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Economic potential for improving the nutritional characteristics of feed grains*

John P. Brennan, Rajinder Pal Singh and Inder Pal Singh†

A comprehensive set of potential new feed grains for Australia was evaluated to help establish the options with the highest priorities for research. The cost-reducing impacts of the different options were analysed using a linear-programming model that determined the least-cost feed rations for the different livestock industries. Economic welfare analysis was then used to estimate the size and distribution of the benefits of research from the feed grains quality-improving research. The analysis revealed that there are only limited opportunities to improve the productivity and competitiveness of Australia's livestock industries by improving the nutritional characteristics of feed grains.

1. Introduction

A total of over 8 million tonnes of feed grains are used each year by the livestock industries in Australia (Hafi and Rodriguez 2000), at a value of over $1 billion per year. However, little attention has been paid to developing grain varieties that specifically address the needs of the different livestock industries.

Feed grains researchers have suggested a number of options for improving the nutritional composition of feed grains that would make them more valuable to the livestock industries that use them (GRDC 1995). The aim of most of these new options is to introduce specific characteristics through genetic means to improve the nutritional value of the grains targeting the needs of a particular livestock industry.

In the present paper, the objective is to determine the relative merits of a range of technologies designed to alter the nutritional characteristics of feed

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† John Brennan is Principal Research Scientist (Economics) with NSW Agriculture at the Wagga Wagga Agricultural Institute, Wagga Wagga; Rajinder Pal Singh is Economist with NSW Agriculture at the Yanco Agricultural Institute, Yanco; and Inder Pal Singh is Economist with Department of Land and Water Conservation, Sydney.

grains to assist in research priority setting. The potential benefits from each of the new feed grains, if they were to be successfully developed and produced commercially, are identified but the feasibility and cost of developing those new feed grains are not addressed. In the next section the economic approach to the analysis is outlined. The potential new feeds are then described and an explanation given of the methods and data used. The results of the analysis are then presented and discussed before some conclusions are drawn in the final section.

2. Economic approach to analysing feed grains improvement

The literature on measuring the benefits from research is vast. Alston *et al.* (1995) reviewed the broad scope of the literature and identified the wide range of options available and the methods that can be used. The concept of economic surplus provides the most common means of assessing both the size and distribution of research benefits.

Research that leads to genetic improvement of the nutritional characteristics of feed grains may allow livestock producers to obtain feed with particular desirable characteristics at a lower cost. The higher-quality (in terms of nutritional composition) feed grain has the effect of lowering the feed costs and therefore increasing the efficiency of production in the livestock sector. In the livestock sector the cost reduction translates into a downward shift in the supply curve of livestock products (whether meat, eggs or milk). The magnitude of the downward shift in the supply curve depends upon the relationship between the amount of feed used and the output of livestock product.

One of the key characteristics of feed grains is that they are substitutes for each other both in supply and in demand. In general, different feed grains are substitutes in supply because grain producers can switch between feed grains depending on the relative returns from the different grains. While the extent of the substitution varies in different regions, in almost all cases there are substitution possibilities in the feed grains sector. At the same time, livestock industries can readily substitute between grains in determining their feed rations. The precise mix of feed grains will depend on the prices of the various feed components.

This substitutability of feed grains in both supply and demand makes it difficult to have confidence in the distribution of gains between producers and consumers (e.g. see Piggot *et al.* 1995; Hill *et al.* 1996). Therefore, the focus of the present paper is on the aggregate potential benefits.

Our analysis was conducted at the level of livestock markets. Consumers are those who use the livestock products, whether they are food or fibre processors or the final consumers of the livestock products, while producers are the livestock producers (whether they are cattle feedlots, dairy producers, pig producers, etc.) and their input suppliers which includes the grain producers. Following Alston and Pardey (1996, p. 173), consumers in such a model represent everyone beyond the 'farm gate' and producers represent everyone up to the farm gate (in this case the livestock producers and those who supply them with inputs). The analysis does not allow determination of the benefits that flow to grain producers rather than livestock producers.

The changes in economic welfare from a parallel downward shift in the supply curve (see Alston *et al.* 1995, p. 210) can be expressed as follows:

$$\Delta_{cs} = -P_0Q_0Z(1 + 0.5Z\eta)$$

$$\Delta_{ps} = P_0Q_0(K - Z)(1 + 0.5Z\eta)$$

$$\Delta_{ts} = P_0Q_0K(1 + 0.5Z\eta)$$

where P_0, Q_0 and K are the initial equilibrium price of the livestock product such as meat, equilibrium quantity and the relative downward shift in the supply curve, respectively; Z is the relative reduction in the equilibrium price ($Z = K\epsilon/(\epsilon + \eta)$) due to the research, relative to its initial value; and ϵ and η are the absolute values of the price elasticity of supply and demand, respectively. K is the relative supply shift at the initial equilibrium price so that $K = k/P_0$, where k is the absolute cost reduction.

In the present study no attempt was made to measure the broader general equilibrium outcomes of changes in the quality of feed grains. Rather, the task was limited by assuming no change in livestock output and an offsetting change in feed availability when new feeds are introduced. This approach allows us to rank the alternative new feeds to assist in priority setting for research. It is possible that the rankings developed can be overturned by spillover effects in a general equilibrium setting. However, it is unlikely that any of the grains considered hold such a unique position, in terms of markedly different price responses, in another industry that general equilibrium effects would overturn our findings.

The steps in the analysis reported in the present paper were as follows. First, the potential new feed grains for inclusion in the analysis were identified. Second, the feed cost reduction for each livestock category as a result of the introduction of each of the new feed grains was estimated. Third, the supply shift in each livestock industry resulting from those feed cost reductions was calculated. Finally, the changes in economic surplus that resulted from the shifts in the supply curves for each of the livestock sectors were estimated.

3. Potential new feed grains for analysis

A comprehensive set of options for new feed types identified by scientists and industry specialists were evaluated to help establish the options with the highest priorities for research. The options evaluated are listed in Table 1. The options involving nutritional improvement are classified as follows:

- feeds involving a change in protein content;
- feeds involving a change in amino acid profile;
- feeds involving an improvement in feed digestibility and efficiency;
- feeds involving a reduction in anti-nutritional factors.

The nutritional composition of each of the new feeds was determined and was compared to the 'standard' or unimproved feed grain. In some of the options the nutritional quality of the grain can be changed without affecting its yield, and without any change in agronomic practices or the cost of

Table 1 Options evaluated for improving feed grains

Feeds involving change in protein content
High protein feed wheat
High protein barley
High protein oats
High protein lupins
Feeds involving change in amino acid profile
High lysine wheat
High methionine wheat
High threonine wheat
High sulphur amino-acid lupins
Feeds involving improvement in feed digestibility and efficiency
Hull-less barley
Low seed coat content barley
High seed coat digestibility barley
Naked oats
High oil barley
High oil oats
High oil sorghum
High oil maize
High oil lupins
Waxy sorghum
Low protein degradability lupins
Feeds involving reduction in anti-nutritional factors
Low arabinoxylan wheat
Low beta-glucan barley
Low beta-glucan oats
Low lignin oats
Low tannin sorghum
Low oligosaccharide lupins

production. In others, there were associated yield changes or changes in the level of inputs that would be needed to produce the nutritionally improved feed grain.

4. Methods and data

4.1 Livestock industries analysed

To account for differences between livestock industries in their nutritional requirements and feed demand, 12 different livestock categories were used in the analysis (Table 2). For convenience, the data and results reported in the present paper are aggregated into six broad industry groups: poultry broilers; poultry layers; pigs; dairy; feedlot cattle; and other livestock.

4.2 Model description and assumptions

The livestock industries are the end users of feed grains. Therefore, the economic value of nutritional improvements in different feed grains can be analysed by examining the extent to which they lead to reductions in the feed cost. In the livestock industries feed rations are formulated to provide the required nutrient intake at the least cost; nutritional sources are substituted on the basis of nutrient price. The feed industries minimise the cost of producing a given quantity of mixed feed by exploiting the substitutability and complementarity between feed ingredients. Least-cost linear-programming models are widely used in the industry for this purpose.

Table 2 Livestock industries analysed

Industry groups	Industries in analysis
Poultry broilers	Broilers – Starter Broilers – Finisher
Poultry layers	Layers – Pullet Layers/Breeders
Pigs	Weaners Growers/Finishers Breeders
Dairy	Dairy
Feedlot cattle	Feedlot cattle
Other	Live sheep exports Grazing ruminant supplement Other, including horses

A linear-programming model was developed for this study (Singh and Brennan 1998; Brennan *et al.* 1999) (see the appendix for a more detailed description of the model). The model is an aggregate (national-level) feed demand model with the same basic structure as the ABARE model (Hafi and Andrews 1997) from which it was derived except that it had no regional disaggregation. The features of the aggregate model (Brennan and Singh 2000) are:

- the feed ingredients, the nutritional composition, dietary requirements and livestock categories and numbers were the same as those in the ABARE regional model;
- the aggregate feed supply availability was the same as the total availability in the ABARE model;
- prices were the average of the local equivalent of the free on board (FOB) prices used in the ABARE model for its projections.

The model considers 43 feed ingredients and estimates the least-cost feed mix for the 12 livestock industries simultaneously (Hafi and Andrew 1997). The model determines the allocation of the feed ingredients across the 12 livestock industries simultaneously in such a way as to minimise the total feed costs of all industries. The feed ingredients included in the determination of the least-cost feed rations are detailed in the appendix.

The model identifies the combination of feeds that meets the nutritional requirements of each livestock category at the least cost. When a new feed is introduced with improved nutritional characteristics for some livestock categories the mix of feeds in the optimal solution changes, as does the total cost of the feed mix.

A key assumption underlying this model is that livestock numbers and the output from livestock industries are fixed and unresponsive to changes in the prices of the livestock products within the framework of the analysis. Each of the 12 livestock industries has pre-defined minimum and maximum nutritional requirements which the feed mix ration must provide. The model developed covers all feed ingredients of a balanced diet and identifies the cheapest source to meet these nutritional requirements. There are some upper limits on the levels of particular feed ingredients permitted in some feed rations because of digestibility limits. The model has been defined to take into account all of these nutritional limits.

With one exception, the availability of feed grains was limited to average (domestic) production less exports. The exception was soybean meal, the only feed grain imported into Australia in recent years. The cost of the imported meal was $70 per tonne above the domestic price used in the analysis (Hafi and Rodriguez 2000). For grains such as wheat and barley that have uses as both food and feed, the data used was based on estimates of the proportion sold as feed grain only.

To assess the impact of a new feed option on the reduction in the total cost of livestock feed, an arbitrary quantity of 100,000 tonnes of each new feed was made available in the market. To ensure that the nutritional benefits of the new grain were estimated, and not just an increase in the overall supply of grains, the supply of standard grain of the same type was reduced by the same amount. Thus, 100,000 tonnes of hull-less barley, for example, was introduced and the availability of standard barley was reduced by 100,000 tonnes.

In evaluating the new feed grains with improved nutritional characteristics, the price at which they could be made available was estimated. For the majority of the new feed grains being analysed the price used was the same as for the standard variety, because there would not need to be any adjustment for yield or inputs (Brennan and Singh 2000). For two feeds (naked oats and hull-less barley) breeders indicated that there would be yield consequences accompanying the nutritional change. For those two feeds the change in yield was used to adjust their price. The price used was the minimum price at which a farmer would supply the new grain, which was estimated as the price that would give the same gross returns as would be obtained by growing the standard variety (Brennan and Singh 2000). This approach relies on the assumption that grain producers will only produce the new feed if it provides at least as much return as the feed grain it replaces. The analysis aims to identify the price at which the new feed could be made available. Given the degree of substitution between feeds, this approach allows the potential benefits of the new feed grains to be identified.

For some new feed grains, in addition to the nutritional change there is an additional benefit through the saving in processing costs for the livestock industry. These feeds are hull-less barley, low seed coat content barley, high seed coat digestibility barley, and naked oats. Using each of these feeds means that the grain would not need to be processed before feeding to ruminants. The extent of the saving depends on the feed processing system used by the livestock industry. In the present analysis we assume a processing cost saving of $10 per tonne of the new feed used by the ruminants (A. Kaiser, NSW Agriculture, pers. comm.).

4.3 Data used in empirical analysis

Data on livestock numbers and feed rates for each of the 12 livestock industries was derived from Hafi and Rodriguez (2000) based on projections for the year 2004. The minimum nutritional requirements for the 12 livestock industries and details of nutritional components for each of the ingredients considered were supplied by Tony Edwards of ACE Livestock Consulting

Ltd after wide consultation and review by other animal researchers. The nutritional composition of the key feed grains and the proposed new feed grains are provided in Brennan and Singh (2000).

The feed rates reflect the total consumption of the selected feed ingredients (in kg/head) for the animals in that category in a production cycle. For example, broiler chickens are put on a 'starter' ration for a short period before they are moved to the 'finisher' ration. The total quantity of the feed diet consumed as a 'starter' is 1 kg/head and as a finisher is 4 kg/head. Pullets and layers go through similar phases, as do pig weaners and grower-finishers. For animals for which the feed rations are a supplement to pastures, the feed rate is the amount of feed ration in addition to the (unmeasured) quantity of intake from pastures.

The feed prices used in the model are those developed by Hafi and Rodriguez (2000) from their supply and demand projections (see Brennan and Singh 2000). The feeds included in the analysis account for the full feed ration for several livestock categories, but relate only to supplementary feed for the livestock categories of dairy, live sheep exports and grazing ruminant supplement. For those industries, the percentage of the total feed consumed that is included in this analysis was estimated from feed conversion efficiency ratios and livestock production data (Brennan and Singh 2000). Feed conversion efficiency is defined as the ratio of the feed used to the gain in live-weight (meat production), or to milk or egg production. It varied from 2.2 in dairy to 5.5 for other meat-producing ruminants.

To estimate consumers' and producers' shares of the total economic benefit, information on equilibrium quantities and equilibrium prices of products of different livestock categories was required. The data on the total production of livestock products (Brennan and Singh 2000) were estimated from Hafi and Rodriguez (2000). The data on Australian market prices of these products are shown in Table 3.[1]

The supply and demand elasticities used (Table 3) are medium-term (3–5 years), based on the markets for livestock products and are derived from a number of studies. Where data were not available for a given livestock sector they were extrapolated from available data for similar industries.

4.4 Baseline feed demand

The baseline data on livestock numbers and grain production used in the analysis were derived from projections for 2004 (Hafi and Rodriguez 2000). Rather than use recent averages we used those projections as the baseline

[1] Because the only available prices for the poultry sector were at the retail level, the interpretation of producer and consumer surplus for those industries is not consistent with those for other industries.

Table 3 Equilibrium quantities and prices of livestock products

Livestock type	Quantity	Price†	Elasticities‡	
			Supply	Demand
Poultry – Broilers	844 kt	$3.00/kg	2.00	0.50
Poultry – Layers	138 m. dozen	$1.20/doz.	2.00	0.50
Pigs	419 kt	$2.27/kg	1.00	1.50
Dairy	8708 m. litres	$0.29/L	1.50	0.50
Cattle – feedlot	448 kt	$1.75/kg	1.00	1.50
Others	2693 kt	$1.75/kg	2.00	1.50

† Livestock prices are average sale yard prices, expressed as liveweight equivalent, poultry prices are retail; milk prices are farm-gate prices.
‡ Price elasticities differ for the different component industries of Poultry, Pigs and Other groups. Those reported here are for the predominant component.
Source: Production data based on estimates derived from Hafi and Rodriguez (2000). Price data from Australian Bureau of Agricultural and Resource Economics, *Australian Commodities*; Elasticity estimates from G.R. Griffith (Pers. comm., January 1999).

data for our analysis as it is likely to be the best available estimate of future feed grains availability in the research planning period. As part of the validation of those projections, ABARE consulted widely with the industry throughout 1999 so that the baseline data had general industry acceptance before being used in this analysis. To the extent to which those projections prove to be inaccurate, then the assessment of the value of the different new feed grains may need to be revised. However, this was assumed as the best data available at the time of the analysis. The data for the average feed demand per head for each livestock category were also based on Hafi and Rodriguez's (2000) projections for 2004.

From the baseline run of the model, demand for feed grains by the livestock sector in 2004 was estimated to be 9.88 million tonnes, of which 7.39 million tonnes was comprised of grains and meals (Brennan and Singh 2000). The total cost of feed was estimated at $1817 million in that year, or an average of $183.77 per tonne. The feed grain demand by each livestock industry is shown in Figure 1. The industries that use the most feed grains are the dairy, feedlot cattle, broiler finishers and pig grower/finishers. The feedlot cattle sector uses the most feed. The feed quantities illustrated in Figure 1 are used as the baseline against which the new feed grains are measured.

In this analysis, no account was taken of the substitution between grains and pastures. The total intake of grains by each industry was taken as fixed. To the extent that some industries may substitute grain for pasture if feed grain costs can be reduced, the measured benefits will underestimate the true benefits. However, the extent of any such underestimation is likely to be small, given that for the dairy and grazing ruminant industries the changes in feed grain cost analysed in the present study are relatively small.

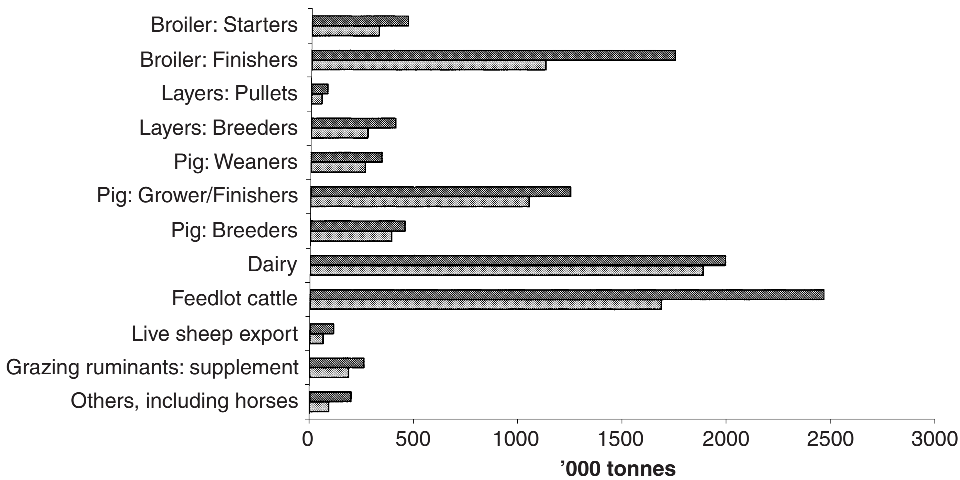

Figure 1 Baseline demand for feed grains and total feed mix in 2004. ■ Total feed mix; ■ Feed grains.

5. Aggregate analysis of improved feed grains

5.1 Estimating *k*, the supply shift

The estimated supply shift (and k, where k is the absolute cost reduction) that would result from the availability of each new feed was constructed as follows:

- the model was run initially without any of the new feeds available, to provide the baseline feed mix and feed cost for each livestock industry;
- for each of the new feeds, the model was run with 100,000 tonnes of that feed being made available, resulting in changes in the feed mix and feed cost for different industries;
- the reduction in feed cost for each livestock industry compared to the baseline run was determined;[2]
- the cost reduction for feed was converted to cost reduction for livestock product by dividing by the feed conversion efficiency for each industry.

This cost reduction was taken as the value of k for each industry. Once these k-values for each industry were determined the welfare analysis was run for all industries simultaneously. Note that for most feeds only one or two industries used the available supplies of the new feed so that most of the industries had a k-value of zero. The aggregate feed mix model was run separately for each of the 25 options for feeds of improved nutritional

[2] Note that the feed cost reductions resulting from each new feed varied for the different industries, depending on the degree to which they incorporated it into their least-cost feed mix.

composition. The detailed *k*-values for each industry from each of the options are shown in Table 4. In some cases, the uptake of the new feed by another industry can increase the cost of the feed available to an industry so that there are negative *k*-values for those industries. These are explained below.

5.2 Economic benefits from feeds with improved nutritional composition

Using the model and the data described previously, we derived estimates of the total annual economic benefit resulting from the introduction of each new feed (Table 5). The analysis shows a wide range of total benefits for different alternatives examined, ranging from $0 for several options to $4.86 million for high oil lupins. The new feeds that had virtually no benefits included high threonine wheat, waxy sorghum, low protein-degradability lupins and low tannin sorghum. Low beta-glucan oats has a negative, rather than a zero, impact because of the manner in which the analysis was carried out, whereby this new feed became available at the same time as a reduction in the availability of standard oats. When some industries used low beta-glucan oats with a small benefit it meant less standard oats was available to other industries and they were forced to purchase more expensive alternative feed. As a result, the overall feed costs were higher.

High oil lupins and naked oats are the two options with the highest level of economic benefits. Only a further seven feeds (high oil sorghum, high protein lupins, low arabinoxylan wheat, hull-less barley, high oil maize, low seed coat content barley and high seed coat digestibility barley) provide sufficient returns to allow them to be classified as better than low-return options. A detailed description of the findings of the analysis for each of the new feed grains analysed is provided in Brennan and Singh (2000).

As noted in Brennan *et al*. (1999) there are a number of instances in which the supply curve for a particular livestock industry shifts upwards rather than downwards with an improvement in feed nutritional quality. That occurs because:

- in some cases, the industries with the higher shadow prices on some feeds use up all available supplies of the preferred grain, forcing those putting less value on those feeds into more expensive alternatives;
- in other cases, the availability of a cheaper complementary feed means an increase in demand for a particular feed grain from other livestock industries, and hence a reduction in availability for some industries.

These effects can lead to a loss of welfare for some industries with the introduction of new feed grains.

Table 4 Supply shift in animal product with each new feed

	Broiler starter ($/t)	Broiler finisher ($/t)	Layer pullet ($/000doz)	Layer breeder ($/t)	Pig weaner ($/t)	Pig finisher ($/t)	Pig breeder ($/000l)	Dairy ($/t)	Feedlot cattle ($/t)	Live sheep export ($/t)	Grazing ruminants ($/t)	Others
High protein feed wheat	−18.50	6.73	0.00	−10.79	0.00	0.00	0.00	−0.01	0.58	0.00	−0.03	0.00
High protein barley	−18.50	6.78	1.34	−11.96	0.00	0.00	0.08	−0.02	0.77	0.00	−0.03	0.00
High protein oats	−16.92	6.72	1.85	−11.96	0.00	4.50	0.00	−0.10	0.00	0.00	−0.03	0.00
High protein lupins	−15.41	6.85	0.00	−11.96	0.00	7.05	0.00	0.00	0.00	0.00	0.00	0.00
High lysine wheat	0.00	2.08	0.00	−11.96	6.73	0.22	0.00	0.00	0.00	0.00	0.00	0.00
High methionine wheat	0.00	0.06	0.00	−0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
High threonine wheat	−18.50	6.73	0.00	−11.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
High sulphur amino-acid lupins	0.92	2.07	0.00	−11.96	0.00	−0.05	0.00	0.00	0.00	0.00	0.00	0.00
Hull-less barley	0.00	2.06	0.00	−11.96	0.00	0.00	0.00	−0.04	4.45	0.00	−0.03	0.00
Low seed coat content barley	−19.87	6.93	0.00	−11.96	0.00	1.29	0.09	−0.03	3.32	0.00	−0.03	0.00
High seed coat digestibility barley	−19.87	6.82	0.00	−11.96	0.00	1.02	0.00	−0.01	2.97	0.00	−0.03	0.00
Naked oats	1.18	8.38	0.00	0.00	0.00	−0.14	0.00	−0.13	0.00	0.00	−0.03	0.00
High oil barley	−18.50	6.73	0.00	−11.96	0.00	0.00	0.00	−0.02	2.89	0.00	−0.03	0.00
High oil oats	7.38	−0.59	0.00	0.00	0.00	5.67	0.00	−0.13	0.00	0.00	−0.03	0.00
High oil sorghum	3.00	1.68	0.00	−11.96	−1.71	−2.88	0.00	0.00	6.90	0.00	0.04	0.00
High oil maize	0.85	0.23	0.00	0.00	−1.91	−0.56	0.00	0.00	3.50	0.00	−0.02	0.00
High oil lupins	−18.50	6.73	0.00	−11.96	0.00	0.00	0.00	0.00	10.63	0.00	0.04	0.00
Waxy sorghum	−18.50	6.73	0.00	−11.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low protein degradability lupins	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low arabinoxylan wheat	−16.73	6.73	0.00	−6.04	0.00	4.96	0.00	−0.02	0.00	0.00	−0.03	0.00
Low beta-glucan barley	0.00	0.20	−6.70	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00
Low beta-glucan oats	1.93	−1.31	0.00	0.00	0.00	4.77	0.00	−0.10	0.00	0.00	−0.03	0.00
Low lignin oats	5.96	−0.95	0.03	0.00	0.00	5.51	0.00	−0.12	0.00	0.00	−0.03	0.00
Low tannin sorghum	−18.50	6.73	0.00	−11.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low oligosaccharide lupins	0.00	0.00	0.00	0.00	0.00	4.14	0.00	0.00	0.00	0.00	0.00	0.00

Table 5 Aggregate welfare effects across all livestock categories (Gross Annual Research Benefits)

	Total surplus ($m)
High protein feed wheat	0.28
High protein barley	0.18
High protein oats	0.46
High protein lupins	2.39
High lysine wheat	0.58
High methionine wheat	0.04
High threonine wheat	0.00
High sulphur amino-acid lupins	0.16
Hull-less barley	1.60
Low seed coat content barley	1.40
High seed coat digestibility barley	1.25
Naked oats	4.66
High oil barley	1.03
High oil oats	1.13
High oil sorghum	2.60
High oil maize	1.53
High oil lupins	4.86
Waxy sorghum	0.00
Low protein degradability lupins	0.00
Low arabinoxylan wheat	2.01
Low beta-glucan barley	0.18
Low beta-glucan oats	0.33
Low lignin oats	0.62
Low tannin sorghum	0.00
Low oligosaccharide lupins	1.05

The improvement of nutritional characteristics in the new feed options is generally aimed at addressing the specific needs of a particular livestock industry, so that there can be negative as well as positive effects on other industries. Although some industries gained due to substitution among feed ingredients, other industries experienced losses, while some other industries remained unaffected. Detailed welfare effects for each of the new feed options are shown in Brennan and Singh (2000).

6. Discussion of results

6.1 Impacts of potential new feed grains

The analysis suggested that there are opportunities to improve the productivity and competitiveness of Australia's livestock industries by improving the nutritional characteristics of some feed grains. The feeds found to provide the largest welfare benefits were high oil lupins and naked oats. The potential benefits from several other feeds are also sufficient to make them worthwhile research targets and these include high oil sorghum, high protein lupins, low arabinoxylan wheat, hull-less barley, high oil maize, low seed coat content barley, and high seed coat digestibility barley.

The analysis did not suggest that all of these options should be developed. Before industry priorities can be established consideration must be given to the expected research costs, probabilities of success and the time lags involved in developing these feeds by plant breeding. However, the analysis indicated that the returns when these feeds were developed could be sufficient to make them worth developing. Conversely, there are many technically feasible potential new feed grains that are not likely to produce sufficient benefits to make them a reasonable research target, given even moderate research costs. Of the 25 feeds with improved nutritional characteristics that were analysed, 10 had total welfare benefits of less than $0.3 million per year and a further six had benefits of less than $1.2 million per year. Given the expected research costs, probabilities of success and the time lags involved in developing these feeds by plant breeding, it is unlikely that these options will provide a satisfactory rate of return on the research funds required. Research funds used for these projects could well be applied to more productive projects.

In the analysis presented in the present paper, the supply of new feed grains was constrained to the same quantity of 100,000 tonnes to provide a consistent basis for examining the economic potential of each new feed grain. While that assumption provided a consistent basis for comparison, it does not accurately assess the potential that some feeds may have. For example, because of the different amounts demanded of different feeds, for some new feed grains the potential usage may be well in excess of 100,000 tonnes, while for others the potential is for lower quantities. Only when the full level of demand for each new feed, given its price and the location of production, had been determined could the full potential be analysed in more detail. The benefits per tonne were found to be very insensitive to the quantities involved within a range of 50,000–250,000 tonnes of the new feed grains.

6.2 Developing research priorities for feed grains

In assessing research priorities, the analysis undertaken indicated that there are some important issues that need to be considered. First, some options for nutritional improvement involve the development of alternatives for which there are ready substitutes. For example, the development of high lysine wheat has a relatively low benefit because synthetic lysine is readily available. New feed grains with nutritional characteristics for which there is no ready and low-cost substitute are likely to have higher research pay-offs.

Second, some improved feed grains result in important benefits for one industry but costs to other industries. It is of course likely that different industries will have different priorities and that the gains for some industries may only be obtained at the expense of other livestock industries.

Third, reliability of demand is clearly an important issue in ensuring that the new feed grains are made available. Where there are likely to be close substitutes, demand is likely to vary as prices of substitutes change. Therefore, the development of a feed grain for which the demand will fluctuate widely would be more risky than one for which there is no readily available substitute. Given the general level of substitutability between feed grains the examples where this is the case are relatively rare.

Our analysis identified the feeds likely to produce the highest returns for each industry (Table 6). It is apparent that there are considerable differences in the priorities for the different industries and the extent to which benefits are likely to flow to particular industries. For each industry up to ten options were identified in order of returns to that industry. Some industries had few profitable options.

For the broiler industry there were many options to choose from, while for layers no feeds with improved nutritional composition were identified. For dairy, as with layers, there were no nutritional improvements that would provide benefits. On the other hand, the feedlot cattle industry had a large number of options for improved nutritional composition. High oil sorghum was the only feed that provided benefits for the 'other livestock' category. Overall, the highest priorities were high oil lupins and naked oats.

Of the industries that benefit from the improvements, broilers and pigs are most often the beneficiaries from nutritional improvement. The poor results for dairy were at least partly because the options selected for analysis were focused on those likely to produce benefits for industries with complete rations specified, rather than the supplementary feeding common in the dairy industry. None of the new feed options analysed provided important benefits for the layer industry.

In this analysis, no account has been taken of the risk and uncertainty associated with the parameter estimates. Given the variability of prices and quantities and the assumptions required to incorporate the livestock rations, there is considerable uncertainty surrounding the findings of this analysis. In addition, the risk faced by farmers who produce a specialty feed grain can be significant if market conditions change between the time the decision to produce is made and the marketing of the grain. However, assessment of the risks involved is beyond the scope of the present analysis.

7. Conclusion

The use of modern scientific practices such as biotechnology in agriculture has made it possible to introduce a specific characteristic in a particular grain

Table 6 New feed grains producing the highest returns for particular industries

Broilers	Pigs	Feedlot	Other	Total
Naked oats (40%)	High protein lupins	High oil lupins	High oil sorghum	High oil lupins
Low arabinoxylan wheat	High oil oats	High oil sorghum		Naked oats (40%)
High protein oats	Low lignin oats	Hull-less barley (10%)		High oil sorghum
High oil sorghum	Low arabinoxylan wheat	High oil maize		High protein lupins
High S amino-acid lupins	Low beta-glucan oats	Low seed coat cont. barley		Low arabinoxylan wheat
High protein barley	High protein oats	High seed coat digest. barley		Hull-less barley (10%)
High lysine wheat	Low oligosaccharide lupins	High oil barley		High oil maize
High protein feed wheat	High lysine wheat	High protein barley		Low seed coat content barley
High threonine wheat	Low seed coat content barley	High protein feed wheat		High seed coat digestibility barley
High oil lupins	High seed coat digestibility barley			High oil oats

that can improve its efficiency as a livestock feed. Numerous options have been put forward as potential means of improving the nutritional composition of feed grains that would address the specific needs of different livestock industries. The objective of the present study was to contribute important information about the economic merit of a selection of proposals for feed grain improvement, and thereby aid in the allocation of the increasingly limited funds for research and development.

The relative benefits from alternative forms of improvement of nutrition of feed grains have been assessed through an analysis of the cost-reducing impacts of the different options. They have been analysed using a linear-programming model of least-cost feed rations for each of the different livestock industries. Economic welfare analysis was then used to estimate the size of the benefits from the feed grains quality-improving technology and an indication of their distribution.

When the economic benefits of the feeds were analysed a large number of the options were found to have small returns that would not justify a significant research input, given the likely level of research costs, the lags in development and the probabilities of research success. Only a small number of options were found to provide benefits sufficiently large as to merit further consideration. The options with the highest aggregate benefits were high oil lupins and naked oats, while others that provided important benefits included high oil sorghum, high protein lupins, low arabinoxylan wheat, hull-less barley, high oil maize, low seed coat content barley and high seed coat digestibility barley. These are the feeds for which priority should be given in research and development funding. However, none of those leading options for nutritional improvement were able to provide universal benefits to all the industries included in the analysis. As a result, different industries would rank the potential new feed grains in different ways, often markedly dissimilar.

The selection of which, if any, of the new feed grains to develop needs to be undertaken carefully. While the analysis in the present study enabled those feeds with economic potential to be identified, and provided important economic information to help establish research priorities for feed grains, further information and assessment is needed to ensure that scarce research and development funds are used to provide the best returns.

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Appendix: Description of linear programming model

Model description

A linear programming model (using What's Best® for Excel®) has been developed for the present study (Singh and Brennan 1998; Brennan *et al.* 1999). The model considers 43 feed ingredients (Table A.1) and estimates the least cost feed rations for the 12 livestock industries (Hafi and Andrews 1997). The model determines the allocation of the feed ingredients across the 12 livestock industries simultaneously in such a way as to minimise the total feed costs across all industries.

The nutritional composition of each of these feed ingredients was defined, identifying the major nutrients in each feed, the amino acid composition and balance, the mineral composition and other key nutrients (Table A.2). The detailed nutritional composition of each of the main feeds is shown in Brennan and Singh (2000).

The model specification involves constraints relating to three areas:

- *Minimum requirements for nutrients in each diet:* Each of the 12 livestock industries has pre-defined minimum nutritional requirements, which the feed mix ration should supply for the proper growth and maintenance of the livestock. The model developed covers all the feed ingredients and identifies the cheapest source to meet these nutritional requirements.

Table A.1 Feed ingredients included in analysis

Grains	
	Wheat,† barley,† oats,† maize,† sorghum,† triticale†
Pulses	
	Lupins,† peas,† faba beans,† mung beans
Grain by-products	
	Groats, mill-mix, rice pollard, oats hulls
Roughage	
	Cereal hay, lucerne hay
Protein meals	
	Canola meal,† soybean meal,† full fat soya, sunflower meal, cottonseed meal, meat meal, fish meal, blood meal
Dairy products	
	Skim milk, buttermilk, whey powder
Synthetics	
	Lysine–HCl, tryptosine, methionine, threonine, sodium bicarbonate, urea, dicalphos, choline chloride, vitamin/mineral premix
Other	
	Whole white cottonseed,† molasses, tallow-mixer, vegetable oil, salt, limestone, rock phosphate

†Also available for import in unlimited quantities at higher price. Source: Adapted from Hafi and Andrews (1997).

Table A.2 Nutrients specified in analysis

Major nutrients	Amino acids	Minerals	Other
Dry matter	Lysine	Ash	Salt
Digestible energy	Available lysine	Calcium	Linoleic acid
Net energy	Methionine	Total phosphorus	Interfat
Metabolisable energy	Methionine + cystine	Available phosphorus	
Protein	Threonine	Sodium	
Fat	Isoleucine	Potassium	
Fibre	Tryptophan	Chloride	
	Methionine/lysine	Magnesium	
	(Methionine + cystine)/lysine	Choline	
	Threonine/lysine		
	Isoleucine/lysine		
	Tryptophan/lysine		

A total of 58 constraints were defined relating to minimum and maximum requirements for nutrients.

- *Upper bounds on individual ingredients in the diet:* some minimum and maximum limits within which a particular feed ingredient must enter into some feed rations were defined on the basis of animal nutritional constraints. A total of 50 constraints were defined relating to the upper bounds of feed ingredients.

- *Limits on supply availability:* Two sources of supply availability of feed grains are allowed in the model: domestic production of feed grains, and feed grain imports. Domestic production of feed grains, pulses and meals is limited to average production less exports. Imports are available for those grains and meals (see Table A.1) in unlimited quantities, at a price of $70 per tonne above the domestic price used in the analysis to account for the costs of handling and transport to get the grain to Australia. For grains such as wheat and barley that have uses as both food and feed, the availability was based on estimates of the proportion sold as feed grain only. A total of 13 constraints were defined relating to domestic supply of feeds.