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Feedlot grain processing review

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Abstract

A. Review of technologies not used in Australia

A comprehensive review was undertaken to evaluate potential new grain processing technologies that could be adapted for use in the Australian feedlot industry. Although there have been improvements in grain processing over the last decade, there is still a continued need to refine systems and identify potential methods and technologies that can improve animal performance, efficiency and cost of grain processing. A number of new technologies and approaches were identified that may have the potential to be used in the Australian feedlot industry. These include i) computerised control systems and the use of in-line NIRS/NIR, for automatic assessment and segregation of grain, control of wetting augers and feedback on particle size and distribution; ii) investigation of NIR for rapid assessment of faecal starch; iii) use of the Flake Colour Index System (FCIS) to evaluate starch availability in steam-flaked grains, iv) heated water to improve imbibition in tempering; v) ozone treatment of steeping water and its influence on imbibition rate; vi) comparative studies to assess the impact of different particle sizes, grains and dietary grain inclusions; vii) studies on high moisture corn, or fermented sorghum diets compared with dry rolling, tempered rolling and steam flaking on cattle performance; viii) exploration of the use of a modified Pork CRC hand-held sieve for feedlot cattle to determine grain particle size distribution; ix) technologies to reduce the energy cost of processing (such as boiler efficiency, fuel alternatives; and agents to reduce milling friction).

B. Best Practice Grain Processing Manual

A “Best Practice Grain Processing Manual” was compiled to cover i) type of grains used in the feedlot industry; ii) grain receival, handling and storage; iii) grain digestion in feedlot cattle; iv) grain processing methods (dry rolling, sodium hydroxide treatment, tempering, steam flaking, high moisture harvesting and storage, reconstitution and fermentation); v) processing costs and efficiency; vi) occupational health and safety and vii) comparative performance studies. A selected number of feedlot operators were interviewed and feedlot consultants were also consulted to ensure that the content of the manual is user-friendly, informative and easily understandable with accompanying diagrams and photographs of equipment, machinery and processed grains.

C. Research gap and opportunities

The knowledge gaps and opportunities in grain processing methods were identified. These included i) greater use of NIR technologies; such as hand-held device for rapid assessment of faecal starch on wet faeces; for computerised monitoring of water addition during tempering; for measuring the distribution of particle size for dry rolling; for direct measure of starch availability for steam flaked grains; and in-line NIR technology to monitor grain quality, ii) feeding studies (e.g. high moisture corn or fermented sorghum diets *vs.* conventional grain processing methods, and impacts of different grains, quantity and particle sizes on cattle performance, iii) processing methods, targets and milling efficiency, wetting auger design and operation (RPM, residence time, capacity), interactions between grain species, morphology and site of digestion and their ultimate impact on feed conversion ratio (FCR), and surfactants and emulsifiers to enhance moisture uptake in tempering.

Executive summary

This project aimed to review the technologies that are not currently practiced in the Australian feedlot industry, and how these technologies can complement current technologies and ultimately their effects on cattle performance. A best practice manual was also developed to be used by feedlot operators as a guideline on grain processing. The research gaps in grain processing and feeding practices were explored to identify the opportunities that can enhance the efficiency of grain processing methods that are cost-effective and can improve animal performance.

A. Review of grain processing technologies not used in Australia

A comprehensive review was undertaken to evaluate potential new grain processing technologies that could be adapted for use in the Australian feedlot industry. Although there have been improvements in grain processing over the last decade, there is still a continued need to refine systems and identify potential methods and technologies that can improve animal performance, efficiency and cost of grain processing. This review identified the following processing methods and technologies that warrant further investigation:

- Computerised control systems and the use of in-line NIR, to present clean, consistent grain at the commencement of processing and during processing, and to regulate processing systems based on end-product specification feedback.
    - Automatic assessment and segregation of grain at arrival based on starch availability or metabolisable energy
    - Automation of wetting augers to improve water addition consistency and distribution
    - Processed grain feedback in the form of particle size and distribution or flake density
- Further investigation of NIR for rapid assessment of faecal starch that can be used in commercial feedlots.
- Use of the Flake Colour Index System (FCIS) to evaluate starch availability in steam-flaked grains.
- Heated water to improve imbibition in tempering.
- Ozone treatment of steeping water and its influence on imbibition rate.
- Feeding trials on animal production with different processing methods, particle sizes or bulk densities, different grains and at varying grain inclusions to reflect commercial practices.
- Feeding studies to explore the impact of high moisture corn or fermented sorghum diets on cattle performance compared with conventional grain processing methods (e.g. dry rolling, tempered rolling and steam flaking).
- Exploring the suitability of a modified Pork CRC hand-held sieve to determine grain particle size distribution after milling.
    - Assessing technologies that can reduce the energy cost of processing such as boiler efficiency (design and maintenance), fuel alternatives, and agents to reduce milling friction and/or increase throughput

B. Best Practice Grain Processing Manual

A “Best Practice Grain Processing Manual” was developed that can be used by feedlot operators as a guideline to improve the efficiency of grain processing of different types of grains with a list of equipment, machinery and potential risks and benefits. This manual aimed to cover the following:

1. Grain types used in the Australian feedlot industry
2. Grain receival, handling and storage
3. Grain digestion in feedlot cattle
4. Grain processing methods
    - Dry rolling
    - Sodium hydroxide treatment
    - Tempering
    - Steam flaking
    - High moisture harvest and storage
    - Reconstitution
    - Fermentation
5. Determining processing costs and efficiency
6. Occupational health and safety
7. Comparative performance

The project aimed to prepare this manual according to the approved outlines by MLA to facilitate the delivery of ALFA Nutrition and Milling workshops. The project team consulted with feedlot operators and feedlot consultants to ensure that the content of this manual is user friendly, informative and easily understandable with accompanying diagrams and photographs of equipment, machinery and processed grains. The descriptions, methodology and operating procedures of these methods were detailed. The suitability of different methods for various types of grains, their costs and effects on cattle performance were comprehensively reviewed. The potential risks and benefits of each method were also discussed, to assist feedlot operators to make an informed decision on the cost-effectiveness and practical suitability of the processing method that suits their operation. Photographs of under- and over-processed and optimum processed grains were provided, to allow feedlot operators to visually evaluate the efficiency of processing methods.

A number of grain processing research gaps and opportunities were identified that have potential applications in monitoring the efficiency of processing methods and feeding practices. These included:

NIR technologies

- ✓ Development of NIR (hand-held device) for rapid assessment of faecal starch on wet faeces
- ✓ Research into the use of NIR and computerised control of water addition during the tempering of grains.
- ✓ NIR for measuring the particle size distribution of grains for dry rolling processing methods.
- ✓ Development of an accurate direct method to test starch availability (taken below the rolls) in steam flaked grains.

- ✓ Further research into the viability and use of in-line NIR technology to improve grain processing quality with the aim to improve animal performance. This includes in-line NIR measurements that may link directly to systems that automatically make adjustments.

Feeding studies

- ✓ Performance of cattle fed high moisture corn or fermented sorghum diets, compared with the conventional grain processing methods such as dry rolling, tempered rolling and steam flaking.
- ✓ Comparative studies - feeding trials to explore animal performance with different processing methods. This includes the effects of different grain processing methods, types and amount of grains fed, particle sizes and bulk densities, and the interactions between these.

Processing methods, targets and milling efficiency

- ✓ Research into better understanding the optimum processing targets for tempered rolled grain.
- ✓ Further exploration of wetting auger design and operation (RPM, residence time, capacity) for different grains.
- ✓ Research into evaluating the effects of processing method, particle size, interactions between grain species, morphology and site of digestion on Feed Conversion Ratio (FCR). This data and information could be developed into a spreadsheet that can be used by feedlot operators to estimate the cost of gain. For similar growth rates (and therefore effects on output and inventory cost) the main driver of profitability is FCR and ultimately the cost of gain.
- ✓ There is a lack of robust comparative data on surfactants and emulsifiers aimed at increasing moisture uptake in tempering, and putative effects on increasing mill throughput and prolonging roll life.

Abbreviations

ADF	Acid detergent fibre
ADG	Average daily gain
CGC	Coarse ground corn
CRC	Cooperative research centre
CV	Coefficient of variation
CP	Crude protein
DM	Dry matter
ESS	Enzyme susceptible starch
FCIS	Flake colour index system
FCR	Feed conversion ratio
FGC	Fine ground corn
PGLP	Premium grains for livestock program
HMC	High moisture corn
MGC	Medium ground corn
NIR	Near infrared reflectance (spectroscopy implied)
NIRS	Near infrared reflectance spectroscopy
NCV	Net calorific values
PLC	Programmable linear control
PEM	Polioencephalomalacia
RPM	Revolutions per minute
SA	Starch availability
SFC	Steam flaked corn
SRC	Steam-rolled corn
UV	Ultraviolet

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1 Background

1.1 Review of grain processing technologies not currently utilised in the Australian Feedlot Industry

Effective processing of grain is an integral part of a feedlot enterprise. Feed cost and utilisation are the most important factors driving cost of gain and operation efficiency. Grains are used in finishing diets to improve the performance and efficiency of feedlot cattle by increasing the energy density of diets over maintenance energy requirements. Most of the energy in grains is in the form of starch. As cost of energy inputs (electricity, fuel, labour) increase, there has been interest in increasing the efficiency of grain processing. New technologies in the field of grain processing are being developed or have been utilised in the pig, poultry and flour milling industries. These processes, not commonly used by feedlot operators, need to be reviewed to assess their potential application in the Australian feedlot industry.

This final report delivers a comprehensive review to identify grain processing technologies not currently utilised (available both in Australia and internationally) and assesses their potential application in the Australian feedlot industry.

1.2 Produce a Print-Ready "Best Practice Manual" for grain processing and identify knowledge gaps or opportunities for future research on grain processing in the Australian feedlot industry

The most common grain processing methods for ruminants are dry processing, high moisture harvest and storage, fermentation, reconstitution, and steam flaking. The primary aim of this project was to produce a "Best Practice Manual" on grain processing that can be used by feedlot operators. This manual can be used for training and investigating requirements for upgrading grain processing system. The manual covers methods used for grain processing and their advantages and limitations, current grain processing practices, grain chemistry and digestion, quality control, standard procedures for receival and storage of grains, maintenance of equipment and occupational health and safety issues in commercial feedlot operations.

Feedlot operations rely on feedlot staff to operate the chosen grain processing method for feeding their cattle. Therefore, it is important that they are skilled and trained and understand the principles of feedlot nutrition and animal performance. The feedlot operators should be equipped with appropriate cattle feeding practices and troubleshooting methods to have a good understanding of grain chemistry, processing and digestion to minimise the losses and improve long-term profitability of the feedlot operation. This manual aims to cover the grain processing methods that are currently practiced in Australia and provide guidelines on best management practices to ensure that the grain is processed efficiently. This manual can be complemented by regular training through workshops and field days.

This report also highlighted the knowledge gap in grain processing technologies and identified the research projects required to address deficiencies in current and emerging grain processing methods.

2 Project objectives

2.1 Review of grain processing technologies not currently utilised in the Australian Feedlot Industry

Efficient and cost-effective processing of grain is integral to the success of the Australian feedlot industry. Whilst there have been significant investments in milling technologies across the feedlot industry over the past 15-20 years, there is still a continued need to refine systems and identify potential methods and technologies that can improve animal performance, efficiency and cost of grain processing.

The objective of this project was to deliver a comprehensive review to identify grain processing technologies not currently utilised (available both in Australia and internationally), to assess their potential application in the Australian feedlot industry, and to identify their cost and benefits for animal health, performance and carcase characteristics.

2.2 Produce a Print-Ready "Best Practice Manual" for Grain Processing

2.2.1 Collate a Best Practice Management Guide for grain processing for feedlot staff to complement the ALFA milling and nutrition workshops conducted annually.

The terms of reference (ToR) from MLA require the project to produce a Print-Ready "Best Practice Manual" for grain processing that can complement the ALFA nutrition and milling workshops. The project will deliver against the objectives as specified in the ToR. A comprehensive user-friendly manual was prepared to provide the required information about each method. This included the description of each method, suitability of each method for different types of grains with pictures and diagrams, required equipment and machinery, and strengths and limitations of each method. The manual covers:

a. Objectives of grain processing
b. Basic grain chemistry (Wheat, Barley, Sorghum, Corn, Triticale, Oats)
c. Basic grain digestion (Digestive Anatomy & Physiology)
d. Receival and storage of grains (Standards and testing)
e. Grain processing techniques (Early Harvesting, High Moisture Grains, Reconstitution, Dry-Rolling, Tempering, and Steam-Flaking – basic process and equipment required)
f. Comparative animal performance between techniques (feed intake and carcase response)
g. Quality control in grain processing (Flake Density, Dry Matter Testing, Faecal Starch)
h. Metabolic disorders (Degree of processing, Dry Matter consistency)
i. Measuring energy efficiency of grain processing
j. Maintenance (Roll Design, Roll Changes, Maintenance for various processing techniques)
k. Boiler Operation and Technology
l. Occupational Health and Safety
m. Trouble-shooting common problems

2.3 Identify knowledge gaps or opportunities for future research on grain processing in the Australian feedlot industry

2.3.1 Knowledge gaps in grain processing technology

This milestone report described the identified knowledge gaps and opportunities for further research on grain processing in the Australian feedlot industry. This includes research projects that need to be conducted to address deficiencies in current grain processing methods and potential technologies and equipment that can assist in improving overall efficiencies of grain processing methods.

3 Methodology

3.1 Grain processing methods currently used in the Australian feedlot industry

A review of grain processing methods currently utilised by the Australian feedlot industry was compiled. This review was based on the project team's industry knowledge, published literature and from discussion with industry experts. A questionnaire was compiled to assist individual project team members address questions such as processing equipment, processing methods and quality assurance. A review of current grain processing methods and grain handling procedures was required to identify new technologies that may be suitable and adaptable to the feedlot industry. Also, the reasons for grain processing and why different processes are used for different animal species was outlined to provide background for consideration of whether processing techniques utilised in other industries, such as the flour milling or pig and poultry industries, are relevant to the Australian feedlot industry

3.2 Review of new technologies

A number of different industries, both in Australia and internationally, were identified that might provide information on new technologies suitable for the Australian feedlot industry.

These included:

- Feedlot industry in the USA (equipment manufacturers and industry experts)
- Flour milling
- Wet milling and the ethanol industry
- Mono-gastric industries

Other technologies with potential application in feedlot grain processing were identified:

- Reducing agents
- Grain imbibition
- Microwave technology
- Boiler technology
- Wetting auger technology

- Technologies to reduce shrink and improve fermentation (fermented and high moisture grains)
- NIRS technologies and in-line NIR (at grain receival, pre-processing and processing functions)

The individual areas were allocated to the project team members and an extensive review was compiled by searching the literature and also approaching relevant industries and seeking their views on different grain processing technologies that may be applicable in feedlot operations.

All technologies that were identified with potential to be used in the Australian feedlot industry were evaluated in terms of their cost and benefit for animal health, performance and carcase characteristics.

3.3 Best Practice Grain Processing Manual

The outline of the "Best Practice Manual" was prepared by the project team in conjunction with MLA Project Manager Dr. Joseph McMeniman. The approved outline aimed to cover the following:

1. Grain types used in the Australian feedlot industry
2. Grain receival, handling and storage
3. Grain digestion in feedlot cattle
4. Grain processing methods
    - Dry Rolling
    - Sodium Hydroxide Treatment
    - Tempering
    - Steam Flaking
    - High Moisture Grains
    - Reconstitution
    - Fermentation
5. Determining processing costs and efficiency
6. Occupational health and safety
7. Comparative performance

The processing methods and their suitability for different types of grains were comprehensively reviewed. This included the description of each method, required equipment, processing procedures, strengths and limitations of each processing method and its suitability for different grain species. The structure, chemistry, digestion and metabolism of grain following various processing methods were discussed. The associations between different processing methods and grain species, and performance of cattle (e.g. ADG, feed efficiency, etc.) were discussed where the information was available. In some sections, the provided information was limited to some grains, because of lack of information on alternative grains. These limitations were outlined as knowledge gaps in current grain processing methods.

We attempted to ensure that the outline and content of the prepared manual were consistent with the objectives of ALFA Nutrition and Milling workshops. This facilitates the use of the manual as a source of information on grain processing for all feedlots across the country and ensures consistency in delivery of evidenced-based information to feedlot operators.

At the completion of this project, the final draft of the manual will be provided to a selected number of feedlot operators and consultants to obtain their feedback. This will help the project team to ensure that the content and format of the manual make it readily accessible to the target audience.

3.4 Identify research gaps in grain processing technology

The collated information on current and new technologies was used to identify the knowledge gaps in grain processing and potential opportunities to cost-effectively improve the efficiency of current technologies. The knowledge gaps identified include: research into the application of NIRs/NIR for measuring the efficiency of grain processing methods; evaluating the performance of grain-fed cattle using different technologies; and milling efficiencies.

4 Results

4.1 Background to grain processing and animal species differences

The objectives of grain processing and why different processes are used for different animal species are outlined. The review considers the applicability of processing techniques used in other industries, such as the flour milling or pig and poultry industries, to the Australian feedlot industry. Differences in cereal grain structure are important considerations for determining the benefit when grain is processed by different methods.

4.1.1 Cereal grain structure

The general structure of cereal grains is shown in Figure 1. The starchy endosperm, comprising the majority (≈ 60-95%) of cereal grain, is surrounded by the aleurone layer and the outer pericarp, or husk/hull. The pericarp is composed largely of plant fibrous material, whereas the endosperm contains cells filled with starch granules, protein bodies and protein matrix. Light microscopy of a cross-section of a barley grain shows the structural arrangement of the endosperm (Figure 2). The endosperm cell walls vary widely between grain species, generally being thicker for barley than wheat, which has thicker cell walls than sorghum or rice. There are also large differences between grain species in the size of starch granules. Starch granules tend to be larger in barley than wheat, which has a combination of large and small granules. Oats and rice have smaller starch granules than wheat or sorghum. The starch granules in sorghum comprise those in the floury layer, which are generally round and loosely packed and those in the corneous layer, which are tightly packed and have flattened sides. Starch granules in the corneous section of sorghum grain are completely surrounded by a protein matrix and embedded protein bodies (Figure 3). The matrix is composed of prolamin. Prolamin is a major storage protein in all cereal grains, except oats and rice. The prolamins have different names depending on the grain from which they are derived (Bewley and Black, 1994). For example, the prolamins of wheat, barley, corn and sorghum are known as gliadin, hordein, zein and kafirin, respectively. Prolamin is hydrophobic (repels water), non-soluble and is primarily associated with starch. Prolamin content is generally expressed as a proportion of the grain starch content. The prolamin content of wheat and barley is low (3%), high in corn (7%) and very high in sorghum (>10%). High prolamin content grains have greater interaction between the prolamin and the starch which lowers starch digestibility.

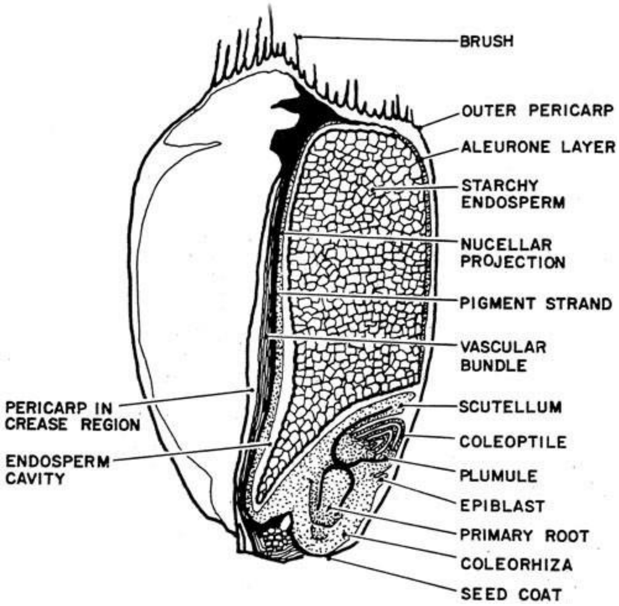

Figure 1. Diagram of the physical structure of cereal grains. (Source: http://www.abchansenafrica.co.za/silos/why_do_we_dry_grain.php).

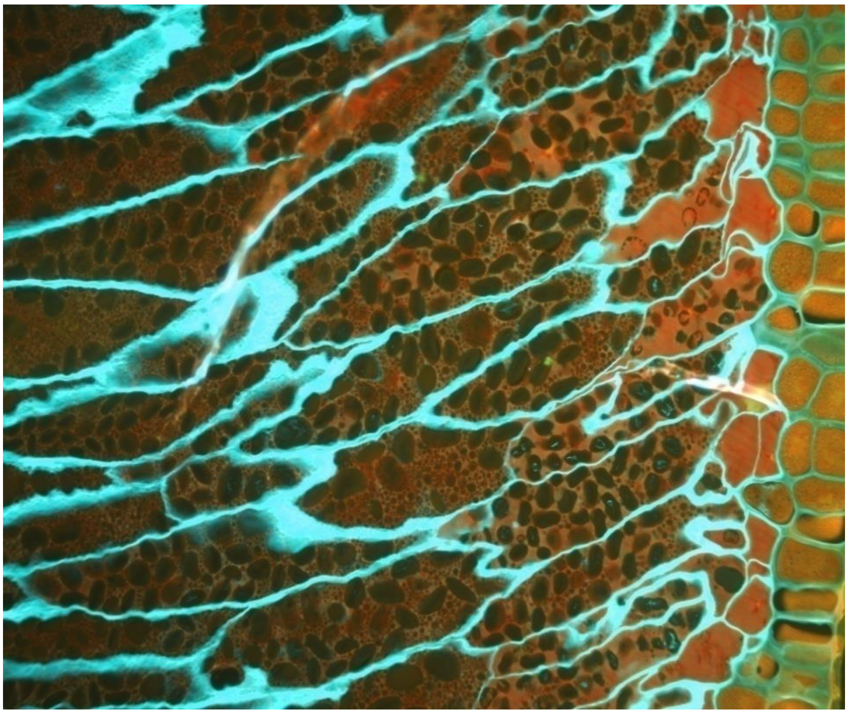

Figure 2. A light microscope cross section of a barley grain showing aleurone cells on the right of the picture, endosperm cells distinguished by the blue cell wall structures, individual starch granules as dark images within the cells and background orange coloured protein matrix (Source: Black, 2008).

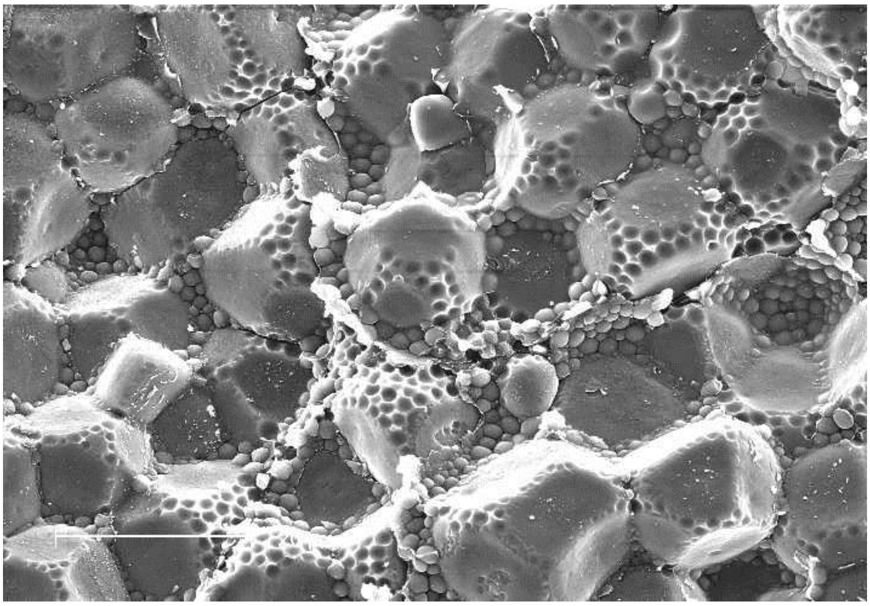

Figure 3. An electron micrograph of starch granules in the corneous endosperm of sorghum showing the protein matrix with embedded protein bodies surrounding each granule. Indentations from the protein bodies can be seen on the starch granules (Source: Courtesy of Ian Godwin, University of Queensland).

Starch is composed of chains of glucose units joined by α-(1–4) bonds. Starch is classified by the presence of branches in the glucose chains. Chains without branches are known as amylose, those with branches, amylopectins. (Figures 4 and 5). Amylose chains contain from 500 to 2,000 glucose units, which roll into a tight 'ball'. Amylopectin has an open structure with glucose chains rarely exceeding 30 units, but many joined through α-(1–6) bonds. Amylose chains are frequently coiled around a central, hydrophobic lipid complex. Consequently, the hydrophilic amylase enzyme penetrates amylopectin molecules faster than amylose molecules with a resulting rate of digestion several-fold greater for amylopectin starch.

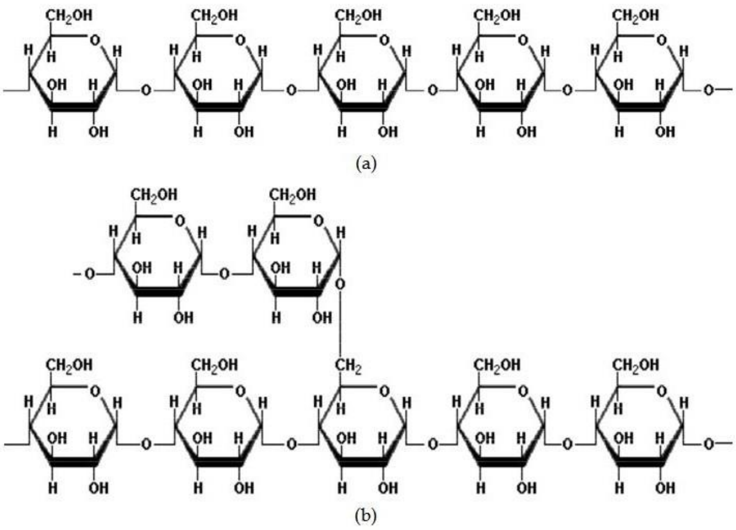

Figure 4. Amylose molecule (a) as a chain of glucose molecules linked by α-(1–4) bonds and amylopectin molecule (b) with glucose chains linked through α-(1–6) bonds (Source: Saunders et al., 2011).

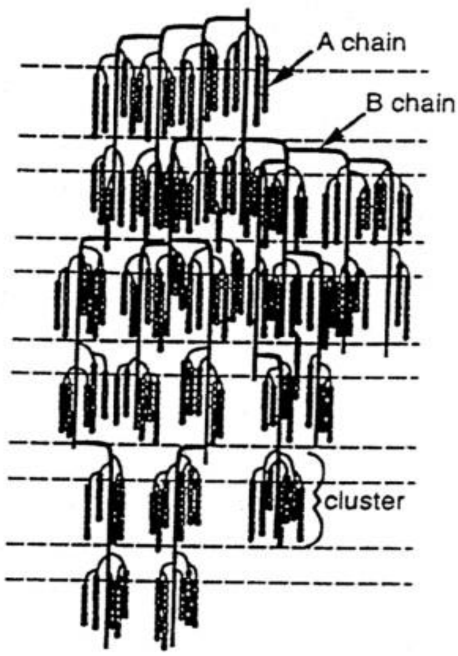

Figure 5. Structure of an amylopectin molecule, showing A chains linked by branching B chains (Source: http://discovery.kcpc.usyd.edu.au/9.2.2/9.2.2_Starch.html).

The structure and chemical composition of cereal grains is affected by cultivar. However, research within the Premium Grains for Livestock Program (Black 2008) showed growing season to have a greater impact on grain characteristics than genotype. Figure 6 shows light microscope images of the same cultivar of wheat grown at the same location in different years.

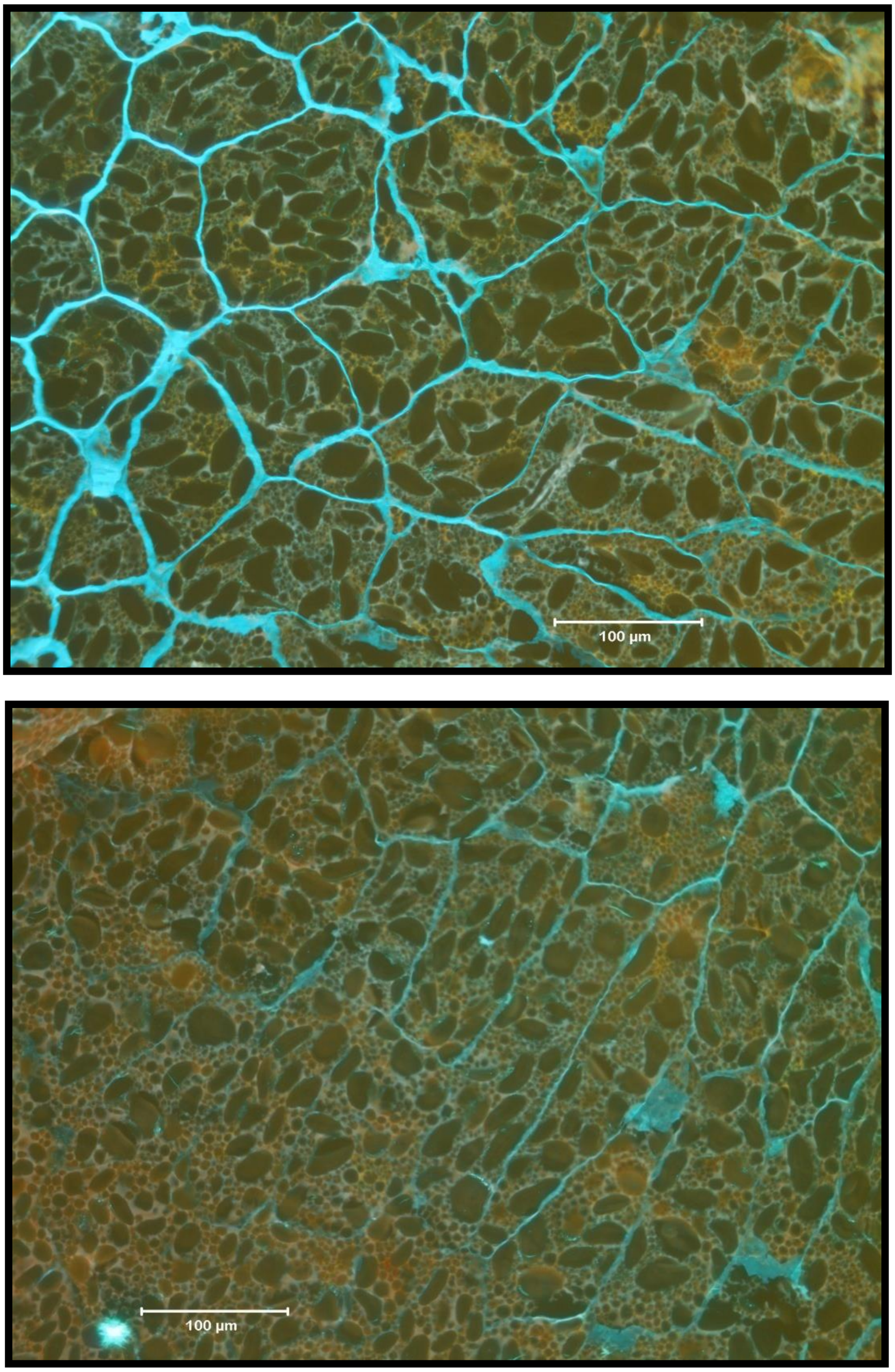

Figure 6. Light micrographs of samples of the wheat cultivar, Oxley, grown at Narrabri, NSW in 1999 (top, low rainfall) and 2000 (bottom, average rainfall), illustrating the effect of growing conditions on cell wall and cell size development (Source: Black, 2008).

4.1.2 Aims of grain processing

The aims of grain processing are to change the chemical and physical characteristics of a grain to improve the supply of nutrients to an animal for metabolism. These improvements may be achieved by:

- an increase the rate and extent of digestion of one or more components of a grain
- a change in the site of digestion within the digestive tract to reduce energy losses inherent to microbial fermentation
- alteration of the biochemical pathways during microbial fermentation to trap more energy in volatile fatty acids and/or to avoid acidosis
- more synchronised delivery of nutrients to tissues to promote productive processes and reduce unnecessary nutrient catabolism.
- presenting feedstuffs to animals in a physical form that will minimise wastage and promote feed intake
- facilitating the movement of feeds through mechanical handling equipment.

There is strong evidence to support the concept that the rate and extent of digestion relating to grain processing depends on:

- diffusion rate of enzymes into the substrate as affected by the chemical and physical characteristics of the grain,
- time the enzymes and substrate are in contact as affected by rate of passage of the substrate through the digestive tract compartment.

The principle methods for processing cereal grains to improve nutrient supply to animals for metabolism are:

- change grain particle size by milling or other mechanical means. Al-Rabadi et al. (2009) showed that amylase diffusion rate into cereal grains decreased with the inverse square of the particle size. Doubling particle size resulted in a four-fold decrease in the rate of starch digestion.
- breaking physical barriers to enzyme diffusion such as cell walls, starch granules embedded in a protein matrix or proteins and cellulose bound to lignin in grain hulls.
- heating starch with water to increase hydration and cause gelatinisation. Cereal grain starches are insoluble in water at room temperature and thus are relatively resistant to water and enzyme penetration. However, heating starch in water weakens the hydrogen bonds, allows water absorption and the starch granules to swell. Amylose chains straighten in the process and the rate of enzyme penetration is increased.
- cooling gelatinised starches can result in the glucose units rebinding to one another in an uncoordinated manner. This process, called starch retrogradation, generally restricts enzyme penetration to a greater extent than occurred for the native starch.
- hydration of the grain over time without heat to allow water penetration without gelatinisation. This allows swelling of the grain, which commences the germination process. Endogenous enzymes are released during germination to break down the physical barriers of cell walls and the protein matrix, commence starch hydrolysation and enhance diffusion rates of animal or microbial derived enzymes into the grain.

Germination beyond two days results in increased metabolism and respiration within the grain and reduces the energy content of the grain.
- adding selected enzymes to breakdown physical barriers to amylase diffusion such as xylanases and β-glucanases for cell walls and longer chain polyphenols or proteases for the protein matrix.

Several processing methods are likely to improve enzyme diffusion rates, rates of digestion and impact on rate of digesta passage to improve the utilisation of specific batches of cereal grains. Feedlot managers need to consider the grain processing method chosen and degree of processing to be undertaken in relation to the cost and efficiency of processing. For example, the efficiency of fuel use, rate of throughput of grain and continuous flow through the equipment are important for reducing costs of processing. However, there will be an economic optimum relating to reducing processing costs and increasing grain digestion and cattle performance. This optimum should be calculated for each feedlot processing method and the specifications of the cereal grain to be processed.

4.2 Grain processing methods currently used in the Australian feedlot industry

4.2.1 Introduction

Greater grain nutrient availability for cattle requires seed coat fracture to expose the endosperm for ruminal microbial fermentation. Additional processing methods increase nutrient availability and animal response by degrading the structural characteristics of starch and starch interaction with protein. Specifically, this includes disrupting the structure of starch (amylose and amylopectin) and degradation of the protein matrix. Different grains have different starch characteristics which directly influence the response to different grain processing methods.

To assess a preferred grain processing method, the benefits of improved cattle performance must be weighed against capital costs, operating and maintenance costs of the processing equipment, skill level of labour, energy efficiency and general cattle management practices.

Grain processing can be broadly categorised as “wet” (e.g. tempering, reconstitution, steam flaking) or “dry” (e.g. rolling, grinding). Grain processing techniques currently being practised, or available for use, in the Australian feedlot industry include dry rolling, grinding, tempering, steam flaking, reconstitution and high moisture harvest and storage. The different processing methods are summarised in Table 1.

Table 1. Grain processing methods

Category	**Processes**				
Cold processing (no heat)	Grinding	Dry rolling			
Cold processing (with water)	Tempering				
Dry processing (with heat)	Micronizing	Roasting	Popping	Exploding	Extruding
Hydrothermal (heat and water)	Steam flaking	Pelleting	Pressure flaking	Steam rolling	
Chemical			Acid-treatment	Chemical conditioning	
Bacterial	High moisture	Fermentation			
Enzymatic	Reconstitution	Enzyme treatment			

4.2.2 Dry cold processing

Cold processing is undertaken to reduce grain particle size. Grain particle size is typically measured as the geometric mean diameter (D_{gw}) and geometric standard deviation (S_{gw}) (ASABE 2008). Grain particle size is determined by recording the mass or volume of grain retained on each sieve in a series of sieves varying in orifice size. Figure 7 illustrates the effect of different grain size distribution (S_{gw}) when the mean particle size is constant.

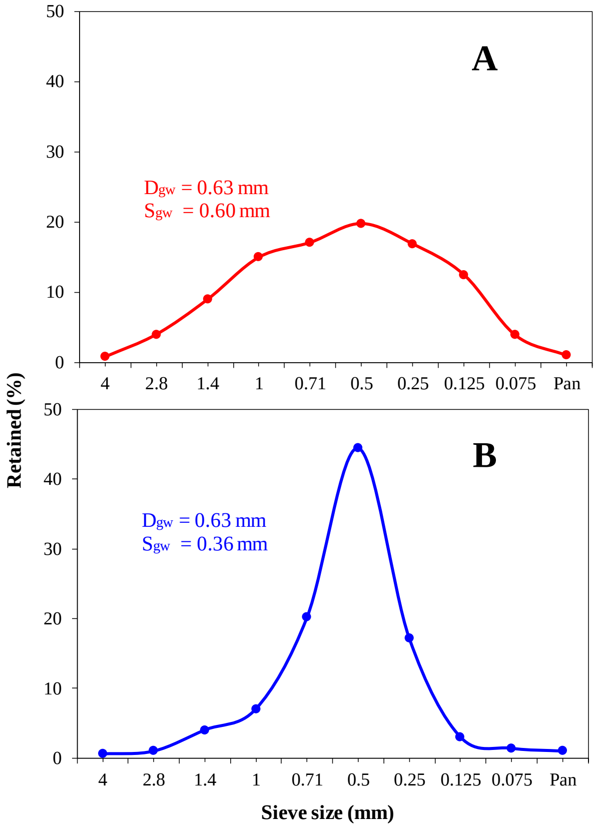

Figure 7. Broad (A) and narrow (B) particle size distributions, showing different S_{gw} and the same D_{gw} (Source: Sopade P et al., 2016).

The most common methods for reducing particle size in stockfeed manufacture are hammer, disc and roller mills.

4.2.2.1 Grinding

This is usually done with a hammermill (Figure 8). Factors influencing the fineness of the end product include screen size, hammermill size, power and speed, type of grain and moisture content of grain. Differences in animal performance reported in the literature are likely due to variations in "fineness" of grind in various experiments. Adjustment of the sieving screen and the speed of the hammers determine the particle size of the resultant processed grain. A larger screen allows a higher through-put but permits the passage of a greater number of uncracked grains. A fine screen results in more extensive processing and a higher level of fines (<1 mm particle size). Hammer mills do not allow for fine adjustment of the level of processing and are renowned for over-processing with the production of a high level of fines). Because of this, their use is not recommended where high levels of grain are fed to ruminants. Hammer mills are not found in large scale commercial beef cattle feeding systems with the exception of mills manufacturing pellets.

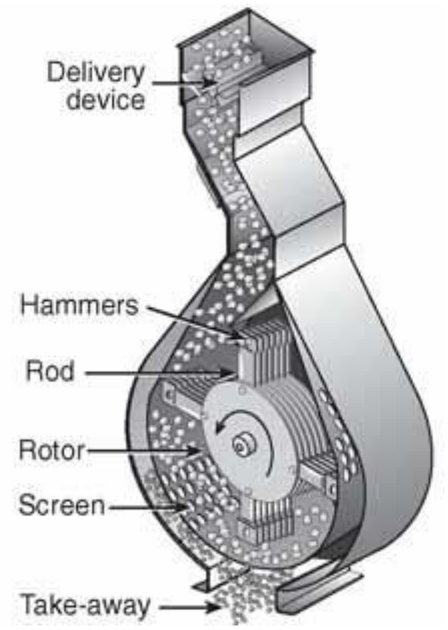

Figure 8. Hammer mill (Source: www.feedmachinery.com).

Disc mills (Figure 9) grind, cut or shear grain as the grain is fed between opposing discs or plates that may be grooved, serrated or spiked.

Figure 9. Disc mills (Source: Courtesy of Vacuum and Milling Solutions, 2016).

The opposing discs can be adjusted to control particle size. Disc mills are more efficient than hammer mills in operation (energy consumption, noise, heat and dust emissions) and processing (reduced variation in particle size for both coarse and fine grinding, reduced fines and whole grains). The grinding principle of a disc mill is shown in Figure 10. A distribution ring distributes the grain into the grinding elements and the grain is ground between a rotary and a stationary disc. The distance between the discs determines the particle size of the ground material.

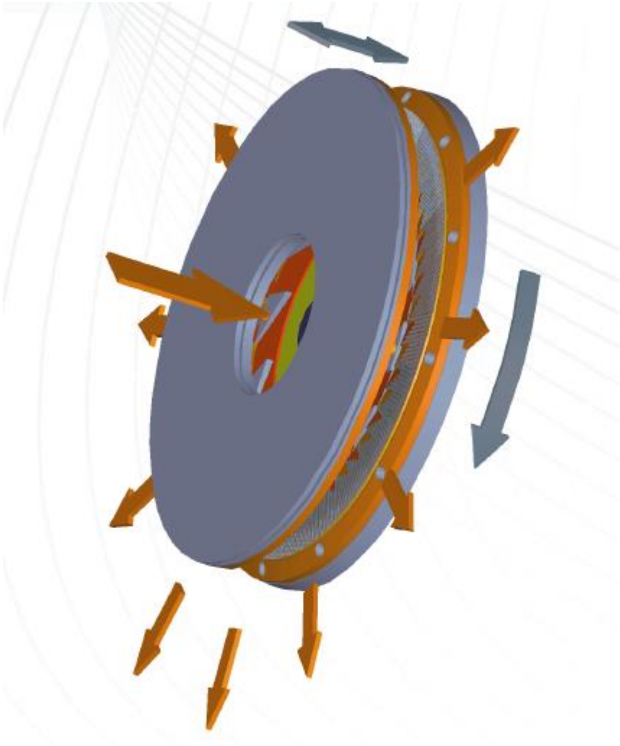

Figure 10. Grinding principle of a disc mill (Source: Courtesy of Vacuum and Milling Solutions, 2016).

Compared with a roller mill, the disc mill requires greater power input (kWh) for targeted capacity (Table 2) and produces more fines (particles less than 1mm). Figure 11 shows that a grinding gap of 2 mm produces 39.3% fines.

Table 2. Disc mill production rates and power requirements for different grains). (Capacity = ton/hr). (Source: Courtesy of Vacuum and Milling Solutions, 2016)

Type	**SK 2500**		**SK 5000**			**SK 10000**		**SK 780**	
KW	5,5	7,5	15	22	30	55	75	160	200
Barley	0,7-1,4	1-1,9	1,7-3,2	2,4-4,7	3-6	5-10	6-13	9-19,5	12-26
Wheat	0.75-1,5	1-2	1,8-3,5	2,5-5	3,2-6,5	5-12	6-15	9-22,5	12-30
Maize	0,5-1,5	0,7-2	2-3,5	2,5-5	3-6,5	5-12	6-15	9-22,5	12-30
Oats	0,6-1	0,8-1,3	1,4-2,3	2-3,2	2,4-4,5	4-9	5-12	9-18	12-24
Peas	,05-1,5	0,75-2	2-3,5	2,5-5	3-6,5	4-9	5-12	9-18	12-24

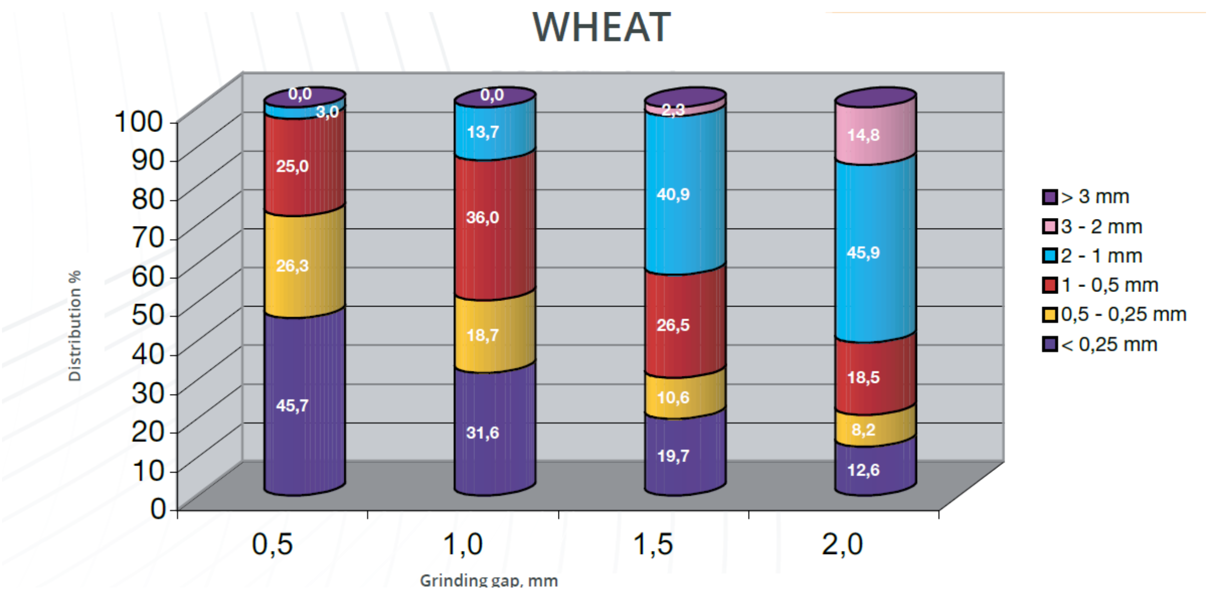

Figure 11. Particle size at different grinding gap settings (Source: Courtesy of Vacuum and Milling Solutions, 2016)

Dry rolling involves the mechanical reduction of grain particle size by two rotating grooved rolls. The grain is drawn into the nip (gap between the rolls) which breaks the grain into smaller particles under the influence of compression, shearing and friction (Figure 12).

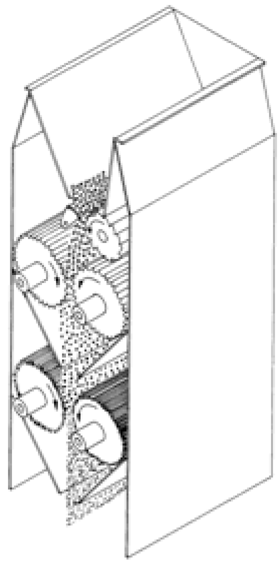

Figure 12. Double stack roller mill (Source: Owens and Heimann, 1994).

The components of a roller mill include:

- Surge bin
  Removes the variation of grain delivery rate to the roller mill. Avoids over-loading the mill (pressure on bearings and shafts) and promotes processing consistency (reduced proportion of whole grains).

- Grain delivery system
  Provides even continuous flow of grain to the entire roll, improving production capacity and ensuring even roll wear. Grain delivery systems include gate, roll or pin feeder.

- Magnets
  Trap foreign metal objects and prevent damage to the rolls

- Pair of single set of rolls mounted horizontally in a rigid frame
    - A single pair of rolls is adequate for processing grain to the desired particle size. Additional roll sets (double or triple stack) are used when a finer particle size is desired (flour production).
    - One roll is fixed in position, the other can be adjusted closer or further from the fixed roll (adjust nip, alter particle size reduction, maintain roll set in tram).
    - Roll adjustment to alter the roll gap and processed grain particle size
      Roll adjustment system should maintain rolls in parallel.

(a) (b)

Figure 13. Operating configuration of roller mill rolls (a) in parallel, (b) in tram (Source: www.efeedlink.com).

- Rolls counter rotate
    - Same speed generates compression
    - Differential speed generates shearing and compression

- Roll groove
    - Number
      Vary with grain size and desired particle size
    - Profile
      There are a number of profiles available as described in Figure 14. Profile selection depends on the purpose, e.g. dry rolling use a flat bottom V,

tempering use a round bottom V (prevents moisture accumulation on rolls), steam flaking use a Stevens.

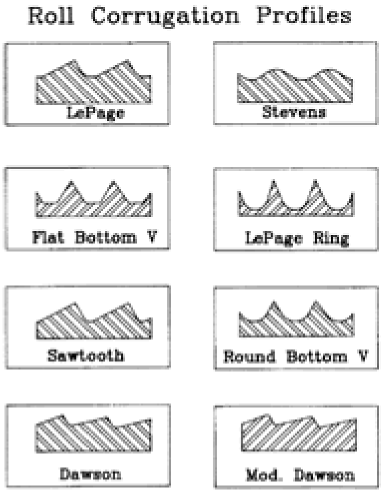

Figure 14. Roll corrugation or groove profiles (Source: Owens and Heimann, 1994).

- Cut
  Grooves generally cut straight, perpendicular to roll ends. However, a spiral cut (3-10%) increases shearing action.

- Inspection hatches
  Positioned directly under the rolls for ease of grain sampling. Sampling is required to ensure the grain is processed to the desired particle size (adjust roll setting) and that the rolls operate in a parallel position (avoid uneven wear, maintain processed grain consistency, enhance production capacity).

Quality control for dry cold processing methods evaluates particle size. For example, this may include evaluation of whole grains and fines (particles less than 1mm). Evaluation of particle size occurs through visual assessment, reference samples or sieves. Consistency of particle size generated from a roller mill is directly influenced by physical quality (screenings, test weight) of the incoming grain.

4.2.2.1.1 Measuring particle size

Several methods are used to determine mean particle size and particle size distribution following milling of cereal grains. The most common method is to use a vertical set of 5-7 sieves, decreasing in sieve size, and to measure the weight of grain held on each sieve (ASABE, 2008). The sieves are generally placed on an electrical shaker, such as commercially available Ro-Tap sieves, but they can also be hand shaken. Grain and grain particle sizes can also be measured using laser and machine vision technology (Guevara-Hernandez and Gomez-Gil (2011).

The Pork CRC has developed a hand-held sieve for determining grain particle size distribution following milling (Figure 15; Sopade et al., 2011). The sieve has been used in commercial mills and by smaller pig producers. The research group found a close relationship between the weight and volume of grain retained on each sieve, making assessment of the mean and grain particle size distribution easy to assess. The hand-held sieve could be modified to enlarge sieve sizes, particularly for the sieves with greater gaps, for use in feedlots. Appropriate sieve sizes may be 4.0 mm, 3.0 mm, 2.5 mm, 2.0 mm, 1.4 mm, 0.5 mm for the feedlot industry.

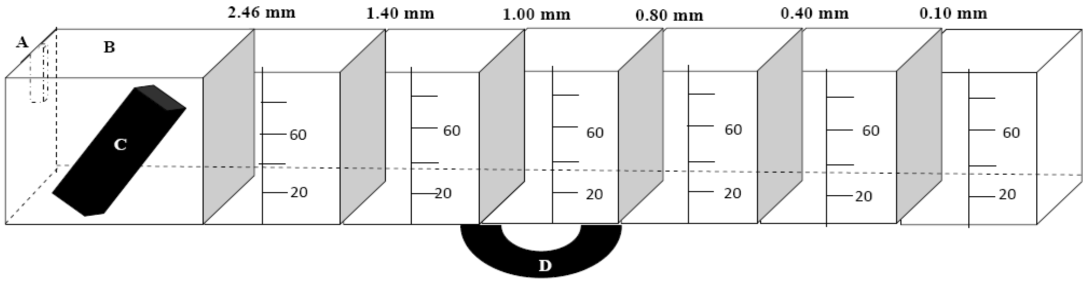

Figure 15. A manual sieving device to evaluate particle size distribution. A = lock, B = sliding part (left to right), C = stopper to cover the top sieve while filling the device, D = handle (Source: Sopade et al., 2011).

4.2.2.1.2 Variation in particle size in commercial Australian feedmills

Research within the Pork CRC has shown there is a large variation between commercial feed mills, grain type and milling method on mean particle size and size distribution measured by the sieve in Figure 15 (Figure 16). Although hardness of a grain affects its fracture characteristics, mean particle size is controlled largely by mill settings.

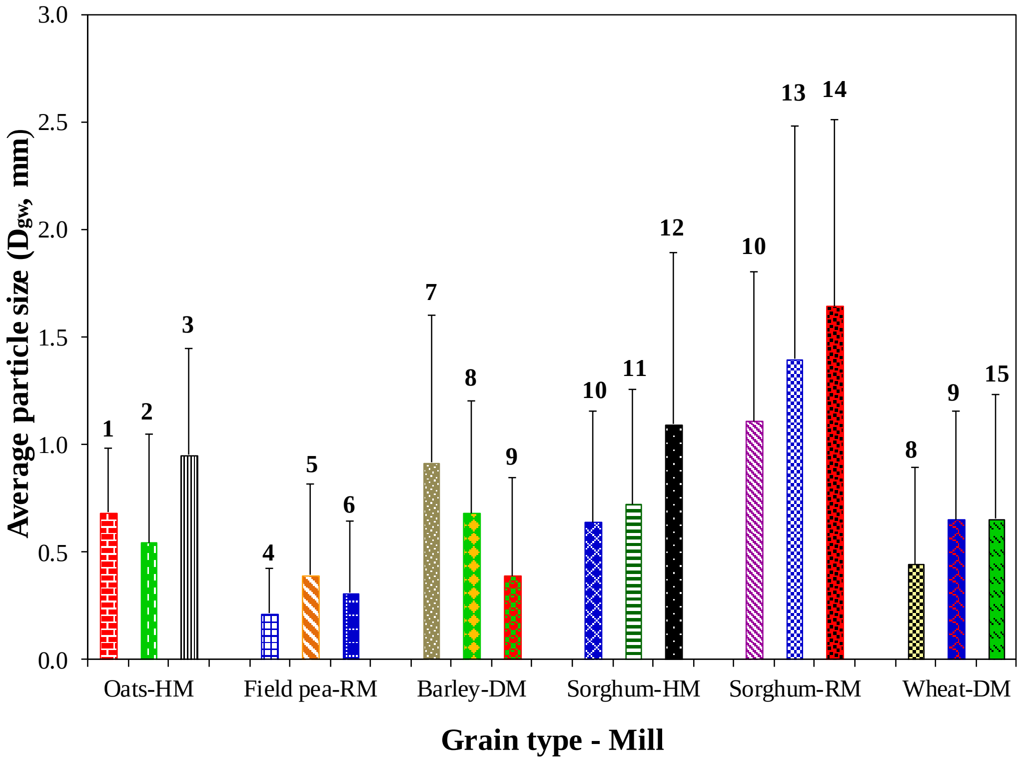

Figure 16. Average particle size (D_{gw}) of similar grains and mill types in different mills with particle size dispersion (S_{gw}) shown as error bars. 1 - 15 are feed mill codes. (Source: Sopade et al., 2016). HM = hammer mill, RM = roller mill, DM = disc mill)

4.2.2.1.3 Optimal particle size for cattle

Benefits to performance of feedlot cattle have been demonstrated from dry rolling or hammer milling whole grain to reduce particle size (Owens et al., 1997; Mathison et al., 1997; Corona et al., 2005; Richards and Hicks, 2007; Schwandt et al., 2015). However, while reducing grain particle size increases digestion in the rumen, feed intake can be inhibited if this results in rumen pH depression thereby reducing overall feed efficiency. In the studies where digestion of starch has been measured along the whole digestive tract, either directly or indirectly by examining starch content of faeces, greater reduction in particle size continues to improve starch digestion by cattle (Mathison et al., 1997; Callison et al., 2001; Zinn et al., 2007). However, an increase in the proportion of fine particles increases the risk of rumen acidosis.

The effect of particle size for milled corn on extent and site of digestion has been measured in dairy cows compared with steam-rolled corn (Table 3, Callison et al., 2001). The mean particle sizes were 4.8, 2.6 and 1.2 mm for coarse, medium and fine ground corn. The density of the steam-rolled corn was 0.53 kg/L. Fine grinding of corn significantly increased total tract digestibility of the starch component of corn to 98%, compared with 92.2%, 91.3% and 95% for the medium, coarse ground and steam-rolled corn. However, there were large effects of particle size on the site of digestion. More than 70% of the starch was digested in the rumen for the finely ground corn compared with 34% for the medium ground corn. Ruminal digestion was intermediate for the coarse ground and steam rolled corn. Three times more of the starch was digested in the small intestine for the medium than fine ground corn. More of the coarse ground corn was fermented in the large intestine than for the other treatments. However, there was only a small overall effect of particle size or steam-rolling on energy available to the cows (Table 3). Assuming 15% of energy released by digestion in the rumen is lost to the animal as heat of fermentation and methane and allowing for the differences in total tract digestibility, cows offered the fine and medium ground corn captured almost identical amounts of energy from the grain component, with the least being captured from the coarse ground. Steam-rolling was intermediate. Grain treatment did not affect milk yield or composition.

Table 3. Effect of particle size of milled corn or steam-rolling on the extent and site of digestion of non-structural carbohydrate (starch) in dairy cows (Source: Callison et al., 2001).

Variable	**Treatment**				
	FGC	**MGC**	**CGC**	**SRC**	**P-value**
Total tract digestibility (% intake)	98.0	92.2	91.3	95.0	0.001
Rumen digestibility (% total tract digestibility)	71.4	33.8	38.1	54.5	0.001
Small intestine digy (% total tract digestibility)	19.9	60.2	47.7	46.7	0.001
Large intestine digy (% total tract digestibility)	8.6	8.4	14.2	8.6	NS[1]
Total energy available[2] (% intake)	86.0	85.9	83.9	85.5	

Fine, medium and coarse ground corn (FGC, MGC, CGC) and steam-rolled corn (SRC)
[1]Not significant. [2]Accounting for differences in total tract digestion and allowing 15% energy loss through microbial fermentation in the rumen and large intestine.

The results presented by Callison et al. (2001) and from their discussion suggest that reducing particle size of grain particles has a smaller effect on animal performance in ruminants than in monogastric animals. However, corn particle sizes approaching 5 mm are likely to reduce overall digestion of starch and increase fermentation in the large intestines. Fine grinding of corn did not improve performance of cows compared with steam-rolling.

Similar findings were made by Corona et al. (2005), where starch digestion was significantly increased by grinding corn compared with dry rolling, but cattle performance was not increased. Corona et al. (2005) also showed the benefits in both starch digestion and cattle performance of steam flaking compared with dry particle size reduction.

Optimum particle size for feedlot cattle fed corn would appear to be around 2-2.5 mm. However, the passage of larger particles from the rumen to the small intestines where they are digested by animal enzymes with higher energetic efficiency may be the reason why differences in particle size have little effect on live weight gain of cattle fed corn based diets.

Corn (maize) is not used widely in Australian feedlots. There is evidence corn and sorghum are similar in their reaction to processing (Richards and Hicks, 2007). However, cattle fed wheat and barley based diets may respond differently to variations in grain particle size than those fed corn or sorghum. Mathison et al. (1997) found the efficiency of feed use for live weight gain increased significantly as particle size of barley grain was reduced from 2.70 mm, 2.56 mm to 2.31 mm, respectively, by slightly rolling, medium rolling or crushing barley grain. However, these researchers recommended that the range in particle size should be such that less than 10% of grain particles passed through a 2.0 mm screen to avoid the chances of acidosis. However, Bengochea et al. (2005, Trial 3) found that reducing particle size of barley from 2.0 mm to 1.3 mm improved feed conversion efficiency and apparent net energy of barley based diets for feedlot cattle. The different conclusions regarding target grain particle size of Mathison et al. (1997) and Bengochea et al. (2005) are explained by the differences in grain inclusion. It is not surprising that the high roughage grower diet fed in the Bengochea et al. (2005) diet, with only approximately 40% barley, resulted in differences in feed efficiency with a change from a particle size or 2.0 mm to a lower particle size of only 1.3 mm. The inherent buffering capacity of the high roughage diet would allow a smaller particle size and greater grain utilisation without the risk of ruminal acidosis. On the other hand, the diet fed by Mathison et al. (1997) was approximately 90% barley, which prompted their conclusion that minimum barley particle size should be approximately 2.0 mm. Considering the paucity of data on the relationship between processed Australian wheat and barley particle size and productivity, and the frequency of the inclusion of these in Australian feedlot diets, there is a need for Australian feeding studies to determine the target particle size of Australian grains at a range of inclusions that reflect commercial feeding practice.

4.2.3 Wet cold processing (steeping and tempering)

Tempering is the process of adding water (8-10%) to whole grain with a period of storage (8-24 hours) to enhance water absorption (target grain moistures 20-22%) prior to processing with a roller mill. The addition of moisture to grain has the effect of dramatically reducing fines, allowing a more consistent roll and reducing the energy cost of milling.

Tempering can be a stand-alone grain processing system or incorporated into other systems (reconstitution, steam flaking) which rely on increased grain moisture for efficacy and efficiency of processing.

Additional components of a roller mill used in a tempering system include grain cleaner, wetting auger and steeping bin:

- Grain cleaner
  Removal of fine contaminants from grain enhances the efficiency and consistency of water addition and the processing of tempered grain.

- Wetting auger
  The addition of water and mixing with grain takes place in a wetting auger. Water addition rate is controlled through a flow meter. Final moisture consistency is achieved with the use of a weigh auger.
  The wetting auger has open flighting and paddles. The design increases residence time and the mixing action of grain with water.

- Steeping bin
  Steeping is the process of storing tempered grain to enable water absorption (imbibition). The steeping period (hours) varies with type of grain and target moisture content. Sorghum and corn require longer steeping periods (24-48 hours) compared with wheat and barley (12-24 hours).

- Roller mill
  Tempered grain is processed by a roller mill. Tempering softens and swells grain, reducing mill power requirements and reducing roll wear, but decreasing mill capacity. Round bottom grooves reduce moisture accumulation on roll surfaces. The grain is processed by compression only, thereby maintaining particle size.

Quality control for wet cold processing methods relates to moisture consistency of tempered grain using a calibrated moisture meter or oven, calculating a processing index (Corbett, 2000) (weight of tempered rolled grain divided by weight of whole dry grain), calculating bulk density of processed grain and visual assessment.

4.2.4 Steam rolling

Steam rolling is similar to steam flaking except dry (un-tempered) grain is exposed to steam for a limited duration (20 to 40 minutes). Steam rolling increases production capacity and reduces moisture addition (16-18% final grain moisture). Use of flake coolers or driers can bring grain moisture back to 12 to 14% final moisture). The reduced exposure to steam also reduces starch gelatinisation. Steam rolling is used for processing wheat, barley and corn. The process maintains rolled grain kernel integrity, increases surface area, and aroma compared with cold processing.

4.2.5 Steam flaking

Steam flaking is the process of tempering and cooking grain. Steam flaking involves 40-60 minutes of steaming at a temperature between 95 and 110°C. After steaming, the grain is rolled to produce thin flakes that contain 16 to 25% moisture and ranging in density from 28-45 kg/hL depending on grain type and grade.

Whilst steam flaking is an expensive process in terms of capital establishment and running costs, improvements in feed conversion ratio over dry rolling are substantial. Acceptable improvements in efficiency for steam flaking over dry rolling include sorghum up to 25%, barley up to 15%, wheat up to 10%, and corn 8% (Huntington GB 1997; Owens et al., 1997).

Flake thickness, expressed as density, is a critical factor in improvements in feed conversion efficiency. Holcomb and Klett (1994) reviewed the literature on steam flake density. The results are shown in Table 4. Heavier flakes achieved higher daily gains whereas lighter flakes improved feed efficiencies. While these data agree with the bulk of that published, Holcomb and Klett note that it does not emphasise the increase in digestive disturbances in commercial feedlots when extremely light, thin flakes (<28.32 kg/hL) are fed. Also, it should be noted that optimal flake densities are general in nature and will relate to the grain inclusion and the characteristics of the roughage component of the ration.

Table 4. Daily weight gain (kg/hd/day) and feed efficiency (kg of feed DM/kg gain) at 3 different steam flake densities (Source: Holcomb and Klett, 1994).

	Flake density (kg/hL)		
	38.62	**32.18**	**25.75**
Daily weight gain (kg/hd/day)	1.19	1.17	1.13
Feed efficiency (kg feed/kg gain)	6.53	6.42	6.26

The cooking process occurs in a steam chest. The combination of moisture (which hydrates the starch granules), heat (which swells the starch granules) and the shearing action of the rolls (which rupture the starch granules and fracture the protein matrix) increases starch availability. The benefits of steam flaking are only achieved when moisture, heat and the shearing action of rolls are combined.

- Steam chest temperature and residence time
  Steam is generated by a boiler and transferred to the chest by steam pipes. Depending on the dimensions of the steam chest (width and height), steam enters the chest by three or four inlet tubes. Each inlet has a steam manifold, which distributes the steam within the chest.
  Residence time is regulated by the speed of the peg feeder or feeder bar.

The components of a steam flaker are shown in Figure 17.

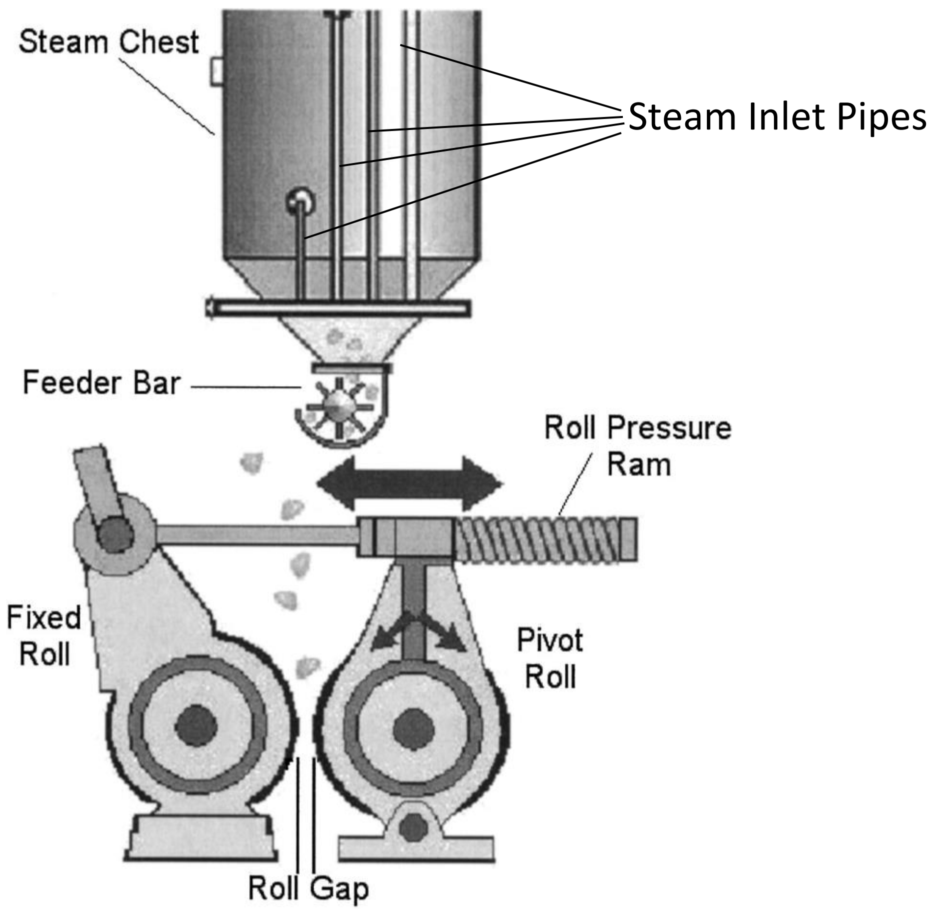

Figure 17. Components of a steam flaker (Source: Zinn et al., 2002).

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- Roll characteristics
  A steam flaking roller mill has several characteristics which differ from a dry roller mill. These include:
  - Roll dimensions
    Larger diameter rolls are required in a steam flaker to withstand higher operating temperatures that can otherwise warp the rolls.
  - Groove profile
    A Stevens cut (Figure 14) is a commonly used profile on steam flaking rolls. The function of the groove is to generate a shearing action, but maintain flake integrity. The grooves have a round bottom to prevent moisture accumulation.

- Roll gap and tension
  When grain exits the steam chest it passes through the roll gap to produce a flake. Flaking squashes the grain, physically disrupting the protein matrix and rupturing and releasing the swollen starch granules. The flake size or density (kg/hL) and thickness (mm) is controlled by adjusting the rolls and altering the roll gap. The rupturing of the starch maintains flake integrity by acting like a glue to hold the flake together, thereby maintaining flake size and minimising fines.

The efficacy of steam flaking can be assessed by several methods including:

- Moisture
  Assesses efficiency of tempering and steam quality (dry / wet). Tempering provides the primary method of moisture addition and absorption (19-20%) with a smaller proportion derived from steam application (2-3%). Moisture is assessed at the same time as flake density using a calibrated moisture meter or oven to determine dry matter.

- Flake density
  Flake density can be assessed at any time during steam flaking, when stored or before loading into mixers for ration delivery.

- Visual assessment
  Gelatinised starch loses its chalky appearance and brittle nature and becomes translucent with flakes that resist breakage.

- Starch availability
  Several laboratory tests assess starch availability by solubility or enzyme activity. These testing methods are not immediate but provide useful and repeatable reference results which can be used to assess processing and to determine relationships to production.

- Faecal starch
  Flake density is poorly related to starch digestion. In contrast, faecal starch has shown a close relationship to ruminal and total starch digestibility. Accuracy of the method relies on sampling technique (sufficient sample size, requires all fresh faecal material to be collected over a 24 hour period to adequately account for variation in

feed intake and passage rate). Faecal starches are most accurate when the total digestibility of starch in the digestive tract exceeds 95% (Zinn et al., 2007).

4.2.6 Steam Flaking utilizing rapid cooling to prolong shelf life

Cooling systems have been employed in combination with steam flaking as a method of preventing starch retrogradation. Retrogradation is the limited reorganisation, after starch gelatinisation, of amylose and the linear components of amylopectin into a crystalline structure through hydrogen bonds. In practice, it occurs primarily through the reorganisation of amylose because retrogradation of amylopectin takes weeks to months to occur (Lii et al., 2004). This means grains with a high amylose content (corn) are more subject to retrogradation. Retrogradation is a risk in steam flaked grain that requires storage prior to feeding because higher temperatures within the stockpile can dramatically accelerate the rate of amylose retrogradation (Jouppila et al., 1998).

The extent of retrogradation depends upon several factors including moisture content and temperature (Rooney and Pflugfelder, 1986) and therefore it seems very likely that method of storage for steam-flaked grains may influence retrogradation. Recent studies have suggested that the method of handling steam-flaked corn after the flaking process, may influence dry matter digestion and starch availability (SA). Ward and Galyean (1999) demonstrated a 39% reduction in SA but a 4% increase in *in vitro* dry matter disappearance (IVDMD) for steam-flaked corn that was taken to a storage bin by a drag chain and elevator and stored as compared with samples taken directly below the rolls. McMeniman et al. (2007) demonstrated a 6% reduction in IVDMD and a 48% reduction in SA for steam-flaked corn collected on exit from an elevator filled storage bin as compared with flakes collected directly beneath the rolls. This indicates an increased retrogradation of starch and/or altered protein-starch interactions of steam flaked corn at the higher storage temperature in the elevator filled bins. McMeniman and Galyean (2007) studied simulated air lift and conveyor elevator transfer systems for steam-flaked corn. Simulated conveyor elevator samples had 40% lower SA and 6.5% lower IVDMD at 24 h incubation as compared with samples from a simulated air lift system. It is not known whether these differences in SA or IVDMD have an influence on cattle performance and further research into this is warranted. Hot flaked grain is often commodity piled for greater than 1 hour and it remains to be determined if this elicits a difference in animal performance in Australian feedlots, particularly with grains other than corn.

Some Australian mill design has moved away from automated batching systems to loading grain by buckets into batch-boxes or directly into the mixer. This can mean that at times the duration of storage is short and the temperatures may be too low for significant retrogradation of starch to occur (McAllister et al., 2006).

Further research into starch retrogradation of steam-flaked grains is required to determine possible effects on animal performance. If such effects are identified, potential benefits and the cost-effectiveness of rapid cooling technologies for steam-flaked grains should be investigated further.

4.2.7 Reconstitution

Reconstitution is the process of increasing moisture content of whole mature grain to 30% and storing it in a vertical sealed air limiting silo (Harvestore) for 21 days. The moisture and initial aerobic environment initiates germination, which is then halted by the absence of oxygen. Grain is removed from the Harvestore and processed by roller mill.

Factors that influence the reconstitution process include water temperature, ambient temperature, oxygen limiting ability, amount of foreign material in the grain, consistency of moisture in storage and the proportion of viable seed (seed that can germinate). Reconstitution is limited to larger commercial feedlots due to the large capital costs involved in building anaerobic silos.

Accepted improvements in efficiency with reconstitution over dry rolled grains are similar to the efficiency improvements achieved with steam flaking.

Variables of reconstitution include:

- Grain moisture content
  A dual wetting system is required to consistently achieve the 30% target grain moisture. The dual system uses tempering to achieve 24-26% moisture and a final moisture application of 4-6% as grain fills the Harvestore.

- Germination
  Germination is a critical aspect of reconstitution. Requirements of germination include:
  - Viable seed
    Processing (rolling/grinding) grain prior to reconstitution does not improve protein/starch availability. An intact aleurone layer is required for activation of enzymes.

  - Oxygen
    Presence of oxygen is required to initiate germination. Nutrient availability of sorghum increased with 6 days of aerobic storage compared with 21 days of continual anaerobic storage.

  - Moisture
    Moisture absorption alone is not associated with germination capacity. Non-viable or processed grain absorbs water. However, in combination with oxygen, moisture stimulates hormone release and enzyme activation.

- Establish anaerobic environment
  The Harvestore is designed to provide sufficient oxygen to initiate germination, but not enough to sustain development of the radicle and coleoptile. The reconstituted grain moisture concentration and initial effects of germination (some aerobic respiration) generates grain shrink (<4.0%).

4.2.8 Fermentation

Fermentation involves the addition of water (20-25%) and an inoculant to mature dry rolled grain to achieve a target moisture level of 35%. Water is added to rolled grain via a mixer or wetting auger. The grain is formed into a bun, rolled, compacted and covered. The bun remains undisturbed for 30 days to ferment.

Grain is rolled prior to moisture addition to facilitate water addition and mixing, to reduce particle size thereby facilitating compaction (air removal), and to increase the surface area of the exposed endosperm for access by fermentative bacteria.

Grain fermentation relies on the same principles as silage production (removal of oxygen, fermentation produces lactic acid and depresses pH). As long as anaerobic conditions are maintained, the feedstuff remains stable. The inoculant plays an important role in rapidly establishing lactic acid producing bacteria (which out-compete undesirable microorganisms), decreasing pH Inoculant use prevents quality loss and limits shrink.

Fermented grain is highly susceptible to secondary fermentation once the bun is opened for use. Use of inoculants and bun hygiene is critical to minimise aerobic losses.

This grain processing system is generally reserved for sorghum. The water absorption (starch hydration) and lactic acid produced during fermentation degrades the protein starch interaction, increasing protein solubility and improving starch availability.

4.2.9 High Moisture Grain Harvest and Storage

High moisture grain involves a processing system similar to that of fermented grain. The major difference is that grain is harvested earlier and at higher moisture (25-33%, maximum 40%), rather than adding water to mature dry cracked grain. Corn and sorghum are suitable for the high moisture grain process.

Considerations of high moisture grain production include:

- Timing of harvest
  Using grain moisture as an indicator, the ideal harvest time is soon after grain achieves its physiological maturity (25-33% moisture). This window minimises losses in the field and during storage. Grain moisture levels less than 25% adversely affect feeding value and efficiency.

- Processing
  High moisture grain can be processed by large capacity roller mills on delivery or processed during harvest (harvesters fitted with kernel processors). Particle size reduction is important for compaction.

- Storage

  Similar to fermented grain, high moisture grain is stored in pits, buns or bags for approximately 30 days. Limiting oxygen is the key to controlling shrink. Fermentation losses average 3-4% of dry matter.

As with fermentation, the performance improvements for high moisture grain relate to degradation of the protein-starch interaction and specifically the degradation of cross-linking (Benton et al., 2005a, Hoffman et al., 2011). Indicators of protein matrix degradation and increased ruminal *in-vitro* starch digestibility include ammonia nitrogen (derived from bacterial deamination of amino acids), soluble crude protein and final pH (Ferraretto et al., 2014). Hicks and Lake (2008) reported that soluble crude protein provided an indicator of dry matter digestibility. Soluble crude protein concentrations less than 40% indicated low digestibility, 50-60% was considered ideal and greater than 60% increased the risk of digestive upset leading to depressed feed intake. Research has identified grain moisture at harvest, particle size of processed grain, and ensiling period, as the factors that directly influence digestibility. Hicks and Lake (2008) reported ideal harvest moisture levels for corn of 30% and the ideal particle size distribution of less than 2.5% and 20% whole grain and fines (particles less than 1mm) respectively. Extending the ensiling period to 240 days (Hoffman et al., 2011) and more than 350 days (Benton et al., 2005b) also promotes digestibility.

4.2.10 Other processing methods

- Chemical conditioning

  The main agent that has been used in chemical conditioning of grain is sodium hydroxide (NaOH, caustic soda). Dry pellets of caustic soda are mixed with the grain, then water is added, and mixing continued. The caustic soda hydrolyses ester linkages between the structural components of the seed coat, thereby making the starch inside more available to the rumen microbes.

- Enzyme Treatment

  Enzyme treatment has been used primarily with tempered grain. Products containing a range of enzymes such as cellulases, amylases and proteases have been commercially trialled based on benefits generated in the monogastric industries. The aim is to digest the seed coat to facilitate access of rumen microbes to the starch and to initiate starch digestion to further increase the availability of the starch. See section 5.3.3.2.1.

4.2.11 Grain handling and storage

A grain storage and handling facility includes grain receival, grain movement, grain cleaning, reclamation, storage and possibly drying and cleaning. Storage and handling facilities should be compatible for whole and processed grains.

Grain receival and handling

Grain handling and conveyor systems should be designed to minimise damage to grain and promote throughput. A wide variety of grain-handling equipment and systems is used in the Australian feedlot industry.

Grain receival hoppers

A high-capacity receival system is needed for efficient transfer of grain from trucks to grain storage. Ideally, it should be possible to deposit a trailer load and pull away from the unloading area within minutes. An in-ground receival hopper is normally fitted with a screw conveyor or auger to raise grain for conditioning or storage. Foreign materials and dust must be removed to eliminate problems within the grain storage and handling system. A grain conditioner or scalper removes foreign particles, weed seeds, small-size grain, straw and husk while a dust extraction and collection system prevents dust entering the environment. All foreign metal objects must be detected and removed before they can cause damage to machinery. A permanent or electro-magnet can be located in the chute feeding the grain conditioner but needs to be checked and cleaned regularly.

Belt-and-bucket elevators

Bucket elevators are used mainly to lift grain vertically to silos or other storages. They usually deliver the grain directly into silos using diverters that direct grain into a gravity chute to the selected silo, or by using belted conveyors to transfer grain horizontally to the various silos. A flat belt between crowned pulleys at the top and bottom of the casing has small buckets attached at regular intervals to carry the grain from the elevator bottom to the top. Bucket elevators are self-cleaning (when grain is dry) by design and are typically fixed in position.

Auger (screw conveyors)

Auger elevators are one of the cheapest methods of elevating grain, and can be either fixed or portable. They are available in a wide range of lengths and capacities and are usually powered by an electric motor. They are comparatively light in weight, dependable in their operation and popular due to their portability—long augers may be mounted on wheels for easy transport. The angle of operation is adjustable but the capacity declines as the auger is raised. High moisture content in grain also reduces the capacity of the auger. Old augers with worn flighting can damage split-prone grain.

Belt conveyors

Belt conveyors are normally used to transfer grain horizontally. Inclines up to 15° are possible—even up to 30° with ribs fitted to the belt. Belt conveyor capacity is high, and grain can be loaded anywhere along the belt. Belt conveyors do not damage the grain, and raise little dust.

Drag chain conveyor

Drag-chain conveyors or paddle conveyors use a series of paddles fixed to a loop of chain moving inside a fully-enclosed conduit. The paddles are sized so they fit snuggly within the conduit. This fully enclosed system prevents dust within a building or other space. Drag chains can move grain at any angle, including horizontal, and are largely self-cleaning, although corners of the chain-loop will normally require attention. Drag-chain conveyors are a permanent installation but can be easily extended for facility expansion.

Mobile equipment

Mobile augers, mobile belt conveyors, grain throwers and pneumatic conveyors may be used to load grain into storage facilities. Mobile augers or belt conveyors with fixed and guarded cross-sweeps, or a front-end loader can be used to empty the pad. Pneumatic conveyors also suit this job, and allow easy final clean-up of grain.

Grain storage
All storage systems must be designed to adequately protect and preserve the quality of the grain. Where moisture becomes elevated in storages, whole grain can sprout, it can develop mould growth, and will also attract insects and rodents. In general, grain in long-term storage should be held cool and dry.

Options for grain storage include smooth wall or corrugated steel silos, concrete silos, and underground pits. Steel silos are the most common method of long-term storage of grain at feedlots. Silos come in a variety of sizes, configurations and materials, including flat-bottom or cone base, gas-tight sealable or non-sealed, aerated and non-aerated. The size of fully constructed, transportable silos is limited by road transport regulations within each state but, as a general guide, fully constructed silos can be up to 140t capacity. Most smaller (50–70t) cone-bottom silos are generally prefabricated and transported. Cone-bottom silos are self-emptying, but are limited to capacities of less than 300 tonnes. Feedlots may require air-tight/gas-tight storage facilities of greater capacity; however, the increased surface area of a larger silo requires more sheet metal joins, providing more opportunity for air or gas to escape.

Temporary grain storage may be necessary when on-site storage capacities are likely to be exceeded during unusually large harvests or for opportunity storing/buying of large quantities of grain at an economical price. Temporary storage may be a ground dump with or without a cover. Covered ground dumps include grain bags, sheds and bunkers. Good hygiene within grain handling and storage premises will maintain the quality of the products handled. Problems with grain caking on silo walls, being damp and mouldy in the base of the store and sprouting in the headspace are caused by poor grain management or poor maintenance of the grain store.

4.3 Review of new technologies

Efficient and cost-effective processing of grains is integral to the success of the Australian feedlot industry. Whilst there has been significant investment in milling technology across the feedlot industry over the last 15-20 years, there is still a continued need to refine systems and identify potential methods and technologies that can improve animal performance efficiency, and cost of grain processing. This chapter reviews the potential for new grain processing technologies that may be adaptable to the Australian feedlot industry.

4.3.1 Steeping and tempering

4.3.1.1 Reducing agents

Introduction
The chemical definition of a reducing agent is an element or compound that loses or donates an electron (oxygen or hydrogen) to another element or compound and thereby is oxidised. Reducing agents are involved in redox (reduction, oxidation) reactions. In terms of reducing agent function in grain processing, these compounds react with the biological structure of the grain. Reducing agents have been shown to facilitate water uptake of grain by degrading the

seed coat. This promotes rate of water uptake and structural changes within the endosperm, promoting water penetration and swelling of starch granules.

The mode of action of reducing agents is different to conditioning agents. Conditioning agents reduce surface tension of grain, thereby increasing the capacity of water to adhere to the grain surface and promoting water intake through the grain's specific moisture entry point. Conditioning products may contain acid, but this is not related to a reducing agent function, rather, the acids emulsify oil and promote water adherence to the grain surface. Grain conditioners do not affect integrity of the seed coat.

Examples of reducing agents include β-mercaptoethanol, a range of acids (sulphurous, phosphoric, sodium-metabisulphite, acetic, citric, ascorbic, lactic), alkalis (potassium hydroxide, sodium hydroxide), organic compounds (cysteine) and enzymes (gibberellic acid, proteinases, cellulases).

Increased moisture uptake and changes to endosperm structure enhance processing of grain by tempering and steam flaking. Reducing agents are particularly beneficial to the processing of sorghum, and to a lesser extent, corn. Reducing agents have limited effects on wheat and barley.

Seed Coat Degradation and Imbibition Rate

As discussed previously, an intact pericarp resists water movement directly into the endosperm of grain. When the pericarp is intact, water can only enter through the specific area near the germ (micropyle in wheat and barley, tip cap in corn, stylar and hilum in sorghum). Removal of the pericarp promotes initial water absorption rate. Ruan et al. (1992) reported 12% moisture in corn germ occurred within 30 minutes with the pericarp removed compared with 1 ½ hours in corn with an intact pericarp. However, rate of moisture transfer through the endosperm remained the same for both treatments. However, when corn with an intact pericarp was steeped with 0.55% lactic acid, moisture absorption increased, particularly in the soft and hard endosperm. Treatment with lactic acid provided higher moisture content after 6.5 hours of steeping as shown in Figure 18. Acid treatment increased water mobility and altered endosperm sorption capacity.

McDonough et al. (1998) reviewed the effect of a number of reducing agents on seed coat integrity of sorghum. Both β-mercaptoethanol and sulphurous acid degraded the waxy cuticle of the seed coat. Very little of the waxy cuticle remained after treatment with β-mercaptoethanol, whereas approximately half the cuticle was removed with sulphurous acid. The loss of pericarp integrity was shown by cracks in the sorghum grains after steeping.

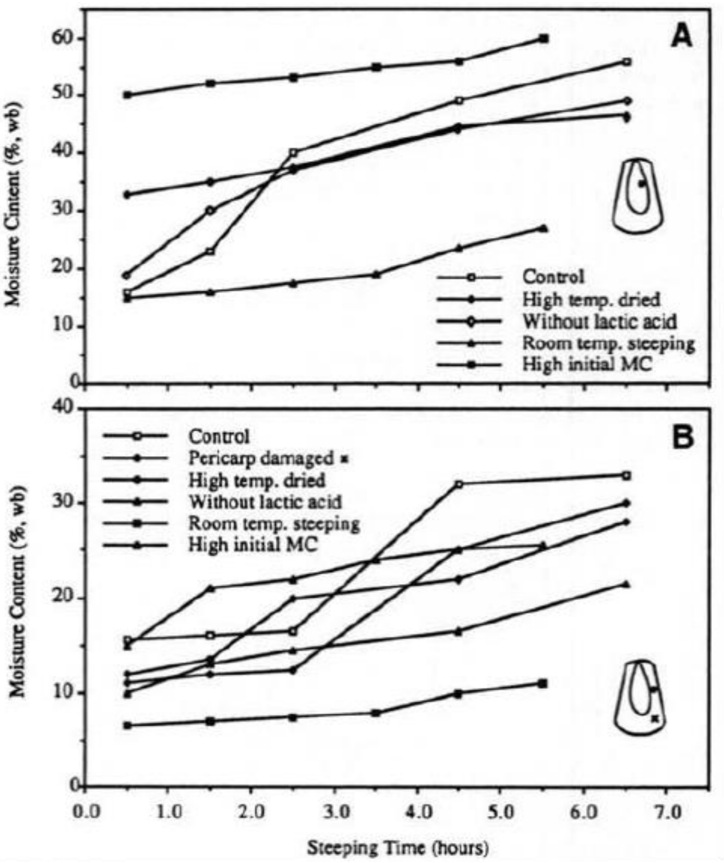


Figure 18. Effect of grain treatments on the moisture content of the germ (A) and the endosperm (B) of corn during steeping. The control was corn steeped with water at 53^{0}C and 0.55% lactic acid (Source: Ruan et al., 1992).

Structural Changes to Endosperm

A major factor influencing starch availability is the structure of the endosperm. Hard endosperm is characterized by a close association between starch and protein (protein matrix). The increased water uptake and swelling potential of grain steeped with reducing agents is related to degradation of the protein matrix (Rom et al., 1992) and cleaving of the disulphide bonds that exist between starch and prolamin (Du et al., 1996; McDonough et al., 1998).

Benefits to Grain Processing

Processing grain in combination with reducing agents promotes both starch and protein digestibility. Truong et al (2015) reported increased available metabolisable energy and protein solubility in poultry when varieties of sorghum were treated with sodium metabisulphite.

McDonough et al. (1998) tempered sorghum with a range of conditioning treatments (β-mercaptoethanol, sulphurous acid, phosphoric acid, cellulose enzyme) using 30-35^{o}C water, steeped for 24 hours to reach a moisture of 20%. Post tempering, steam flaking was replicated using a pressure cooker (100^{o}C for 30 minutes).

The physical characteristics of the flaked sorghum (lower test weight, larger thinner flake, less fragility) suggests the reducing agents increased imbibition and starch solubility as described in Table 5.

Table 5. Physical properties of steam flaked sorghum, tempered with various conditioners (Source: McDonough et al., 1998).

	Test Weight (kg/hL)	**Whole Flake (%)**	**Fragility (%)**	**Breakage (%)**	**Diameter (mm)**	**Thickness (mm)**
Non-temp	32.1[a]	60.6[c]	19.4[a]	31.1[a]	5.94[c]	1.31[a]
Water only	26.8[b]	66.6[b]	14.6[b]	26.1[c]	6.97[ab]	1.05[b]
Com Cond	27.3[b]	68.2[b]	14.7[b]	26.6[c]	6.72[bc]	1.11[ab]
BME	27.2[b]	61.1[c]	9.8[c]	29.1[b]	7.04[ab]	0.90[bc]
S acid	27.0[b]	75.0[a]	8.4[d]	22.9[d]	7.68[a]	0.77[c]
LSD	1.84	2.02	1.34	0.89	0.95	0.25

Com Cond = Commercial conditioner, BME = β-mercaptoethanol S acid = sulphuric acid
Means in the same column with different letters[a,b,c,d] significantly different $P<0.05$.

Steeping sorghum with reducing agents also increased starch availability as described by Table 6.

Table 6. Enzyme susceptible starch (ESS) of steam flaked sorghum tempered with various conditioners (Source: McDonough et al., 1998).

	ESS %
Raw grain	31.9[c]
Non-tempered	82.2[b]
Water only	88.7[ab]
Commercial conditioner	88.2[ab]
B-mercaptoethanol	95.2[a]
Sulphuric acid	94.0[a]
LSD	6.32

Means in the same column with different letters[a,b,c,d] significantly different $P<0.05$.

Reducing agents promote protein digestibility, which is generally not changed with steam flaking. Table 7 shows the effect of adding various concentrations of L-cysteine hydrochloride, sodium metabisulphite or ascorbic acid to sorghum flour cooked in boiling water for 20 minutes on in vitro protein digestibility.

Table 7. Effect of cooking sorghum in the presence of reducing agents on *in vitro* protein digestibility (Source: Elmoneim et al., 1999).

	Reducing Agent Concentration (M)				
	0	**0.05**	**0.10**	**0.25**	**0.50**
Cysteine	10.7[c]	44.7[d]	50.5[c]	61.2[a]	58.3[b]
Sodium metabisulphite	10.7[i]	39.8[d]	42.7[c]	47.6[b]	50.5[a]
Ascorbic acid	10.7[i]	16.5[e]	26.2[f]	19.4[g]	16.5[e]

Means with different letters[a,b,c] in the same row significantly different $P<0.05$.

Cleaving of the disulphide bonds that link starch granules with the protein matrix promotes protein digestibility. Haymaker et al. (1987) showed treatment of uncooked and cooked sorghum with 2-mercaptoethanol increased protein digestibility by 11 and 25% respectively.

A number of reducing agents improve protein digestibility as described by Figure 19. Degrading these structural components of the grain enables greater water uptake and swelling of the starch granules.

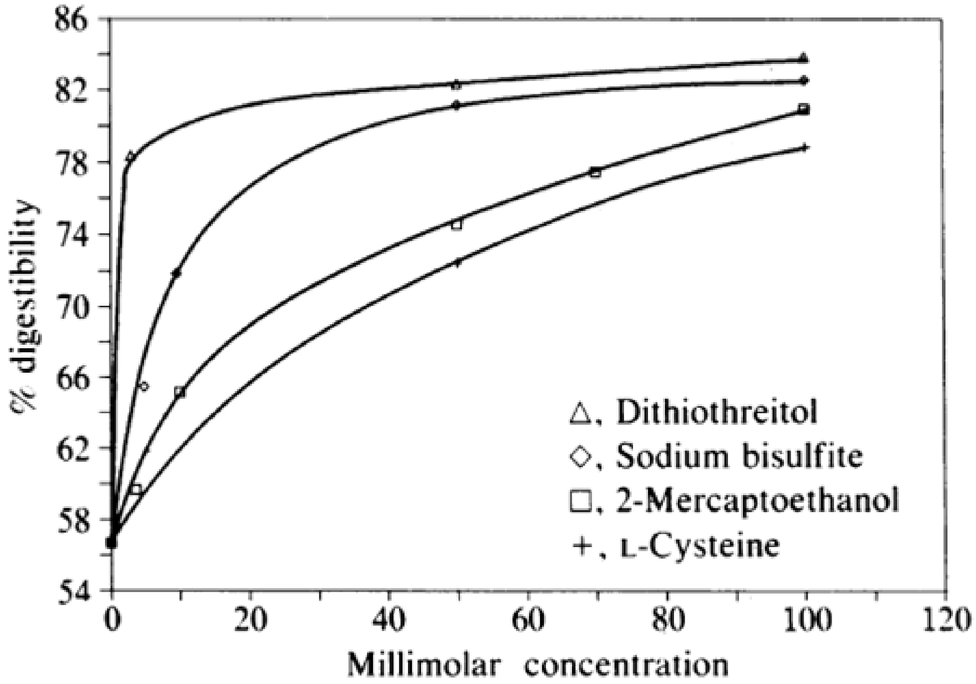


Figure 19. Effect of reducing agents on pepsin digestibility of cooked sorghum (Source: Haymaker et al., 1987).

Considerations for Use

Reducing agents are highly reactive. Table 8 describes some physical characteristics of reducing agents used in grain milling industries. The corrosive nature of these compounds would require feedlots to develop protocols relating to workplace health and safety and legislation relating to storage and handling of hazardous chemicals. Specific considerations relate to storage, handling (emergency protocols, spill controls), mixing and/or dosing systems and handling of any free steep water. The impacts of reducing agent on total levels of dietary sulphur should also be considered to limit animal performance and health issues.

Table 8. Physical characteristics of reducing agents used in grain milling systems (Sourced from relevant Material Data Safety Sheets).

Agent	Formula	Form	Solubility%[#]	pH
Sodium metabisulphite	$Na_2S_2O_5$	Powder	45	4.2
Ascorbic acid	$C_6H_8O_6$	Powder	30	2.4
B-mercaptoethanol	HSC_2H_4OH	Powder	100	6.5
Sulphurous acid	H_2SO_3	Liquid	100	1.5
Phosphoric acid	H_3PO_4	Liquid	100	1.5
Potassium hydroxide	KOH	Granule	100	12
Sodium hydroxide	NaOH	Granule	100	14
Acetic acid	CH_3COOH	Liquid	100	2.4
Citric acid	$C_6H_8O_7$	Liquid	65	2.2

#Solubility in water at 20^oC.

Du et al (1996) reviewed the effect of a number of acidic reducing agents on water pH pre- and post-steeping of corn. The steep water remained acidic as described in Table 9.

Table 9. The effect of acidic reducing agents added at 0.55% on steep water pH in the wet milling of corn (Source: Du et al., 1996).

	Steep water pH	
Treatment	**Before Steeping**	**After Steeping**
Control	5.93[a]	5.86[a]
Lactic	2.93[c]	4.34[c]
Phosphoric	2.07[d]	4.58[b]
Acetic	3.50[b]	4.59[b]
Citric	2.92[c]	4.20[c]
Hydrochloric	1.66[e]	2.87[e]
Sulphuric	1.28[e]	1.67[e]

Means with different subscripts in the same column are significantly different P<0.05.

Equipment must be manufactured from stainless steel for handling treated steep water and grain.

Conclusions

Reducing agents degrade the seed coat and endosperm structure (interaction between protein and starch). These processes enable greater water uptake rate and increased swelling of starch granules. Reducing agents increase digestibility of both starch and protein.

Reducing agent benefits are greatest in sorghum and corn, as these grains have a protein matrix surrounding the starch granules and additional disulphide bonding, compared with wheat and barley.

Reducing agents in a liquid form with high solubility would promote ease of use, for example, acetic acid compared with sodium metabisulphite. Depending on purity and container size, reducing agents cost between $350 to $550/tonne. At a 0.55% inclusion rate (5.5kg/tonne of grain), addition of these products adds $1.90 to $3.00 per tonne of treated grain.

A further consideration relates to agents that contain sulphur. Dietary sulphur intakes that exceed 0.35% increase the risk of inducing polioencephalomalacia (PEM). Sodium metabisulphite (approximately 34% sulphur) added at 0.55% to grain meets two thirds of the animals daily sulphur requirement. Additional sulphur sources in feedstuffs would risk exceeding the desired maximum sulphur intake.

The corrosive nature of many of these agents requires handling equipment made from stainless steel. Feedlot operators would need to review workplace safety and storage/handling protocols relating to legislation for hazardous chemicals.

4.3.1.2 Grain imbibition

Introduction

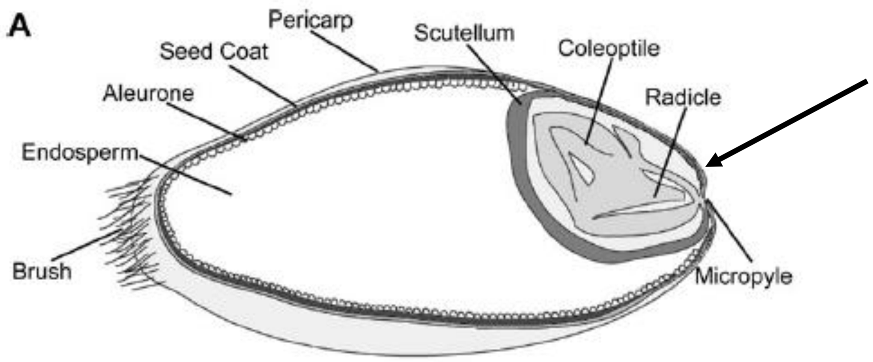
Imbibition is the term used to describe water uptake and swelling of grain. Several factors are known to impair imbibition including grain characteristics (storage period and grain age, grain type, grain size, starch and protein characteristics, moisture content) and water quality (water temperature, solute content).

Pre-wetting of whole grain is an important component of several grain processing systems including tempering (temper rolled), steam flaking and reconstitution. Consistent targeted grain moisture concentration increases operation efficiency and improves grain processing outcomes.

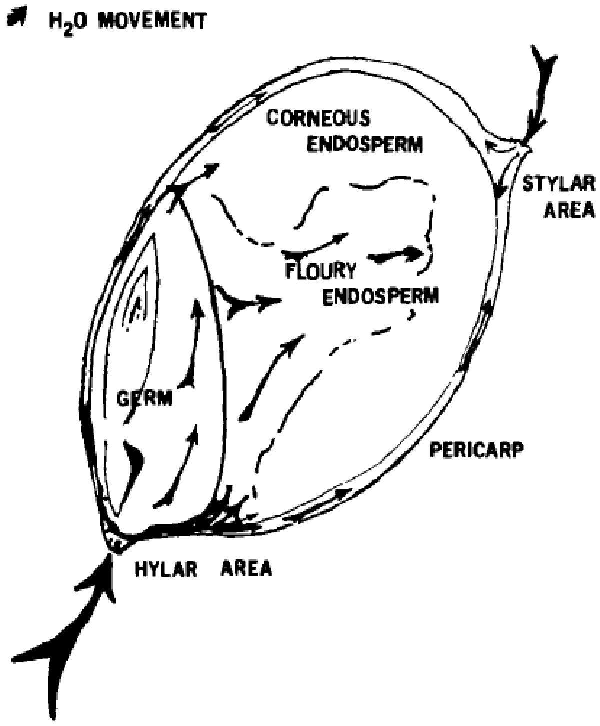
Pathway and Rate of Water Movement

The pathway of water movement is similar in cereal grains. Water cannot pass directly through the intact seed coat into the endosperm (Rathjen et al., 2009). Rather, water enters the seed where there are gaps in the seed coat. Primary sites of water entry include the micropyle at the base of the seed in wheat and barley, at the tipcap in corn and at the hilum and stylar in sorghum as described by Figure 20.

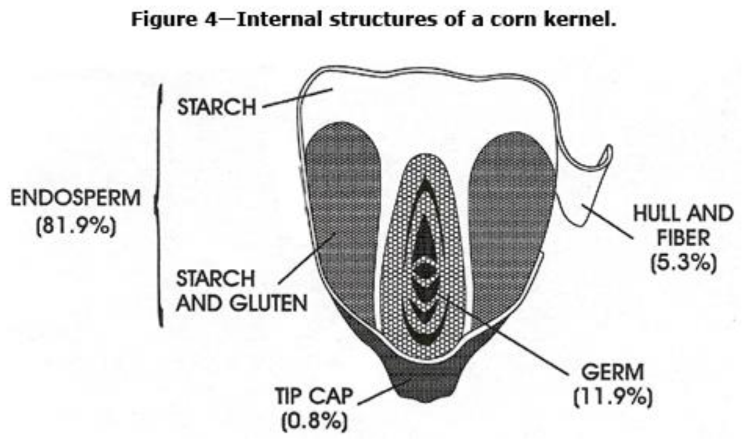
During initial stages of imbibition, water enters and fills the embryo and scutellum and then diffuses through the endosperm, firstly filling the floury endosperm and filling the corneous endosperm last. The diffusion of water through the endosperm is the main mechanism that controls rate of imbibition (Montanuci et al., 2013). Grains with higher proportions of corneous endosperm (sorghum and corn) have slower imbibition rates. Water is also transferred around the grain via the seed coat, between the pericarp (inner coat) and testa (true outer seed coat). These layers of the seed have wick like properties which facilitate water movement.


A
Pericarp
Seed Coat
Scutellum
Coleoptile
Aleurone
Radicle
Endosperm
Brush
Micropyle

a)


H_2O MOVEMENT
CORNEOUS ENDOSPERM
STYLAR AREA
FLOURY ENDOSPERM
GERM
PERICARP
HYLAR AREA

b)



c)

Figure 20. Water entry point of cereal grains a) micropyle in wheat & barley (Source: Rathjen et al., 2009) b) hylar & stylar in sorghum (Source: Rooney and Pflugefelder, 1986), c) tip cap in corn (Source: http://bioweb.sungrant.org).

The process of imbibition can be separated into three phases as described by Figure 21. Phase I (6-10 hours) and part of phase II (10-20 hours) are relevant to the steeping period and required moisture concentrations for grain processing (8 to 18 hours, 20-22% moisture).

Phase I is characterized by rapid water uptake, whereas phase II is characterized by a slower rate related to initial hydrolysis of starch and changes to osmotic pressure within the grain.

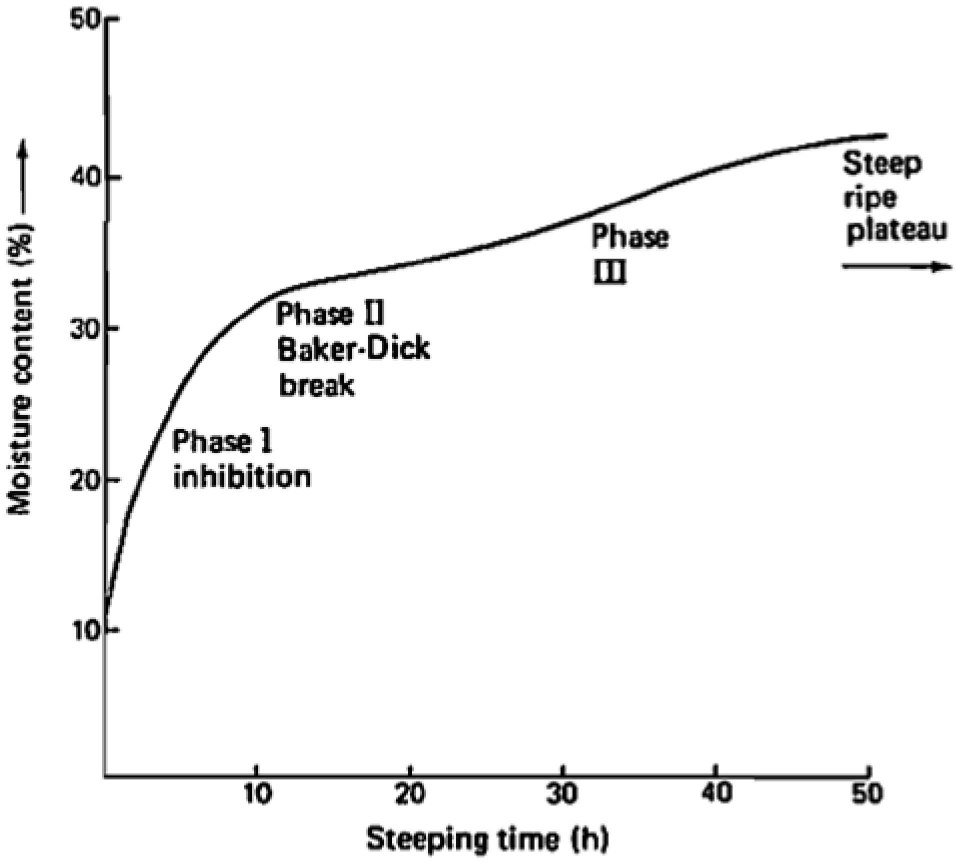


Figure 21. Water uptake pattern during the steeping of barley (Source: Lovett and MacWilliam, 1976).

Much of the initial water uptake of phase I occurs in the embryo as described in Table 10.

Table 10. Moisture concentrations of barley components during steeping (Source: Reynold and MacWilliam, 1966).

	Moisture (%) after steeping at 13°C for:			
	2hr	**4hr**	**6hr**	**24hr**
Scutellum	18.5	36.8	50.0	57.9
Embryo axis	33.0	43.6	51.3	57.9
Pericarp + testa + alcurono	11.4	15.6	26.8	36.4
Starchy endosperm	10.0	12.5	21.4	35.0
Husk	40.5	43.1	44.9	47.1
Whole grain (by direct estimation)	21.6	25.9	28.6	38.4
Whole grain (by summation)	20.9	24.8	27.1	37.5

Factors Inhibiting Imbibition

Factors that reduce the rate of imbibition include:

- Limited storage period

Newly harvested grain retains an intact waxy cuticle. The cuticle increases surface tension thereby preventing grain from being coated with a film of water. The cuticle is also present over the channel leading to the micropyle. Increased storage duration and handling appears to wear down this waxy cuticle.

- Grain moisture

Initial water uptake (phase I) is reduced in grain with moisture concentrations higher than commonly measured harvest moisture values (wheat & barley 12%, sorghum 13.5%, corn 14%). High grain moisture concentration reduces the water potential gradient between the grain and water, thereby slowing the transfer rate.

- Endosperm characteristics

Densely arranged starch granules and interaction with protein (peripheral endosperm found in sorghum, hard or corneous endosperm found in sorghum and to a lesser extent in corn) inhibit the rate of water intake and distribution throughout the endosperm (Montanuci et al., 2013). The peripheral and corneous endosperm are the last areas to absorb water (Rooney & Plugefelder, 1986).

- Weather damage

Rate of imbibition is more rapid in non-weathered wheat compared to weathered wheat (0.0136 vs 0.0130 g per hour) (Clarke and DePauw, 1989).

- Grain size

Larger grains imbibe water more rapidly than small grains (Lovett and MacWilliam, 1976).

- Solute content of steeping water

Dissolved minerals in the steeping water reduce the rate of imbibition (Rathjen et al 2009). Depending on the size of the dissolved compounds, water might not readily pass around the cuticle protecting the channel to the embryo.

Methods of Promoting Imbibition

- Heated Water

  Heated water reduces diffusion resistance and expands and softens grain, which increases the imbibing rate and reduces steeping duration. A survey conducted by Richardson et al. (1993) of feedlots using sorghum in the southwestern USA reported 42% of those who tempered prior to steam flaking used hot water and Richardson and Anderson (1982) reported that heating water improved the effectiveness of some wetting agents.

  The effect of water temperatures on imbibing rates are described in Figure 22. The pattern of imbibition is the same for all water temperatures, but increasing heated water temperature increases grain moisture content within a set duration.

  Considerations for the use of heated water in tempering include the requirement for sufficient capacity for large quantities of water to be heated, and minimizing shrink. Operations with steam flaking already have the energy source to heat water, although diverting heated water from the boiler may reduce boiler efficiency (see comments relating to condensate in section 5.3.4 Boiler Technology).

Shrink increases with water temperature. Shrink is generated by the leaching of nitrogenous compounds, sugars, minerals and vitamins. The heated water temperatures that promote imbibition the greatest also generate the highest leaching as shown by Figure 23. Grain shrink increases as water temperatures approach starch gelatinisation temperatures.

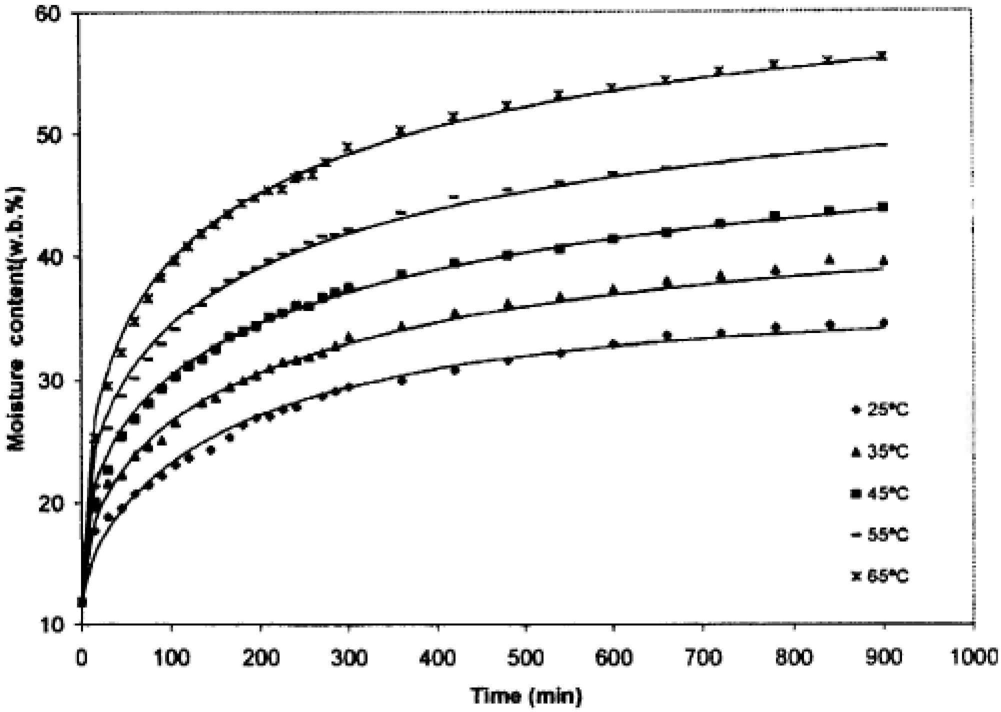


Figure 22. Effect of soaking time (minutes) and water temperature (^oC) on the water uptake of wheat (Source: Kashaninejad and Kashiri, 2007).

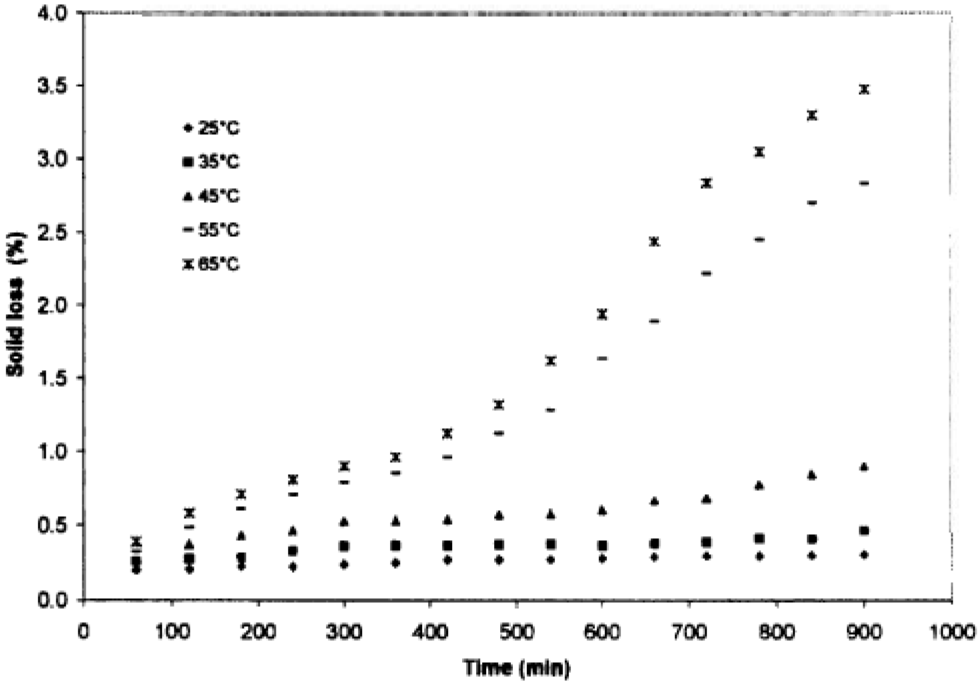


Figure 23. Effect of soaking time (minutes) and water temperature (^{0}C) on the total solids leach loss from wheat (Source: Kashaninejad and Kashiri, 2007).

- Grain scarification

  Scarification is the partial removal of the seed coat, causing a loss of its integrity thereby compromising the barrier it presents to the entry of water into the grain. Mechanical scarification has been used as a method to overcome physical dormancy of some grains (Huarte and Carcia, 2009) which inhibit a number of factors required for germination including water uptake. However, there is little evidence that this technology is currently in use within the Australian or USA feedlot industry.

  Mechanical methods of scarification include abrasion (grinding seeds with abrasive material or surfaces) or impaction (shaking). Scarification is designed to increase the rate of imbibition. However, the response is dependent on duration. Extended treatment increases the risk of seed breakage, whereas insufficient treatment may not be sufficient to promote a response. Grains which possess thick extensive pericarps such as legume seeds tend to respond well to scarification, indicated by increases in germination rates. Cereal grains are less responsive due to thinner seed coats and there is an increased risk of seed breakages. Clarke and DePauw (1989) reported that damage to the seed coat by a threshing method did not influence water uptake but may improve uptake of oxygen.

- Oxygenated Water

  Treating steeping water with oxygen (ozone) may also promote imbibition rate. Ozone (O_3) has a very high biological activity and reacts rapidly with both inorganic and organic substances in water, improving water quality. Ozone works well for enhancing water taste, aiding in coagulation and limiting microbial contamination (Glaze et al., 1987). Although no research has been done on the effects of ozone treated steeping water on imbibition, improvement in water quality with ozone treatment may remove those water characteristics which impede imbibition rate. Oxygen has been shown to promote endosperm activity which may also promote water uptake rate (Clarke and DePauw, 1989).

Conclusions
The method of improving imbibition of grain relates to promoting entry of water and diffusion rate within grain. Heated water achieves both these requirements; however, the cost of heating water requires review. Heating large quantities of water for delivery at high flow rates requires a high energy input (gas) or heating infrastructure (solar heating system). On the other hand, the heating costs of operations with access to heated artesian water should be low. Heated steeping water has additional costs relating to shrink. The amount of shrink increases with increasing temperature and steeping duration (1% shrink at 65^{o}C for 6 hour steeping, 2.75% for 12 hour steeping). The capacity to recycle steeping water will not eliminate shrink losses completely due to the heat volatilising nitrogen compounds and degrading vitamins.

The effects of grain scarification are limited. For additional infrastructure, the response is variable with increased risk of breaking grain into smaller particles.

The use of oxygenated water in feedlot grain processing warrants further investigation. This method of water treatment removes many of the factors which inhibit imbibition. An ozone generator can be simply fitted to existing plumbing, requiring no additional infrastructure.

4.3.1.3 Wetting auger technologies

Introduction
A wetting auger is a critical component for any grain processing systems which require moisture addition. This includes tempering, steam flaking, reconstitution and fermenting. These grain processing systems require both targeted moisture addition (total target moisture concentrations of 20-22% tempering and steam flaking, 30% reconstitution, 35% fermenting) and moisture consistency. The wetting auger design and function must not only provide sufficient transfer capacity (tonnes/hour) but also apply and distribute targeted quantities of water uniformly to each grain.

Objectives of a Wetting Auger
The objectives of a wetting auger include:

- Apply and distribute targeted quantities of water (8 to 12% for tempering and steam flaking, up to 20% for reconstitution, up to 25% for fermentation) uniformly to grain
- Ensure even distribution of water to the grain surface to avoid fluctuating moisture concentrations
- Promote adherence of water to the grain surface to enhance imbibition rate
- Minimise or eliminate free water
- Prevent transfer of free water into the tempering bin and throughout the grain handling equipment
- Provide continuous mixing and delivery to meet production requirements (tonnes/hour)

- Account for variations with grain (density, particle size, received moisture content) and environment (ambient temperature)

Current Wetting Augers

Wetting augers currently available are composed of a combination of auger types fitted within a trough casing. Augers and casing are stainless steel to promote life. The different auger designs are described in Figure 24.

- Ribbon
  Promote residence time within mixer auger
- Paddle
  Promote mixing of grain with water and transfer of grain through auger

a)

b)

c)

Figure 24. Wetting auger types including a) Ribbon (www.conveyoreng.com), b) Paddle (Source: www.phxequip.com), c) Combination or Conveyor Paddle (Source: www.turbokopar.com).

Limitations of current wetting auger design include:

- Limited residence time
  Wetting augers operating to maximise capacity (tonnes/hour) fail to distribute the required quantities of water uniformly. These augers tend to produce high levels of free water, particularly when targeting high water addition rates (>10%). High capacity augers require greater length and/or angle (up to 30^{o}) to promote residence time.

  Total mixing time requirements for the addition of liquids is based on the mixing duration required to achieve a desired co-efficient of variation (15%). The minimum wetting mixing time is 75% of this time (Evonik Industries, 2010). For example, if the wetting auger is rated at 2 minutes to achieve a CV of 15%, the minimum mixing time is 90 seconds. Commercial feedlot operations may have tolerances for tighter moisture variation of processed grain (e.g. CV < 5 %).

- Over-filling
  Attempting to maximise capacity by over-filling the wetting auger compromises distribution of water to the grain, thereby increasing moisture variation.

- Operation flexibility
  Wetting auger operation often lacks flexibility. Equipment operates at the same speed irrespective of changes to grain quality (density, particle size, grain type, hydrophobic characteristics) or the quantity of water required to achieve target moisture concentrations.

Alternative Wetting Auger Designs and Technology
Design considerations which promote function of the wetting auger include:

- Maximise residence time
  - Achieved through appropriate length and angle of elevation of the auger
  - Incorporate two-stage wetting systems used in reconstitution
  - Change the angle of the mixing blades
    Modify capacity and retention time depending on grain characteristics and moisture target and uniformity.

- Incorporate a surge bin for delivery of grain to the wetting auger. Promotes consistency of grain presented to the wetting auger, and promotes consistency of water addition

- Incorporate automation to remove variation
  - In-line NIR moisture and water flow rate meters
    Allows for constant measuring of moisture content of incoming and exiting grain to and from the wetting auger. Connecting this information to a variable speed motor and/or flow meter improves the water addition consistency and distribution.
  - Use of weigh augur or impact weigher to determine the dry-grain transfer rate

- Classification system to define operation
  Wetting augers are currently defined in terms of capacity (tonnes/hour). Incorporating a classification that also relates to mixing ability and uniformity such as proportion of free water would improve functional description.

4.3.2 International and precision technology

4.3.2.1 Technologies from USA

Introduction
A number of industries in USA were interviewed regarding new technologies that may be applicable to the Australian feedlot industry (Appendix I, Table 1). The views of industry experts were:

- The US use primarily corn based feeding systems and grain is delivered with low moisture variation and quality grade
- The recent expansion of the ethanol industry removed processing equipment capacity limitations
- The conversion of mills from bins to bunkers to store flaked grain has allowed milling equipment utilisation to be maximized

- More advanced technology has not rapidly been adopted due to:
    - Language barriers
    - Staff turnover
    - Equipment costs
    - Training

- Processing methods that have been adopted to reduce cost and improve consistency include:
    - Improved grain cleaning
    - Longer steeping period (12 hours)
    - Automated steam control
    - Improved steam distribution
    - Larger roller mills
    - Greater flaked grain storage (bunks)
        - The objective of these improvements is to deliver a clean grain of consistent moisture to the flaker, control the quality and thermal delivery rate of steam, and to set the grain flow at maximum that will produce a desired flake.

It was pointed out (Owens, 2016, Per Comm.) that there is greater value in preparing grain for the flaking process rather than modifying the flaking process itself (roll gap adjustments, peg feeder speed, on-line temperature/moisture measurements) to compensate for variation in grain, as this results in losses in efficiency and production capacity. The feedlot mills in USA do not use heated water due to cost and a perception of low effectiveness.

The views of Ferrell-Ross Roll Manufacturing indicated that it is difficult to predict feedlot industry trends for the application of new technology. The following summarises their observations

- Roll gap adjustment
  No true automatic roll gap adjusters, the challenge is setting a 0 gap
  Manual positive stop roll adjustment is standard
- Use of Programmable Linear Control (PLC) to automate some aspects of the process (variable speed motors)
- In-line sensors
  Ferrell Ross uses a sensor in the steam chest that modulates steam valves through PLC control (temperature & moisture in chest). Most yards prefer manual steam control.
- No application of systems to assess flake quality.
- Wetting auger technology remains the same, but Ferrell Ross uses a conditioning auger, which operates on the same principles as a wetting auger. The auger and trough are sized to the capacity of the steam chest, with paddles to promote mixing, variable speed motors to ensure maintenance of the correct speed for the grain delivery rate, and a metering system for controlled addition of water/surfactant. Grain residence time is 30 to 90 seconds.
- No use of heated water.

- Groove design and configuration has not changed - 14 grooves for flaking corn, 16 grooves for barley, wheat & sorghum.
  Some new designs for European distiller operators (modified Dawson with spiral, 25mm lands)

The views of an Australian milling equipment manufacturer (Satake Australia, www.satake.com.au) on possible applications of new technology were:

- Merits in Increasing the size of steeping bins to ensure a sufficient steeping period
- Some application of NIR, mainly at receival

4.3.2.2 Near Infrared Reflectance Spectroscopy (NIRS or NIR)

A key aspect of improving consistency of grain processing is using equipment that can measure production factors during operation. The opportunities relating to grain processing include:

- Improving the ability to monitor the grain processing performance (related to animal performance as well as production costs) in real time.
- Measuring the quality of incoming grain and using these parameters to adjust equipment settings to optimise processing efficiency, grain utilisation and animal performance.
- Automatically measuring and adjusting the processing settings when quality control limits are exceeded, to adjust the processing performance back to within specification.

Using technology to monitor grain processing quality can assist in achieving an optimised balance between production costs and processed grain quality for feedlot cattle.

4.3.2.2.1 Monitoring particle size distribution

An opportunity exists to improve the quality of processed grain by monitoring and controlling particle size of processed grain in real time. Near Infrared Reflectance Spectrometry (NIRS or NIR) is a technology that can measure particle size (Ilari *et al*., 1988; Ciurczak *et al*., 1986). NIRS uses infrared light absorbance to relate the observed spectra to known physical and chemical characteristics of the subject material. Particle size is a physical characteristic which strongly influences NIR spectra. Compared with traditional stack sieve methods, NIR is quicker and little sample preparation is required to complete the test. It also requires little operator training. However, accurate results from NIR are dependent on robust calibrations of the machines against known conventional analytical techniques (e.g. laboratory measurement of starch digestibility, physical measurement of particle size distribution). Typically, hundreds to thousands of physical measurements are required to develop a robust NIR calibration.

4.3.2.2.2 Monitoring steam flaking processing

The opportunity to utilise NIR with steam flaking is to automatically measure and adjust processing settings to maximise animal performance and minimise processing costs. Firstly, a method to determine starch digestibility, which correlates to animal performance is needed. The test method will need to be rapid and able to be run in a commercial production system. Industry research through the Premium Grains for Livestock Program (PGLP) was successful in publishing and commercialising rapid tests for available energy content of grains for monogastric animals and ruminants. The PGLP research used animals to measure energy disappearance from cereal grains along the entire digestive tract, which was used to generate NIRS calibrations for digestible energy content of cereal grains in pigs and metabolisable energy in poultry, beef cattle and sheep (Black, 2008). There are also NIRS calibrations developed to measure the starch percentage and physical characteristics of grain. While this research work concentrated on whole and ground grain, further research and funding could be used to develop a method to test steam flaked grain for starch availability and also to develop NIRS calibrations to measure digestible starch values in steam flaked grain which relate to animal performance measurements. Preston et al. (1993) evaluated the use of NIR and its potential to measure starch availability in steam-flaked grains and found that starch availability in steam-flaked sorghum grain can be described with a high degree of precision.

The PGLP (Black, 2008) also developed a NIR calibration for starch in cattle faeces to assess the effectiveness of grain processing. The calibration was based on over 300 faecal samples collected from individual steers offered feedlot rations containing barley, wheat, triticale and sorghum grains processed to varying degrees. The faeces contained from 0.01 to 48.7% starch on a dry matter basis. The process required drying faeces at 55-60ºC, then grinding through a laboratory mill with a 1 mm screen before scanning with a near infrared spectrometer. The calibration was extremely robust with a cross-validation correlation (R^2) of 0.99. Also, Fredin et al. (2014) investigated if total-tract starch digestibility by lactating dairy cattle could be predicted accurately from the concentration of starch in faecal dry matter. They found that faecal starch concentration was closely and linearly related to total-tract starch digestibility ($R^2 = 0.94$). They also found that differences in faecal sampling time for faecal starch, such as day within week or week, did not influence determination of faecal starch concentrations and concluded that on-farm collection of faeces from individual cows or pens of cows could be done only once per day for reliable results. An equation was developed to predict faecal starch concentrations using NIRS of dried ground faecal samples that had moderate to good accuracy (R^2 = 0.83–0.94) and a low standard error of prediction.

Most feedlots have drying ovens and could grind samples and therefore this method could be used to determine faecal starch concentrations in commercial feedlots. However, the problem with drying samples is that it takes up to 72 hours. More rapid analysis could be achieved if NIR technologies could be used on fresh faeces for measuring faecal starch. There has been limited work done on the use of NIR on fresh faeces. The challenge with using fresh faeces is the high moisture content (around 80%) which means that the concentrations of the nutrients of interest are much lower. It may be that NIR cannot measure accurately at these lower concentrations. Also, a large error is generally observed at lower concentrations. The effects of whole grain and a wide distribution of grain particle size may also make development of a NIR calibration for starch in fresh faeces difficult. Further research is needed to explore if a NIR calibration for measuring faecal starch on wet faeces is sensitive enough to be commercially viable.

4.3.2.2.3 Monitoring grain quality parameters prior to processing

Measuring nutritional characteristics of grain prior to processing, can assist in optimising the settings of the processing equipment, to produce a consistent quality processed grain for operational efficiencies as well as enhanced animal performance. NIRS technology has successfully been used to measure nutritional content of grain, quickly and accurately. For example, moisture levels in grain can be easily determined by NIRS (Ward, 2016). Using the moisture readings to adjust settings such as equipment processing speed or cooking time, can assist in improving operational efficiency as well as produce a more uniform processed grain product within specification for improved animal performance. NIR calibrations from PGLP for predicting chemical composition, metabolisable energy content and the likelihood of a grain causing acidosis are now available commercially through the UK company, Aunir, under licence from the Pork CRC.

4.3.2.2.4 Automatic monitoring of grain processing performance

NIRS technology has traditionally been setup as a bench top instrument, however it can also be used directly in the production line (i.e. In-line NIRS), to automatically measure the performance of the grain processing, continuously during production (Ward et al. 2014). The advantage of In-line NIRS is that sample collection is not required and results are generated more frequently. Figure 25 shows the In-line NIRS of sorghum during processing measuring ground sorghum moisture concentrations as the product is flowing over the NIR measurement head without having to trap a sample.

With the use of computer controllers, In-line NIRS can be further integrated into the production process by being connected to an alarm to notify operators if the processed grain is outside the expected parameters and this integrated system can be structured to automatically adjust processing parameters to realign processing back within the control limits. Automatic measurements reduce the effects of sampling error as the processed product is being measured regularly and ensures processing issues are identified early.

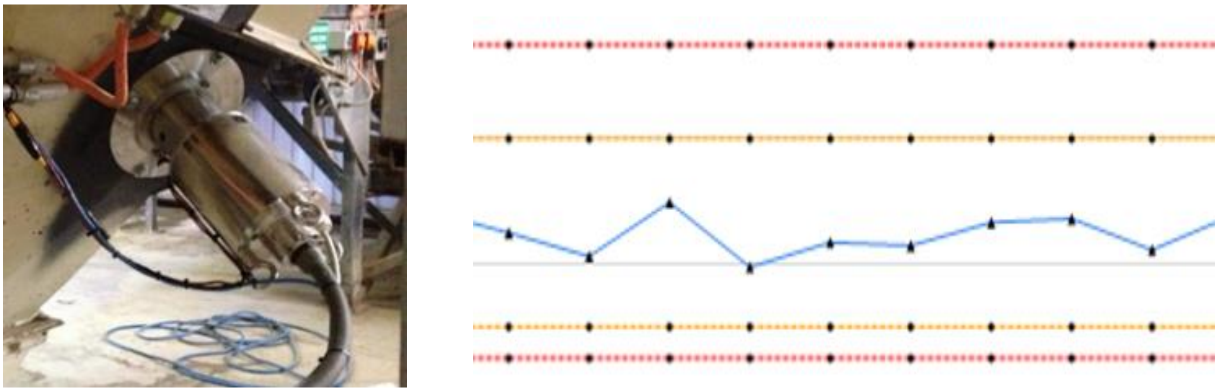


Figure 25. In-line NIRS of sorghum during processing measuring ground sorghum moisture concentrations. The measured values are blue lines with limits of orange warning lines and red alarm lines. The photo is of an installed Bruker in-line NIR emission head (Source: Courtesy of I Ward, Agri-Torque, 2016).

With In-line NIR technology, opportunity exists to improve grain processing quality with the aim to improve animal performance.

There is a raft of new NIR technologies that have the potential to be scaled up to in line whole grain NIR analysis with segregation of grain parcels based on their chemical properties and therefore their nutrient densities. Current commercially available in-line whole grain analysers use a remote sampling head to trap a sample of grain taken from the intake elevator at timed intervals before returning the grain to a conveyer belt that can segregate the grain. Typically, a reflector lamp is passed through the trapped sample of grain, a fibre optic cable collects the light that passes through the grain sample and transmits the NIR light back to the spectrometer and the grain is segregated based on the pre-determined calibration. However, despite considerable research in this field, there have been few commercial studies on barley grain composition variability using NIR spectroscopy in closed systems like a feedlot, and the application of this to the management of the quality of feed rations. Harding et al. (2013) evaluated the use of NIRS for nutrient prediction of barley and wheat grains. They found that NIRS technology can adequately predict CP of barley and wheat grain and accurately predict DM of barley grain. The authors concluded that additional research must be done to improve current calibrations evaluating DM of wheat and starch content of barley and wheat grain. Similarly, O'Neill et al. (2013) found that NIRS technology can adequately predict DM and CP of barley (sampled in Western Canada), but found that prediction accuracy decreased with variation in the population sampled. Nevertheless, they concluded that accurate predictions can be obtained for DM and CP concentration of barley arriving at feedlots in western Canada using commercially available NIRS prediction equations, but that starch concentration is not accurately predicted with this current application. This is contrary to results from PGLP (Black, 2008) where the R^2 relating NIR predicted to measured starch content in 186 cereal grain samples was 0.95 and starch content was predicted with an accuracy of ± 3.5%.

Examples of manufacturers of NIR equipment are Foss and Bruker. Pricing for NIR equipment depends largely on the feedlot and their requirements. Hardware from these manufacturers that measures a restricted range of nutrients is priced from about $30,000 and equipment that measures a broader range of measurements is priced from approximately $70,000. The in-line system will eliminate the need for sample collection, reduce the potential of human error and reduce sampling error, as many more data points are measured per quantity of product. The indicative price of an in-line system is from $110,000 (I Ward; Agri-Torque, Per Comm. 2016).

If lot feeders are to capture the maximum possible value from investment in technology such as NIR, there needs to be increased understanding of the variability in grain composition at feedlot receival. Further, more robust calibrations need to be developed that are feedlot specific rather than "off the shelf calibrations" that do not reflect regional and environmental differences.

The aim of such an approach would be to improve the efficiency of livestock feeding through developing differential feeding programs based on feed characteristics as estimated by NIR and to decrease the variation in feedstuffs delivered. An adoption pipeline is proposed below (Figure 26).

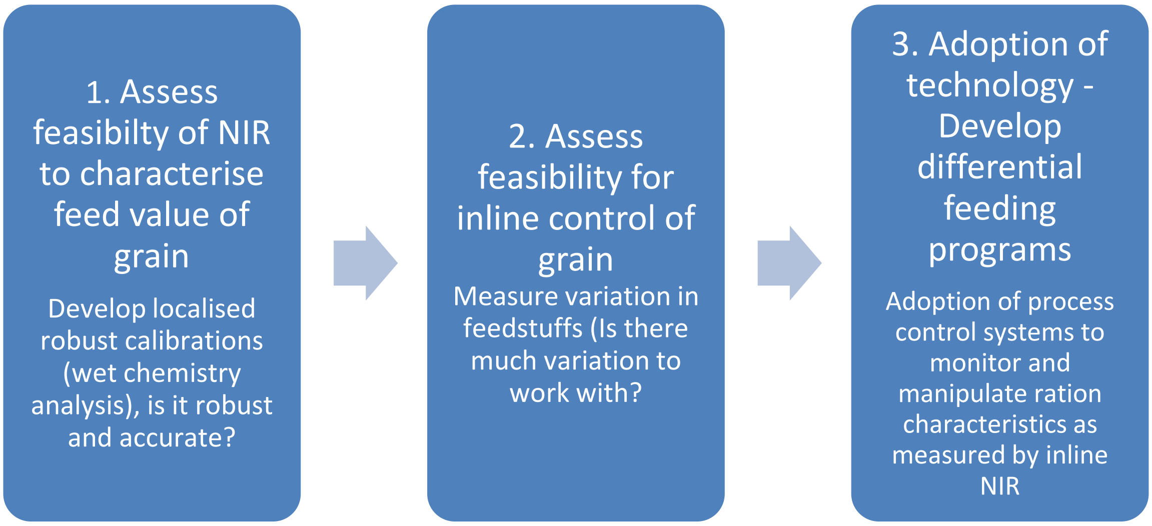


Figure 26. Proposed adoption line of NIRS technology and In-line NIR for the feedlot industry (Source: Courtesy of Kenton Porter, University of Adelaide, 2016).

The NIR application most likely to generate immediate benefit for the feedlot sector is the use of in-line NIR in conjunction with a computerised controller to manage accurate water application in wetting augers in the tempering process.

4.3.2.3 Flake Colour Index System

The degree of starch gelatinization or starch availability (SA) of steam flaked corn (SFC) can be estimated using analytical procedures such as enzymatic hydrolysis, gas production, and SFC gelatinization methods (Vasconcelos and Galyean, 2007). Schwandt et al., 2015 used the Flake Colour Index System (FCIS), a proprietary colour intensity measurement device (Lextron Inc., Greeley, CO) that can be used for the estimation of starch availability (R2 = 0.89; $P < 0.01$). Regular evaluation of starch availability provides an effective quality control method to standardise the steam flaking process to ensure within-day and day-to-day manufacturing consistency. With the FCIS, a modified colour meter is measures the colour of fresh flakes taken beneath the rolls. This measurement is purportedly correlated with the degree of gelatinisation and SA, although no publicly available research has been conducted with the FCIS. McDonough et al. (1997) studied the structural characteristics of steam flaked sorghum and, based on subjective evaluation, birefringence and scanning electron microscopy, poor quality flakes were opaque, chalky in appearance and prone to breakage, compared with good-quality flakes that were translucent, thin and strong, with little chalkiness and low levels of dust and fines. In good-quality flakes, starch had a high degree of gelatinization, and the dehydrated starch continuous phase surrounding the granules decreased the amount of air space within the flake, thereby increasing translucency.

Methods used to measure the amount of available starch have been evaluated (Xiong et al., 1990). Vasconcelos and Galyean (2007) surveyed feedlot consulting nutritionists and found that the enzymatic method to determine starch availability was preferred by 44.83% of the nutritionists, whereas a gas production method was preferred by 13.79% and gelatinisation by 6.90%. Five nutritionists (17.24%) used a combination of the enzymatic method with gas production, gelatinisation, FCIS, or the Kansas State University refractometer method (Sindt et al., 2000). Enyzme hydrolysis is costly and time consuming (Xiong et al., 1990), and sampling procedures and inherent variation within the assay could influence results

McMeniman and Galyean (2007) studied simulated air lift and belt conveyor elevator systems for steam-flaked corn and used FCIS measurements as one of the methods to determine SA. Flaked grain samples were sampled both immediately and after a 4 h storage period. Whilst the 4 h FCIS measurements did not differ between treatments, there were differences in SA after 4 h. The authors suggested that if starch retrogradation occurred in the belt conveyor elevator samples, translucency of the flakes, as measured by the FCIS, was not altered by retrogradation. FCIS has the potential to be used as a measure of starch availability provided the grain used and the milling system does not result in retrogradation, and warrants further research.

4.3.3 Comparison of technologies across industries

4.3.3.1 Comparison of processing methods for sorghum

The Premium Grains for Livestock final report (Black, 2008) examined a number of different processing methods for improving the digestibility of sorghum grains for cattle. The processes evaluated were either being used by the animal industries or designed to increase the digestion of starch by disrupting the protein matrix surrounding the starch granules. The main processes examined were targeted to physically damage the protein matrix: rupturing it through expansion of starch during gelatinisation; digesting it with added chemicals; digesting it with endogenous enzymes released during germination; or use a combination of mechanisms. The treatments of sorghum grain included grinding through various screen sizes, cooking in water, extraction of protein using tert-butanol and dithriothreitol, ensiling with urea for 5 months, reconstitution (steeping in water to approximately 30% moisture), reconstitution and anaerobic ensiling (to mimic a harvestore silo), germination, germination followed by ensiling, steam-flaking, steam-pelleting, extrusion at >125˚C and greater than atmospheric pressure, and microwaving.

The *in vitro* enzyme digestion of starch is shown in Table 11 for each of the processing methods investigated and compared with unprocessed normal and waxy sorghum samples. The observed range in enzyme starch digestion is shown when more than one sample of sorghum was examined in a process. The same sample was used for the steeping, germination and anaerobic ensiling processes.

Table 11. Effects of different processing methods on the *in vitro* enzyme digestion of sorghum starch (Source: Black, 2008).

Treatment	***In vitro* enzyme digestion of starch (% starch)**
Unprocessed normal sorghum	23-43
Unprocessed waxy sorghum	42-56
Fine grinding (1mm screen)	42
Protein extraction (58% protein removed)	49
Urea ensiling (5 months)	43
Steeping (24 hr to 30% moisture)	27
Steeping and 21day anaerobic ensiling	27
Germination (5 days)	35
Germination (5days) + anaerobic ensiling (16 days)	43
Steam flaking	70-84
Grinding and steam pelleting	54-64
Extrusion	89-94
Microwaving	70-82
Cooking (5-10 mins > 85˚C)	90

The results suggest that only those processes that involve some degree of starch gelatinisation (steam-flaking, steam-pelleting, extrusion, microwaving or cooking) show major improvements in the digestion of starch in sorghum. Variability in the extent of starch digestion between samples undergoing the same process appears to be greater in those processes where the proportion of gelatinisation varies (steam-flaking, steam-pelleting and microwaving) between batches, but was more constant during extrusion. It is particularly difficult to obtain uniform gelatinisation of the starch in sorghum over time during the steam-pelleting process. This is due to its high gelatinisation temperature and often high moisture content which limits the increase in temperature that can occur with the application of steam before the moisture content of the mixture pre-pelleting exceeds the maximum allowed of 17-18%. Moisture content above this maximum is often associated with jamming of the pellet press.

Samples from pelleted, extruded and microwave treatments, examined with an electron microscope, showed substantial disruption of the starch-protein matrix structure. The pelleted sample showed substantial breaking of the protein matrix, but individual starch granules were still clearly visible (Figure 27). Extrusion appeared to completely destroy the starch granule-protein matrix structure into a largely amorphous material (Figure 28), whereas microwaving appeared to blow the starch granules from the protein matrix leaving the skeleton of the matrix intact (Figure 29).

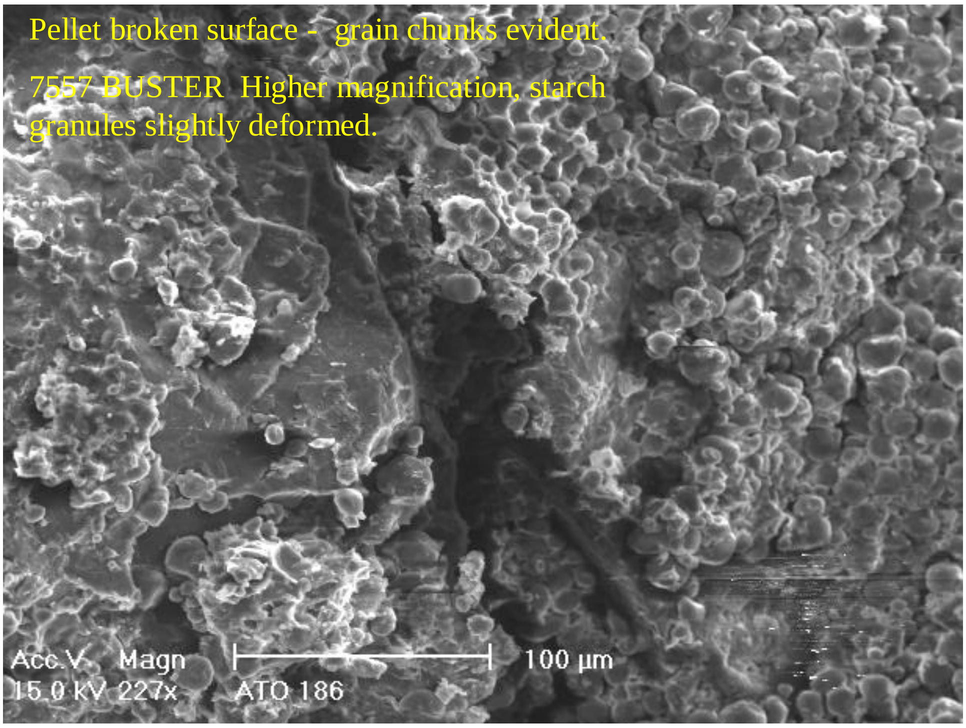


Figure 27. Electron micrograph of a pellet made from sorghum showing slightly deformed, but still intact starch granules partially dislodged from the encapsulating protein matrix (Source: Black, 2008).

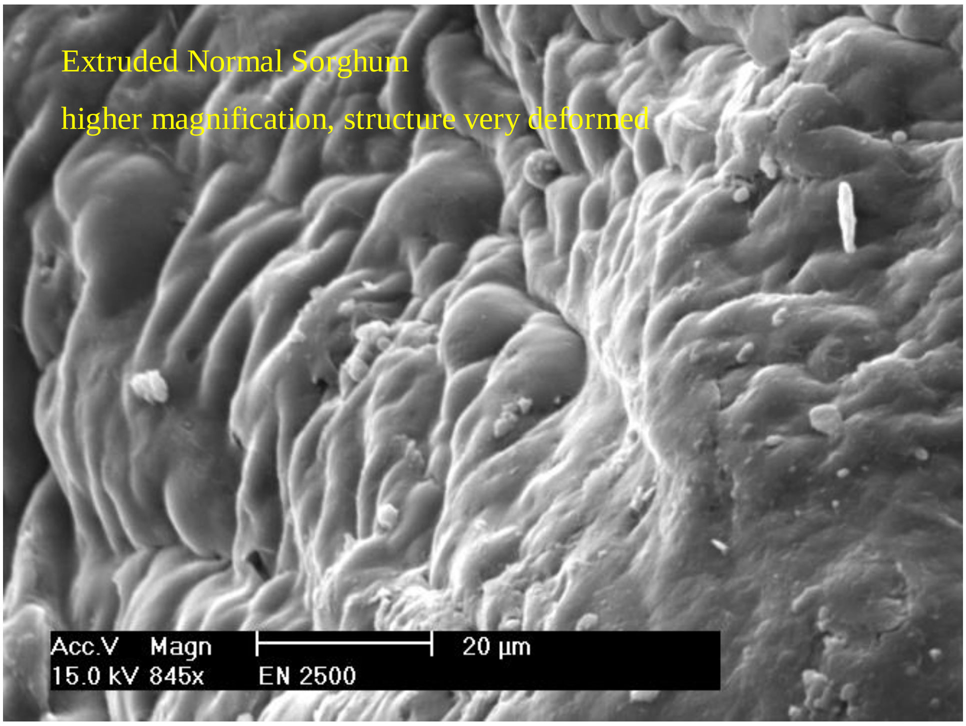


Figure 28. An electron micrograph of extruded sorghum showing almost complete destruction of the microstructure of the starch granules and protein matrix (Source: Black, 2008).

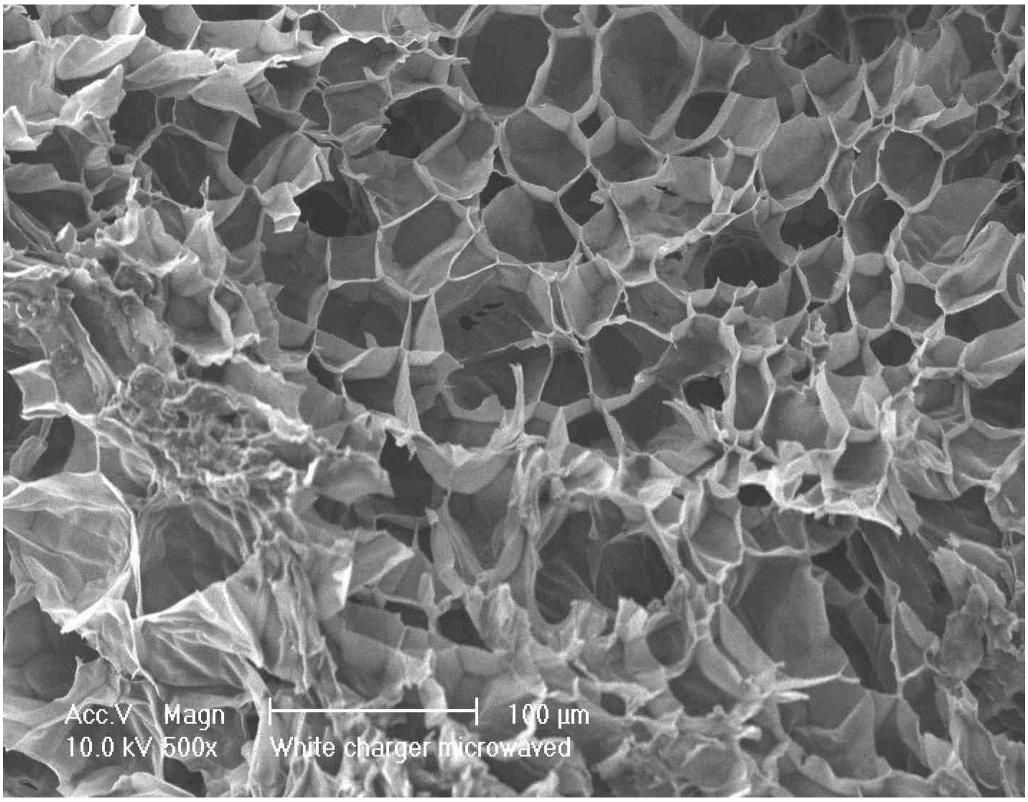


Figure 29. An electron micrograph of sorghum following microwaving showing the 'popping' open of the protein matrix and disappearance of the starch granules (Source: Black, 2008)

The physical disruption of the protein matrix by fine grinding or its partial removal using reducing chemicals caused significant, but only moderate, improvement in starch digestion compared with the processes that resulted in gelatinisation. Although germination significantly improved ($P<0.05$) *in vitro* starch digestion relative to the unprocessed control (Balogun *et al.,* 2000), the improvement was less than that observed with grinding and protein extraction. Anaerobic ensiling of sorghum for 21 days did not significantly improve starch digestion relative to the control. However, 16 days anaerobic ensiling following 5 days germination resulted in a synergism with significantly more starch being digested than with germination alone. The variable results reported from the use of Harvestores™ may be due to differences in the extent of germination of grain before the anaerobic ensiling is initiated.

In summary, the experiments using *in vitro* assays to investigate the suitability of different processing techniques for improving the digestion of sorghum by cattle suggest that almost total disruption of all protein matrix envelopes surrounding starch granules is required for near complete starch digestion. Such a high consistency of protein matrix disruption appears to be achievable only through gelatinisation of the starch within the envelopes. However, the relatively high gelatinisation temperature and often limited capacity to add steam resulted in substantial variation between batches in the digestibility of steam-pelleted or steam-flaked material. More consistent high digestibility was obtained with extrusion and microwaving where higher grain hydration could be achieved. However, the practicality of microwaving large amounts of grain for feedlot cattle is questionable (refer to Chapter 5.3.3.5).

4.3.3.2 Technologies used in the monogastric industries (pigs and poultry)

The monogastric industries use various methods of grain processing such as milling, steam conditioning and pelleting, extrusion, expansion, popping, sieving and adding specific enzymes, microbes or live yeasts to dry or wet feed. Due to the costs involved with those processing systems novel to the feedlot sector, in combination with assessment of performance benefits, it was concluded that the use of exogenous enzymes was the only technology from these industries that might have potential application in the Australian feedlot industry.

4.3.3.3 Exogenous enzymes

Enzymes not produced within an animal digestive tract and derived from other sources are termed 'exogenous' enzymes. Exogenous enzymes are used widely in pig and poultry diets (Bedford, 2000; Bedford and Partridge, 2010; Ravindran, 2013). Pure and specific enzymes can be produced cheaply in microbial cultures using gene transfer technologies. Enzymes are added to animal diets to:

i) increase the digestion of specific nutrients, such as phytate bound phosphorus and calcium;
ii) increase the accessibility of animal enzymes to specific nutrients to increase digestibility, such as xylanases and glucanases to degrade endosperm cell wall structures to improve amylase accessibility to grain starch granules;
iii) enhance the effectiveness of animal enzymes by predigesting specific nutrients and increasing overall digestibility within the digestive tract;
iv) degrade compounds that bind either nutrients or animal derived enzymes and reduce digestibility, such as trypsin inhibitors, lectins, tannins and other polyphenols.

The enzyme groups that can be added as supplements to domestic animal diets are:

i) phytases, for the degradation of phytate and release of phosphorus, calcium and other nutrients bound by phytate;
ii) xylanases, glucanases and cellulases for the degradation of plant cell walls and cellulose;
iii) amylases, β-mannanases, pectinases and α-galactosidases for the degradation of starches, oligosaccharides and other shorter chain carbohydrate complexes;
iv) proteases for the degradation of dietary proteins and protein based anti-nutritional factors such as trypsin inhibitors and lectins;
v) laccases and tannases for degradation of polyphenols, lignin and tannins.

Phytases, xylanases and glucanases are regularly added to pig and poultry diets, whereas the other enzymes have been used only intermittently.

Phytases

Phytases degrade phytic acid, which is an inositol ring with six phosphate ester bonds and is the primary storage of phosphorus in seeds including cereal grains. Phytate bound phosphorus is almost indigestible in monogastric animals with most passing through the digestive tract to the environment (Dersjant-Li et al., 2014). Phytic acid binds to di- and trivalent minerals and other compounds in the small intestines of animals. Phytic acid in cereal grains results in reduced nutrient utilisation, increased protein, energy and mineral requirements and can reduce animal performance (Dersjant et al., 2014).

Phytases in ruminant diets
In contrast, rumen microbes are a source of highly active phytases, which degrade phytate within the rumen (Nakashima et al., 2007). However, these microbial enzymes do not release all the phytate bound phosphorus in cereal grains (Humer and Zebeli, 2015). Several experiments have shown exogenous phytases when added to cereal based ruminant diets decrease intake of phytate bound phosphorus and increase overall phosphorus digestibility (Beauchemin and Holtshausen, 2010; Jarrett et al., 2014). However, the magnitude of the effects are generally small and no increase in productivity of feedlot cattle or dairy cows has been observed. The greatest impact of added phytase is likely to occur when cattle are fed barley or wheat based diets, because the phytate in these grains is primarily located in the aleurone which is more resistant to microbial degradation than the endosperm.

Xylanases and glucanases
Xylanases and glucanases are added to most poultry diets and some pig diets in combination with phytases. Xylanases and glucanases are used in pig diets to degrade grain endosperm cell walls because pigs masticate feed poorly and do not break many cell walls when chewing grains. Xylanases and glucanases are added to poultry diets primarily to reduce the chain length of the non-starch polysaccharides, β-glucans and arabinoxylans, and to reduce the viscosity of digesta. The use of these enzymes in pigs and poultry increases the accessibility of amylase enzymes to starch granules.

Xylanases and cellulases for ruminant diets
Cellulase and xylanase enzymes are produced by many rumen microorganisms. The effects of adding exogenous enzymes to the diets of ruminants have been reviewed by Beauchemin et al. (2002) and Beauchemin and Holtshausen (2010). These reviews suggest that although there are a few experiments that suggest positive effects of added exogenous enzymes on ruminant performance, the majority show no responses. These results showing no response to added enzymes have been confirmed in more recent publications (Phakachoed et al., 2012; He et al., 2014, 2015). The effects of these enzymes appear to be greater for diets containing high amounts of forage and appear to have little place in feedlot diets.

Conclusions for inclusion of enzymes in feedlot diets
Evidence presented suggests there is little advantage to be gained by adding exogenous enzymes to diets for feedlot cattle because these enzymes are produced in large amounts by microbes within the rumen.

4.3.3.4 Technologies from the flour milling industries

Introduction
The views of industry experts on flour milling technology and its application in the Australian feedlot industry were explored. The only technology used in the flour milling process with potential application in feedlot grain processing was the intensive dampener.

The intensive dampener
This machinery is used to apply water rapidly to grain with a 3 to 5 second spray in a chamber housing 3 rows of high speed beaters. If this process could be employed in feedlot mills, it could reduce the water application time required for tempering grain from hours to minutes for 10 to 20 tonne batches, but it is important to note that there is no reduction in the

required dwell time of 12 to 24 hours subsequent to the application of the water. Further, grain moisture is only increased to approximately 15% in flour milling and the maximum percentage moisture increase on a pass through the intensive dampener is 5%. To increase grain moisture to 22 to 23% as required for tempered-rolled grain in a feedlot mill would require 3 passes through the intensive dampener, with an 8 to 24 hour dwell period between each pass. Similarly, to increase grain moisture to 17% prior to steam flaking would require 2 passes through the intensive dampener. Thus, the limit to the amount of water that can be added on one pass through the intensive dampener results in no reduction in total tempering time. In addition, an intensive dampener to handle 10 to 15 t/hr costs approximately 3 times more than a conventional stainless steel wetting auger of similar capacity and requires additional investment in a computerised control unit equivalent to 3 to 3 ½ times the cost of a conventional wetting auger for efficient operation (pricing as of July 2016: intensive dampener to handle 15 t/hr = $105,000 versus conventional wetting auger to handle 15 t/hr, of 6 m length at a 3° incline = $30,000). Intensive dampeners to handle 30 t/hr are common in the flour milling industry with the only limit to capacity being the scope to add additional lines. However, there is a commensurate increase in price with the addition of each line. Therefore, the use of intensive dampeners in feedlot mills is precluded on the grounds of the requirement for repeated passes and dwell periods due to the limit of 5% moisture increments achieved at each pass, and markedly greater cost. A list of manufacturers that contributed to this assessment is provided in Appendix I (Table 2)

4.3.3.5 Technologies from the wet milling and ethanol industries

Introduction

The potential application in the feedlot sector of technology from the wet milling and ethanol industries in Australia and other countries was investigated by consultation with industry experts (Appendix I, Table 3). It appeared that the experts in these fields were not fully aware of the differences between standard milling procedures and those that are applicable to the feedlot industry.

4.3.3.6 Microwave treatment – Microwave conveyor

Introduction

Microwave technology has been commercially available since the 1950's. It is currently used in a number of food production processes (drying, baking, cooking, thawing) where conventional (thermal) heating may compromise product quality (Shaheen et al., 2012).

A microwave uses radio waves (electromagnetic radiation) generated by a cavity magnetron, which converts electrical energy to electromagnetic energy. The waves are produced at a specific frequency to agitate water molecules in food. The agitation generates heat, which in turn generates the cooking process. Domestic microwave ovens operate at 2450 MHz with a wavelength of 12.2 cm. Large industrial microwaves operate at 915 MHz with a wavelength of 32.8 cm. The longer the wavelength, the greater the penetration.

The microwave conveyor belt oven/furnace has been applied in production systems that require continuous flow. Examples of this technology are shown in Figure 30.


(a)

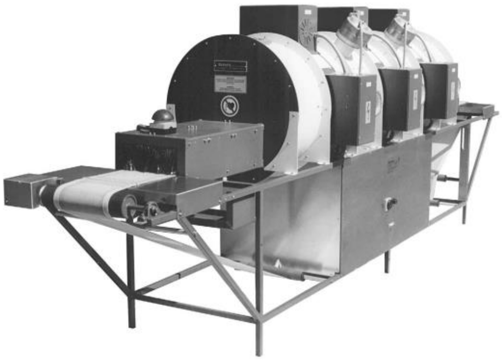

(b)

Figure 30. Microwave conveyor belts (a) Frickle and Mallah continuous microwave heating systems, (b) 4.5m continuous microwave belt furnace (Source: Vega-Mercado et al., 2001).

The equipment is composed of a conveyor (heat resistant to 250^{0}C) that moves material through a chamber that is fitted with a number of magnetrons along its length, situated above and below the conveyor belt. The number of magnetrons depends on the length of the chamber, production requirement, the characteristics of the feed material and heating requirements. Magnetrons are often a combination of both 2450 and 915 MHz to promote penetration and even heating. The conveyor moves over floor plates that are fitted with secondary radiators which concentrate the electromagnetic field. The inlets and outlets of the chamber are provided with absorbance material to prevent leakage of electromagnetic radiation.

Benefits of the microwave conveyor include:

- No requirement for additional moisture application to the grain
- Grain can be treated pre- or post-milling
- Rapid with no heat transfer (grain directly heated, material holds heat)
- Safe; microwave energy is changed to heat as soon as it is absorbed, with no residual radiation remaining

Results

Microwave treatment of grain increases ruminal starch availability by gelatinising starch (loss of structure) as described in Figure 31.

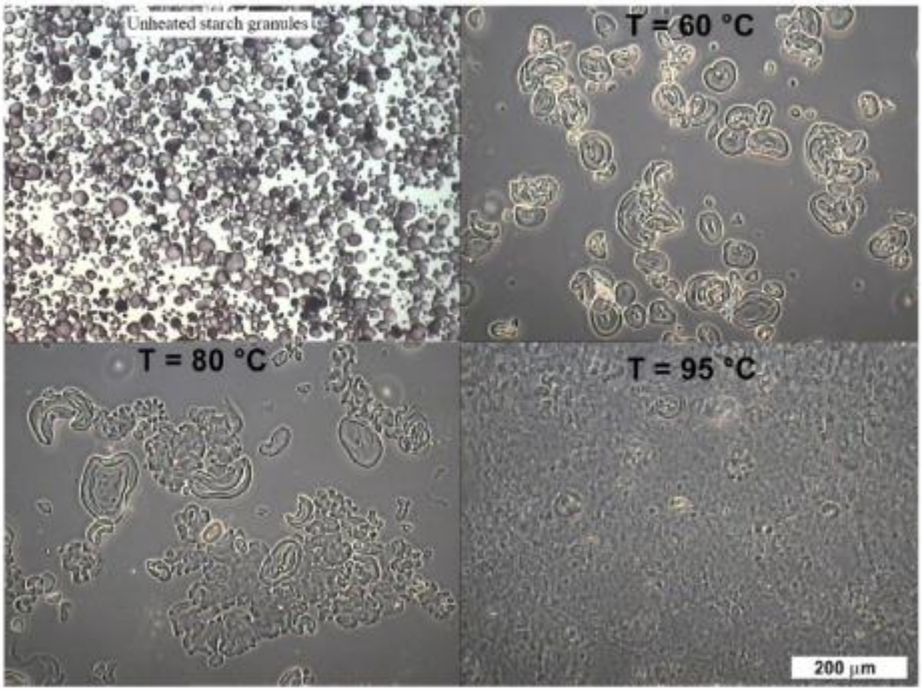


Figure 31. Light micrographs of wheat starch gelatinisation under microwave heating (Source: Bilbao-Sainz et al., 2007).

The gelatinisation process of starch is the same as any other heating method (swelling, loss of shape, loss of structure). Microwave treatment can result in complete degradation of starch when heated sufficiently. For example, Figure 31 shows the effect of heating wheat to 95°C with complete degradation of the glucose chains of amylose and amylopectin. (Bilbao-Sainz et al., 2007, Chang et al., 2011). This is the same ultimate outcome as steam flaking, but with significantly less heating time as described in Figure 32.

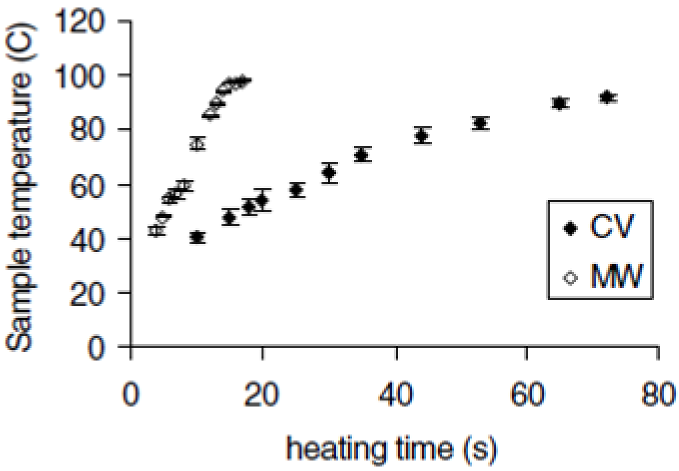


Figure 32. Time-temperature profiles of starch heated by conventional (CV) and microwave (MW) heating (Source: Bilbao-Sainz et al., 2007).

Ultimate heating time depends on the characteristics of the starch, which in turn influence gelatinisation temperature as described in Table 12.

Table 12. Gelatinisation temperature ranges of common cereal grains (Source: Sullivan and Johnson, 1964; Tester and Morrison, 1990).

	Grain			
	Sorghum	**Corn**	**Wheat**	**Barley**
Gelatinisation temperature (^oC)	68 – 75	62 - 72	52 - 63	43 - 58

Starch characteristics which increase gelatinisation temperature include:

- At least 30% starch in the form of amylose
- Interaction between amylose and amylopectin
- Low protein solubility
- Interaction between protein and starch
- Existence of cross linking between protein and starch

Grains with high gelatinisation temperatures provide the greatest response when microwave treated, such as wheat described in Table 13. Lewandowiz et al. (2000) also found that starch with amylose (wheat, corn) yielded a greater gelatinisation response to microwave treatment compared to starch with no amylose (waxy corn). However, results summarised in in Table 11 (5.3.3.1) show substantial improvements in sorghum digestibility following microwaving.

Table 13. Effect of microwave irradiation (2450 MHz, 900 W) on cumulative gas production of wheat and sorghum grain during *in vitro* fermentation assays (Source; Parnian et al., 2013).

Microwave (min)	Wheat				Sorghum				SEM	Contrast P-value			
	0	3	5	7	0	3	5	7		WL	WQ	SL	SQ
Cumulative Gas production													
2 h	11.8	10.9	16.9	15.6	14.9	15.4	15.8	18.0	1.40	*	NS	NS	NS
4 h	60.1	59.9	58.6	59.5	37.9	49.5	48.6	53.3	4.21	NS	NS	NS	NS
6 h	105.1	97.0	97.4	96.2	60.1	78.1	77.9	81.7	3.81	NS	NS	*	NS
8 h	165.4	156.0	151.3	146.2	87.5	107.3	151.3	146.2	4.50	**	NS	*	NS
12 h	224.2	218.8	206.4	204.3	117.3	139.1	144.9	141.4	5.32	**	NS	*	NS
16 h	254.4	250.2	244.3	243.8	146.4	170.4	178.6	171.2	5.64	NS	NS	*	*
24 h	272.9	264.4	275.3	277.3	190.2	219.1	229.3	215.1	5.83	NS	NS	*	*
36 h	288.6	278.3	301.3	306.5	242.6	275.3	286.6	267.9	5.89	**	NS	*	**
48 h	298.5	289.5	315.8	325.7	272.2	306.5	313.8	298.5	4.97	**	NS	**	**
72 h	307.3	297.2	327.7	338.7	293.0	327.5	335.5	320.2	4.83	**	*	**	**
96 h	311.7	302.7	335.5	346.5	304.2	336.2	344.8	327.7	4.93	**	NS	**	**

Discussion

The efficiency of the microwave conveyor is influenced by the interaction of the following factors:

- Grain characteristics
  - Type of starch (amylose:amylopectin ratio)
  - Moisture content

    Water has a high heat capacity. Although some moisture (5%) is required to generate heating through agitation of water molecules, higher moisture contents (+10%) increase time required to reach target temperatures. Chang et al, (2011) reported that moistures of 1-5% provided a rapid rise in temperature, 7-15% reduced the rate of temperature increase and moistures greater than 20% caused temperature to plateau until moisture level was reduced.

- Size, shape and density
    - Dielectric properties

      The dielectric property of a material describes its capacity to store and dissipate heat. This property is determined by a constant. The higher the dielectric constant, the greater the rate of heating. Examples of dielectric constants include Rye 6.0, Oats, 4.9, Corn 3.6, Sunflower seed 2.0 (Vadivambal et al, 2010).

Table 14 describes the effect of different grains on treated temperature level for specific exposure time of 28 seconds at 14% moisture.

Table 14. The effect of different grains on treated temperature (ºC) for specific exposure time of 28 seconds at 14% moisture (Source: Vadivambal et al., 2010).

	Microwave Power Level (Watts)				
Temperature (ºC)	**0**	**200**	**300**	**400**	**500**
Rye	27.6	49.2	59	72.1	82.5
Oats	27.2	33.1	35.5	46.6	51.4
Sunflower	23.3	30.6	35.1	39.2	43.6

- The effectiveness of microwave operation is determined by
    - Frequency and power
    - Material characteristics (temperature, moisture, specific heat)
    - Height of material on conveyor belt
    - Penetration depth of electromagnetic radiation
        - Penetration depth is influenced by dielectric properties of grain (Lewicka et al., 2015). Combinations of both 2450 MHz and 915 MHz magnetrons promote penetration of radiation into material.
    - Non-uniform distribution of electrical field (Methlouthi et al., 2010)
        - Poor electromagnetic distribution results in hot spots or “thermal run-away” (Brodie, 2012).
    - Distribution is promoted by conveyor design and operation

- Production
    - Treatment time (minutes)
    - Desired production rate (tonnes/hour)

Conclusion

Review of the literature and email correspondence with microwave conveyor manufacturers (Max Industrial Microwave and Fricke und Mallah) highlight current limitations to applying this technology to grain processing for the feedlot industry due to:

- Limited production capacity
- Variation of incoming material (moisture, temperature, grain type)
- Equipment cost

- Sophisticated control systems
- Available expertise

For example, the following is a description of the requirements of a 200 kW microwave conveyor processing wheat at 10 t/hr. Assumptions are based on a wheat moisture concentration of 12%, specific heat of 1.55 and initial temperature of 25^{o}C. The target temperature is 63^{o}C (upper temperature required for gelatinisation of wheat starch).

Two options:

1. Use two 915 MHz microwave generators each 100 kW
   Cost over $AUS 1 million. (650,000 euros)
   Advantages:
   - High penetration depth allowing greater height on conveyor belt
   - Compact size
   - Inexpensive

2. Use 34 2450 MHz 6 kW generators
   Cost $AUS 1.4 million (903,000 euros)
   Advantages:
   - Excellent distribution of electro-magnetic field
   - Frequency level available worldwide
   - Allow up to 10% failure of microwave generators

In conclusion, microwaving appears not to provide results superior to steam flaking (Table 11, section 5.3.3.1) and is more expensive.

4.3.4 Boiler technology

Introduction

The basic definition of a boiler is a closed vessel in which water is heated under pressure to generate steam. A boiler is designed to absorb the maximum amount of heat released from the combustion of a fuel source and transfer the heat to water by radiation, conduction and convection (Teir, 2002).

A key component of boiler efficiency is to maximise heat transfer. Efficiency of heat generation is known as combustion efficiency and efficiency of heat transfer is known as transmission efficiency. The overall efficiency is known as boiler efficiency.

Boiler efficiency = Heat exported as steam / Heat provided by fuel x 100

Boiler efficiency accounts for the effectiveness of heat exchange as well as heat losses (radiation, convection). Technology that minimizes heat loss promotes efficiency and reduces maintenance. Promoting efficiency has a greater impact on the cost of boiler operation than sourcing a cheaper fuel.

Boilers can be designed to use a range of fuel sources. Technologies that either improve combustion efficiency (burner technology) or enable combination of fuel sources reduce the cost of operation. Environmental considerations are increasing interest in boilers that can use biomass fuel sources (plant, recycled material, waste products). However, the value of alternative fuel sources should be related to boiler efficiency.

Enthalpy of Water and Steam Types

Steam is the gas phase of water, generated by adding sufficient heat to cause it to evaporate. The transition of water to steam occurs over a number of phases as described in Figure 33. The first phase is pre-heating. This is when sufficient heat is added to water that it no longer exists as a liquid (saturation point). The second phase is known as evaporation, where additional heat converts the liquid phase to the vapour phase. When all the water has been evaporated, the steam is called dry saturated steam.

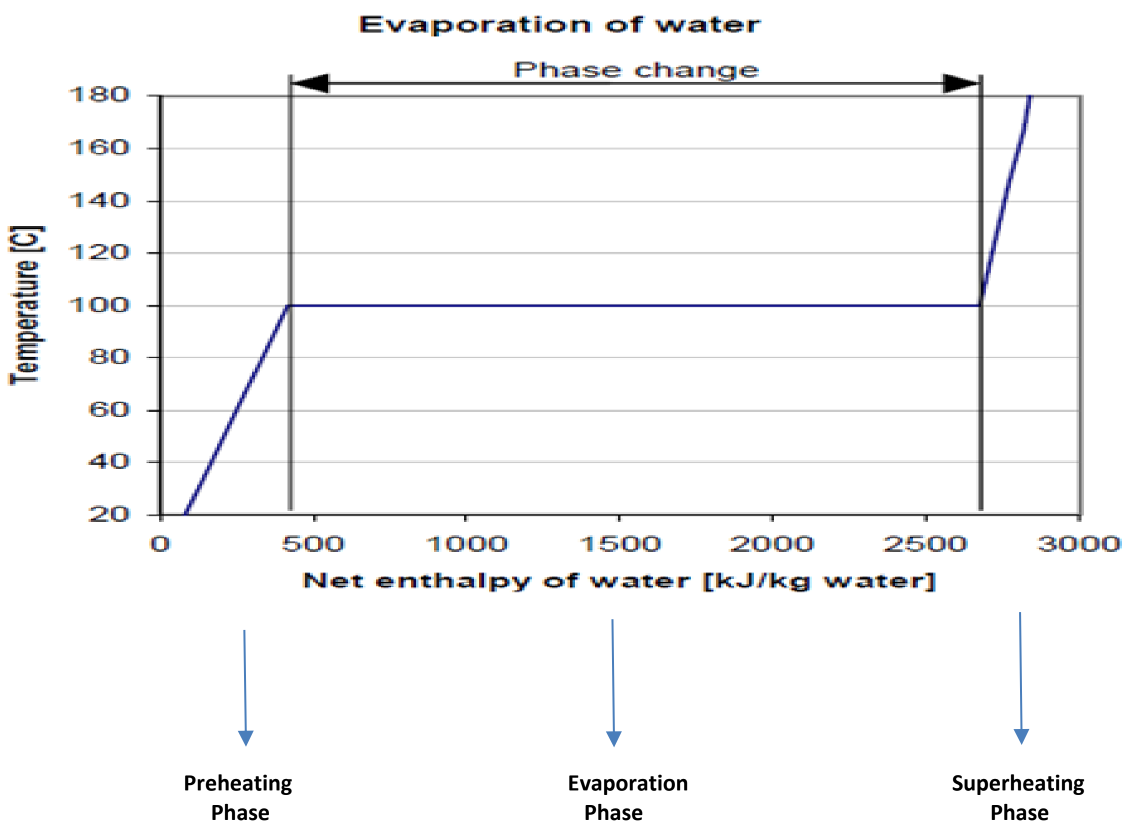


Figure 33. Changes in the enthalpy of water with conversion to steam (Source: Teir, 2002).

The total heat or enthalpy held by liquid water at boiling temperature is known as sensible heat. The heat that results in water transition from liquid to vapour is known as latent heat. The total heat in steam is the sum of latent and sensible heat. The final phase is superheating where steam is heated beyond boiling point. Superheated steam is steam with no moisture. Table 15 describes the different characteristics of the three steam types (wet, saturated, superheated).

Table 15. Characteristics of types of steam (BTU = British Thermal Units) (Source: Heimann, 1999).

	Wet	**Saturated**	**Superheated**
Temperature (^oC)	Saturation (100 ^oC @ Atm)	Saturation (100 ^oC @ Atm)	>Saturation (>100 ^oC @ Atm)
Energy content	978 BTU/# 100 ^oC 85% quality	1150 BTU/# 100 ^oC 100% quality	1384 BTU/# 371 ^oC Superheated
Phase	Liquid & Vapour	Vapour only	Vapour only
Condensation	Immediate	Immediate	Must cool first
Temperature rise per % moisture added	4.4 ^oC	2.22 ^oC	1.11 ^oC

Boiler Types

There are two basic types of boilers, fire tube and water tube. A fire tube boiler illustrated in Figure 34 has the heat generated from combustion held within tubes which are surrounded by water.

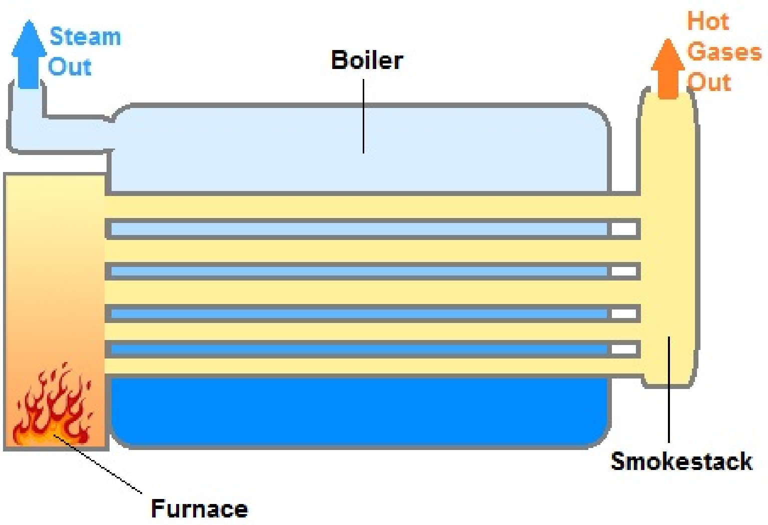


Figure 34. Fire tube boiler (Source; www.globalspec.com).

A water tube boiler illustrated in Figure 35 has water held in tubes which are heated by combustion of fuel.

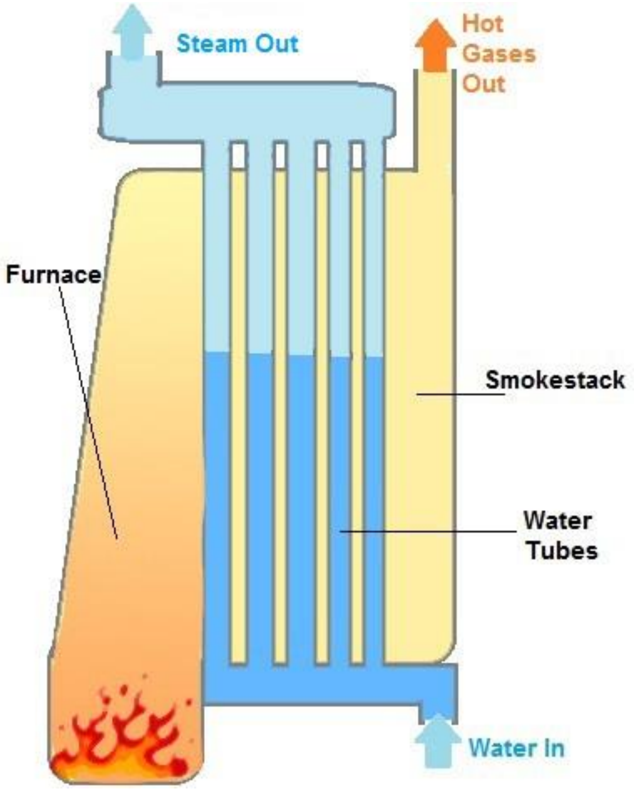


Figure 35. Water tube boiler (Source: www.globalspec.com).

Each type of boiler has advantages and disadvantages as described in Table 16.

Table 16. Operation comparison of fire tube and water tube boilers (Source: Cleaver Brooks, 2010).

	Boiler Type	
	Fire Tube	**Water Tube**
Advantages	Provide energy reserve One furnace tube & burner Lower maintenance	Low water requirement Produce superheated steam Lower fuel usage Longer life Larger output
Disadvantages	Limited output & pressure Higher operating cost	Higher maintenance Complex control systems

Sources of Heat Loss

Boiler efficiency accounts for both the effectiveness of the heat exchange as well as heat losses. On average boilers have an efficiency of 70-85%. Reducing heat loss has significant influence on boiler efficiency. Heat loss can occur from a number of sources including flue (stack) gas temperature, fuel energy content, extra air, ambient temperature and humidity, heat loss from radiation and convection and inadequate maintenance.

Flue (stack) gas temperature

The flue or stack gas temperature is the temperature of combustion gases exiting the boiler. It represents the major portion of energy not converted to steam. Table 17 describes the effects of increasing flue gas temperature on boiler efficiency in combination with the effect of excess air. Reducing flue gas temperature by 5% improves boiler efficiency by 1%.

Table 17. Effect of excess air and flue gas temperature on boiler efficiency (Source: Bhatia, 2012)

Express (%)		Combustion efficiency for natural gas				
		Flue gas temperature less combustion air temp, ^{o}F				
Air	**Oxygen**	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

Note: Assumes complete combustion with no water vapour in the combustion air

Fuel energy content

The energy value of fuel sources is expressed as a net calorific value or NCV. The NCV of fuel accounts for components which reduce energy value or are non-combustible. These include moisture, hydrogen and ash content. Moisture absorbs heat generated by combustion of fuel. Similarly, hydrogen is converted to water vapour during combustion. Water vapour uses energy as it changes phase in the combustion process (latent heat). Ash is non-combustible.

All fuel sources contain some moisture and non-combustibles. Identification and access to fuels which minimise these components contribute directly to boiler efficiency. Figure 36 describes the effect of the hydrogen to carbon ratio of fuel sources and its effect on efficiency. Variation in hydrogen to carbon ratios is responsible for 2.5 to 3.0% difference in boiler efficiency.

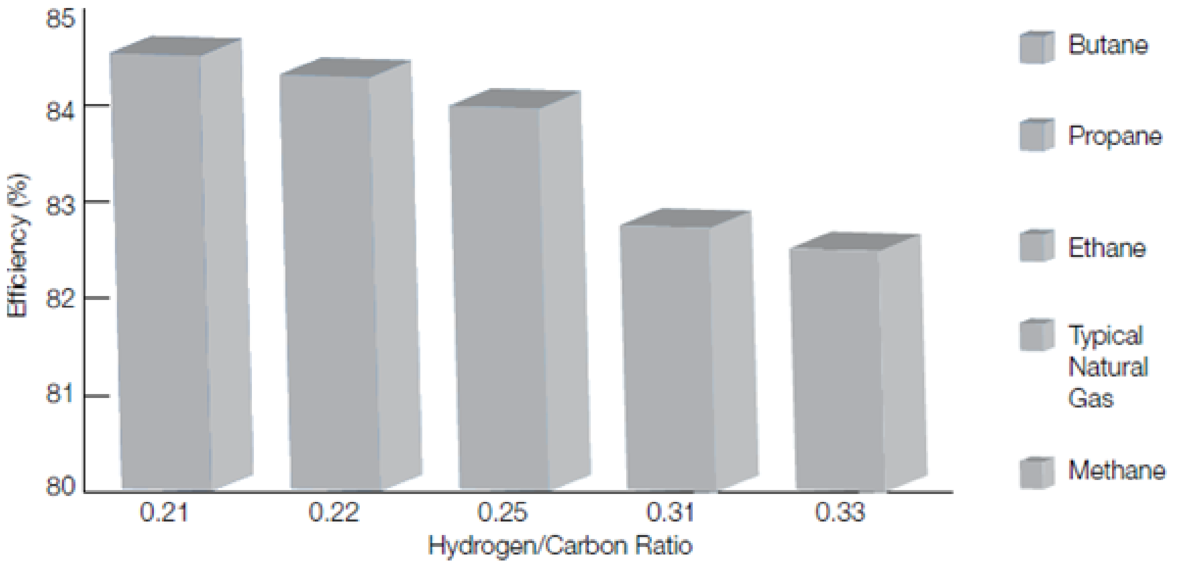


Figure 36. Effect of hydrogen to carbon ratio of different gas fuel sources on boiler efficiency (Source: Cleaver Brooks, 2010 (http://www.cleaver-brooks.com/Reference-Center/Resource-Library/Tip-Sheets/2010-Tip-Sheets/index.aspx)) .

Extra air

The objective of boiler operation is to achieve complete combustion. When all fuel is burned using minimal air additional to the theoretical air requirement (extra air), combustion efficiency is highest and pollution is minimal (Teir, 2002). Extra air is the additional air above the minimal requirement to ensure complete combustion. All boilers rely on some extra air as a safety factor. However, excessive extra air reduces the heat transfered to water. The effect of extra air on boiler efficiency is described in Figure 37.

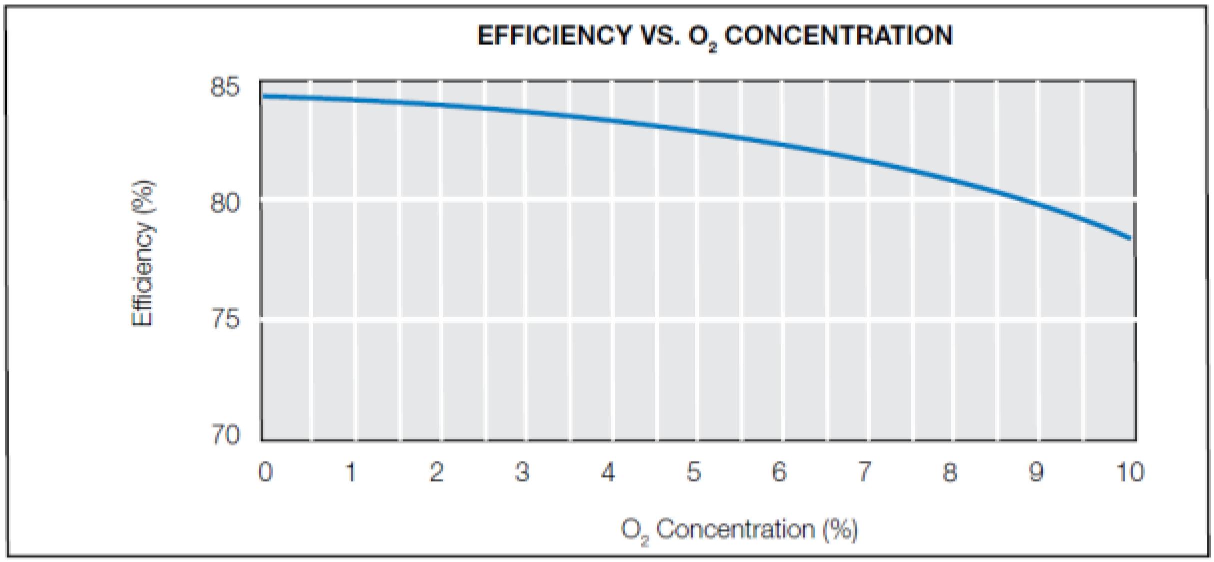


Figure 37. Effect of extra air on boiler efficiency (Source: Cleaver Brooks, 2010 (http://www.cleaver-brooks.com/Reference-Center/Resource-Library/Tip-Sheets/2010-Tip-Sheets/index.aspx)).

A reduction in extra air of 15% improves boiler efficiency by 1%. Alternatively, every 1% reduction in extra oxygen improves boiler efficiency by 0.5%.

Table 19 also illustrates the interaction between extra air and flue temperature on boiler efficiency. As discussed, increasing flue temperature reduces boiler efficiency, but efficiency is further reduced with increasing quantities of extra air.

Fuel source NCV also influences the requirement for extra air. Fuel sources with lower NCV (higher moisture and non-combustibles) increase the extra air requirement as described in Table 18.

Table 18. Theoretical oxygen (O2) quantities required for combustion of various types of fuel (Source: Bhatia, 2012).

Fuel type	**Minimum (%)**	**+ Excess recommended (%)**	**= Total O_2 (%)**
Natural gas	0.5 – 3.0	0.5 – 2.0	1.0 – 5.0
Fuel oils	2.0 – 4.0	0.5 – 2.0	2.5 – 6.0
Pulverized coal	3.0 – 6.0	0.5 – 2.0	3.5 – 8.0
Coal stocker	4.0 – 8.0	0.5 – 2.0	4.5 – 10.0

Air temperature and humidity

A boiler house is critical infrastructure to promote efficiency and to minimise exposure of the boiler to ambient conditions (wind, decreasing air temperature, changes in humidity). Figure 38 illustrates the relationship between ambient temperature and boiler efficiency.

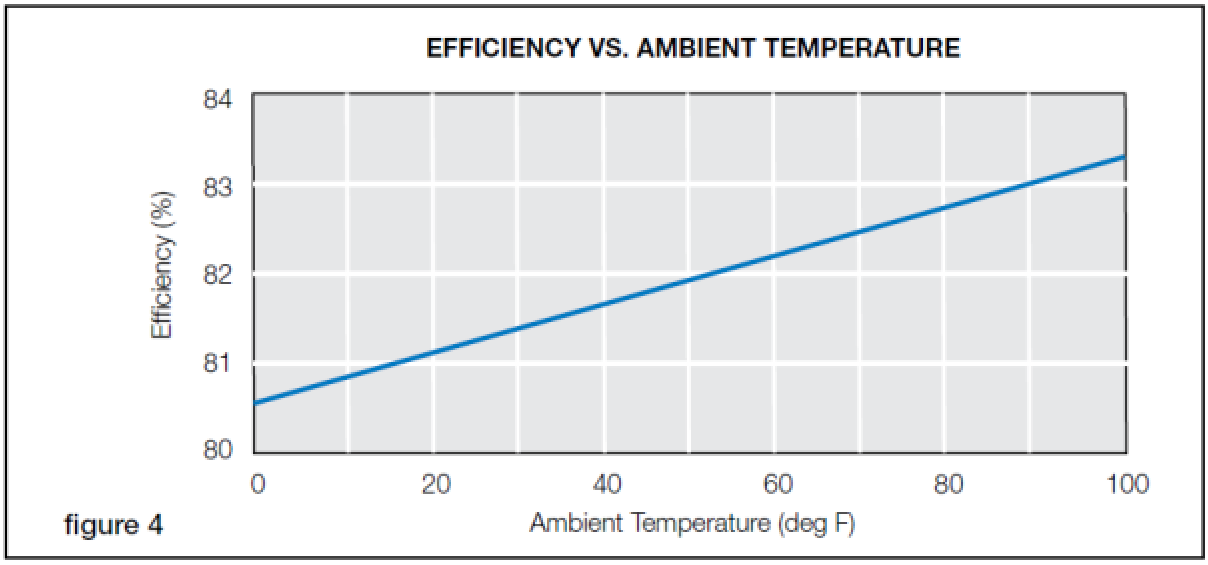


Figure 38. Effect of ambient temperature on boiler efficiency (Source: Cleaver Brooks, 2010)

Boiler efficiency calculations are conducted in still air at a temperature of 26.7°C. An increase in air temperature of 12°C increases boiler efficiency by 0.5%. Humidity values greater than 30% decrease efficiency.

Boilers exposed to decreasing air temperature require higher levels of extra air to achieve combustion. The effect of this relationship is described in Figure 39.

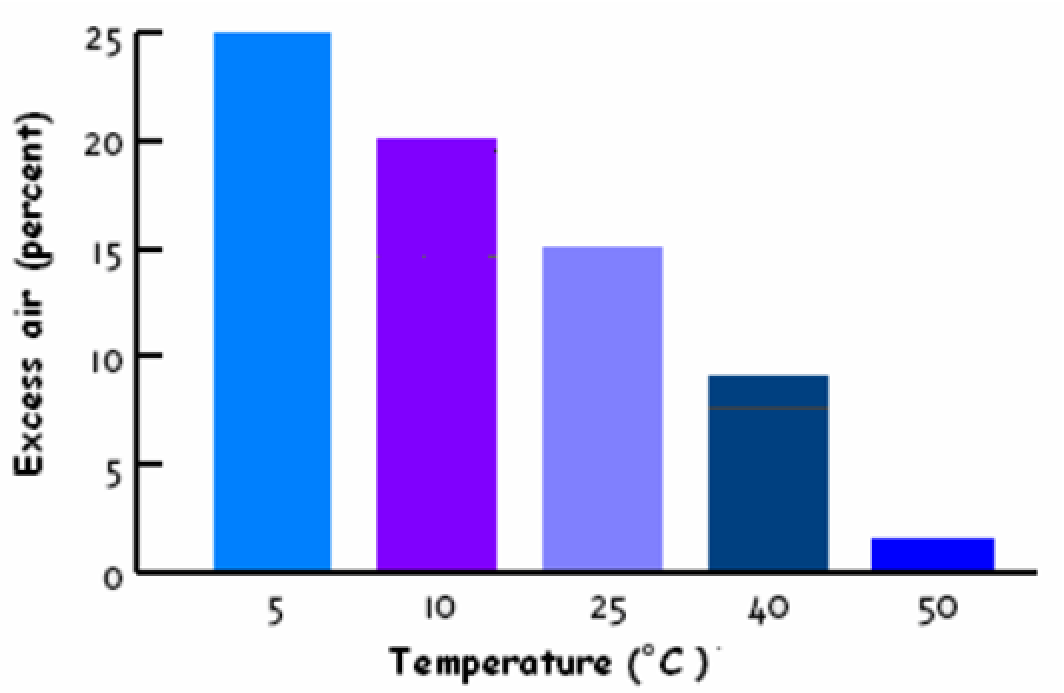


Figure 39. Effect of ambient temperature on excess air requirements (Source: Bhatia, 2012).

Heat loss from radiation and convection

Boilers lose heat from all external surfaces by radiation and convection. Insulation in combination with protection offered by a boiler house reduces these forms of heat loss. External surface heat loss increases as boiler output is reduced as described by Figure 40.

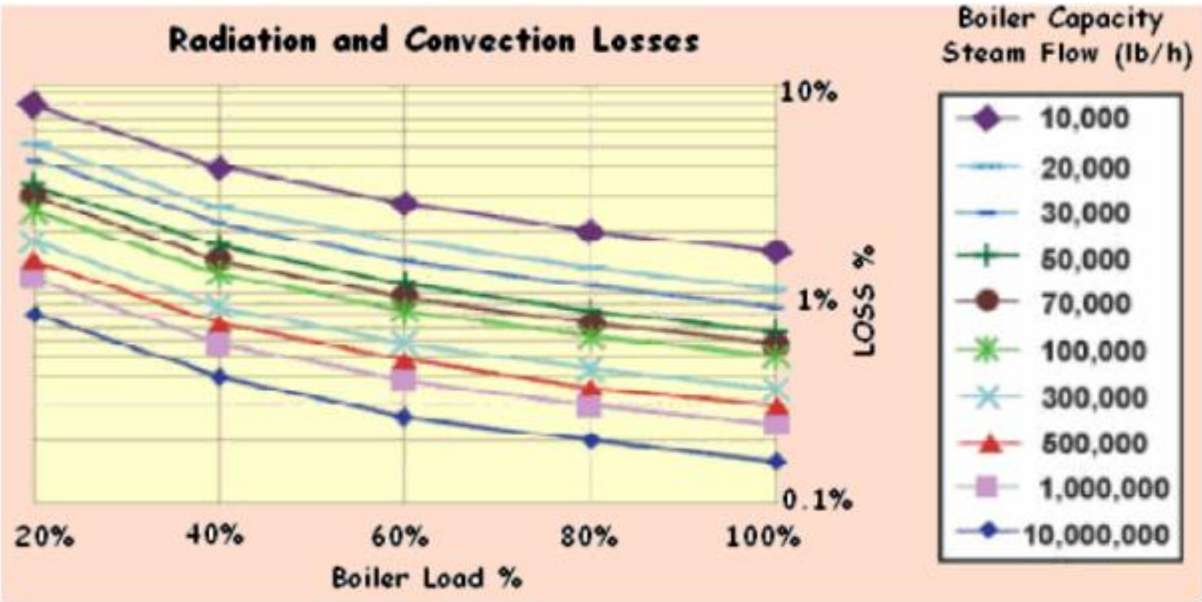


Figure 40. Effect of boiler load and capacity on radiation and convection losses (Source; Bhatia, 2012).

Maintenance

To maximise transfer of heat to water the tubes within a boiler must be clear of any debris. Fire tube boilers reduce efficiency of heat transfer when soot accumulates in the tubes. Soot is unburnt carbon particles. Reported effects of soot accumulation include:

- A 0.8mm soot layer reduces heat transfer by 9.5%, reduces boiler efficiency by 12%, and increases fuel usage by 15%
- A 4.5mm soot layer reduces heat transfer by 69%
- Flue temperature increases by 55°C for each 1mm layer of soot

Scale is a maintenance concern for both fire and water tube boilers. Scale insulates and slows heat transfer to water. In water tube boilers it narrows tubes and impedes flow. Figure 41 describes the effect of scale thickness in inches on heat transfer and Figure 42 on fuel costs. Scale increases flue temperature and fuel usage.

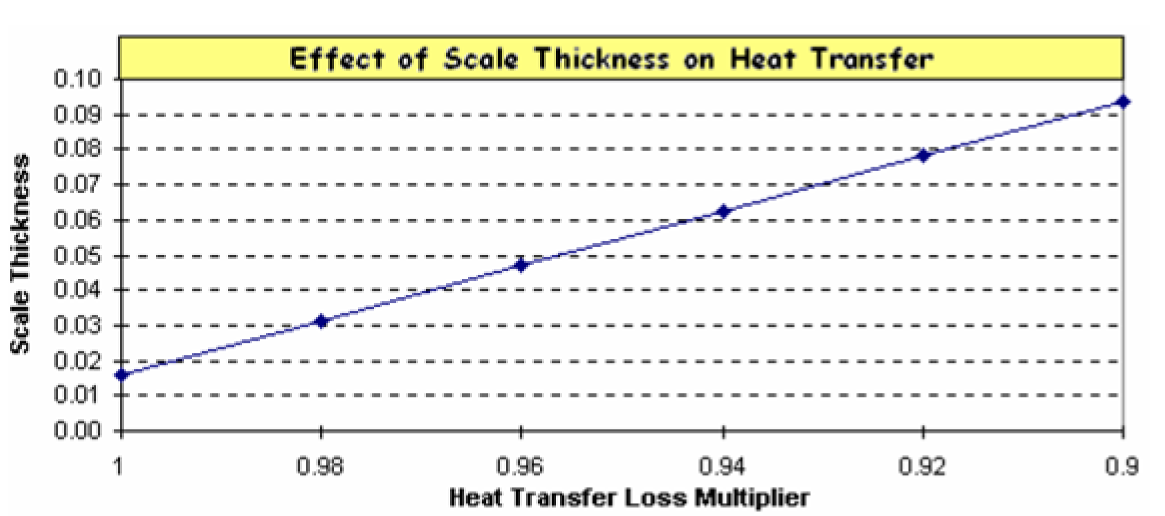


Figure 41. Effect of scale thickness (inches) on heat transfer (Source: Bhatia, 2012).

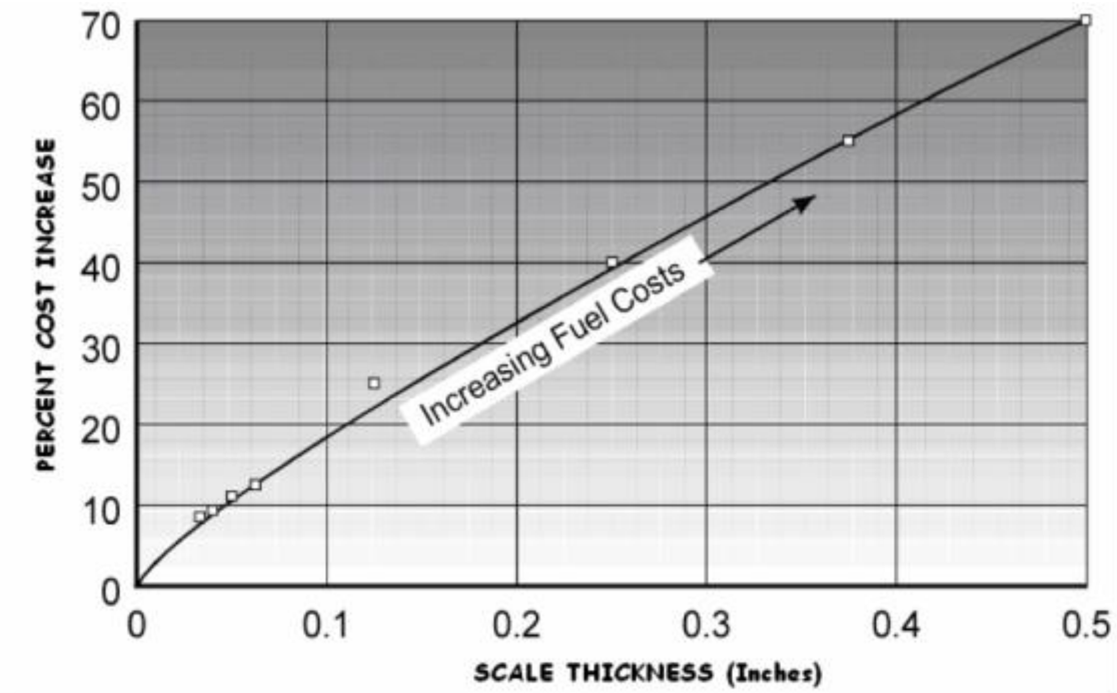


Figure 42. Effect of scale thickness on boiler fuel usage (Source: Bhatia, 2012).

Boiler Technology

The factors responsible for reducing boiler efficiency are not independent. They cover many aspects of boiler function including criteria associated with daily operation, fuel source and maintenance. For example, soot accumulation increases flue temperature, fuel high in hydrogen to carbon ratio increases the requirement for extra air, and decreasing ambient air temperature increases the requirement for extra air. Boiler efficiency can be improved by assessing the application of the following boiler technologies.

Tube pass number (fire tube)

Improving the transfer of heat to water is a primary driver of the boiler efficiency equation. In fire tube boilers heat transfer is improved by increasing the number of times heat from combustion is passed across the boiler. The more passes not only promotes greater heat transfer, but also reduces flue temperature and fuel usage. Table 19 describes the effect of increasing tube passes on boiler efficiency for different boiler types.

Table 19. Effect of tube passes on fire tube boiler efficiency (Source: Spirax Sarco, 2012)

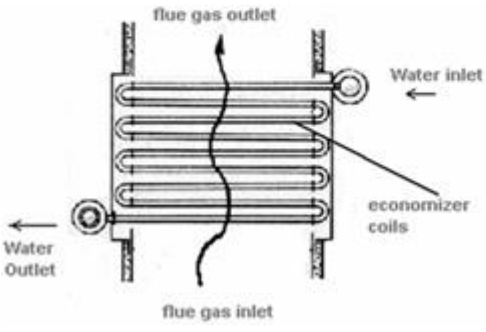
Type of boiler	**Net efficiency (%)**
Packaged, three pass	87
Water-tube boiler with economiser	85
Economic, two pass	78
Lancashire boiler	65
Lancashire boiler with economiser	75

Boiler pass design

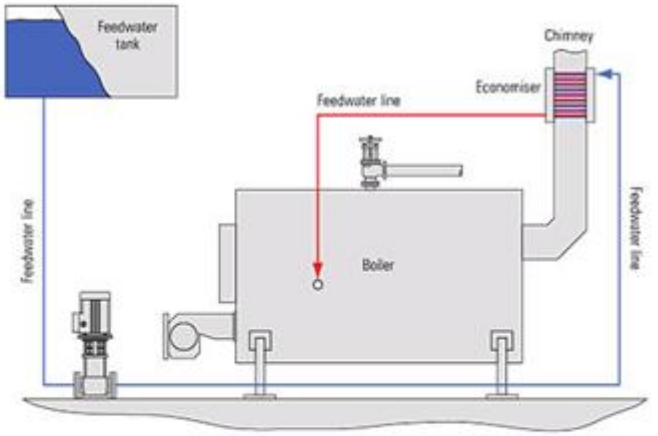
Boiler pass design can increase flue gas velocity, which in turn promotes heat transfer while minimizing soot accumulation.

Economiser

An economizer extracts part of the heat contained in flue gas and uses it for heating the feed water as described in Figure 43. It is a counter-current heat exchanger, with hotter gas in contact with hotter water and cooler gas in contact with cooler water, thus minimising heat losses. An economizer reduces fuel usage and promotes boiler efficiency as shown by Table 20.



a)



b)

Figure 43. Function (a) (Source: www.rentalboilers.com) and location (b) (Source: www.my.ilstu.edu) of a boiler economizer.

Condensate

As discussed, steam contains two types of energy, latent (enthalpy from transition of liquid to vapour) and sensible (enthalpy of liquid at boiling). When steam is applied, the steam vapour releases the latent energy and condenses to a liquid condensate. The condensate retains the sensible energy. Depending on the steam pressure, the condensate can have 10-16% of the total steam energy. When condensate is not returned, the boiler must make up the energy loss from cold, untreated raw water. Capacity to recover and return condensate to the boiler not only improves boiler efficiency but also reduces operation cost as the condensate still contains the water treatment chemicals. To maximise recovery of condensate, recovery equipment (tanks, pipes, valves, fittings) must be well insulated.

Automated control systems

Control technology allows for improved boiler operation and efficiency. Examples include:

- Independent control of fuel and combustion air promotes accurate and consistent air to fuel ratio control which in turn increases combustion control
- Excess air control (match burner air flow to fuel flow)
  Reduce excess air requirement from 4 to 6% to less than 3%.
- Oxygen trim systems (promote efficiency of combustion of fuel sources that vary in quality)
- Damper design (control quantity of air admitted to furnace)
- Combustion air fan controls (deliver stable and controllable supply of air)
- Flue gas recirculation (a portion of the flue gas is circulated back into the combustion zone to lower the flame temperature and reduce nitrogen-oxide formation)

- Fuel delivery systems

  Liquid fired boilers require a high fuel surface to volume ratio and require a liquid particle diameter range of 20-40 µm - beyond this range combustion efficiency is reduced

  Account for changes in viscosity of fuel with temperature

Burners

An important function of burners is turndown rate. This is the maximum firing rate over the minimum controllable firing rate. Typical turndown rates have been 4:1 or 5:1. New burner design allows for 10:1. At 10:1 the burner can operate at 10% capacity compared to 4:1 at 25% capacity. When fuel demand falls below 25% the boiler will cycle-off until demand increases. At a 10% capacity, the boiler can turndown without cycling-off, preventing energy loss.

Dual fuel burners

These are burners that can deliver more than one fuel type. The burner provided in Figure 44 is an example of a gas and oil burner. Duel fuel burners allow operation to take advantage of differences in fuel cost and quality (NCV).

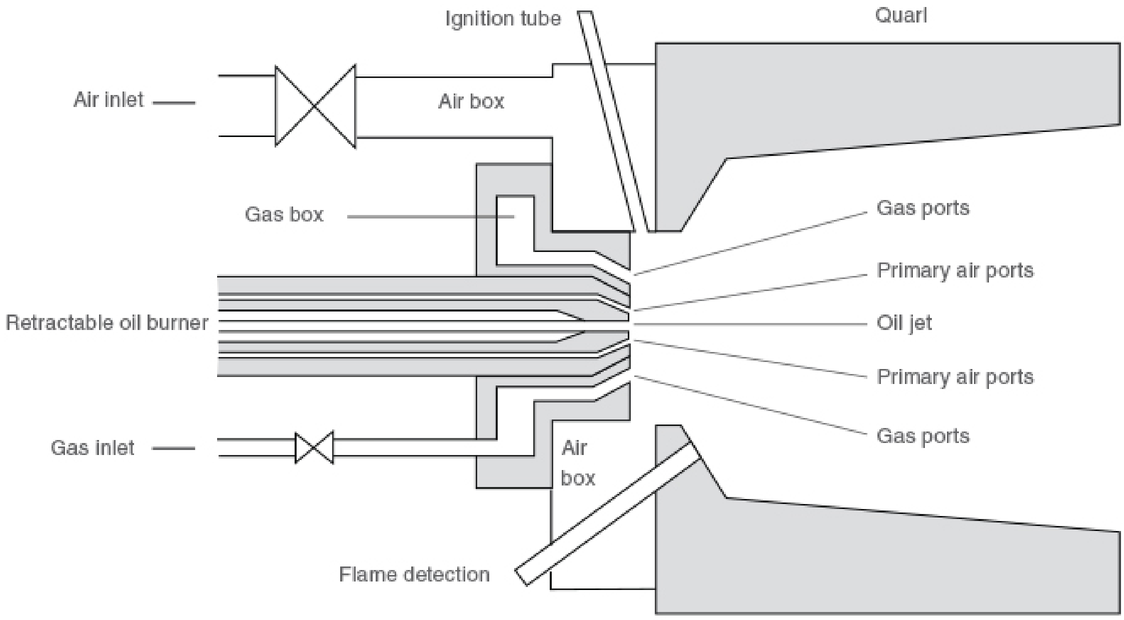


Figure 44. A dual fuel burner (Source: Spirax Sarco, 2012).

Fuel quality

Energy content of fuel is described by a net calorific value (NCV), expressed in British Thermal Units (BTU). The NCV quantifies the combustible value of the fuel and accounts for energy lost in moisture, hydrogen and ash (non-combustible material) as described in Table 20.

Table 20. Theoretical fuel NCV (net calorific values) (Source: www.engineeringtoolbox.com)

Fuel Source	BTU / unit	Usage (per hour)**
Coal (kg)	14500 kg	292 kg
Diesel (L)	137490 L	257 L
LPG (L)	84950 L	416 L
Methane (L)	86030 L	411 L
Woodchip (kg)	8406 kg	504 kg
Cereal Stubble (kg)	7308 kg	580 kg
Feedlot Manure* (kg)	6102 kg	692 kg

**contains 20% moisture & 10% ash, **based on 200 HP boiler, producing 6900 lbs/hour steam at 83% efficiency at 690 kPa pressure.*

Fuel sources differ markedly in NCV. Efficiencies can be gained through sourcing fuels with known NCV (minimal variation, known fuel usage, combustion efficiency, low soot production, low maintenance), particularly when assessing the value of alternative fuels as described in Table 21.

Use established boiler production equations such as the fuel usage example provided:

Fuel usage in L or kg/hour = [Steam produced x (heat steam – heat feedwater) / (Boiler efficiency x NCV)]

Conclusion

A number of technologies are available to improve boiler efficiency and operational flexibility. These technologies are not new, but there is scope for increased boiler efficiency in the feedlot industry, which is particularly important with increasing energy costs. Importantly, a range of operational practices can also have direct effects on efficiency. Examples include keeping the boiler well maintained, sourcing the highest quality fuel available (low in moisture, hydrogen content and ash), storing the boiler in a boiler house (protected from wind, and insulated to maintain air temperature and reduce humidity).

4.3.5 Technology to reduce shrink and to improve fermentation

When ensiling forages, high moisture corn or fermented grain, the main outcome is to produce a palatable, waste free and high quality product. The two key requirements are to drop the pH of the ensiled crop quickly and exclude oxygen. Failure to do so will result in spoilage, waste, loss of nutrients and potentially, the production of mycotoxins.

4.3.5.1 Products that minimise fermentation related shrink

Ensiling is a process of crop preservation by acidification. The fermentation is an anaerobic process (no oxygen) during which sugars in the crop are converted to organic acids such as lactate, acetate and propionate. The organic acids are produced by bacterial activity. Specific bacteria are added via an inoculant to ensure that the fermentation is rapidly dominated by beneficial bacteria. The aim is to have a rapid initial drop in pH down to approximately pH 4.0. This ensures that spoilage bacteria do not have an opportunity to proliferate, as they can only become active at a higher pH.

- Inoculant
  Inoculants reduce pH at the start of the fermentation process, giving protection to the crop when pH is above 5.0 during early fermentation. Inoculant use has been shown to reduce dry matter (DM) losses, improve aerobic stability and improve intakes (Adesogan, 2004; Weinberg, 2007; Kung, 2003; Kung, 2014). Inoculants that include strains that scavenge oxygen reduce losses associated with secondary fermentation (heating, spoilage) during feed-out.
  Bacterial inoculants, based on homofermentative lactic acid bacteria are commonly added to silages to improve fermentation and increase DM and energy recovery. However, most of these inoculants are not very effective in inhibiting the growth of yeasts because they tend to maximize the production of lactic acid (poor antifungal activity) and decrease the accumulation of other organic acids that have good antifungal activity. Muck and Kung (1997) summarized the literature and found that treatment with commonly used homolactic acid-based inoculants improved aerobic stability about one third of the time, had no effect about one third of the time but made aerobic stability worse about one third of the time.

  Lactobacillus buchneri, an obligate heterolactic acid bacterium, has been used as a silage inoculant to specifically enhance aerobic stability by converting moderate amounts of lactic acid to acetic acid in a variety of silages from maize, sorghum, barley, lucerne, ryegrass, orchard grass, etc. (Dreihuis et al., 1999a, Kung and Ranjit, 2001). Concerns relative to the potential of large DM losses from silages treated with *L. buchneri,* because of its heterolactic nature, have not been substantiated (Kleinschmit and Kung, 2006). Whilst some have suggested that high levels of acetic acid in silages may depress intake, studies have shown that ruminants fed silages treated with *L. buchneri* consume similar amounts of DM as those fed untreated silages (Dreihuis et al., 1999b, Kung et al., 2003).

- Oxygen impermeable covers
  Covers that are not permeable to oxygen greatly reduce aerobic losses. Standard plastic covers can protect the pit or bun but they allow transfer of oxygen through the plastic and create difficulties with eliminating air from under the plastic sheets.
  Research shows that a loss of around 20% will be seen in the top 1 metre using conventional 125 micron black and white plastic with tyres. In contrast, oxgyen impermeable covers (Silostop®) can reduce these losses by 50% to less than 10% DM loss in the top 1m (Wilkinson JM and Rimini R 2002; Borreani G et al 2007; Muck RE 2011; Muck RE and Holmes BJ 2009).

Figures 45 and 46 show the result of using the Silostop two step system – Silostop plastic and UV covers.

Figure 45. High moisture corn (HMC) covered with Silostop plastic (Source: Courtesy of Trevor Schoorl, Lallemand Animal Nutrition, 2016 http://lallemandanimalnutrition.com).

Figure 46. Effects of aerobic spoilage (Source: Courtesy of Trevor Schoorl, Lallemand Animal Nutrition, 2016 http://lallemandanimalnutrition.com).

The economics of using the oxgyen impermeable plastic (Silostop®) is shown below.

1m^2 of silostop plastic covers 650 kg DM in the top 1m^3. Silostop reduces DM loss to 10%.

High moisture corn (HMC) @ $300.00/t @ 70% DM = $430/DM t

= 650 kg DM x $0.43/kg DM x 10%

Saving = $27.86 in HMC over every square metre

If the dimensions of the silage pit is 10m * 50m * 1m (top 1m) = 500m^3 or 423 t of HMC

Saving on HMC in the top 1m^3 = $12,690 (423 t * $300/t * 10%)

1 roll silostop (50*12 m) = $810.00

ROI = 15 : 1

If covering reconstituted grain at $250/t (same density as HMC) a ROI of 13:1 can be achieved (423 t of reconstituted grain * $250/t * 10% = $10,575).

4.4 Best Practice Grain Processing Manual

A comprehensive manual on current grain processing technologies used in Australian feedlots was compiled. The manual covered the suitability of available technologies for different types of grain in diverse feedlot practices. The advantage and disadvantages of these technologies were explored and operating procedures of machineries were provided to assist feedlot operators to choose the technology that suits their operations. A simple Excel spreadsheet was developed to estimate the cost associated with different processing methods.

4.5 Identify research gaps in grain processing technology

Although there have been some improvements in grain processing technologies over the past decade, there is still a continued need to fine-tune these methods and also to identify potential new technologies that can facilitate grain progressing practices which are cost-effective and can optimise animal performance. This final report has delivered a comprehensive review to evaluate potential new processing technologies that could be adapted by the Australian feedlot industry. The project team identified the following research gaps and opportunities for grain processing:

4.5.1 NIRS/NIR Technology

- ✓ Development of NIR (hand-held device) for rapid assessment of faecal starch in real time on wet faeces that can be used in commercial feedlots (this has by all project team members been deemed the most important point in regards to research gaps because faecal starch is a prime indicator of the efficiency of grain processing).

- ✓ Research into the use of NIR and a computerised controller monitoring water addition during tempering of grains.

- ✓ NIR for measuring the average and distribution of particle size of grains for dry rolling processing methods.

- ✓ For steam flaking, opportunities exist to automatically measure outcomes and to adjust processing settings to maximise animal performance and minimise processing costs. Firstly, a method to determine starch digestibility which correlates to animal performance is needed. Further research should develop a method to analyse starch availability in steam flaked grains. The most efficient tool to achieve this appears to be NIRS, where calibrations are required to measure digestible starch values in steam flaked grain which relate to animal performance measurements.

- ✓ With In-line NIR technology, an opportunity exists to improve grain processing quality with the aim to improve animal performance. NIRS technology has traditionally been used as a bench top instrument; however, it can also be used directly in the production line, to continuously automatically measure the performance of grain processing. The advantage of In-line NIRS is that sample collection is not required and results are generated more frequently. Further research should be conducted into the viability of in-line NIR measurements that may link directly to systems that automatically make adjustments. The most obvious initial application is the management of moisture content (as in II) for several of the grain processing systems that enhance animal performance through wet processing techniques.

4.5.2 Feeding studies

I. There are limited published data on the performance of cattle fed high moisture corn or fermented sorghum diets. Research that studies the performance of Australian feedlot cattle fed high moisture corn, or fermented sorghum diets, compared with the conventional grain processing methods such as dry rolling, tempered rolling and steam flaking would be beneficial to the industry.

II. Controlled comparative Australian feeding trials on animal production with different processing methods to produce a range of particle sizes or bulk densities, using a range of grains, and at varying grain inclusions to reflect commercial practices.

4.5.3 Processing methods, targets and milling efficiency

I. Research into better understanding of optimum processing targets for tempered rolled grain.

II. Further exploration of wetting auger design and operation (RPM, residence time, capacity) for different grains.

III. Research into evaluating the effects of processing method, particle size, interactions between grain species, morphology and site of digestion and their ultimate effects on Feed Conversion Ratio (FCR). This data and information could be developed into a spreadsheet that can be used by feedlot operators to estimate the cost of gain. For similar growth rates (and therefore effects on output and inventory cost) the main driver of profitability is FCR and ultimately the cost of gain based on the cost of achieving a given FCR.

IV. There is a lack of robust comparative data on surfactants and emulsifiers aimed at increasing moisture uptake in tempering, and putative effects on increasing mill throughput and prolonging roll life.

V. Potential improvements in rate and extent of imbibition during steeping with the application of ozone to the steeping water, or the use of heated water, warrant further investigation.

5 Discussion

Review of new technologies not used in Australia

A comprehensive review was undertaken to evaluate potential new grain processing technologies that could be adapted for use in the Australian feedlot industry. Although there have been improvements in grain processing over recent decades, there is still a continued need to refine systems and identify potential methods and technologies that can improve animal performance, efficiency and cost of grain processing.

A number of different industries both in Australia and internationally were identified with the potential to provide information and a knowledge base around new technologies for grain processing. These included the feedlot industry in the USA (equipment manufacturers and industry experts), flour milling, wet milling and the ethanol industry, and the monogastric industries.

The industry experts in USA suggested that the processing methods with potential to reduce costs and improve consistency include i) improved grain cleaning ii) longer steeping period (12 hours) iii) automated steam control and iv) improved steam distribution (steeping period of approx. 12 hours is standard in Australia so perhaps US feedlots have used more rapid steeping periods compared to practices found here). The objective of these improvements was to deliver a clean grain with consistent moisture to the flaker, control the quality and thermal delivery rate of steam, and to set the grain flow at the maximum that will produce the desired flake. The North American (USA) industry experts suggested that the value of preparing grain for the flaking process rather than modifying the flaking process itself (roll gap adjustments, peg feeder speed, in-line temperature/moisture measurements) is essential to compensate for variation in grain quality which results in losses in efficiency and production capacity. It appears that heated water is not used in the US, predominantly because of cost and perceived low effectiveness.

The monogastric industries use various grain processing methods such as dry milling, steam conditioning and pelleting, extrusion, expansion, popping, sieving and adding specific enzymes to dry or wet feed. Exogenous enzymes are used widely in pig and poultry diets. Cellulase and xylanase enzymes are produced by many rumen microorganisms and the effects of adding exogenous enzymes to the diets of ruminants have been extensively examined, with the majority of experiments showing no ruminant performance response. Rumen microbes produce large amounts of equivalent enzymes which make the response to exogenous enzymes unlikely.

Grain particle size is important in feedlot diets and The Pork CRC has developed a hand-held sieve for determining grain particle size distribution following milling. This sieve has been used in commercial mills and by smaller pig producers. It is suggested that this hand-held sieve could be modified to enlarge sieve sizes for use in feedlots.

An opportunity exists to improve the quality of processed grain, animal feed efficiency and animal growth rates by monitoring and controlling particle size of processed grain in real time. Near Infrared Reflectance Spectroscopy (NIRS/NIR) is a technology that can measure particle size. The advantages of using NIRS technology, as compared to traditional stack sieve methods, are that it is quicker and little sample preparation is required to complete the test. It also requires little operator training. For steam flaking, opportunities exist to automatically measure outcomes and to adjust processing settings to maximise animal performance and minimise processing costs. Firstly, a method to determine starch digestibility which correlates with animal performance is needed. Further research should develop NIR analysis of steam flaked grain starch availability, with robust calibrations that relate to animal performance measurements.

Measuring the nutritional characteristics of grain prior to processing and during processing, can assist in optimising the settings of the processing equipment, to produce a consistent quality processed grain for operational efficiencies as well as enhanced animal performance. NIRS technology can quickly and accurately measure the nutritional content of grain. For example, moisture concentration in grain can be easily determined by NIRS. Using the moisture concentration to adjust settings such as equipment processing speed or cooking time, can assist in improving operational efficiency as well as producing an enhanced processed grain product for improved animal performance.

With In-line NIR technology, an opportunity exists to improve grain processing quality with the aim to improve animal performance. NIRS technology has traditionally been used as a bench top instrument, however, it can also be used directly in the production line, to continuously automatically measure the performance of grain processing. The advantage of In-line NIRS is that sample collection is not required and results are generated more frequently.

Information from industry experts within the flour milling industry identified the potential application of the intensive dampener. This machinery is used to apply water rapidly to grain with a 3 to 5 second spray in a chamber housing 3 rows of high speed beaters. If this process could be employed in feedlot mills, it could reduce the water application time required for tempering grain. However, to achieve the desired grain moisture for tempered-rolled grain or steam flaked grain, it would require more passes through the intensive dampener and therefore no reduction in total tempering time. In addition, an intensive dampener to handle 10 to 15 t/hr costs approximately 3 to 3 ½ times more than a conventional stainless steel wetting auger of similar capacity.

The use of reducing agents was evaluated. Reducing agents degrade the seed coat and endosperm structure which enables greater water uptake rate and increased swelling of starch granules. Therefore, processing grains in combination with reducing agents can increase digestibility of both starch and protein with benefits greatest in sorghum and corn compared with wheat and barley. Reducing agents promote protein digestibility, which is generally not changed with steam flaking. However, reducing agents are highly reactive. The corrosive nature of these compounds would require feedlots to develop protocols relating to workplace health and safety and legislation relating to storage and handling of hazardous chemicals. Specific considerations relate to storage, handling (emergency protocols, spill controls), mixing and/or dosing systems and handling of any free steep water. Effects of sulphur reducing agents on dietary sulphur requirements should also be considered.

Those methods and technologies that can improve the imbibition of grain have the potential to promote water entry and diffusion rate within grain. It appears that heated water achieves both these requirements. However, the costs of heated steeping water need to be evaluated before it can be recommended. Heating large volume of water at high flow rates will need high energy input (gas), hot artesian water, or heating infrastructure (solar heating system, or methane generation from anaerobic manure storage). The use of ozonated water warrants further investigation. This method of water treatment removes many of the factors which inhibit imbibition. An ozone generator can be simply fitted to existing plumbing, where no additional infrastructure is required.

A wetting auger is a critical component of any grain processing system which requires moisture addition. However, the current wetting auger design has some limitations; such as limited residency time, overfilling and a lack of operational flexibility. A number of designs have been suggested to improve the function of the wetting auger, including i) maximising the residence time ii) incorporating a surge bin for delivery of grain to the mixing auger iii) automated water application (in-line moisture meter) and iv) a classification system to define operations (wetting augers are currently defined in terms of capacity (tonnes/hour). Incorporating a classification that also relates to mixing ability and uniformity such as proportion of free water would improve functional description). The wetting auger should have an inclination of approximately 3 degrees and the length should be calculated by the manufacturing engineers to correspond to the water application rate and tonnage throughput.

A number of technologies are currently available to improve boiler efficiency, and these should be promoted to the Australian feedlot industry. Examples of these include techniques and procedures that can minimise heat loss to promote efficiency and reduce maintenance. Promoting energy efficiency has a greater effect on the cost of boiler operation than sourcing cheaper fuel. Technologies that either improve combustion efficiency (burner technology) or enable combining fuel sources reduce the cost of operation. Environmental considerations notwithstanding, the value of alternative fuel sources should account for their effects on boiler efficiency. A range of boiler operational practices can have direct effects on efficiency. Examples include keeping the boiler well maintained, sourcing the highest quality fuel available (low in moisture, hydrogen content and ash), and storing the boiler in a boiler house (protected from wind, insulated to maintain air temperature and reduce humidity).

A review of microwave technology for potential use in the Australian feedlot industry showed that the microwave treatment of grain increases ruminal starch availability by gelatinising starch. Further, no additional moisture application to the grain is required, grain can be treated pre- or post-milling, and the process is rapid with no heat transfer. Evidence from fermentation assays suggest that digestion of microwaved grain was similar to that achieved by steam flaking. However, the potential application of this technology for grain processing in the feedlot industry is limited, because of lower production capacity, equipment cost, and the requirement for sophisticated control systems and operational expertise.

It appears that there has been limited development in grain processing technologies and equipment use over the past 10-15 years, however, there have been significant improvements in control mechanisms both in the feed milling industries and at the feedlot level (Stuart Barclay, QLD Manger Baiada Poultry, 2016, Per. Comm). These improvements include control of consistency of commodities at receival (moisture, quality) and of processed grain (e.g. particle size, flake density, etc.). Similarly, it has been suggested by other industry experts (John Spragg, Chairman of Australian Stockfeed Association, 2016, Per. Comm.) that there has been limited development (i.e. new technologies) in the feed milling industry in the past 20-30 years.

It has been suggested that those technologies that can reduce the cost of power, which is one of the most significant factors in grain processing, would be beneficial to the industry (Dr Simone Holt, Feedlot Consultant, 2016, Per. Comm.). It seems that very few feedlot operations in Australia are currently using high moisture grains (high moisture corn or sorghum) and further investigation into this type of grain processing method will be advantageous. There is a lack of evidence in the literature on the relative performance of Australian feedlot cattle fed high moisture corn or fermented sorghum diets, compared with the conventional grain processing methods of dry rolling, tempered rolling and steam flaking. More field studies are needed to explore some of these technologies.

When reconstituting grain, making high moisture corn (HMC) or ensiling forages, the main objective is to produce a palatable, waste free and high quality product. The two key requirements are to drop the pH of the ensiled crop quickly and to exclude oxygen. Failure to do so results in spoilage, waste, loss of nutrients and potentially, the production of mycotoxins which affect animal performance and health. Those technologies that promote the fermentation process and provide aerobic stability at feed-out can enhance quality and minimise the losses associated with secondary fermentation. A secure coverage of high moisture corn pits or bun stacks is critical to reduce shrink, spoilage and nutrient loss (Silostop®, Lallemand Animal Nutrition, 2016 http://lallemandanimalnutrition.com).

Best Practice Grain Processing Manual

A comprehensive manual on current grain processing technologies used in Australian feedlots was compiled. The manual covered the suitability of available technologies for different types of grain in diverse feedlot practices. The advantages and disadvantages of these technologies were explored and operating procedures of machinery and equipment were provided to assist feedlot operators to choose the technology that suits their operations. A simple Excel spreadsheet was developed to estimate the cost associated with different processing methods.

6 Conclusions/recommendations

6.1 Review of technologies not used in Australia

The following processes and technologies warrant further investigation:

- Computerised control systems and the use of in-line NIR, to present clean, consistent grain at the commencement of processing and during processing, and to regulate processing systems based on end product specification feedback.
    - Automatic assessment and segregation of grain at arrival based on starch availability or metabolisable energy
    - Automation of wetting augers to improve water addition consistency and distribution
    - Processed grain feedback in the form of particle size and distribution or flake density

- Further investigation of NIR for rapid assessment of faecal starch that can be used in commercial feedlots.
- Use of the Flake Colour Index System (FCIS) to evaluate starch availability in steam-flaked grains.
- Heated water to improve imbibition in tempering.
- Ozone treatment of steeping water and its influence on imbibition rate.
- Controlled comparative Australian feeding trials on animal production with different processing methods to produce a range of particle sizes or bulk densities, using a range of grains, and at varying grain inclusions to reflect commercial practices.
- Controlled Australian feeding studies on the performance of Australian feedlot cattle fed high moisture corn, or fermented sorghum diets, compared with the conventional grain processing methods of dry rolling, tempered rolling and steam flaking.
- Exploration into modifying The Pork CRC hand-held sieve to be suitable for feedlot cattle to determine grain particle size distribution following milling.
- Exploration into technologies to reduce the energy cost of processing.
    - Boiler efficiency in terms of design and maintenance, and fuel alternatives
    - Agents to reduce milling friction and/or increase throughput

6.2 Best Practice Grain Processing Manual

A draft of the manual titled “Best Practice Grain Processing Manual for Australian Feedlot Operations” was compiled to cover the following:

1. Grain types used in Australian feedlot industry
2. Grain receival, handling and storage
3. Grain digestion in feedlot cattle
4. Grain processing methods
    - Dry Rolling
    - Sodium Hydroxide Treated Grains
    - Tempering
    - Steam Flaking
    - High Moisture harvest and storage
    - Reconstitution
    - Fermentation
5. Determining processing costs and efficiency
6. Occupational health and safety
7. Comparative performance

The project team comprehensively addressed the main processing methods for the grains that are commonly used in the Australian feedlot industry. The content of this manual was in line with the MLA ToR, and will provide a resource for the ALFA Nutrition and Milling workshops. The project team consulted with feedlot operators and consultants to ensure that the manual can effectively deliver what the feedlot industry needs. The manual contains pictures of processed grains (under- and over-processed and optimum) to help the users to easily understand the content and implement the necessarily changes to enhance the efficiency of grain processing in their feedlots. A number of diagrams were also produced to ensure the users can understand the physiology and mechanism of grain processing and digestion.

6.3 Research gaps and opportunities

The following research gaps and opportunities on grain processing were identified:

NIRS/NIR Technology

- ✓ Development of NIR (hand-held device) for rapid assessment of faecal starch on wet faeces.
- ✓ Research into the use of NIR and a computerised controller monitoring water addition during tempering of grains.
- ✓ NIR for measuring the average and distribution of particle size of grains for dry rolling processing methods.
- ✓ Development of an accurate direct method to test starch availability (taken at the chest) in steam flaked grains
- ✓ Further research into the viability and use of In-line NIR technology to improve grain processing quality with the aim of improving animal performance. This includes In-line NIR measurements that may link directly to systems that automatically make adjustments. The most obvious initial application is the management of moisture content for several of the grain processing systems that enhance animal performance through wet processing techniques.

Feeding studies

- ✓ Performance of cattle fed high moisture corn or fermented sorghum diets, compared with the conventional grain processing methods such as dry rolling, tempered rolling and steam flaking.
- ✓ Comparative studies - conducting feeding trials to explore animal performance with different processing methods. This includes the impact of different types and amount of grains fed, particle sizes and bulk densities.

Processing methods, targets and milling efficiency

- ✓ Research into better understanding of optimum processing targets for tempered rolled grain.
- ✓ Further exploration of wetting auger design and operation (RPM, residence time, capacity) for different grains.
- ✓ Research into evaluating the effects of processing method, particle size, interactions between grain species, morphology and site of digestion and their effects on Feed Conversion Ratio (FCR). This data and information could be developed into a spreadsheet that can be used by feedlot operators to estimate the cost of gain. For similar growth rates (and therefore effects on output and inventory cost) the main driver of profitability is FCR and ultimately the cost of gain based on the cost of achieving a given FCR.
- ✓ There is a lack of robust comparative data on surfactants and emulsifiers aimed at increasing moisture uptake in tempering, and putative effects on increasing mill throughput and prolonging roll life.

- ✓ Potential improvements in rate and extent of imbibition during steeping with the application of ozone to the steeping water, or the use of heated water, warrant further investigation.

7 Key messages

7.1 Review of technologies not used in Australia

The review of new technologies showed that there are some processing methods that are used in the US and other species that could be modified and used in feedlot operations. In addition, there are existing technologies in Australia, such as NIR, where work on applications in the feedlot sector has scope for substantial increases in grain processing efficiency. These technologies can be complementary to those currently used in Australia, and have the potential to improve feed conversion ratio and reduce the cost of processing. Further studies are needed to explore the application of new technologies in feedlots and to examine their cost-effectiveness.

7.2 Best Practice Grain Processing Manual

A manual on current grain processing was compiled to provide a comprehensive guideline for feedlot operators and consultants. This manual covered the description, equipment and machinery that are needed for each processing method. Standard operating procedures for each processing method were provided to assist with improvements in operational efficiency by feedlot mill operators. A cost-analysis spreadsheet was developed in Excel to provide a framework to evaluate the cost of grain processing. The manual also included a section on comparative performance; highlighting 2 case studies using different processing methods and their potential outcomes.

7.3 Research gaps and opportunities

The collated information on current and new technologies were used to identify the knowledge gap in grain processing and potential opportunities for cost-effective improvements in the efficiency of current technologies. The knowledge gap includes the application of NIRs/NIR for measuring the efficiency of grain processing methods, and evaluation of the performance of grain-fed cattle using different technologies and milling efficiencies.

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9 Appendix

Table 1. List of American industry contacts questioned about grain processing technologies in the USA

Industry	Contact name	Affiliation/location	Email	Web address	Phone
Owen Associates	David Owens	6003 Durrett Drive, Amarillo, TX 79124	dho33@sbcglobal.net	None provided	Tel: +1-806-676-9622
R&R Machine Works	Warren Cornelius	1006 Liberal St., Dalhart, Texas 79022	sales@r-rmachine.com	www.randrmachineworks.com	Tel: 1-806-244-5686
Ferrell-Ross Roll Manufacturing, Inc.	David Ibach	3690 FM2856, Hereford, Texas 79045	dibach@ferrellross.com	www.ferrellross.com www.ferrellrossrollmfg.com www.flo-more.com	Tel: +1 806-364-9051
Satake Australia	Graham Podboj	Satake Australia	info@satake.com.au	www.satake.com.au	Tel: +61 2 4725 2600

Table 2. Manufacturers that contributed to the potential application of flour milling technologies to grain processing in the Australian feedlot sector

Industry	Contact name	Affiliation/location	Email	Web address	Phone
Buhler Machinery Australia	Torsten Rohrbeck	Unit 1/181 Rooks Road, Vermont Victoria 3133 Australia	torsten.rohrbeck@buhlergroup.com	www.buhlergroup.com	Tel: +61 3 9872 7900 Fax:+ 61 3 9872 7999 M: +61 477100045
Quayle Milling		133 Lovell St, Young NSW 2594 Australia	info@quaylemilling.com.au	www.quaylemilling.com.au	**Tel: +61 2 6382 1988**
Cambooya Welding		- 494 Cambooya Connection Rd Cambooya, QLD 4358 - North Star Depot 69 Wilby Street	cambweld@hotkey.net.au	www.cambooyaweldingworks.com.au	Tel: +61 7 4696 1244 M: 0427 763 055

Table 3. List of identified wet milling and ethanol industries

	Contact name	Affiliation/location	Email	Web address	Phone/Fax
Expert/ Academic	Dr Terry Klopfenstein	University of Nebraska Animal Science Department Lincoln, NE 68583-0908, USA	tklopfenstein1@unl.edu	http://animalscience.unl.edu	Tel: +1 (402) 472-6443 Fax: +1 (402) 472-6362
	Dr David Johnston	United States Department of Agriculture, Agricultural Research Services, Wyndmoor, PA 19038, USA	David.Johnston@ars.usda.gov	https://www.ars.usda.gov/oc/np/errc-research-highlights/errcresearchhighlightsintro/	Tel.: +1 (215) 836 3756 Fax: +1 (215) 233 6406
Industry	Mr. Ming Leung	Mill Manager Manildra Group	ming.leung@manildra.com.au	http://www.manildra.com.au/	Mobile: 0400 853 637
	Dr Rick Stock	Feed Product Line Manager at Cargill	Rick.Stock@cargill.com	https://www.cargill.com/feed/	
	Mr. Grahame Peacock	Mill Manager Defiance Maize Products P/L, Lot 2 Churchill Dr Warwick, QLD Australia	grahamep@corson.co.nz	http://www.truelocal.com.au/business/defiance-maize-products-pty-ltd/warwick	Tel: (07) 4661 1233 Fax: (07) 4661 3749
	Mr. Mark Hawes	LGPM Process Innovation, 12 Keith Campbell Crt, Scoresby VIC 3179, Australia	info@lgpm.com.au	http://lgpm.com.au/	Tel: (03) 9702 4855 Fax: (03) 9702 4865
	Mr. Frank Geurts	Manufacturing Manager Ingredion ANZ P/L	frank.geurts@ingredion.com	http://www.ingredion.com	
		Satake Australia 15 Leland Street Penrith, NSW 2750 Australia	info@satake.com.au	http://satake.com.au/	Tel: (02) 4725 2600 Fax: (02) 4725 2601

Table 4. List of industries on microwave technology

Industry	Contact name	Affiliation/location	Email	Web address	Phone/Fax
MAX Industrial Microwave		3 Chufeng St, Shifu District Yantai City, Shandong Province, Yantai 264000	info@maxindustrialmicrowave.com	maxindustrialmicrowave.com	Tel. +0086 535 6203363
Fricke und Mallah Microwave Technology GmbH		Werner-Nordmeyer-Str. 25, 31226 Peine, Germany	marcel.mallah@microwaveheating.net	www.microwaveheating.net	Tel. : 0049 (0)5171 / 5457-0, DW: -19 Fax : 0049 (0)5171 / 5457-26 Mobil: 0049 (0)170 / 48 11 239