (1997) Effect of soaking, germination and enzyme treatment of whole barley on nutritional value and digestive tract parameters of broiler chickens. *British Poultry Science* **38**: 390-396.

TEETER, R.G. and BELAY, T. (1996) Broiler management during acute heat stress. *Animal Feed Science and Technology* **58**: 127-142.

VUKIC VRANJES, M. and WENK, C. (1995) Influence of dietary enzyme complex on the performance of broilers fed on diets with and without antibiotic supplementation. *British Poultry Science* **36**: 265-275.

WHEELER, R.S. and JAMES Jr., E.C. (1950) The problem of wet poultry house litter. The influence of total dietary protein and soybean meal on water intake and urinary and faecal water elimination in growing chickens. *Poultry Science* **29**: 496-500.

WHEELHOUSE, R.K., GROVES, B.I., HAMMAT, C.A., VAN DIJK, C. and RADU, J. (1985) Effects of coccidiostats and dietary protein on performance and water consumption in broilers chickens. *Poultry Science* **64**: 979-985.