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The use of calcium hydroxide to improve the nutritional properties of whole cottonseed

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Certificate

I certify that the substance of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used have been acknowledged in this thesis.

[redacted]

Glen Walker
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Forward and Acknowledgments

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General Introduction

The continuing decline in the terms of trade of the Australian rural industries is maintaining pressure on agricultural industry to assess and modify the manner in which resources are applied to the production of food and fibre. Management practices in industries based on ruminant livestock are changing, particularly with an increase in the economic importance of grain based feedlots and the use of nutritional supplements for livestock on pasture in the meat, wool and dairy industries. These changes result from a need to use particular feed supplements as a means of manipulating and optimising production systems with respect to some limiting resource or factor. Such factors include periodic reductions in pasture quality or a window of opportunity for feeding to meet the production requirements of a particular market.

There is also greater acceptance by the livestock industries of the use of novel feed materials, generally the byproducts of the cropping and horticultural industries, as nutritional supplements for cattle and sheep on pasture. Modification of a novel feed material to change its physical and/or nutritional form is often required before it can be optimally incorporated into a livestock production system. Processing increases the cost of the material. There are therefore financial benefits to the livestock producer in using feed supplements that require little processing. Cottonseed is a significant feed resource for ruminant livestock production in eastern Australia. The irrigation districts of Queensland and New South Wales, currently growing all of Australia's cotton crop, produce on average of 583 kT of cottonseeds each year (1990 to 1996) as a byproduct of cotton lint production (ABARE 1996).

Cotton is an annual crop, harvested in autumn. Ginning separates the harvested crop into lint, fuzzy white cottonseeds and trash with both the trash and cottonseeds used as stockfeed. Fuzzy white cottonseed is so called because of the short pieces of lint (linters) that remain attached to the seed coat or hull following ginning. Cotton trash includes pieces of cotton leaf, stem, floral bracts and fruit wall that has been separated from the lint and seed. Some of the cottonseed is crushed to produce edible oil with cottonseed hulls and cottonseed meal as byproducts. Cottonseed hulls and cotton trash can be fed to ruminants as a source of roughage while cottonseed meal is an important source of protein for the livestock industry. Contractual arrangements for ownership of the seeds and trash vary between growers so that the seeds and or trash can be returned to the grower for sale or use, sold on to a third party or retained by the gin to offset the cost of ginning to the grower. Cottonseeds not utilised for crushing can therefore enter the stock feed market by three routes, grower, ex gin or through seed and grain traders.

Table 1. Cost of some concentrate feeds as of mid September 1997 when delivered to Moree, NSW, Australia.

Feed	[1]M/D MJ ME/kg	[1]Crude Protein %	[1]Ether Extract %	[2]Cost $/Tonne	Cost $/GJ ME
Barley	13.7	12	2	190	13.85
Wheat	13.8	12	2	195	14.15
Oats	11.4	10	6	180	15.75
Lupins	13.3	32	6	290	21.80
Cottonseed meal	10.9	42	1	250	22.95
Rumentec Lipid®	21.5	29	34	710	33.00
Whole cottonseed	14.5	22	20	180	12.40

1. NRC 1984 except data relating to Rumentec Lipid® which was provided by McGregor pers. comm. 1997.
2. Austgrain International pers. comm. 1997 and McInness Group pers. comm. 1997 except data relating to Rumentec Lipid® which was provided by McGregor pers. comm. 1997.

Whole cottonseeds are cheaper than cereal grains on an energy basis and contain more protein (Table 1). The ether extract is mostly triglyceride and the crude protein is predominantly true protein with twice the lysine content in protein compared to cereal grains (NRC 1989). Given that triglyceride is not metabolised in the rumen and that a portion of the dietary true protein will not be fermented in the rumen, whole cottonseeds should have a higher efficiency of use of both the protein and energy for maintenance or gain compared to cereal grains. While this suggests that their net value is much higher than is indicated by their current price there are reasons for their apparent undervaluation and therefore under utilisation by the livestock industry. These include:

i) the presence of toxins in the seed kernel;

ii) difficulty in handling and transporting the fuzzy white seeds;

iii) resistance by the animal to consume whole cottonseed; and

iv) a reduction in intake of the basal diet when used as a supplement, particularly in roughage fed livestock.

The toxins in whole cottonseed include two cyclic LCFA's, malvalic and sterculic acid, and a group of closely related polyphenolic compounds collectively termed gossypol (SCA 1990, Risco *et al.* 1992). They form part of the lipid fraction of the seed and are removed with the oil during its extraction. A processor may decide to return these compounds to the oil extracted fraction, i.e., the cottonseed meal, so that their concentration in the oil free meal can be higher than for whole cottonseed. The cyclic LCFA's may constitute 1.2 to 2.4% and gossypol from 0.5% to 1.45% of dry matter basis when measured in mixed batches of whole cottonseed sourced from the gin (Gurr and Harwood 1991 p.377, Sullivan *et al.* 1993, Cusack 1994). The gossypol content of some specific varieties may be as high as 1.6% (Cusack 1994).

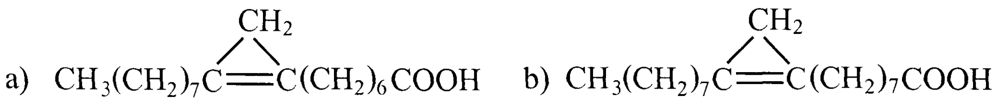

Figure 1 The structure of the cyclopropene long chain fatty acids, malvalic acid a), and sterculic acid b) (Gunstone and Herlsöff 1992 p.56 and p.87).

Malvalic and sterculic acids are termed cyclic LCFA's as they possess a cyclopropene ring (figures 1a and b) (Gunstone and Herlsöff 1992). The cyclopropene ring structure binds to at least one type of desaturase enzyme in animals and yeasts preventing the formation of oleic acid from stearic acid (Gurr and Harwood 1991 p.377). In sufficient quantity they can poison animals and yeasts by increasing the amount of stearate present in their membrane lipids and altering the structure and function of the membrane. Rats consuming sterculic acid at 5% of their digestible energy intake die within a few weeks while female rats lose their ability to reproduce at 2% of energy intake (Gurr and Harwood 1991 p.377). The capacity of these fatty acids to disrupt the desaturation of stearic acid is reduced following their passage through the rumen suggesting that rumen bacteria may be able to hydrogenate the double bond of the cyclopropene ring (Coppock *et al.* 1987). Ruminant's may therefore be more tolerant to the levels of the sterculic and malvalic acid found in both whole cottonseed and cottonseed meal.

Gossypol is a membrane active compound (Risco *et al.* 1992). In animals it causes haemolysis, edema in lungs and body cavities, damages heart muscle, reduces sperm production and sperm motility and reduces cellular immunity, depressing numbers of leukocytes, lymphocytes and eosinophils (Patten 1985, Sotelo *et al.* 1982, Risco *et al.* 1992, Cusack 1994). Gossypol poisoning can therefore result in male infertility, anaemia, increased susceptibility to heat stress and parasitism and death due to heart failure (Patten 1985, Sotelo *et al.* 1982, Risco *et al.* 1992). It is however largely inactivated in the rumen where it binds with Fe^{2+}, Ca^{2+} and the epsilon amino group of lysine (Reiser and Fu 1962). The content of free gossypol in whole cottonseed then appears to be less important as a factor in predicting the incidence of gossypol poisoning in ruminants than diet (Coppock *et al.* 1987).

The possibility of poisoning, either from the cyclic LCFA's or gossypol, must be considered when feeding whole cottonseed to ruminants, particularly when fed to breeding and preruminant livestock. Recommended maximum levels of intake of whole cottonseed for ruminants have not been established. There is however a considerable body of research that indicates that whole cottonseed does not cause poisoning in non breeding sheep and cattle when included up to 50% of intake in nutritionally balanced rations and for periods up to 114 days (Coppock *et al.* 1987, Keele *et al.* 1989, Pena *et al.* 1986, Arieli 1992, Smith *et al.* 1993). It seems prudent therefore to avoid feeding whole cottonseed to preruminant and breeding animals and animals fed any diet that may have a low content of calcium or iron or perturb normal rumen function. The likelihood of poisoning in animals with a normally functioning rumen and fed a balanced diet appears to be small and should not prevent greater utilisation of whole cottonseed by the livestock industry.

The second reason given for the apparent undervaluation of whole cottonseed by the livestock industry was the comparative difficulty in handling, transporting and storing whole cottonseed compared to other concentrate feeds. This is caused by the tendency of the linters both to bind the seeds together and to produce a low bulk density (Table 2). The tendency for the seeds to bind together prevents the use of grain augers and silos. Their low bulk density increases the volume of space required for their transport and storage when compared to cereal grains. The handling characteristics and storage requirements of whole cottonseed are then closer to that of loose roughages and their cost of storage, handling and transportation is higher than for their equivalent in protein or energy from other concentrate feeds.

Table 2. Bulk density of some grains and whole cottonseed.

	[1]Bulk Density (kg/m^3)
Wheat	750
Barley	620
Oats	450
Whole cottonseed	285

1. Agfacts (1989) except for whole cottonseed which was reported by Sullivan *et al.* (1993).

Removal of the linters will overcome these problems. It is performed commercially using HCl gas and heat but this process is uneconomic for the production of a stockfeed. An alternate processing method is extrusion. Extruding whole cottonseed separates and compacts the linters so that the extruded full fat product has a higher bulk density (Pena *et al.* 1986) and lower handling, transport and storage costs per unit weight. Extruded whole cottonseed is not commercially available in Australia. This suggests that the financial benefits to producing a processed whole cottonseed product currently exceed the costs of processing.

The main impediment to greater utilisation of whole cottonseed by the livestock industry may then relate to the problems of low intake of the seed and reduced intake of the basal diet in supplemented livestock. The resistance by the animal to consume whole cottonseeds is attributed to the presence of the linters and hull which appear to make the feed unpalatable (Bird and Dicko 1987). Cracking the hull to expose the seed kernel may sufficiently change sensory cues to overcome this problem given that animal's readily consume cottonseed meal. A reduction in intake of the basal ration appears to be caused by a reduction in the rate of digestion of plant fibre in the rumen of animals supplemented with whole cottonseed. This is attributed to its triglyceride content

(Moore *et al.* 1986, Bird and Dicko 1987, Coppock *et al.* 1985, Coppock *et al.* 1987, Smith *et al.* 1993). The component of a triglyceride that interferes with the digestion of plant fibre is the long chain fatty acid released upon hydrolysis of triglyceride in the rumen (Galbraith *et al.* 1971, Galbraith and Miller 1973a, Maczulak *et al.* 1981). Free long chain fatty acid is toxic to certain groups of microorganisms including the bacteria responsible for the digestion of plant fibre in the rumen (Galbraith *et al.* 1971, Galbraith and Miller 1973a, Maczulak *et al.* 1981).

There are indusexperiment processes that can be applied to feed materials that reduce the exposure of rumen microorganisms to triglyceride and/or LCFA. This enables more triglyceride or LCFA to be incorporated into a diet before their effects on digestion of plant fibre become apparent. One product available in Australia, Rumentec Protected Lipid®, encapsulates the triglyceride in a matrix of plant protein that has been treated formaldehyde (Ashes *et al.* 1992, Goering *et al.* 1977). The matrix resists degradation in the rumen so that rumen microorganisms are not exposed to the triglyceride. The cost of processing however makes it expensive compared to other energy supplements (Table 1).

Ruminant's have however adapted to consume the LCFA found naturally in their diet up to 3% of their dry matter intake (Van Soest 1982). Natural processes exist in the rumen that reduce the toxicity of LCFA. One of these processes is the precipitation of LCFA with calcium to form calcium soap (Palmquist *et al.* 1986). Calcium soap is not toxic to rumen microorganisms and the LCFA becomes available for absorption by the animal upon its acid hydrolysis in the abomasum (Palmquist 1984). Augmentation of this natural process by increasing the availability of calcium ion in the rumen may allow an animal to increase its intake of LCFA without affecting the digestion of plant fibre. This would be beneficial in that it would reduce processing costs and it has general application to feeds with a high LCFA content. Calcium hydroxide (Offer and Offer 1992) and calcium chloride (Palmquist *et al.* 1986), compounds that provide calcium in a rumen soluble form, have been added to diets with a high LCFA content to augment the rate of formation of calcium soap in the rumen. This approach, both simple and cheap to implement, prevented a reduction in the rate of digestion of plant fibre in the rumen in the presence of LCFA in both studies. Adding rumen soluble calcium to the diet of animals supplemented with cottonseed oil or whole cottonseed may also prevent a reduction in the rate of digestion of plant fibre in the rumen by removing long chain fatty acid arising from these supplements as insoluble calcium soaps.

A program of research was commenced to determine a source and level of inclusion of rumen soluble calcium that will maintain the rate of digestion of plant fibre and feed intake in animals fed a roughage (oaten chaff) based diet and supplemented with cottonseed oil or whole cottonseed. Initial studies were directed at establishing the relative importance of cottonseed oil and soluble calcium as factors affecting the digestion of plant fibre in the rumen and feed intake in sheep. Further studies were directed at determining changes in lean and fatty tissue accretion in response to feeding calcium hydroxide, cottonseed oil and cottonseed protein. Final studies were directed at determining the production and flow of microbial cells from the rumen in response to supplementing sheep with calcium hydroxide and cottonseed oil.