PROJECT REPORT No. 270

NUTRITIVE VALUE OF WHEAT FOR BROILER CHICKENS: EFFECTS OF STORAGE TIME AND HEMICELLULASE ADDITION

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by

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Contents

Quality statement

Roslin Nutrition Ltd (RNL) throughout this trial was working to ISO 9002 standards. This covered all areas (feed manufacture, farm facilities and analytical laboratory). Accreditation has now been gained (November 2000).

Abstract

This project set out to test whether there is validity in the hypothesis that the quality of wheat (as judged by its viscosity-inducing properties) for broiler chickens is affected by the time for which it is held in storage. Any interactions between its initial quality (low, medium and high viscosity) and the period of time for which it was stored were also examined.

Three varieties of wheats [Consort (low viscosity), Brigadier (medium viscosity) and Rialto (high viscosity)] were identified and purchased immediately after harvest (31st August 1999). They were monitored after intervals of 1, 9, 17, 25, 33 and 53 weeks in storage (on 7/9/99, 2/11/99, 28/12/99, 22/2/00, 18/4/00 and 5/9/00 for dry matter, oil (B), nitrogen (crude protein) and ash, as well as for specific weight, 1000 grain weight and viscosity of aqueous solutions. Isocaloric and isonitrogenous diets containing the wheats at commercial inclusion rates (605.4 g/kg) were formulated to meet the requirements of broiler chickens and fed to 6 groups of 5 birds for 3 weeks at each of the storage ages. Performance parameters (weight gain, food intake and food conversion efficiency) were monitored and dietary apparent metabolisable energy (AME_N) values derived. True metabolisable energy (TME_N) values of these diets and the individual wheats were determined at the same time and with identical birds of the same age. The effects of the addition to the diets of a commercial hemicellulase (Avizyme 1300) were also evaluated simultaneously.

Summary

Objectives

This project set out to test whether there is validity in the hypothesis that the quality of wheat (as judged by its viscosity-inducing properties) for broiler chickens is affected by the time for which it is held in storage. Any interactions between its initial quality (low, medium and high viscosity) and the period of time for which it was stored were also examined.

Three varieties of wheats [Consort (low viscosity), Brigadier (medium viscosity) and Rialto (high viscosity)] were identified and purchased immediately after harvest (31st August 1999). They were monitored after intervals of 1, 9, 17, 25, 33 and 53 weeks in storage (on 7/9/99, 2/11/99, 28/12/99, 22/2/00, 18/4/00 and 5/9/00 for dry matter, oil (B), nitrogen (crude protein) and ash, as well as for specific weight, 1000 grain weight and viscosity of aqueous solutions. Isocaloric and isonitrogenous diets containing the wheats at commercial inclusion rates (605.4 g/kg) were formulated to meet the requirements of broiler chickens and fed to 6 groups of 5 birds for 3 weeks at each of the storage ages. Performance parameters (weight gain, food intake and food conversion efficiency) were monitored and dietary apparent metabolisable energy (AME_N) values derived. True metabolisable energy (TME_N) values of these diets and the individual wheats were determined at the same time and with identical birds of the same age. The effects of the addition to the diets of a commercial hemicellulase (Avizyme 1300) were also evaluated at the same time.

Composition of the wheats

The proximate compositions of the 3 wheat varieties were not very different from each other (Table 4), although the protein content of Rialto (105.8 g/kg) was slightly higher than those of either Consort (93.8 g/kg) or Brigadier (88.6 g/kg). It should be noted that with all 3 wheat varieties the dry matter contents were lower, by approximately 5

percentage points, than wheat that would normally be fed to commercial broilers. This was because the wheats were deliberately not subjected to drying after harvest. The wheats did not change markedly in proximate components during storage although the oil content appeared to rise permanently by about 0.7 percentage units across all 3 varieties between 17 and 25 weeks in storage.

Likewise, thousand grain weight and gross energy were remarkably consistent across the 3 varieties examined and showed no meaningful changes during storage.

Consort had the lowest viscosity (4.0 cps) and Rialto the highest (9.6 cps), with Brigadier intermediate (5.6 cps). Although the viscosities of the wheats appeared to vary slightly at each of the observation stages, with the exception of Rialto which fell significantly from 12.3 cps after 1 week in storage to around 9 cps at the later stages, no other trends were detectable. It was, therefore, assumed that significant changes to the viscosities of Consort and Brigadier did not occur over the period when the experiments were carried out.

TME_N of the wheats

The mean TME_N value of the 3 wheats over the 6 storage periods was 12.90 MJ/kg. Rialto and Consort had significantly higher TME_N values (12.89 and 12.87 MJ/kg, respectively) than Brigadier (12.58 MJ/kg). Overall the TME_N of the wheats declined with the passage of time during which they had been stored. This decline was linear. Although there was little or no effect of variety on the nature of this response (Figure 1), each of the wheats following a similar pattern, the decline in the TME_N of Rialto, which dropped from 13.86 MJ/kg (the highest of all the values observed) after 1 week in storage to 12.00 MJ/kg (the lowest of all the values observed) after 33 weeks in storage tended to be steeper than those of Consort and Brigadier. This change did not correspond to any of the relative minor changes that were observed in the proximate composition of Rialto.

The response in the mean TME_N of the 3 wheat varieties against the time in storage is shown in Figure 2 and can be described by the following equation:

$$y = 13.43 - 0.028x$$

This indicates that for each 4 weeks during which the wheats had been stored they had lost 0.11 MJ/kg in TME_N. Over a year this translates to a decline of 1.44 MJ/kg or 10.8% of the TME_N value of freshly harvested wheat.

The equations describing the responses in the TME_N values of the individual wheat varieties against the time in storage were similar to the mean response and these are shown in Figure 1.

TME_N values of the diets containing the wheats

The mean TME_N value of the diets (both unsupplemented and supplemented with Avizyme 1300) containing the wheats was 12.92 MJ/kg. There was no significant difference overall between those diets supplemented with Avizyme 1300 and those unsupplemented (13.31 and 13.29 MJ/kg, respectively). The diets containing Brigadier had a significantly higher TME_N value (13.41 MJ/kg) than the diets containing either Rialto (13.26MJ/kg) or Consort (13.23 MJ/kg). This contrasted with the TME_N values derived for the wheats alone, where Rialto and Consort were found to have significantly higher TME_N values than Brigadier.

As was found with the TME_N values of the wheats alone, the period for which they were stored also reduced the TME_N values of the diets containing the wheats in a linear fashion (Figure 3). The response can be described by the following equation:

$$y = 13.76 – 0.022x$$

This indicates that, for every 4 weeks that wheat is stored, the TME_N value of a diet in which it comprises about 600 g/kg will decline by 0.09 MJ/kg. In other words a year in storage would lower the TME_N value of a diet containing 600 g/kg wheat by 1.14 MJ/kg. It can also be seen in Figure 4 that the relationships between the dietary TME_N values and the periods for which the individual wheats had been in store were very similar, although there was a suggestion that the decline in the TME_N value of the diets containing Brigadier was less steep than those of the diets containing either of the other 2 wheats. This was true whether or not the diets had been supplemented with enzyme or not. The differences were noticeable after 9/17 weeks compared to 1 week in storage (13.39 /13.40

and 13.96 MJ/kg, respectively) and further reductions were seen after 25 and 53 weeks (13.06 and 12.68 MJ/kg, respectively). Avizyme 1300 significantly improved the mean TME_N value of the diets containing Rialto (from 13.16 to 13.37 MJ/kg) but it had no effect on those of the diets containing Consort or Brigadier.

With one atypical example (after 1 week storage), when the addition of Avizyme 1300 significantly improved the overall TME_N value of the diets containing the wheats from 13.26 to 13.52 MJ/kg, the addition of the enzyme did not affect the TME_N values of the diets containing the wheats, *i.e.* it did not influence the general decline observed in the TME_N values of the diets over the period of time for which the wheats had been stored.

When individual wheat varieties were considered separately, the period for which they were stored also reduced the TME_N values of the diets in which they were included, although the decline was significantly less steep for the diets containing Brigadier. Here the difference between the mean TME_N value of the diets containing the Brigadier (13.21 MJ/kg) that had been stored for 25 weeks was not significantly different from those of the diets containing the same variety stored for 9 or 17 weeks (13.47 and 13.38 MJ/kg, respectively). Neither was the TME_N of the diet containing the Brigadier that had been stored for 53 weeks significantly different from that containing the same variety stored for 25 weeks.

Interactions between the variety of the wheat, the period for which it was stored and the presence or absence of enzyme were observed, although none concealed or improved the interpretation of the more general effects described above. They were as follows:

- Avizyme 1300 tended to slow down the decline in the TME_N values of the diets containing Rialto. Thus, after the wheats had been 25 weeks in storage the TME_N value of the diet containing Rialto was significantly improved by enzyme addition (from 12.75 to 13.33 MJ/kg). However, after the wheats had been stored for 9 (13.22 to 13.51 MJ/kg) and 53 weeks (12.43 to 12.64 MJ/kg), the differences between the TMEN values of the diets containing Rialto just failed to reach significance.

- A somewhat similar but less marked trend was observed with the diets containing Brigadier, where the addition of Avizyme 1300 also slowed down the decline in the dietary TME_N value observed when the period for which the wheats had been stored lengthened. Thus, although there was no significant difference in the TME_N values of the diets prepared with the Brigadier that had been stored for 17 (13.29 and 13.48 MJ/kg) or 25 weeks (13.26 or 13.16 MJ/kg) whether enzyme was present or not, the TME_N value of the diet supplemented with Avizyme 1300 and containing Brigadier which had been stored for 25 weeks hardly differed from the diet containing the same variety which had been only stored for 17 weeks (13.26 and 13.29 MJ/kg, respectively). However, when no Avizyme 1300 was present, the mean TME_N value of the diets containing Brigadier stored for 25 weeks was numerically lower, just failing to reach significance, than the diet containing the same variety which had been stored for 17 weeks (13.16 and 13.48 MJ/kg, respectively).

- The diets containing Consort behaved anomalously. Thus, with no enzyme present, when Consort had been stored for 17 weeks the TME_N value of the diet was significantly higher than it had been when it had been stored for only 9 weeks (13.66 and 13.24 MJ/kg, respectively). Even after Consort had been stored for 25 weeks, the TME_N value of the diet was relatively high (13.29 MJ/kg) and not significantly different from either of the TME_N values of the diets prepared from the same variety that had been stored for 9 and 17 weeks (13.24 and 13.66 MJ/kg, respectively). The addition of enzyme to the diets containing Consort that had been stored for 17 (13.66 and 13.19 MJ/kg) and 25 weeks (13.29 and 12.60 MJ/kg) reduced the dietary TME_N values significantly.

AME_N of the diets containing the wheats

Overall the mean AME_N of the diets containing the wheats was 11.35 MJ/kg, 14.70% less than the comparable TME_N value. The mean AME_N of the diets containing Brigadier was significantly higher (11.49 MJ/kg) than those containing either Consort (11.38 MJ/kg) or Rialto (11.17 MJ/kg).

Overall, the addition of Avizyme 1300 had no significant effect on the mean AME_N value of the diets containing the wheats (11.32 and 11.38 MJ/kg, respectively). Neither were the AME_N values of the diets containing the individual wheat varieties significantly affected by the addition of enzyme, although in every case the AME_N value of the diet with added enzyme was numerically the higher.

The periods for which the wheat were stored appeared to have a quite random effect on the AME_N values of the diets containing the wheats (Figure 5). It looks as if the results from the diets tested with the wheats that had been stored for 1 and 9 weeks were anomalous. Therefore, ignoring those data, in general the AME_N values of the diets containing the wheats increased with the period of time that the wheats had been in store *i.e.* from 17 to 53 weeks. The most clear-cut effect was seen with the AME_N values of the diets containing Consort (11.25, 11.40 and 11.70 MJ/kg), although the AME_N values of the diets containing the other 2 varieties showed the same tendency to increase. The most substantial change was seen between 25 and 53 weeks in storage, when the mean dietary AME_N value increased from 11.44 to 11.74 MJ/kg. The effect was greatest for the diets containing Brigadier (11.38 to 11.94 MJ/kg) and least for those containing Rialto (11.56 to 11.57 MJ/kg), with those containing Consort intermediate (11.40 to 11.70 MJ/kg).

Enzyme supplementation tended to have little or no effect on the AME_N values of the diets containing the wheats stored for 17 (11.23 and 11.30 MJ/kg), 25 (11.46 and 11.43 MJ/kg) or 53 weeks (11.71 and 11.77 MJ/kg), although there were exceptions to this when the diets containing the individual wheat varieties were examined. For example, after the wheats had been stored for 17 weeks, the diet containing Brigadier had a significantly higher AME_N value without the addition of enzyme (11.62 and 11.20 MJ/kg); the AME_N of the diet containing Rialto which had been stored for 53 weeks was also significantly reduced after enzyme addition (11.73 to 11.42 MJ/kg). In contrast, the diet containing Consort which had been stored for 17 weeks was significantly improved as a result of enzyme addition (11.06 to 11.44 MJ/kg).

Performance of the birds fed on the diets containing the wheats

Weight gain

The average weight gained by the birds over the 5 experiments was 583 g. However, this concealed a substantial variation between the trials (from 511 g with the diets containing the wheats that had been stored for only 1 week to 703 g with the diets containing the wheats that had been stored for 17 weeks. Possible explanations are subtle differences between the genotypes of the different batches of birds, different ages of the parent stock, or differences in the environment of the room in which the birds were grown in the different experiments; all seem rather unlikely. It must be said, however, that with variations of this magnitude in growth it is not possible to make meaningful conclusions in the effect of wheat storage on bird performance, other than to simply state that wheat should be stored for 17 weeks before including it in diets for poultry.

As might have been expected birds fed on the diets supplemented with Avizyme 1300 gained significantly more weight (594 g) than those fed on the diets with no added enzyme (572 g). However, when the results with the individual wheats were considered, although all the birds fed on the supplemented diets gained numerically more weight than their counterparts fed on the diets with no added enzyme, only those fed on diet containing Rialto and Avizyme 1300 gained significantly more (580 compared to 557 g). Furthermore, when the different storage periods are examined only those birds fed on the diets containing the wheats that had been kept for 25 and 53 weeks and were supplemented with Avizyme 1300 gained significantly more weight (639 and 550 g, respectively) than their counterparts fed on the diets with no added enzyme (581 and 512 g, respectively).

Birds fed on the diets containing the wheat varieties Brigadier and Consort gained significantly more weight (594 and 589 g, respectively) than the birds fed on the diets containing Rialto (566 g).

Overall, birds gained significantly most weight when fed on the diets containing the wheats which had been stored for 17 weeks; wheats stored for 25 weeks came next, followed by the wheats stored for 9 and 53 weeks and, finally the wheats stored for 1 week giving the poorest gains.

Food intake

The average food eaten by the birds over the 5 experiments was 930 g. As with weight gain there were very large differences between experiments in the amount of food eaten per bird. The values ranged from 840 g per bird with the diets containing the wheats that had been stored for 1 week to 1077 g per bird with those that contained the wheats that had been stored for 17 weeks.

In common with what was found with weight gain, birds fed on the diets supplemented with Avizyme 1300 ate more food than those birds fed on the unsupplemented diets but unlike weight gain the difference did not attain significance. When the individual wheat varieties were considered, the results were identical to those observed with weight gain. In other words, birds fed on the enzyme-supplemented diets ate numerically more food than their counterparts fed on the diets containing no Avizyme 1300, although none of the differences were significant. While birds ate numerically more of the supplemented diets containing the wheats which had been stored for 9, 17, 25 and 53 weeks than those fed on the unsupplemented diets containing the wheats stored for comparable periods, only the birds fed on the diets with the wheats which had been stored for 25 weeks ate significantly greater amounts of food (973 compared to 901 g).

Birds fed on the diets containing Brigadier ate significantly more food (943 g) than birds fed on the diets based on Rialto (910 g).

Overall, the effects on food intake of the time for which the wheat had been stored were exactly the same as those for weight gain.

Food conversion efficiency

Although generally the differences observed in food conversion efficiency tended to be smaller than those for weight gain and food intake (and frequently did not reach statistical significance) the trends were exactly the same as for these two parameters.

Conclusions

With the possible exception of their oil contents, which increased from 11.3 to 18.6 g/kg, the proximate compositions of the 3 wheat varieties did not alter throughout the periods for which they were in store. The significance of the change in oil, which occurred between 17 and 25 weeks in storage and was observed in all 3 varieties, is unclear. In view of its uniformity it is possibly most likely that it was a consequence of the analytical procedure or one of the reagents used to extract the oil.

As was planned Rialto had the highest viscosity. It also had the highest protein content, although the gross energies of all 3 varieties were remarkably similar and were unaltered by the period in storage. The viscosity of Rialto fell during storage from 12.3 to 8.2 cps, most of the drop occurring between the 1 and 9 week storage periods. This change could not be related to any of the measures of nutritive value or production parameters. Indeed Rialto tended to have the highest TME_N value of all the wheats during the early stages of storage but showed the most rapid decline. Although less marked the same tended to hold for the TME_N values of the diets containing Rialto. The viscosity of Consort was slightly lower than that of Brigadier and neither changed during the periods for which they were stored.

The mean TME_N value of the 3 wheats declined linearly during the time they were in store (Figure 2). The equation describing the decline suggests that newly harvested wheat has a TME_N value of 13.43 MJ/kg (as received) which declines by 0.27 MJ/kg for every 10 weeks for which it is stored. Hence, during a year's storage wheat loses 1.43 MJ/kg of its metabolisable energy content (or just over 10 % of its newly harvested value). This result is essentially substantiated by the TME_N data on the diets containing the wheat, which were also found to decline linearly over the period during which the wheat hade been stored (Figure 3). The equation describing this reduction suggests that the diets containing the newly harvested wheats had a TME_N value of 13.76 MJ/kg (as received) and this declined by 0.22 MJ/kg for every 10 weeks for which the wheat had been stored. This implies that the other energy-yielding components of the diets are also losing energy during storage because a *pro rata* fall in the TME_N of the wheat would only result in a drop in dietary TME_N of 0.16 MJ/kg for each 10 weeks in store. Results from the individual wheats (Figure 1) and diets containing them (Figure 4) show the same general responses as the average of the 3 varieties.

The results from the AME_N experiements (Figure 5) differed dramatically from the above data on TME_N and it is difficult to reconcile the 2 sets under one conclusion. The AME_N values of the diets fell significantly between 1 and 9 weeks in store and then tended to rise steadily for the remainder of the period for which the wheats were stored.

The performance of the birds at each of the 5 storage stages also followed an inconsistent pattern that did not relate to either of the metabolisable energy measurements recorded. Thus the birds performed significantly better on the diets containing the wheats which had been stored for 17 weeks, when both measures of metabolisable energy were about their mid point values. The minor changes in the compositions of the diets at the different experimental periods were considered insufficient to explain the differences recorded.

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The values for the viscosities of the digesta removed from the birds' jejunums generally appear logical. Thus the diets containing Rialto gave the highest viscosities and those containing Consort the lowest. Both were significantly reduced when Avizyme 1300 was included in the diets. However, the diets containing the wheats which had been stored for 17 weeks gave the highest viscosities in the jejunum (exception Consort), and this of course is in stark contrast to the performance responses observed at that time.

In summary, the results of these carefully planned and executed series of experiments have given extremely equivocal results. The clearest message is given by the TME_N data but the response is surprising. It has generally been considered that storage of wheat results in an enhancement in its nutritive value and not a decline. In that respect the AME_N results are, at least partially, what was expected.

The performance data provided few clues to any changes that are occurring in the wheats while they are in store and seemed to be more influenced by other external and unknown factors.

The effects of the enzyme were clear-cut. The addition of Avizyme 1300 to the diets reduced the viscosities of the jejunal contents of the birds fed on the diets containing all 3 wheat varieties, the largest effect being seen with the diets containing Rialto, the wheat with the highest intrinsic viscosity. However, although dietary enzyme inclusion also generally improved performance there were only the weakest effects seen on the metabolisable energy values of the diets. Thus enzyme addition did appear to slow down the rate of decline in the TME_N values of the diets containing Rialto and Brigadier. This promising trend was unfortunately spoilt by the results from the diets containing Consort where several diets containing Avizyme 1300 resulted in poorer performance responses from the birds than those obtained from the diets with no added enzyme. No such clear message could be taken from the corresponding AME_N values.

Materials and Methods

Test articles

The test articles were the 3 whole wheat samples grown in the UK and sourced by Roslin Nutrition Ltd. After delivery to Roslin Nutrition Ltd where they were stored as whole grains in 1000 kg tote bags on pallets in a closed shed. The temperature and relative humidity in the shed were carefully monitored and recorded (every second day) throughout the storage period. The temperature ranged from a minimum of 0^{o}C (February) to a maximum of 25^{o}C (August). The relative humidity varied from 36% (April) to 70% (September). The wheats were ground through a 5 mm screen before analyses, diet preparation and feeding.

Target species: growth studies and AME_N determinations

Day-old Ross 1 cockerels were the target species for this trial. The birds were not acclimatised to any of the diets. The 6 experimental diets which consisted of each of the 3 wheats at 605.4 g/kg, with and without the addition of Avizyme 1300, were fed *ad libitum* to 6 quadrants each containing 5 one-day-old broilers until the birds were 21 days old. The diet formulation is shown in Table 1. The birds and food were weighed at the start and finish of the experiments and weight gain and food intake calculated. AME_N values were derived from samples of the diets and droppings taken from the cages when the birds were 21 days of age. To allow AME_N to be calculated titanium dioxide was added to each of the experimental diets (4 g/kg)

Target species: TME_N determinations

Ross 1 cockerels were reared on a commercial pelleted broiler starter diet for 21 days when they were transferred to individual cages equipped with drinkers and drinking water. They were deprived of food for 48 hours when 8 birds were fed by tube 10 g of each of the experimental diets and each of the samples of wheat. At this point clean trays were placed under each birds cage. The birds were given 10 ml of water by tube 24 h after being fed but otherwise received no further food for the duration (48 h) of the balance period. After 48 h the droppings from each bird were collected quantitatively in aluminium dishes, frozen, freeze dried, allowed to equilibrate to atmospheric moisture for 24 h, weighed, ground to pass through a 1 mm screen and stored in sealed containers to await analyses.

Animals and maintenance conditions

Before the start of the trials the animals were examined for signs of ill-health and injury. Only birds appearing to be in good condition were used for the study.
The birds were assigned to their treatment groups using a recognised randomisation technique. The cages housing the animals were uniquely labelled. In the course of the 5th trial there was a failure in the water supply to the birds and over 20% of the birds died with the remainder suffering a severe set-back. We had no option but to abandon the trial and make do with the results from 5 storage periods.

Environment

The birds were kept in brooders at Roslin Nutrition Ltd under the following environmental conditions

Temperature	28^{o}C
Light	23 h/day
Air changes	10-15 per h
NB: Daily records were kept of the environmental temperatures.	

Water supply

Water was available *ad libitum* throughout the test periods.

Assignment of treatments to growth trials

In each of the 6 trials each of the 6 diets were allocated to 6 quadrants of battery brooders (6 diets x 6 replicates) according to a standard randomisation technique. This approach was taken for the treatment allocations for each of the 6 trials.

Assignment of treatments to TME_N assays

In each of the 6 trials each of the 6 diets and 3 wheat varieties were tube-fed to eight 3-week-old Ross 1 cockerels. The birds had been allocated according to a standard randomisation technique to the cages and the feed samples allocated to the birds in the cage in the same way such that each treatment was fed to 8 birds.

Allocation of birds and feeding

On 6 separate occasions 80 3-week-old Ross 1 cockerels were allocated to individual cages according to a standard randomisation precedure and were starved of food for 48 h. They were then fed 10 g aliquots of either the diets or the wheats by tube and returned to the same cages equipped with clean trays for the quantitative collection of droppings for 48 h (the full TME protocol is shown in Table 2). Eight of these birds received 10 g of glucose and acted as negative controls for the determination of endogenous excretions (energy and nitrogen). All birds had free access to water at all times.

Collection of droppings

Precisely 48 h after feeding the birds the trays were removed and the droppings quantitatively collected, frozen, freeze-dried, equlibrated to atmospheric moisture level, weighed and ground through a 1 mm screen before analyses.

Analyses of droppings

In each of the TMEN trials aliquots of each of the 3 ground wheat samples and the 6 diets containing the wheats and all of the dropping samples were analysed for gross energy and nitrogen according to standard procedures.

In each of the AMEN trials samples of droppings were collected from each brooder quadrant at the end of the trial, frozen, freeze-dried, equilibrated to atmospheric moisture for 24 h and ground through a 1 mm screen before analysing for gross energy, nitrogen and titanium dioxide. Samples of the diets were also analysed for titanium dioxide.

Viscometry

At the end of the experiment the 2 median birds from each quadrant were killed with an injection of sodium pentobarbitone, their jenunums excised and aliquots of the contents analysed for viscosity in a Brookfield viscometer. At the same time aqueous solutions of the wheats were prepared according to Bedford and Classen (1993) and viscosities measured on the supernatants.

Results

Proximate analyses of the wheats

Tables 3, 4, 5 & 6

Other analytical values for the wheats

Tables 7, 8, 9 & 10

Analyses of the diets containing the wheats

Tables 11, 12, 13, 14, 15 & 16

TME_N values of the wheats

Table 17

TME_N and AME_N values of the diets containing the wheats

Tables 18 & 19

Weight gains, food intakes and food conversion efficiencies

Tables 20, 21 & 22

Viscosity

Table 23

Table 1

Diet Composition

Ingredients	Inclusion (g/kg)
Wheat	605.40
Soyabean meal	327.10
Fish meal	10.00
Soya oil	20.00
Sodium chloride	2.30
Sodium bicarbonate	2.30
DL-Methionine	2.10
L-Lysine hydrochloride	0.40
Limestone	11.50
Dicalcium phosphate	13.80
Vitamin/mineral premix	5.00

Table 2

Protocol for TME_N

Monday	0800 h	Food removed from 80 individually caged birds
Monday	1600 h	Each bird given 10 ml aqueous glucose
Tuesday	1600 h	Each bird given 10 ml aqueous glucose
Wednesday	0800 h	Each bird given 10 g of wheat (or glucose) by tube
Thursday	1600 h	Each bird given 10 ml water
Friday	0800 h	Each bird's excreta quantitatively collected

Table 3

Analyses (g/kg, as received) of Consort for dry matter, oil (B), nitrogen (crude protein) and ash after different periods in storage of all UK wheats

Wheat	Storage period (weeks)	Dry matter	Oil (B)	Nitrogen (crude protein)	Ash
Consort	1	823.0	11.2	15.4 (96.0)	12.8
	9	815.0	11.2	15.3 (95.9)	12.8
	17	820.6	11.9	15.6 (97.8)	11.7
	25	818.0	20.7	15.0 (93.5)	14.3
	33	820.1	19.0	14.8 (92.5)	10.9
	53	823.9	21.9	13.9 (86.9)	11.0

Table 4

Analyses (g/kg, as received) of Brigadier for dry matter, oil (B), nitrogen (crude protein) and ash afterdifferent periods in storage of all UK wheats

Wheat	Storage period (weeks)	Dry matter	Oil (B)	Nitrogen (crude protein)	Ash
Brigadier	1	819.6	11.4	13.6 (84.7)	13.1
	9	814.0	10.6	14.3 (89.3)	12.6
	17	824.4	11.2	14.2 (88.5)	11.8
	25	820.0	17.7	15.1 (94.3)	14.8
	33	823.2	15.8	14.3 (89.4)	12.6
	53	819.5	17.1	13.7 (85.6)	12.5

Table 5

Analyses (g/kg, as received) of Rialto for dry matter, oil (B), nitrogen (crude protein) and ash after different periods in storage of all UK wheats

Wheat	Storage period (weeks)	Dry matter	Oil (B)	Nitrogen (crude protein)	Ash
Rialto	1	816.0	11.6	16.5 (103.0)	12.8
	9	813.3	11.5	16.8 (105.2)	12.3
	17	822.3	10.8	17.3 (108.1)	12.2
	25	814.0	17.9	18.0 (112.5)	15.0
	33	824.0	16.6	17.3 (108.1)	13.0
	53	824.7	20.6	15.7 (98.1)	12.6

Table 6

Means of the analyses (g/kg, as received) of the wheats for dry matter, oil (B), nitrogen(crude protein) and ash after different periods in storage of all UK wheats

Wheat	Dry matter	Oil (B)	Nitrogen (crude protein)	Ash
Consort	820.1	16.0	15.0 (93.8)	12.2
Brigadier	820.1	14.0	14.2 (88.6)	12.9
Rialto	819.0	14.8	16.9 (105.8)	13.0
Overall mean	819.8	14.9	15.4 (96.0)	12.7
Period of storage (weeks)				
1	819.5	11.4	15.2 (94.6)	12.9
9	814.1	11.1	15.5 (96.8)	12.6
17	822.4	11.3	15.7 (98.1)	11.9
25	817.3	18.8	16.0 (100.1)	14.7
33	822.4	17.1	15.5 (96.7)	12.2
53	822.7	19.9	14.4 (90.2)	12.0

Table 7

The viscosity (cps), thousand grain weight (g), and gross energy (MJ/kg) of Consort(as received) after different periods in storage

Wheat	Storage period (weeks)	Viscosity	Thousand grain weight	Gross energy
Consort	1	4.0	56.9	15.54
	9	3.8	55.7	15.04
	17	4.0	55.3	15.35
	25	3.8	56.5	15.39
	33	4.0	52.8	15.29
	53	4.2	58.2	15.32

Table 8

The viscosity (cps), thousand grain weight (g), and gross energy (MJ/kg) of Brigadier(as received) after different periods in storage

Wheat	Storage period (weeks)	Viscosity	Thousand grain weight	Gross energy
Brigadier	1	5.9	59.3	15.25
	9	6.0	60.5	15.21
	17	6.7	58.0	15.16
	25	4.6	60.0	15.28
	33	5.4	54.1	15.29
	53	5.4	58.0	15.27

Table 9

The viscosity (cps), thousand grain weight (g), and gross energy (MJ/kg) of Rialto (as received) after different periods in storage

Wheat	Storage period (weeks)	Viscosity	Thousand grain weight	Gross energy
Rialto	1	12.3	57.0	15.36
	9	9.3	54.5	15.16
	17	9.7	54.5	15.30
	25	8.9	55.1	15.34
	33	8.2	53.5	15.50
	53	9.2	53.6	15.35

Table 10

Means of the viscosities (cps), thousand grain weight (g), and gross energy (MJ/kg) of the wheats (all as received) after different periods in storage

Wheat	Viscosity	Thousand grain weight	Gross energy
Consort	4.0	55.9	15.32
Brigadier	5.6	58.3	15.24
Rialto	9.6	54.6	15.34
Overall mean	6.4	56.3	15.30
Period of storage			
1	7.4	57.7	15.38
9	6.4	56.9	15.14
17	6.8	55.9	15.27
25	5.8	57.2	15.34
33	5.9	53.4	15.36
53	6.3	56.6	15.31

Table 11

Crude protein contents (g/kg) of the diets containing Consort

Overall mean	200.2
Unsupplemented (-)	199.4
Supplemented (+)	201.1

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	219.0[a]	191.3[ef]	202.8[bcd]	196.4[de]	195.9[def]	201.0[cd]
Supplemented (+)	202.6[cd]	191.1[ef]	204.6[bc]	210.0[b]	188.6[f]	199.8[cd]
Mean	210.8[a]	191.2[c]	203.7[b]	203.2[b]	192.2[c]	200.4[b]

Values with no common superscript differ significantly ($p<0.05$)

Table 12

Dry matter contents (g/kg) of the diets containing Consort

Overall mean	868.8
Unsupplemented (-)	868.2
Supplemented (+)	869.4

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	912.3[a]	854.6[h]	861.8[de]	857.8[g]	863.2[d]	859.4[fg]
Supplemented (+)	908.0[b]	861.0[def]	860.6[ef]	857.2[g]	868.0[c]	861.6[de]
Mean	910.2[a]	857.8[d]	861.2[c]	857.5[d]	865.6[b]	860.5[c]

Values with no common superscript differ significantly ($p<0.05$)

Table 13

Crude protein contents (g/kg) of the diets containing Brigadier

Overall mean	197.5
Unsupplemented (-)	196.0
Supplemented (+)	199.0

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	206.8[b]	193.2[cde]	203.2[b]	187.6[e]	189.8[de]	195.4[cd]
Supplemented (+)	206.6[b]	173.4[f]	205.6[b]	214.3[a]	194.8[cde]	196.6[bc]
Mean	206.6[a]	183.2[e]	204.4[ab]	201.0[bc]	192.3[d]	197.5[cd]

Values with no common superscript differ significantly ($p<0.05$)

Table 14

Dry matter contents (g/kg) of the diets containing Brigadier

Overall mean	871.0
Unsupplemented (-)	866.2[b]
Supplemented (+)	875.7[a]

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	899.6[a]	850.8[f]	862.5[c]	861.7[cd]	859.4[e]	863.0[c]
Supplemented (+)	901.5[a]	899.7[a]	863.2[c]	860.8[de]	862.2[cd]	867.0[b]
Mean	900.6[a]	875.2[b]	862.8[d]	861.3[de]	860.8[e]	865.0[c]

'alues with no common superscript differ significantly ($p<0.05$)

Table 15

Crude protein contents (g/kg) of the diets containing Rialto

Overall mean	204.4
Unsupplemented (-)	207.0^{a}
Supplemented (+)	201.8^{b}

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	216.2^{b}	202.0^{d}	209.8^{c}	208.0^{c}	196.0^{ef}	210.2^{c}
Supplemented (+)	221.7^{a}	200.2^{de}	198.0^{def}	198.0^{def}	195.2^{ef}	197.8^{def}
Mean	219.0^{a}	201.1^{b}	203.9^{b}	203.0^{b}	195.6^{c}	204.0^{b}

Values with no common superscript differ significantly ($p<0.05$)

Table 16

Dry matter contents (g/kg) of the diets containing Rialto

Overall mean	867.0
Unsupplemented (-)	865.6[b]
Supplemented (+)	868.4[a]

	Storage period (weeks)					
	1	9	17	25	33	53
Unsupplemented (-)	905.0[b]	856.2[g]	860.9[d]	859.0[e]	864.9[c]	864.1[c]
Supplemented (+)	908.8[a]	849.4[h]	858.5[ef]	856.7[fg]	863.1[c]	856.9[fg]
Mean	906.9[a]	852.8[e]	859.7[c]	857.8[d]	864.0[b]	860.5[c]

Values with no common superscript differ significantly ($p<0.05$)

Table 17

TMEN (MJ/kg, as received) of different (viscosity) wheats after different periods of storage

Overall mean	12.92

Storage period (weeks)	Rialto	Brigadier	Consort
1	13.86[a]	12.91[bcd]	13.26[bc]
9	13.22[bc]	13.35[bc]	13.14[bcd]
17	13.35[bc]	12.71[de]	13.37[b]
25	12.88[cd]	12.31[ef]	13.14[bcd]
53	12.00[f]	12.13[f]	12.17[f]
Mean	13.06[a]	12.68[b]	13.02[a]

Values with no common superscript differ significantly ($p<0.05$)

Table 18

TME_N (MJ/kg, as received) of diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzyme

Overall mean	12.92	
	Unsupplemented (-)	Supplemented (+)
	13.3	13.31^{NS}

	Rialto	Brigadier	Consort
Unsupplemented (-)	13.16^{b}	13.44^{a}	13.28^{ab}
Supplemented (+)	13.37^{a}	13.38^{a}	13.17^{b}
Mean	13.26^{a}	13.41^{b}	13.23^{a}

	Storage period (weeks)				
	1	9	17	25	53
Unsupplemented (-)	13.93^{a}	13.26^{c}	13.51^{b}	13.07^{d}	12.67^{e}
Supplemented (+)	13.98^{a}	13.52^{b}	13.30^{bc}	13.06^{d}	12.68^{e}
Mean	13.96^{a}	13.39^{b}	13.40^{b}	13.06^{c}	12.68^{d}
Rialto	13.98^{a}	13.36^{b}	13.40^{b}	13.04^{c}	12.54^{d}
Brigadier	14.00^{a}	13.47^{b}	13.38^{b}	13.21^{bc}	12.97^{c}
Consort	13.89^{a}	13.35^{b}	13.43^{b}	12.94^{c}	12.52^{d}

	1	9	17	25	53
Rialto (-)	13.98^{ab}	13.22^{ef}	13.40^{def}	12.75^{g}	12.43^{g}
Rialto (+)	13.98^{ab}	13.51^{cdef}	13.41^{def}	13.33^{def}	12.64^{g}
Brigadier (-)	14.01^{a}	13.34^{def}	13.48^{cdef}	13.16^{f}	13.19^{f}
Brigadier (+)	14.00^{a}	13.60^{bcde}	13.29^{def}	13.26^{ef}	12.76^{g}
Consort (-)	13.81^{abc}	13.24^{ef}	13.66^{abcd}	13.29^{def}	12.40^{g}
Consort (+)	13.98^{ab}	13.46^{cdef}	13.19^{f}	12.60^{g}	12.63^{g}

Values with no common superscript differ significantly ($p<0.05$)

Table 19

AME_N (MJ/kg, as received) of diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzyme

Overall mean	11.35	
	Unsupplemented (-)	Supplemented (+)
	11.32^{a}	11.38^{a}

	Rialto	Brigadier	Consort
Unsupplemented (-)	11.13	11.6	11.25
Supplemented (+)	11.21	11.4	11.51
Mean	11.17^{c}	11.49^{a}	11.38^{b}

	Storage period (weeks)				
	1	9	17	25	53
Unsupplemented (-)	11.52^{b}	10.57^{f}	11.30^{cd}	11.43^{bc}	11.77^{a}
Supplemented (+)	11.72^{a}	10.79^{e}	11.23^{d}	11.46^{bc}	11.71^{a}
Mean	11.62^{a}	10.68^{d}	11.26^{c}	11.44^{b}	11.74^{a}
Rialto	11.24^{ef}	10.37^{h}	11.12^{f}	11.56^{cd}	11.57^{cd}
Brigadier	11.87^{ab}	10.86^{g}	11.42^{de}	11.38^{de}	11.94^{a}
Consort	11.73^{abc}	10.80^{g}	11.25^{ef}	11.40^{de}	11.70^{bc}
Rialto (-)	11.12^{jkl}	10.14^{n}	11.22^{hijk}	11.45^{defghi}	11.73^{abcd}
Rialto (+)	11.36^{fghij}	10.60^{m}	11.02^{kl}	11.66^{bcdef}	11.42^{efghi}
Brigadier (-)	11.97^{a}	10.83^{lm}	11.62^{bcdefg}	11.52^{cdefgh}	11.91^{ab}
Brigadier (+)	11.77^{abc}	10.90^{l}	11.20^{1ijk}	11.24^{hijk}	11.97^{a}
Consort (-)	11.46^{defghi}	10.73^{m}	11.06^{jkl}	11.33^{ghij}	11.67^{abcdef}
Consort (+)	12.01^{a}	10.88^{lm}	11.44^{defghi}	$11.47^{cdefghi}$	11.74^{abcd}

Values with no common superscript differ significantly ($p<0.05$)

Table 20

Weight gains (g, 0-21 d) of birds fed on diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzyme

Overall mean	583			
	Unsupplemented (-)		Supplemented (+)	
	566^{b}		594^{a}	
	Rialto	Brigadier	Consort	
Unsupplemented (-)	551^{b}	586^{a}	578^{ab}	
Supplemented (+)	580^{a}	603^{a}	599^{a}	
Mean	566^{b}	594^{a}	589^{a}	

	Storage period (weeks)				
	1	9	17	25	53
Unsupplemented (-)	516^{def}	547^{cde}	702^{a}	581^{c}	512^{ef}
Supplemented (+)	506^{f}	570^{c}	704^{a}	639^{b}	550^{cd}
Mean	511^{d}	559^{c}	703^{a}	610^{b}	531^{d}
Rialto	509^{fg}	548^{ef}	683^{ab}	578^{de}	511^{fg}
Brigadier	520^{fg}	552^{ef}	719^{a}	607^{cd}	535^{efg}
Consort	505^{g}	576^{de}	708^{a}	646^{bc}	548^{ef}
Rialto (-)	520^{hijk}	510^{ijk}	669^{abc}	565^{efghi}	490^{k}
Rialto (+)	497^{jk}	586^{defgh}	696^{ab}	591^{defg}	532^{ghijk}
Brigadier (-)	519^{hijk}	612^{cde}	714^{a}	598^{def}	487^{k}
Brigadier (+)	522^{ghijk}	492^{k}	724^{a}	693^{ab}	582^{defgh}
Consort (-)	510^{ijk}	520^{hijk}	723^{a}	580^{defgh}	560^{efghij}
Consort (+)	501^{ijk}	633^{bcd}	693^{ab}	634^{bcd}	536^{fghijk}

Values with no common superscript differ significantly ($p<0.05$)

Table 21

Food intakes (g, 0-21 d) of birds fed on diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzyme different periods in storage

Overall mean	930	
	Unsupplemented (-)	Supplemented (+)
	920.0	941^{NS}

	Rialto	Brigadier	Consort
Unsupplemented (-)	894^{bc}	933^{ac}	931^{ac}
Supplemented (+)	926^{ac}	952^{a}	945^{a}
Mean	910^{b}	943^{a}	937^{ab}

	Storage period (weeks)				
	1	9	17	25	53
Unsupplemented (-)	845^{de}	905^{c}	1073^{a}	901^{cd}	874^{cde}
Supplemented (+)	836^{e}	929^{bc}	1081^{a}	973^{b}	887^{cde}
Mean	840^{c}	917^{b}	1077^{a}	937^{b}	880^{bc}
Rialto	927^{f}	902^{bcdef}	1072^{a}	896^{cdef}	853^{ef}
Brigadier	860^{def}	937^{bc}	1081^{a}	971^{b}	865^{def}
Consort	834^{f}	911^{bcde}	1077^{a}	944^{bc}	923^{bcd}
Rialto (-)	837^{jklm}	867^{hijklm}	1046^{abcd}	871^{hijklm}	848^{ijklm}
Rialto (+)	817^{lm}	937^{efghi}	1098^{a}	$921^{efghijk}$	857^{hijklm}
Brigadier (-)	836^{jklm}	997^{bcdef}	1079^{abc}	930^{efghij}	827^{klm}
Brigadier (+)	$884^{ghijklm}$	$877^{ghijklm}$	1084^{ab}	1012^{abcde}	903^{fghijk}
Consort (-)	862^{hijklm}	851^{hijklm}	1093^{a}	$902^{fghijkl}$	946^{efgh}
Consort (+)	805^{m}	971^{defg}	1061^{abcd}	986^{cdef}	$900^{fghijklm}$

Values with no common superscript differ significantly ($p<0.05$)

Table 22

Food conversion efficiencies (g gain/g food, 0-21 d) of birds fed on diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzymedifferent periods in storage

Overall mean	0.625		
	Unsupplemented (-)		Supplemented (+)
	0.621		0.630[NS]
	Rialto	Brigadier	Consort
Unsupplemented (-)	0.617	0.6	0.619[NS]
Supplemented (+)	0.626	0.6	0.633[NS]
Mean	0.621	0.6	0.626[NS]

	Storage period (weeks)				
	1	9	17	25	53
Unsupplemented (-)	0.612[cd]	0.605[cd]	0.654[a]	0.645[ab]	0.588[d]
Supplemented (+)	0.606[cd]	0.613[cd]	0.651[a]	0.657[a]	0.621[bc]
Mean	0.609[b]	0.609[b]	0.653[a]	0.651[a]	0.604[b]
Rialto	0.615[defg]	0.608[efg]	0.636[abcde]	0.647[abc]	0.601[fg]
Brigadier	0.606[efg]	0.589[g]	0.666[a]	0.663[a]	0.617[cdefg]
Consort	0.607[efg]	0.631[bcdef]	0.656[ab]	0.643[abcd]	0.595[g]
Rialto (-)	0.622[cdefg]	0.588[gh]	0.640[abcde]	0.652[abcd]	0.582[gh]
Rialto (+)	0.608[defg]	0.627[bcdef]	0.633[bcdef]	0.642[abcd]	0.620[cdefg]
Brigadier (-)	0.622[cdefg]	0.616[defg]	0.662[abc]	0.642[abcd]	0.589[fgh]
Brigadier (+)	0.590[fgh]	0.562[h]	0.669[ab]	0.684[a]	0.645[abcd]
Consort (-)	0.591[fgh]	0.611[defg]	0.661[abc]	0.642[abcd]	0.592[fgh]
Consort (+)	0.622[cdefg]	0.650[abcd]	0.651[abcd]	0.644[abcd]	0.598[efgh]

Values with no common superscript differ significantly ($p<0.05$)

Table 23

Viscosities (cps) of jejunal contents taken from birds fed on diets containing different (viscosity) wheats, stored for different periods of time, with and without the addition of enzyme

Overall mean	2.91	
	Unsupplemented (-)	Supplemented (+)
	3.42[a]	2.39[b]

	Rialto (high)	Brigadier (medium)	Consort (low)
Unsupplemented (-)	3.79[a]	3.35[b]	3.13[c]
Supplemented (+)	2.48[c]	2.44[c]	2.25[d]
Mean	3.14[a]	2.90[b]	2.69[c]

	Storage period (weeks) 1	9	17	25	53
Unsupplemented (-)	3.61[b]	3.40[c]	4.06[a]	2.96[d]	3.09[d]
Supplemented (+)	2.31[f]	2.65[e]	2.66[e]	2.05[g]	2.28[f]
Mean	2.96[b]	3.02[b]	3.36[a]	2.51[d]	2.69[c]
Rialto	2.69[ef]	3.36[b]	3.90[a]	2.78[def]	2.95[cd]
Brigadier	3.10[c]	2.81[def]	3.46[b]	2.45[gh]	2.66[fg]
Consort	3.09[c]	2.90[cde]	2.70[ef]	2.30[h]	2.46[gh]
Rialto (-)	3.13[efg]	3.84[b]	4.97[a]	3.52[cd]	3.50[cd]
Rialto (+)	2.25[jklm]	2.89[gh]	2.84[gh]	2.03[m]	2.40[ijk]
Brigadier (-)	3.94[b]	2.97[fg]	3.99[b]	2.91[fgh]	2.94[fgh]
Brigadier (+)	2.26[jklm]	2.65[hi]	2.94[fgh]	1.99[m]	2.37[ijkl]
Consort (-)	3.75[bc]	3.38[de]	3.21[def]	2.46[ij]	2.84[gh]
Consort (+)	2.43[ijk]	2.42[ijk]	2.19[jklm]	2.14[klm]	2.07[lm]

Values with no common superscript differ significantly ($p<0.05$)

Figure 1
TME_N of wheats vs storage

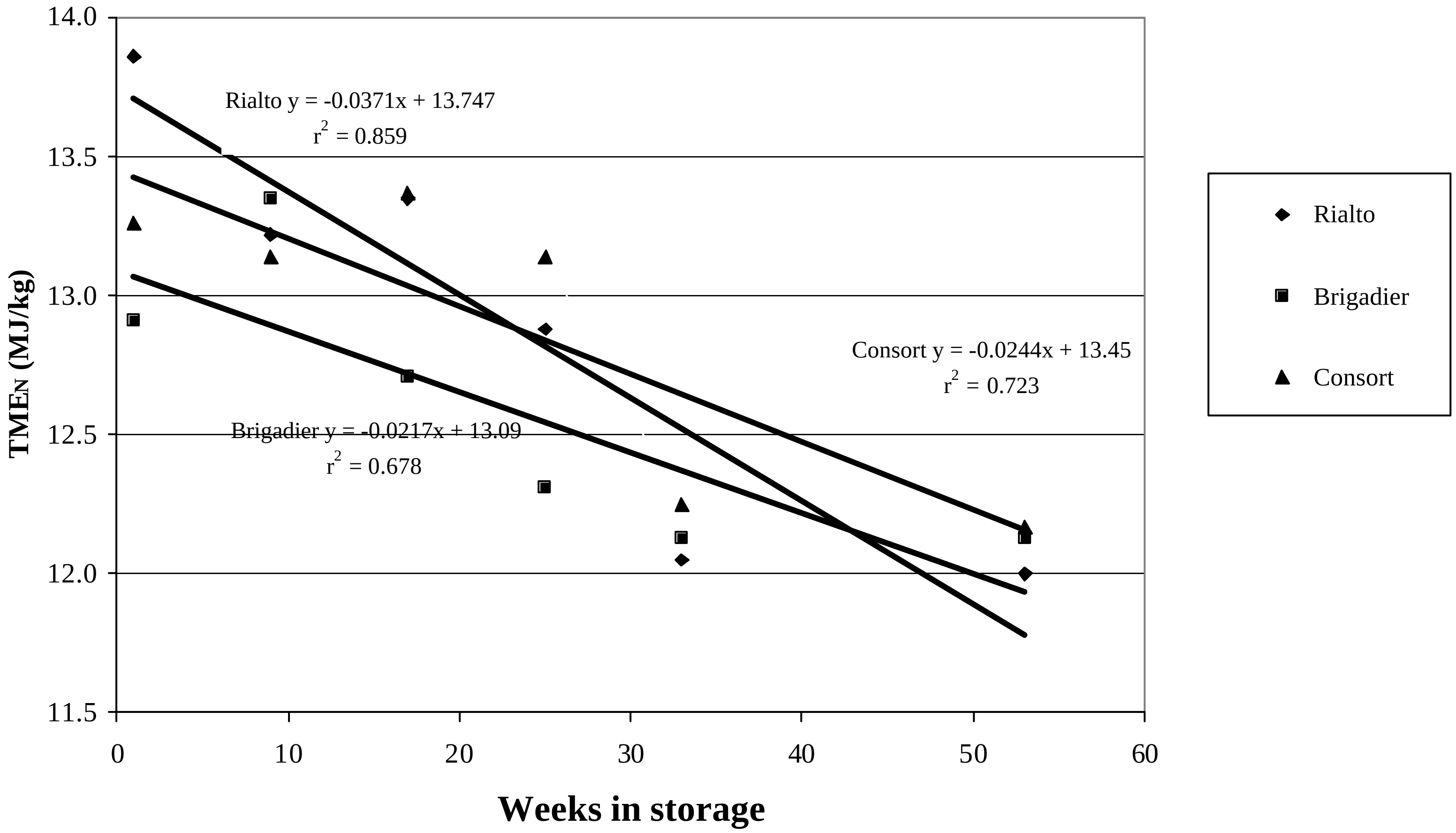


Figure 2
TME_N of wheats vs storage time

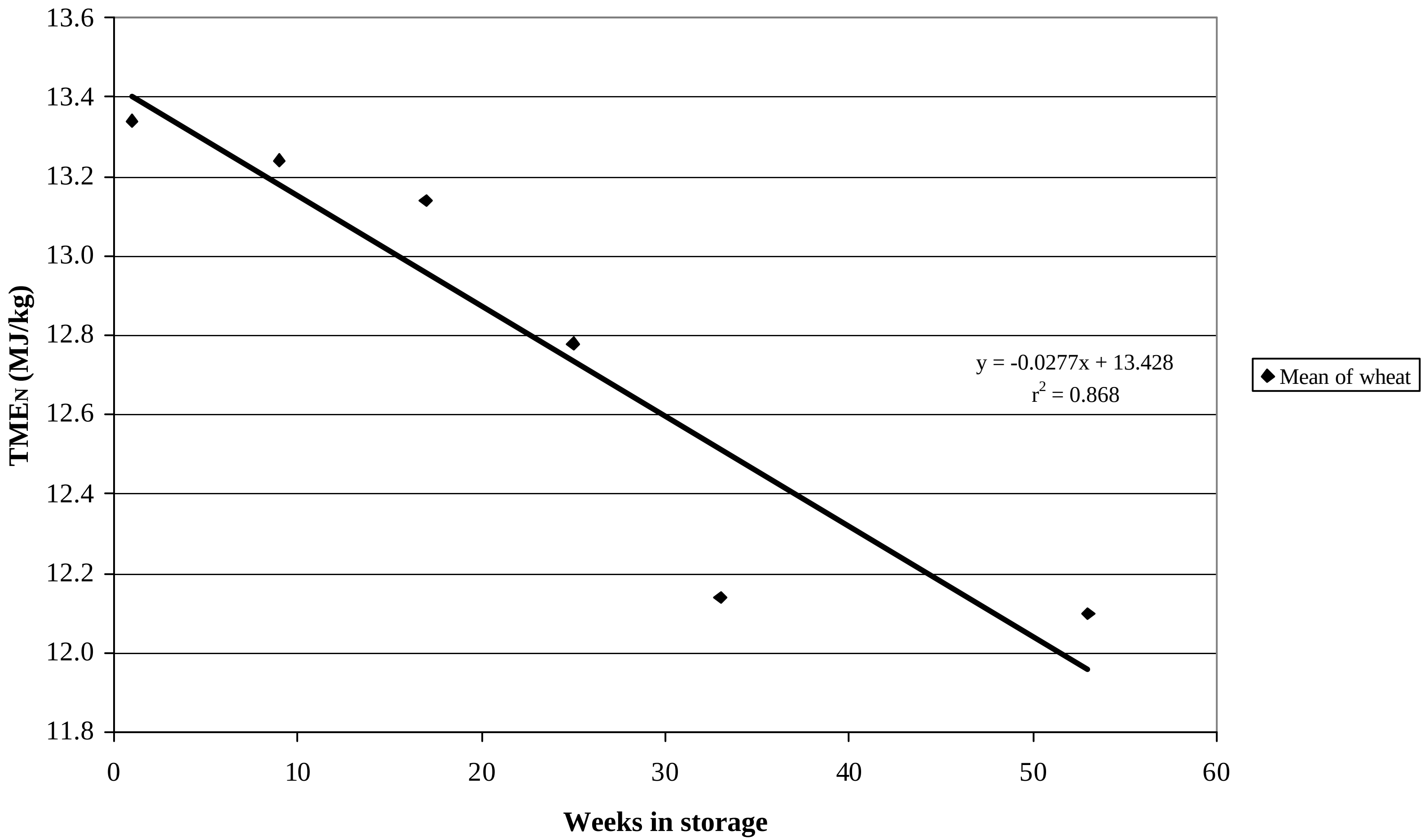
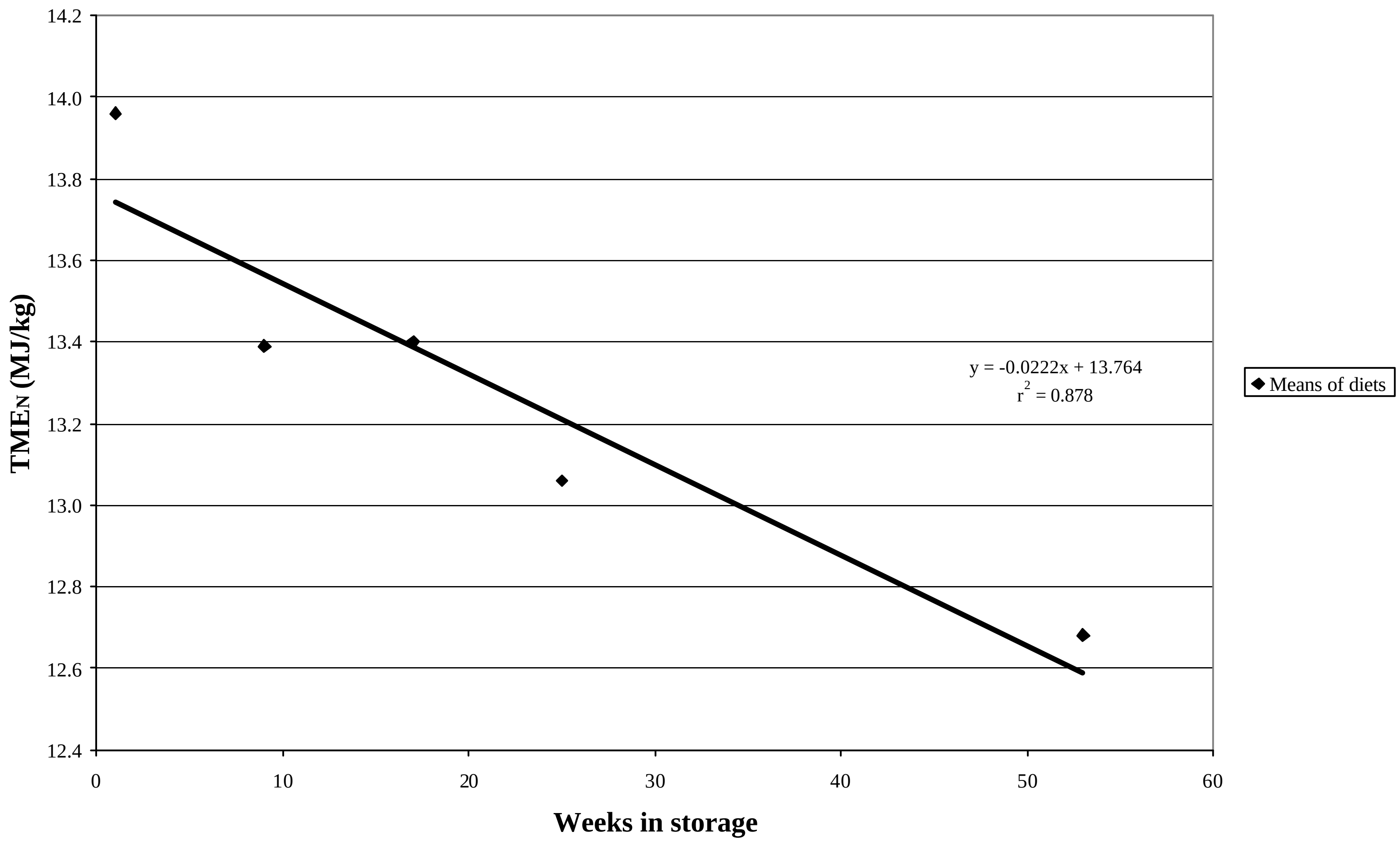


Figure 3
TME_N of diets vs storage time



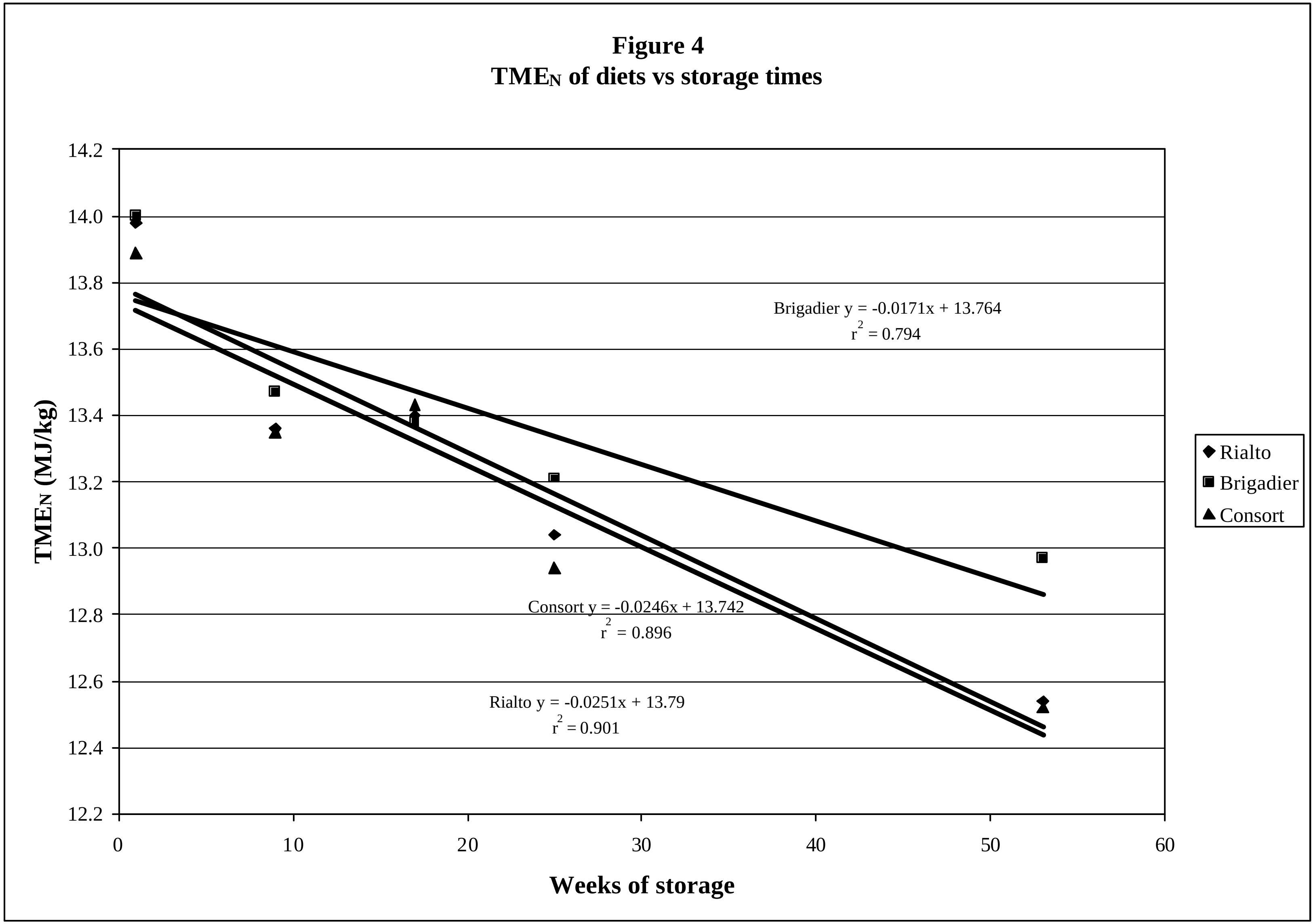


Figure 4
TMEN of diets vs storage times
TMEN (MJ/kg)
14.2
14.0
13.8
13.6
13.4
13.2
13.0
12.8
12.6
12.4
12.2
0
10
20
30
40
50
60
Weeks of storage
Brigadier y = -0.0171x + 13.764
r2 = 0.794
Consort y = -0.0246x + 13.742
r2 = 0.896
Rialto y = -0.0251x + 13.79
r2 = 0.901
Rialto
Brigadier
Consort

Figure 5
AME$_N$ of diets over period of storage of wheats