The Effect of Pre-Germination on Feeding Value of Cereal Grains for Poultry

Tom A.Scott
Agriculture and Agri-Food Canada
PARC, PO Box 1000, Agassiz, BC V0M 1A0
Ken Campbell
Breakthru Seeds Ltd.
55037 – RR 214, Fort Saskatchewan, Alberta T8A3B9

Introduction

Finney (1983) summarized his extensive review of the effect germination has on nutrient value of cereals and legumes as, "based on: (1) nearly 100 years of chemical studies; (2) about 70 years of corroborative rat and other animal feeding studies (3) further corroborated by a few well documented human feeding studies; and (4) on hundreds and in some cases thousands of years of experience by millions of people, it is concluded that carefully controlled, optimal germination of edible cereals and legumes is capable of significantly alleviating today's food problems and avoiding tomorrow's food needs."

Finney's (1983) statement, above, provides a strong challenge to develop an understanding of how the process of germination can be used as a "tool" to improve feeding value of grains. Variation in germination is expected as there can be many genetic and environmental (eg., temperature, light, moisture and time) factors that control germination (Bau et al., 1997), and ultimately the "benefits" for germination.

Typically, for cereal grains, germination is described as that time that radical emergence occurs. In barley, radical emergence may take 48 or more hours to occur. Pre-germination is described here as the time between imibition (water uptake by seed) and before radical emergence. Based on the information found in the literature, it would appear that the majority of the studies involved

germinated (post radical emergence) and sprouted seeds. In our own initial studies we have used pre-germinated grains.

Based on experiences with malt (Cornell and Hoveling, 1988), the minimum requirement for germination of barley was the absorption of 40% of it's weight in water. To maximize and equalize germination of malt barley it was necessary to facilitate equal oxygenation and maintain an optimum constant core temperature. During germination, dormancy of the embryo is broken and the embryo releases a hormone(s) that triggers the release of enzymes such as phytase, amylases, proteases and phosphorlyases, that act on the grain, particularly on the endosperm components (Cornell and Hoveling, 1998). These enzymes break down the starch, proteins, and other materials, producing more soluble materials.

The control of seed quiescence, or dormancy, is generally classified in one of five ways: 1) rudimentary embryos; 2) physiologically immature embryos (inactive enzyme systems); 3) mechanically resistant seed coats; 4) impermeable seed coats; and 5) presence of germination inhibitors (Pomeranz, 1992). Duration of dormancy in most cereal grains is largely determined genetically, however, dry and sunny weather during grain development shortens post harvest dormancy. Dormancy of freshly harvested grain can be artificially broken by pre-drying at 35C, treating with gibberellic acid or hydrogen peroxide, or by removing (mechanically or chemically) the outermost layers of the seed coat. It has been observed (G. Miller, personal communication, Sprouting Health Ltd, Richmond, BC) that breaking dormancy or germination of wheat, reduces the allergic response by some humans that have "gluten" allergies. It has also been observed storage of barley, after harvest, resulted in improvements in broiler chick performance (Fuente et al., 1998). More information is needed on the physio-chemical factors that control seed dormancy and subsequently impact nutrition and health (ie; allergic reaction).

Processing grains (milled) has been observed by Pomeranz (1992) to destroy biological order by changing water absorption capacity and reactivity that may enhance damage from other sources such as oxygen, light and high relative humidity. Consequently, retention of desirable properties is more difficult in milled products than in intact grain. This raises concerns that if pre-germinated grain is processed then we must examine the impact of processing on the shelf life of the product.

Svihus (1997) compared the effects of whole barley feeding after soaking at 0C and room temperature to study changes in enzyme activity that occur with soaking. One treatment used germinated grain (grain soaked for 24 hrs and then allowed to germinate for 48 hrs). This treatment resulted in broiler performance equal to barley with enzyme, attributed to lower digesta viscosity in both treatments. Beta-glucan levels in un-germinated barley being reduced by the added enzyme, beta-glucan of the germinated barley being reduced by the endogenous enzyme released during germination.

With regards to germination of grains and legumes to improve the food/feed value, Finney (1983) listed four criteria that need to be considered; 1)determine those conditions that result in the most seed constituents being “converted” into required nutrients; 2) minimize conditions that favour microbiological infestation; 3) maximize of growth and production; and 4) provide conditions that result in minimal seed nutrient loss and maximal absorption of water soluble constituents from the steep and germination medium. The latter point is important, as the use of germination enhancers (i.e. gibberellin salts) an nutrients (eg., nitrites, ammonium salts, calcium) in the steep water have a direct impact on the seed’s production of and uptake of nutrients.

Table 1/ Summary of research examining the effect of germination of seeds on factors that impact the level of digestibility of nutrients.

Researcher	Grain	Pro/Con	Effect on feeding value of the grain
Ayet etal., 1997	Lentils	+	with 6 days of germination there were reductions in ANF's (tannins and phytic acid)
Bau et al., 1997	Soybean	+ / -	-no change in amino acid profile with germination -decrease in lipid and lysine -niacin content increased -reduced lipase inhibitor activity -decrease in lectins -production of phytase, amylase, proteases
Bau et al., 1997	Soybean	- – -	microbial growth during germination
Kailela and Saastamoinen1 991	Oats	+ ?	Some indication that vomatoxin in grain may be reduced with germination of uncon-taminated grain mixed in with contaminated
Kaukovirta-Norja, et al., 1998	cereal grain	+	-lipase activities increased
Knowler et al., 1994	chick pea	+	-reduction in oligosaccharides and their fermentation in the gut -trypsin inhibitor activity reduced after 2 d, but increased after 3 d
Pomeranz, 1992	wheat	+	-improved bread making qualities (with sprouted grain), by raising alpha-amylase
Smith, 1972	barley	+	-increased lysine content, but may not be of value due to lower cystine content
Svihus et al., 1997	barley	+	-decreased beta glucans -improved performance (gain & conversion) -improved digestibility of DM, protein, fat and energy -reduced digesta viscosity & excreta moisture

Animal Studies using pre-germinated grain at PARC (Agassiz)

Three preliminary studies have been conducted to evaluate the effect of pre-germination of cereal grains on broiler chick performance. The initial study compared control (not germinated) and pre-germinated barley with and without a commercial enzyme (Avizyme – SX, Finnfeeds Int, Marlborough, UK) in the Agassiz broiler chick bioassay. The second study tested 24 treatments, based on six grain sources that were fed "as is" or after pre-germination with or without an appropriate enzyme in the Agassiz broiler chick bioassay. And, the third study measured the performance of broiler chicks, housed in floor pens, fed conventional diets that contained a portion of pre-germinated barley.

Description of the pre-germination process

The G.E.M™ (Growth Enhancement Method) process is a seed priming procedure used by Breakthru Seeds Ltd., on turf and forage species to enhance germination and subsequent production. Priming is a process whereby the chemical process of germination is initiated through the sequential imibition and drying of seed. Previous studies, using germinated seeds for animal feeding, have shown erratic responses. Hence, a secondary process called the Super Feeds process was developed incorporating the G.E.M™ Process to stabilize nutrients and increase the digestibility of pre-germinated seeds.

It was noted that to initiate sequential germination in a composite sample of seeds, that individual seeds required different internal moisture levels to optimize development (figure 1)

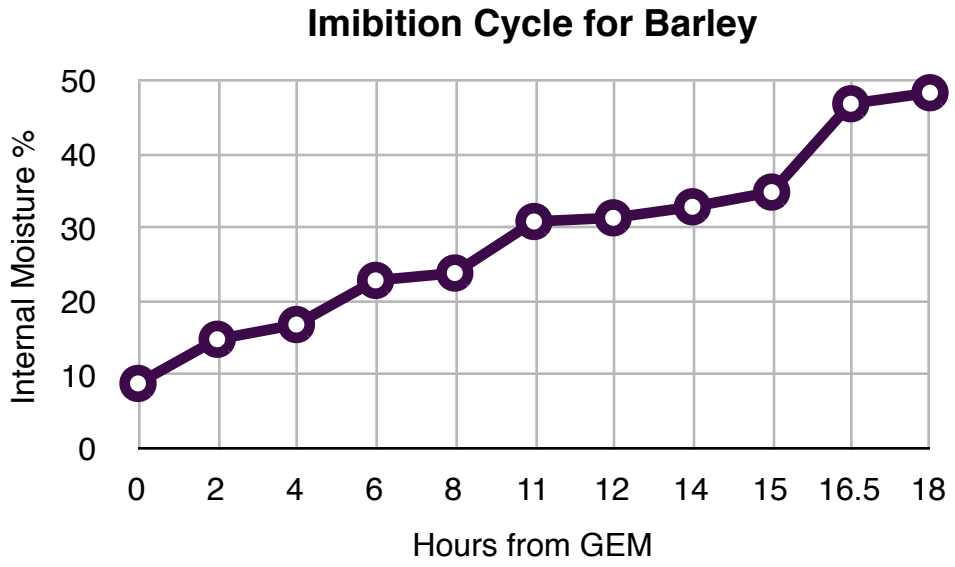

Figure 1. Average internal moisture (%) for barley seeds following GEM™

Most priming procedures are chemical and use organic salts or poly ethylene glycol to control moisture uptake. The G.E.M™ Process accomplishes this by mechanical stimuli. The result is that each individual seed imbibes precise amounts of moisture needed for the different times in the imbition cycle. The synchronized germination of the G.E.M.™ process thus provides uniform enzyme content without compromising the nutritional content of the seeds. The added Super Feeds process enabled stabilization of the material. Currently stabilization of the pre-germinated grains has been maintained for two to three months.

Laboratory analysis (Table 2) of samples of ungerminated and pre-germinated cereals have been conducted. This analysis indicates positive changes in seed crude (13.3%) and soluble (67.9%) protein total lipids (6.4%) and nitrogen free extract (1.2%) with pre-germination of barley. Pre-germination resulted in reduction in crude fat (-5.3%), crude fibre (-30.9%) and ADF (-19.3 %) measurements.

Table 2. Laboratory analysis of samples of ungerminated and pre-germinated cereals, the difference is based on (pre-germinated-ungerminated) ungerminated x 100

Table 2	Barley		% Difference due to G.E.M.™
	Ungerminated	Pre-germinated	
Crude Protein %	9	10.2	13.3
Soluble Protein %	2.8	4.7	67.9
Crude Fat %	1.9	1.8	-5.3
Total Lipids (g)	34.4	36.6	6.4
Crude Fibre %	5.5	3.8	-30.9
ADF %	23.9	19.3	-19.3
N Free Extract %	80.8	81.8	1.2

Bioassay Studies

The Agassiz broiler chick bioassay (Scott et al., 1998) used four cages of six male broiler chicks, fed a diet containing 80% of the test ingredient, plus 20% basal (protein supplement, vitamin and mineral premixes and an acid insoluble ash marker). The chicks are fed ad libitum the appropriate test diet from four to 17 days of age and excreta collected for 24 hrs at 8 and 16 days of age. At 17 Days feed consumption and body weight were recorded and chicks humanely killed to provide digesta for viscosity and ileal digestibility measurements concentrations in the diet. High dietary beta-glucan levels are attributed to cause reductions in feed intake, growth, feed conversions, excreta dry matter and digestibility of nutrients (Bedford, 1995). Ungerminated barley with no enzyme resulted in high digesta viscosity (64.2 cps), supplementation with enzymes reduced digesta viscosity (6.4 cps). Pre-germination of barley (no enzyme) resulted in a 50% decrease in digesta viscosity (32.4 cps) as compared to ungerminated barley with no enzyme. This level of digesta viscosity, observed in

pre-germinated barley with no enzyme, would still be considered high and would be expected to result in reductions in performance. Similar to ungerminated barley, the pre-germinated barley-based diets with enzyme had a low digesta viscosity (7.7 cps), demonstrating that enzymes caused a significant further (>400%) reduction in digesta viscosity of pre-germinated barley. Yet, pre-germinated barley-based diets with or without enzyme had equal and superior broiler performance (i.e., no enzyme response to the parameters).

Excreta dry matter is attributed to dietary beta-glucan levels and subsequent digesta viscosity measurements. In the present study, there was a definite increase in excreta dry matter with enzyme supplementation of pre-or un-germinated barley, but no difference between pre or un germinated barley when measured for those diets with or without supplemental enzyme. However, it has been observed that diets containing pre-germinated barley have a hydrophilic nature, resulting in higher moisture levels than ungerminated barley based diets. This observation is supported by Pomeranz's (1992) observation that processing comparison to changes in whole grain. Diets with pre-germinated barley were observed to have a 3–5% higher moisture level when stored under the same ambient conditions as diets with ungerminated barley.

There was no significant interaction effect on AME measurements of the four diets. The non significant effect of pre-germination and ungerminated treatments remained consistent for the differences measured when diets were fed with or without supplemental enzyme. Again, one would expect a higher AME measurement for pre-germinated barley diets without enzyme based on digesta viscosity measurements being intermediate between diets with enzyme and ungerminated barley without enzyme. The discrepancies in measurements of performance and digesta viscosity, excreta moisture and AME raise our concerns that there are unidentified growth factors involved that impact palatability (voluntary feed intake) and/or availability of other nutrients (e.g., amino acids) to

an extent that performance is improved regardless of digesta viscosity, and energy digestibility.

The first bioassay measured the above parameters for four diets, based on one barley source. The barley source was split, one portion maintained “as is”, the other pre-germinated. Each portion was used to formulate test diets, then split and one portion fed “as is”, the other re-mixed with 0.15% enzyme.

The second bioassay tested six different cereal grain sources, and as described above, each resulted in four test diets. The six cereal sources were based on three barley (hulled, hulless and malt) and three wheat [Hard Red Spring (HRS), Canadian Prairie Spring (CPS) and Durum)] cultivars.

Broiler Feeding Trial

Four practical broiler chicken diets were formulated for each of two broiler feeding periods (started 0–21d; grower/finisher 21–40 d). The three test barley sources were substituted in the starter and grower/finisher diets, respectively, at 35 and 50% of the corn used in the corn-based control. The three barley sources tested were: barley with enzyme; pre-germinated barley (no enzyme); or pre-germinated barley with enzyme. Each diet was fed to 12 pens of 35 broilers to evaluate the performance (growth, feed intake and feed conversion) of broilers during the starter and grower/finisher feeding periods.

Results and Discussion

Bioassay one

Overall, this study has provided some indication that pre-germination of grain had a positive effect on broiler performance (Table 3). There were significant differences in growth, feed intake and digesta viscosity due to pre-germination,

but no significant response in feed conversion, and dry matter and AME measurements based on excreta collected at 16d. Enzyme supplementation, as a main effect, resulted in significant differences in all variables in Table 3.

There were significant interactions between grain source (pre-vs un-germinated) and enzyme supplementation for all variables except excreta dry matter and AME measured at 16d. The interaction for measurements of body weight and feed intake indicate that enzyme supplementation had a more pronounced effect on un-germinated barley as compared to pre-germinated barley. Pre-germinated barley with or without enzyme diets resulted in higher body weight (not significant) and feed intake (significant) than un-germinated barley diets with enzyme. The subsequent fee; gain values showed no improvement due to pre-germination as compared to un-germinated barley without enzyme, these diets all having significantly higher feed; gain than un-germinated barley with an enzyme.

Digesta viscosity interactions between grain source and enzyme supplementation prove interesting. Digesta viscosity is attributed to beta-glucan.

Table 3. The effects of pre-germination and enzyme on broiler chick growth and feed conversion to 17d of age and estimates of apparent metabollsable energy (Dry Matter basis) of the diet.

Pre-germination	Enzyme Addition	Body Wt @ 17 d	Feed Intake g/b/d	Feed: Grain g:g	Digesta Viscosity cps	16d Excrete Measurements	
						DM	AME
Total		429 ±23.3	40.7 ±1.95	1.52 ±0.032	27.7 ±15.00	39.1 ±3.43	3170 ±30
Pre-germination		0.01	0.01	0.41	0.05	0.96	0.58
Yes		404	37.3	1.52	35.9	39.2	3160
No		454	44	1.53	19.4	39.1	3170

	Enzymes	0.03	0.18	0.01	0.01	0.01	0.01
	Yes	443	41.4	1.5	7	54.1	3230
	No	415	40	1.55	48.3	43.3	3100
Pre-germination	**Enzymes**	0.06	0.08	0.01	0.06	0.37	0.69
Yes	**Yes**	456a	43.7a	1.53a	6.4c	45.3	3240
	No	453a	44.2a	1.53a	32.4b	32.9	3100
No	**Yes**	430a	39.0b	1.46b	7.7c	43.8	3230
	No	378b	35.7c	1.57a	64.2a	34.6	3100
a,b,c different letters behind mean values signify significant differences (P>0.05) between mean values for cereal sources							

Bioassay 2

There were only significant precessing (pre-germinated vs un-germinated) treatment effects for body weight and AME measurements (Table 4) in a second study comparing three wheat and three barley samples. Within the three wheat or barley samples, there was considerable variation due to treatments, suggesting that there are real differences in response due to the genetics and/or environment of the sample source.

With regards to differences within cereals with processing effects, the analysis suggests that there were differences between wheat and barley when pre-germinated or not for viscosity and AME measurements, but not body weight or feed conversion. Of interest was the “nominal” drop in AME with processing (as in the previous study) for barley-based diets (1.5%) as compared to wheat-based diets (6.2%). Again, there is sufficient variation in specific sources of wheat or barley as well as the differences between wheat and barley to support that pre-germination requirements may be very marked due to grain differences.

Table 4. The effects of Pre-germination, Enzyme Supplementation and Cereal Source on Broiler Chick growth …….

Cereal Source	Processing Treatment	Enzyme Supplement	Body Wt. @ 17d	Feed:Gain 4 to 17d	Viscosity cps	AME x DM kcal/kg 18d
Total			417	1.42	16.2	2880
Cereal Source			**	**	**	**
Barley			406	1.44	24.6	2770
Wheat			429	1.4	7.7	2990
	Processing Treatment		**	0.28	0.37	*
	Yes		426	1.42	14.8	2820
	No		409	1.43	17.6	2940
		Enzyme	**	**	**	**
		With	434	1.39	4.9	2980
		Without	400	1.46	27.4	2780
Cereal x	**Processing**		0.41	0.55	0.1	0.11
Cereal x		**Enzyme**	0.08	0.73	**	0.16
	Processing x	**Enzyme**	0.16	**	0.93	*
Cereal x	**Processing x**	**Enzyme**	0.52	0.63	0.54	0.6
Barley	**Yes**		423	1.44	20.6	2750
Barley	**No**		400	1.45	28.6	2790
Wheat	**Yes**		440	1.4	8.9	2890
Wheat	**No**		418	1.4	6.5	3080
Yes		**With**	446	1.37	3.6	2980
Yes		**Without**	405	1.47	25.9	2670
No		**With**	422	1.4	6.2	2990
No		**Without**	396	1.45	29	2880

a,b,c Different letters behind mean values signify significant differences (P>0.05) between mean values for cereal sources

The interaction ($P<0.01$) between processing and enzyme supplementation for feed: gain and AME are noted in Table 4. It was apparent that for all grain samples, there was a marked improvement of pre-germinated grains with enzyme for feed: gain measurements. For AME measurements, the pre-germinated grains without enzyme were lower than the same sample with enzyme or the un-germinated diets with or without enzyme.

In this second study, with a total of six grains, we saw a general increase in feed intake with pre-as compared to un-germinated grains (with or without enzyme) and this resulted in an improvement in body weight gain, but not feed conversion. However, the response in this second study was not as definite as that seen in the first study, relating to perhaps differences in the processing methods applied and to differences in the cereal grain itself. The consistent measured drop in AME due to pre-germination was very apparent when the diets did not contain enzyme, and seems out of line with regards to favourable increase in body weight observed when pre-germinated grain with or without an enzyme. Suggesting that perhaps the benefits of the pre-germination are related to factors other than availability of energy, and may perhaps relate to changes in voluntary intake and/or availability of amino acids.

Broiler Feeding Trial

The four diets tested in the broiler feeding trial showed significant differences with regards to diet for growth and feed conversion (Table 5). Again, these test diets differed from the bioassay diets by containing less cereal grain in total, and only a protion of the grain being pre-or un-germinated barley (replacing 35 and 50% of the corn in the control corn-based diet, respectively, in starter and grower/ finisher diets). This was due to difficulty in generating sufficient amounts of pre-germinated grain in the prototype pre-germinator. Broilers fed diets containing pre-germinated grain, without enzyme, performed significantly better than broilers fed the same diet with enzyme or diets containing un-germinated barley (with

enzyme) or corn. This initial data would suggest that there are performance enhancing attributes to lower levels of pre-germinated diet, and that this effect is reduced by supplementing with enzyme.

During germination of grain, beta-glucanase is produced in the seed (Svihus et al., 1997). Depending on the time that germination is allowed to proceed, and mechanical actions to stop germination, there may be some variations in the amount of beta glucan in the sample. The concern being that if beta-glucan levels of the germinated grain are already high, then supplementing them with beta-glucanase may substantially alter the non starch polysacharride (NSP) break down components. NSP breakdown by enzymes reduces gut viscosity, however, it may also generate breakdown products that interfere with digestion of nutrients or cause a proliferation of gut micoflora that are detrimental to broiler performance (Bedford, personal communication, 1998)

In the previous studies, it was observed that pre-germination resulted in a significant reduction (50%) in degesta viscosity. Enzyme supplementation reduced digesta viscosity of pre-germinated grains to a level equal to the un-germinated grain with enzyme. However, this does not provide information on the break down products of NSP by either the pre-germination process or added enzyme supplementation. Rather, it only indicates that NSP water holding capacity in the gut has been reduced. Nor does it provide information on the impact of pre-germination with or without enzyme supplementation on the availability of other nutrients, such as protein (ie. Amino acids)

Table 5. Mean body weight gain(g) and feed conversion (g feed: g grain) for starter (0–21d) and grower/finisher (21–42d) periods for broilers (12 pens of 35 broilers / diet treatment) fed barley (with enzyme)-, corn- and diets containing 30 and 50% pre-germinated (Pre-G) barley (substituted for ungerminated barley) in starter and grower / fisher diets (with (E+) or without (E-) enzyme).

	0 – 21 d	21 – 42 d	0 – 42 d

Table 5. Mean body weight gain(g) and feed conversion (g feed: g grain) for starter (0–21d) and grower/finisher (21–42d) periods for broilers (12 pens of 35 broilers / diet treatment) fed barley (with enzyme)-, corn- and diets containing 30 and 50% pre-germinated (Pre-G) barley (substituted for ungerminated barley) in starter and grower / fisher diets (with (E+) or without (E-) enzyme).

	Gain	Feed:Gain	Gain	Feed:Gain	Gain	Feed:Gain
Total	649	1.55	1573	2.02	2222	1.89
Diet	**	**	**	**	**	**
Barley E+	598c	1.65a	1496c	2.09a	2094c	1.97a
Corn	616c	1.61b	1508c	2.12a	2124c	1.97a
Pre-G E+	671b	1.52c	1612b	1.99b	2284b	1.86b
Pre-G E-	710a	1.43d	1675a	1.89c	2385a	1.76c

a,b,c different letters behind mean values signify significant differences (P>0.05) between the mean value for diets.

Summary

Initial studies on the effect of pre-germinating cereal grains, i.e. barley and wheat, in our laboratory have provided generally a positive impact on broiler performance, in particular influencing voluntary intake of feed and subsequent growth, with little enhancement of feed efficiency as compared to un-germinated grains supplemented with enzyme. Pre-germination resulted in approximately a 50% decrease in digesta viscosity, which was lowered to levels of ungerminated grains with enzyme. However, no improvement or in one instance a negative response was observed with enzyme supplementation of pre-germinated grains. This may indicate that pre-germination of grain may improve: 1) palatability or voluntary intake of the diets; b)solubility and digestibility of other nutrients, for example, amino acids; and c) reduce the impact of other anti-nutritive factors besides levels of NSP, such as those dormancy factors that have been implicated to reduce performance of broilers or to cause flour allergies in humans.

Further research is required to establish those variables that could be manipulated to produce a constant, and desired, end point for pre-germination of grains regardless of the impact of genetics and environment. Other concerns relate to: a) how processing of pre-germinated grain can be completed without any impact on the “shelf-life” of the product; b)the impact of pre-germinated grain in combination with other diet ingredients, including germinated grains; c) microbial contamination (or enhancement?) during the germination process; and d) the impact of NSP enzymes in combination with pre-germinated grains. If one of the by-products of germination of barley is beer, it becomes obvious, that there are good things to arise from this research, even for poultry.

References

Ayet, G., C., Burbano, C. Cuadrado, M.M. Pedrosa, L.M. Robredo, M. Muzquiz, C. De la Cuandra, A. Castario and A. Osagie, 1997. Effect of germination, under different environmental conditions, on saponins, phytic acid and tannins in lentis (Lens culinaris). J. Sci. Food Agric., 74:273–279

Bau, H-M., C. Villaume, J-P Nicolas, L. Mejean, 1997. Effect of Germination on chemical composition, biochemical constituents and antinutritional factors of soya bean (Glycine max) seeds. J.Sci. Food Agric., 73: 1–9.

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

Cornell, H.J., A.W Hovelling, 1998. Wheat; Chemistry and utilization. Published by Technomic Publishing, AG. Missionsstrasse 44 CH-4055, Basel Switzerland.

Finney, P.L., 1983. Effect of germination on cereal and legume nutrient changes and food or feed value: A comprehensive review. In: Recent advances in phytochemistry, “Mobilization of reserves in germination”, eds. C Nozzolillo, P.J. Lea, F.A loewus, Plenum Press, New York. Volume 17: pp 229–305

Fuente, J.M., P.Perez de Ayala, A.Flores, M.J., Villamide, 1998. Effect of storage time and dietary enzyme on the metabolizable energy and digesta viscosity of barley-based diets in poultry. Poultry Science, 77:90–97.

Kallela, K., I. Saastamoinen, H. Saloniemi, 1991. Effect of germination on vomitoxin level in grain. Acta Vet. Scand., 32:483–489

Kaukovirta-Norja, A.R., P.K. Kotiranta, A-M. Aurola, P.O. Reinikainen, J.E. Oikku, S.V. Laakso, 1998. Influence of water processing on the composition, behaviour, and oxidizability of barley and malt lipids. J. Agric. Food Chem. 46:1556–1562

Knowler, K.L., G.P. Savage, D.S. Goulden, 1994. Influence of germination on the trypsin inhibitor activity of New Zealand grown chickpea cultivars. Proceedings of the Nutrition Society of New Zealand, pp. 109–115

Scott, T.A., F.G. Silversides, H.L. Classen, M.L. Swift, M.R. Bedford and J.W. Hall, 1998. A broiler chick bioassay for measuring the feeding value of wheat and barley in complete diets. Poultry Science, 77:449–455

Smith, D.B., 1972. The amino acid composition of barley grain protein during development and germination. J. Agric. Sci., Camb., 78:265–273

Pomeranz, Y., 1992. Biochemical, functional, and nutritive changes during storage. In: Storage of cereal grains and their products, 4th ED. (Editor: D.B. Saurer), American Assoc of Cereal Chemists, Inc., St. Paul, Minnesota. Pp 55–141.

Svihus, B., R.K. Newman, C.W. Newman, 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

/js