# Use of wood ash in the treatment of high tannin sorghum for poultry feeding

**C.C. Kyarisiima[1#], M.W. Okot[1] and B. Svihus[2]**
[1] Department of Animal Science, Makerere University, P.O. Box 7062, Kampala, Uganda
[2] Department of Animal Science, Agricultural University of Norway, P.O. Box 5025, N-1432, Aas, Norway

## Abstract

A study was conducted to investigate the effects of wood ash treatment on the nutritional value of high tannin sorghum. High tannin sorghum was either soaked in wood ash slurry and then germinated for four days or soaked in wood ash extract and germinated for 28 hours or germinated after soaking in water. Chemical composition of the grain thus treated was determined. The feeding value of the wood ash extract treated grain was evaluated in a three-week experiment where sorghum replaced maize in broiler starter diets. Treatment of high tannin sorghum with wood ash extract was effective in reducing the tannin level and did not lower the nutrient content of the grain, unlike the treatment that involved the use of wood ash slurry. There was no significant difference in feed intake between the maize based diet and the diet that contained wood ash extract treated sorghum. There was a significant improvement in growth rate of chicks that were fed on diets that contained treated sorghum. This was also reflected in the improvement of the ileal digestibility of the diets that contained treated grain. Treatment of high tannin sorghum with wood ash extract improves its nutritive value.

**Keywords:** Sorghum, tannins, wood ash, broiler chicks
[#] Corresponding author. E-mail: connie_siima@agric.mak.ac.ug

## Introduction

It is generally agreed that low tannin sorghum grain can completely replace maize in poultry diets (Gualtieri & Rapaccini, 1990; Amira, 1992). However, the cultivation of low tannin cultivars in areas where predation of wild birds is high, is not economical. If such cultivars are produced, the grain is consumed by humans, leaving nothing for domestic animals. In Uganda the local high tannin cultivars are likely to remain important because of their agronomic advantages and their ability to resist bird predation. Research efforts are being focused on the utilization of the high tannin cultivars and the general observation is that these cultivars have deleterious effects and would therefore need to be treated before they can safely be used in poultry diets.

Several studies have shown that treatment with alkalis improves the nutritional value of high tannin sorghum (Muindi *et al*., 1981; Mohammed & Ali, 1992; Mukuru, 1992; Nyachoti *et al*., 1998; Okot & Mujabi, 2001). In an alkaline medium it is thought that tannins polymerize, forming non-toxic compounds. The effectiveness of the alkali treatment depends on the type and concentration of the alkali and the prevailing conditions (Muindi *et al*., 1981). Wood ash, an alkaline substance (Etiegni & Campbell, 1991), is used by the local people of south-western Uganda to reduce tannins in the red, bird resistant sorghum that is cultivated in that region. This traditional technology involves soaking sorghum grain in wood ash slurry and then allowing it to germinate for four days. The resulting material is low in tannin but contains hydrocyanic acid and the treatment results in up to a 20% loss in dry matter (DM) (Mukuru, 1992; Mukuru *et al*., 1992). In the present study this traditional technology was modified to reduce the negative effects associated with it. The modification involved the use of wood ash extract instead of wood ash slurry and a short germination period. The feeding value of the treated sorghum grain was assessed using broiler chicks.

## Materials and Methods

One hundred and eighty day-old broiler chicks, obtained from a commercial hatchery, Ugachick Poultry Breeders Limited, were weighed and randomly distributed into electrically heated cages. The brooder room received 24-hour lighting. Chicks were vaccinated against Newcastle disease at hatch and at seven days of age, and against Infectious Bursal disease at two weeks of age. Chicks were fed on the experimental diets for three weeks. Diets were based on either maize (Maize) or sorghum that has been soaked in wood ash extract and germinated (AG) or sorghum that has been soaked in wood ash extract (AS) or sorghum that has been germinated after being soaked in water (WG) or untreated sorghum (UT). In the last week of the experiment, the chicks were fed on marked diets. Titanium dioxide was added at the rate of five grams per kilogram as a dietary marker (Short *et al*., 1996). At the end of the experiment, eight birds per replicate were killed by cervical dislocation. Each bird was dissected to reveal the lower gastro-intestinal tract. The section between the Meckel's diverticulum and the ileo-caeco-colic junction was excised and the ileal digesta gently squeezed into a small pyrex glass beaker. For each replicate, digesta from four birds of the same sex were pooled. The digesta were then dried in a force-air oven at 105 °C overnight, ground in a kitchen coffee mill and analyzed to determine DM, starch and crude protein (CP) digestibility (Svihus *et al*., 1997). Determination of titanium dioxide was according to the method of Short *et al.* (1996).

The high tannin sorghum grain, a local red cultivar, was obtained in two consecutive seasons from farmers in Kabale district in south-western Uganda. The same farmers prepared the traditionally treated sorghum grain from which samples for laboratory analysis were obtained. The rest of the experimental work was conducted at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK). Two hundred kilograms of sorghum grain were subjected to treatment with wood ash extract. The ash extract was obtained by mixing hard wood ash, collected from the Institute kitchen, with tap water in plastic buckets at the rate of 1 kg ash to 20 L of water. The mixture was stirred for five minutes and left to stand overnight. The resulting supernatant was carefully removed and filtered through cotton cloth. The pH of the ash extract was 11.8. Sorghum grain was soaked either in tap water or wood ash extract at the rate of 1 kg grain to 2 L of soaking medium for 12 hours. Some of the grain that was soaked in wood ash extract was dried in the sun. The rest of the treated grain was allowed to germinate. The germination treatment was done by spreading the soaked grain on freshly cut banana leaves in a room (26 °C) and then covering it with a layer of fresh banana leaves to preserve moisture for 28 hours. The relatively short germination period was aimed at minimizing loss of DM and preventing the accumulation of hydrocyanic acid. Treated grain was dried in the sun to a moisture content of 11%. This time schedule fits in well with the day-to-day work routine of the local communities.

**Table 1** Composition of experimental diets (dry matter basis)

| | Diets[1] | | | | |
|---|---|---|---|---|---|
| | Maize | AG | AS | WG | UT |
| **Ingredient (g/kg)** | | | | | |
| Maize | 500 | - | - | - | - |
| Sorghum | - | 500 | 500 | 500 | 500 |
| Soyabean meal | 408 | 408 | 408 | 408 | 408 |
| Fish meal | 50 | 50 | 50 | 50 | 50 |
| DL-Methionine | 2 | 2 | 2 | 2 | 2 |
| Oyster shells | 25 | 25 | 25 | 25 | 25 |
| Bone ash | 7 | 7 | 7 | 7 | 7 |
| Sodium chloride | 3 | 3 | 3 | 3 | 3 |
| Vitamin-mineral premix[2] | 5 | 5 | 5 | 5 | 5 |
| **Nutrient composition (g/kg unless otherwise stated)** | | | | | |
| Metabolisable energy (MJ/kg) | 13.3 | 13.2 | 13.1 | 13.1 | 13.1 |
| Crude protein | 237 | 235 | 232 | 233 | 232 |
| Methionine | 5.4 | 5.0 | 5.0 | 5.0 | 5.0 |
| Lysine | 11.2 | 11.2 | 11.2 | 11.2 | 11.2 |
| Calcium | 8.5 | 11.0 | 12.1 | 11.2 | 11.2 |
| Total phosphorus | 5.6 | 5.8 | 5.8 | 5.9 | 5.9 |
| Tannins (mg catechin/100 g grain) | 0.00 | 0.12 | 1.55 | 3.20 | 4.13 |

[1] Treatments given to sorghum grain: AG = soaked in wood ash extract and germinated; AS = soaked in wood ash extract; WG = soaked in water and germinated; UT = untreated

[2] Provided per kg diet: Vitamin A - 12500 IU; vitamin D3 - 2500 IU; vitamin E - 20 IU; vitamin $K_3$ - 3.0 mg; vitamin $B_1$ - 1.0 mg; vitamin $B_2$ - 5.0 mg; vitamin $B_6$ - 1.0 mg; vitamin $B_{12}$ - 0.05 mg; nicotinic acid - 11.25 mg; calcium pantothenate - 6.0 mg; choline - 0.1 mg; manganese - 75 mg; iron - 37.5 mg; zinc - 62 mg; copper - 6.0 mg; iodine - 1.0 mg; selenium - 0.12 mg

Samples of the treated and untreated sorghum grain were ground in a laboratory mill and analyzed for DM, ash, ether extract (EE), CP (Kjedahl N x 6.25) and crude fibre (CF), using standard methods (AOAC, 1990). Total phosphorus and calcium concentrations were determined after wet ashing (AOAC, 1990). Tannins in the sorghum grain were determined using the vanillin assay (Price *et al*., 1978). The amino acid composition of the grain was analyzed at the Agricultural University of Norway, by a chromatographic method, with a Biochrom 20 Amino Acid Analyzer (Phamacia Biotec Scientific Software, Inc., USA).

A completely randomized design was adopted with three replicates per diet. Each replicate had 12 chicks. Chicks in each replicate were group fed. Feed and water were provided *ad libitum*. Chicks were individually weighed at the start of the experiment and at the end of each week for three weeks. All feed provided was weighed and feed consumption for each replicate was determined weekly. Mortality was recorded as it occurred. Data on body weight gain, feed intake, feed efficiency and nutrient digestibility were subjected to Analysis of Variance using the procedures of the Statistical Analysis System (SAS, 1990). Means were compared using the Least Significant Differences ($P < 0.05$).

In the feeding experiment, diets were formulated with treated or untreated sorghum grain replacing maize in broiler starter rations. The composition of the experimental diets is shown in Table 1.

**Table 2** Proximate composition, calcium, phosphorus and tannin concentrations of treated and untreated high tannin sorghum (g/kg of dry matter). Standard deviations of the means are indicated in parentheses

| | Treatments[1] | | | | |
|---|---|---|---|---|---|
| | TT | AG | AS | WG | UT |
| Crude protein | 98 (4) | 91 (2) | 90 (2) | 91 (3) | 90 (2) |
| Crude fibre | 10 (0.2) | 12 (1) | 15 (0.8) | 20 (1.1) | 20 (1) |
| Ether extract | 30 (2) | 34 (4) | 35 (4) | 35 (2) | 35 (3) |
| Ash | 31 (10) | 19 (1) | 20 (2) | 19(0.5) | 20 (2) |
| Calcium | 1.6 (0.2) | 0.6 (0.05) | 0.6 (0.3) | 0.4 (0.1) | 0.4 (0.3) |
| Phosphorus | 2.5 (0.5) | 2.6 (0.6) | 2.5 (0.3) | 2.6 (0.2) | 2.7 (0.4) |
| Dry matter loss | 190 (21) | 70 (12) | 40 (1) | 80 (15) | - |
| Tannins (mg catechin/100 g grain) | 0.40 (0.007) | 1.24 (0.09) | 3.10 (0.12) | 6.51 (0.45) | 8.27 (0.56) |

[1] Treatments given to sorghum grain: TT = traditionally treated; AG = soaked in wood ash extract and germinated; AS = soaked in wood ash extract; WG = soaked in water and germinated; UT = untreated

## Results and Discussion

The results of the proximate composition, calcium, phosphorus and tannin concentrations of the untreated and treated sorghum grain are shown in Table 2.

There was a slight increase in CP content of sorghum resulting from the germination treatment. This increase in CP was up to eight percent in the case of the traditionally treated sorghum. This could be attributed to loss of DM that occurred during germination. Treatments where sorghum grain was germinated for 28 hours resulted in a DM loss of seven to eight percent whereas the traditional treatment caused about a 19% loss in DM. Dry matter losses that occur during germination are mainly due to the reduction in the carbohydrate fraction of the grain (Chavan *et al*., 1981), caused by increased respiration of the seed/seedling. There was a decrease in CF content of the grain that was subjected to wood ash treatment, probably due to the alkali treatment. Ash content of the traditionally treated sorghum was about 50% more than that of the untreated grain. This was consistent with findings of Mukuru (1992), indicating that the grain contained wood ash residues, since the treatment involved the use of ash slurry as opposed to ash extract. The relatively high calcium content of this grain was consistent with the high ash content. When compared with the traditional technology, treating the grain with wood ash extract did not cause significant changes in the proximate composition of the grain. The traditionally treated sorghum was almost free of assayable tannins.

There was a 62% reduction in tannins when the grain was soaked in wood ash extract. Germination following treatment with wood ash extract caused up to 85% reduction in the tannin content of the grain. Reduction in tannins in the wood ash treated sorghum grain was in agreement with the findings of other researchers (Mohammed & Ali, 1988; Mukuru, 1992; Mukuru *et al*., 1992; Okot & Mujabi, 2001) and is probably due to polymerization of tannins to other compounds in an alkaline medium or due to reactions of tannins with cations such as potassium, sodium and calcium which are abundant in wood ash. The effect of wood ash treatment on the quality of protein of sorghum grain is presented in Table 3.

**Table 3** Amino acid distribution in treated and untreated high tannin sorghum grain (g amino acid per 16 g nitrogen**)**

| | Treatments[1] | | | | |
|---|---|---|---|---|---|
| | TT | AG | AS | WG | UT |
| **Amino acids** | | | | | |
| Cysteine | 1.65 | 1.75 | 1.72 | 1.70 | 1.73 |
| Methionine | 1.90 | 1.79 | 2.19 | 1.88 | 1.85 |
| Aspartic acid | 7.66 | 7.81 | 7.49 | 7.50 | 7.79 |
| Threonine | 3.45 | 3.48 | 3.44 | 3.44 | 3.46 |
| Serine | 5.00 | 5.01 | 5.21 | 5.00 | 5.10 |
| Glutamic acid | 23.67 | 23.59 | 23.87 | 23.69 | 23.92 |
| Proline | 8.73 | 8.19 | 8.52 | 8.39 | 8.60 |
| Glycine | 3.25 | 3.32 | 3.65 | 3.21 | 3.47 |
| Alanine | 9.00 | 9.30 | 10.66 | 9.39 | 10.24 |
| Valine | 5.52 | 5.44 | 5.74 | 5.50 | 5.71 |
| Isoleucine | 4.72 | 4.82 | 4.95 | 4.76 | 4.77 |
| Leucine | 14.53 | 14.92 | 15.59 | 14.50 | 14.16 |
| Tyrosine | 4.16 | 4.15 | 4.18 | 4.18 | 4.42 |
| Phenylalanine | 5.95 | 5.99 | 6.10 | 5.99 | 5.96 |
| Histidine | 2.00 | 2.13 | 2.25 | 2.20 | 2.18 |
| Lysine | 1.80 | 2.45 | 2.42 | 2.42 | 2.40 |
| Arginine | 3.70 | 4.44 | 4.51 | 4.50 | 4.34 |
| **Protein**[2] | 9.75 | 9.20 | 9.10 | 9.40 | 9.10 |

[1] Treatments given to sorghum grain: TT = traditionally treated; AG = soaked in wood ash extract and germinated; AS = soaked in wood ash extract; WG = soaked in water and germinated; UT = untreated
[2] Protein (N x 6.25)

For most of the amino acids, differences in concentration resulting from the various treatments were small. However, traditionally treated sorghum had lower concentrations of cysteine, alanine, histidine, lysine and arginine. In particular, the concentration of lysine in the traditionally treated sorghum was about 25% less than that in the untreated grain. Similarly, Muindi & Thomke (1981) reported reductions in arginine and lysine when sorghum grain was treated with Magadi soda. The efficiency of utilization of the sorghum protein depends on the amino acid balance as well as tannin content of the grain (Okoh *et al*., 1982). Lysine, which is one of the limiting amino acids in sorghum based diets (Elkin *et al*., 1978) was further reduced by the traditional treatment. The high alkali concentration in the wood ash slurry could be responsible for the negative effect on the quality of sorghum protein. It is likely that wood ash extract was too mild to affect the protein quality of the grain. Treatment of proteins with alkalis has been reported to have negative effects on the protein quality (De Groot & Slump, 1969; Liardon & Hurrell, 1983).

The results of the feeding experiment are shown in Table 4. There was no significant difference in feed intake between the maize based diet and the two diets that contained wood ash extract treated sorghum. However, chicks consumed less ($P < 0.001$) of the diet that was based on untreated sorghum grain. Chicks consuming the maize based diet grew faster ($P < 0.05$) than those receiving the sorghum based diets. Within the sorghum based diets there was an improvement ($P < 0.05$) in growth rate with the ash treated sorghum. A 14% mortality rate was registered among chicks that were fed on the diet that contained untreated sorghum, compared to a mortality rate of five percent for the WG dietary treatment. There were no mortalities in the other dietary treatments. Treatment of sorghum grain with wood ash extract improved ($P < 0.05$) digestibility of the sorghum based diets. However, digestibility of DM and CP for the maize based diet was superior ($P < 0.05$) when compared to diets that contained wood ash treated sorghum. This was probably responsible for the observed growth responses. The reduced weight gain for the diet that was based on untreated sorghum is in agreement with the results reported by several other researchers (Mitaru *et al*., 1983; Banda-Nyirenda & Vohra, 1990; Elkin *et al*., 1990; Jacob *et al*., 1996). Improvements in feed intake, weight gain and nutrient digestibility of the diets that contained wood ash treated sorghum appear to be consistent with the reduced tannin content of the grain. In a similar study Mohammed & Ali (1988) reported a reduction of 81% in tannin content when sorghum was soaked in wood ash extract and a 24% improvement in growth rate when broiler chicks were fed on a diet containing this treated sorghum. Tannins present in feedstuffs are known to reduce protein and amino acid digestibility (Mitaru *et al*., 1985) mainly by way of complexing with both dietary and endogenous proteins (Daiber, 1975). Although germination following the alkali treatment reduced dietary tannins to a very low level, the response to the maize based diet remained superior; suggesting that treated sorghum can best be used for partial replacement of maize in broiler diets.

**Table 4** Effect of replacing maize with treated or untreated sorghum on the performance of broilers (1-21 days)

| | Diets[1] | | | | | s.e.m. |
|---|---|---|---|---|---|---|
| | Maize | AG | AS | WG | UT | |
| **Growth responses** | | | | | | |
| Weight gain (g) | 528[a] | 400[b] | 369[b] | 260[c] | 230[c] | 12.07 |
| Feed intake (g) | 866[a] | 799[a] | 742[a] | 562[b] | 527[b] | 35.50 |
| Feed : gain ratio | 1.64[c] | 1.99[b] | 2.01[b] | 2.16[a] | 2.28[a] | 0.012 |
| **Digestibility coefficients** | | | | | | |
| Dry matter | 0.63[a] | 0.58[b] | 0.55[c] | 0.54[c] | 0.51[d] | 0.957 |
| Crude protein | 0.65[a] | 0.58[b] | 0.58[b] | 0.50[c] | 0.50[c] | 1.183 |
| Starch | 0.97[a] | 0.97[a] | 0.96[a] | 0.94[b] | 0.92[c] | 0.512 |

[1] Treatments given to sorghum grain: AG = soaked in wood ash extract and germinated; AS = soaked in wood ash extract; WG = soaked in water and germinated; UT = untreated
[a, b, c, d] Row means with common superscripts do not differ (P > 0.05)
s.e.m. - standard error of means

## Conclusion

Treatment of high tannin sorghum with wood ash extract is effective in reducing tannins, without affecting its nutrient composition. Germination following wood ash treatment further improves the feeding value of high tannin sorghum but should be limited to less than two days to minimize loss of DM. In places where wood ash is readily available the technology is simple and cheap. It provides a way in which feed manufacturers could utilize the relatively cheap high tannin sorghum, thus minimizing the cost of feeds and sparing maize for human consumption.

## Acknowledgements

This work was supported by the Norwegian Council of Universities' Committee for Development, Research and Education (NUFU).

## References

Amira, C.D., 1992. Small grains in monogastric and ruminant feed formulations: Prospects and problems. In: Utilisation of sorghum and millets. Eds. Gomez, M.I., House, L.R., Rooney, L.W. & Dendy, D.A.V., International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India. pp. 183-190. .

AOAC, 1990. Official methods of analysis (13th ed.). Association of Official Analytical Chemists, Inc., Washington D.C., USA.

Banda-Nyirenda, D.B.C. & Vohra, P., 1990. Nutritional improvement of tannin-containing sorghums (*Sorghum bicolor*) by sodium bicarbonate. Cereal Chem. 67, 533-537.

Chavan, J.K., Kadam, S.S. & Salunkhe, D.K., 1981. Changes in tannin, free amino acids, reducing sugars and starch during seed germination of low and high tannin cultivars of sorghum. Food Sci. 46, 638-639.
Daiber, K.H., 1975. Enzyme inhibition by polyphenols of sorghum grain and malt. J. Sci. Food Agric. 23, 1399-1411.
De Groot, A.P. & Slump, P., 1969. Effects of alkali treatment of proteins on amino acid composition and nutritive value. J. Nutr. 98, 45-56.
Elkin, R.G., Rogler, J.C. & Sullivan, T.W., 1990. Comparative effect of dietary tannins in duck, chicks and rats. Poult. Sci. 69, 1685-1693.
Elkin, R.G., Featherston, W.R. & Rogler, J.C., 1978. Investigations of leg abnormalities in chicks consuming high tannin sorghum grain diets. Poult. Sci. 57, 757-762.
Etiegni, L. & Campbell, A.G., 1991. Physical and chemical characteristics of wood ash. Bioresource Technol. 37, 173-178.
Gualtieri, M. & Rapaccini, S., 1990. Sorghum grain in poultry feeding. World's Poultry Sci. J. 46, 246-254.
Jacob, J.P., Mitaru B.N., Mbugua, P.N. & Blair, R., 1996. The effect of substituting Kenyan Serena sorghum for maize in broiler starter diets with different crude protein and methionine levels. Anim. Feed Sci. Technol. 61, 27-39.
Liardon, R. & Hurrell, R.F., 1983. Amino acid racemization and alkali treated proteins. J. Agric. Food Chem. 31, 432-437.
Mitaru, B.N., Reichert, R.D. & Blair, R., 1983. Improvement of the nutritive value of high tannin sorghum for broiler chickens by high moisture storage (reconstitution). Poult. Sci. 62, 2065-2072.
Mitaru, B.N., Reichert, R.D. & Blair, R., 1985. Protein and amino acid digestibilities for chickens of constituted and boiled sorghum grain in tannin contents. Poult. Sci. 64, 101-106.
Mohammed, T.A. & Ali, O.M., 1988. Effect of wood ash extract treatment on the feeding value and utilisation of high-tannin sorghums by broiler chicks. Anim. Feed Sci. Technol. 22, 131-137.
Muindi, P.J., Thomke, S. & Ekman, R., 1981. Effect of Magadi soda treatment on the tannin content and *in-vitro* nutritive value of grain sorghums. J. Sci. Food Agric. 32, 25-34.
Muindi, P.J. & Thomke, S., 1981. The nutritive value for rats of high- and low- tannin sorghums treated with Magadi Soda. J. Sci. Food Agric. 32, 139-145.
Mukuru, S.Z., 1992. Traditional technologies in small grain processing. In: Utilisation of sorghum and millets. Eds. Gomez, M.I., House, L.R., Rooney, L.W. & Dendy, D.A.V., International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India. pp. 47-56.
Mukuru, S.Z., Butler, L.G., Rogler, J.C., Kirles, A.W., Ejeta, G., Atxell, J.D. & Mertz, E.T., 1992. Traditional processing of high-tannin sorghum grain in Uganda and its effects on tannin, protein digestibility and rat growth. J. Agric. Food Chem. 40, 1172-1175.
Nyachoti, C.M., Atkinson, J.L. & Leeson, S., 1998. Evaluation of Magadi soda-treated sorghum grain for young broilers. Anim. Feed Sci. Technol. 70, 295-304.
Okoh, P.N., Obilana, A.T., Njoku, P.C. & Aduku, A.O., 1982. Proximate analysis, amino acid composition and tannin content of improved Nigerian sorghum varieties and their potential in poultry feeds. Anim. Feed Sci. Technol. 7, 359-364.
Okot, M.W. & Mujabi, S.N., 2001. The response of broiler chicks to dietary Serena sorghum. Uganda J. Agric. Sci. 6, 13-18.
Price, M.L., Van Scoyoc, S. & Butler, L.G., 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. J. Agric. Food Chem. 26, 1214-1218.
SAS, 1990. Statistical Analysis Systems user's guide (Version 6, 4th ed.). SAS Institute Inc., Cary, North Carolina, USA.
Short, F.J., Gorton, P., Wiseman, J. & Boorman, K.N., 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. Anim. Feed Sci. Technol. 59, 215-221.
Svihus, B., Herstad, O. & Newman, C.W., 1997. Effect of high moisture storage of barley, oats and wheat on chemical value for broiler chickens. Acta Agric. Scand. Sect. A. Anim. Sci. 47, 39-47.