IMPROVED PELLET QUALITY FOLLOWING THE IMPLEMENTATION OF A HACCP SYSTEM IN A COMMERCIAL ANIMAL FEED PLANT

by

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SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE MASTERS OF SCIENCE
IN PRODUCTION ANIMAL AND COMMUNITY HEALTH

In the

FACULTY OF VETERINARY SCIENCE
DEPARTMENT OF PRODUCTION ANIMAL STUDIES
UNIVERSITY OF PRETORIA

OCTOBER 2003

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ACKNOWLEDGEMENTS

The author sincerely whishes to thank the following people:

- Dr. Willem Schultheiss for his valued support, motivation and guidance during this project.
- Dr. Hinner Köster for his technical input and Prof. Bruce Gummow for his input and help with the statistical analysis of the data.
- Prof. Keith Behnke and Dr. Joe Hancock from Kansas State University for their valued comments and input on production processes.
- The Isando production manager and HACCP team for their involvement and perseverance during the project.
- My wife for her patients, support and the time she had to sacrifice to allow me the opportunity to complete this project.
- My parents who never stopped believing in me.

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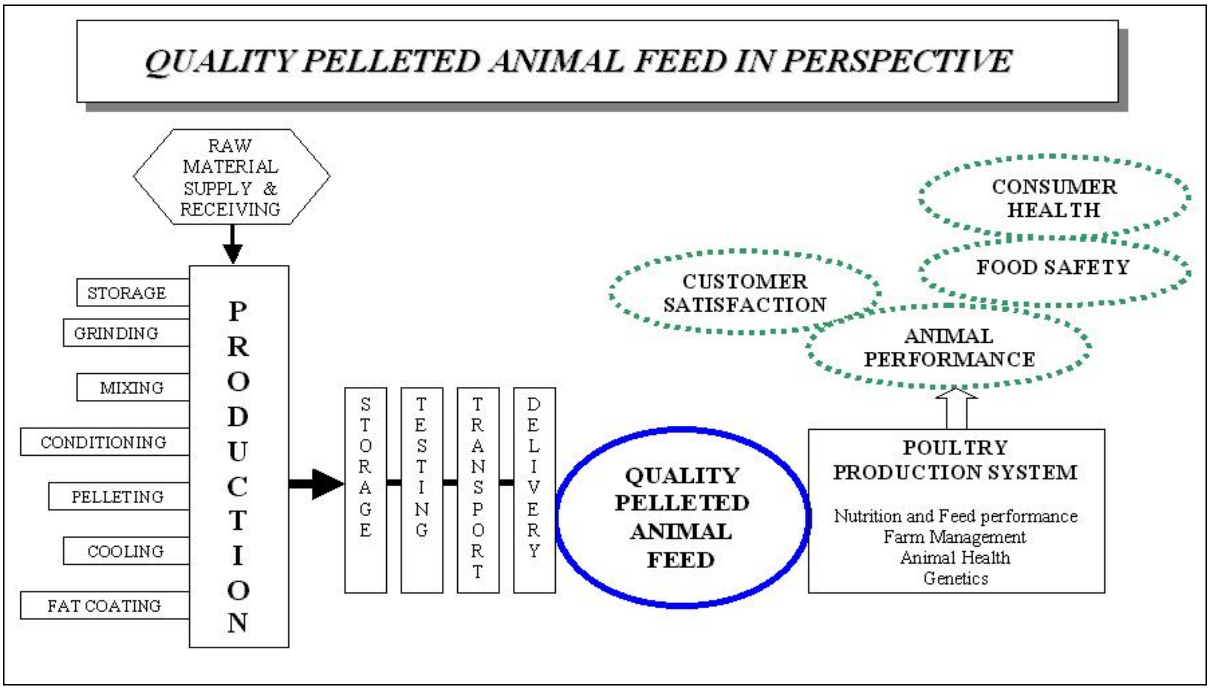
CHAPTER 1

INTRODUCTION

1.1 Background to the study

The feed industry forms an integral part of the feed to food chain and it is becoming increasingly important to have quality assurance systems in place that ensure optimal product performance, consumer safety and client satisfaction.

Figure 1: Schematic representation of the role quality pellet feed plays in the feed to food chain



In 1998 the management of a large feed company was concerned about the variety, and cost of customer complaints on the quality of pelleted animal feeds, especially since these continued to exist within the existing ISO 9002 program (International Standards Organization; Standard 9002:1994) that was being implemented (Personal communication (PC): McCracken, Senwesko Animal Feeds, 1998). The variability and quality of pelleted animal feed was especially of concern in a changing market where feeding pelleted rations to broilers has become the norm rather than the exception (PC: Dunn, Senwesko Animal Feeds, 1999). Examples of poor quality pelleted feed are shown in Appendix I.

The author has been involved with several feed companies over the last five years where pellet quality has always been a matter of great importance and debate (PC: Cottle, 2001. AFGRI Animal Feeds, SA). Personal experience and involvement in this field has highlighted the opportunity to reduce non-conformance costs as a result of poor pellet quality, and to contribute some research towards these issues of importance in the feed industry in South Africa.

The positive relationship between pellet quality and animal (poultry) performance is well documented especially if the percentage of pellets in the feeder decreases below 60% (PC: Hancock, 2001). Due to the cost of feed and its importance in animal production, customers are extremely sensitive about the quality of the pellets they received. Customer complaints relating to a high percentage of fines (physical appearance), poor intake and product inconsistency support this sentiment.

The image of companies is seriously hampered as a result of poor quality pelleted feed and, even though these rations are of high nutritious value this is of little relevance if feed intake, animal performance and customer satisfaction are not fulfilled. For an animal feed manufacturer it is therefore important to produce feed of consistent high pellet quality.

Following a protocol on the investigation of pellet quality complaints and problems (Payne,1998) an assessment of the nature of the customer complaints was made by auditing the relevant pelleting processes. Audits conducted on some critical control points (CCP's) in the production process showed:

- that many production parameters were often not closely monitored or controlled,
- that limits for process parameters, affecting quality, were often non-existent and that final product inspection and testing was not executed correctly,
- the absence, or inadequate availability of testing and monitoring equipment as seen in the case of sieves needed to determine mash fractions prior to pelleting (PC: Hancock, 2001),
- inadequate monitoring-, control- and record keeping systems on the critical control points of the pelleting process, resulted in the deviation of CCP's from target values, leading to increased process parameter fluctuation and complaints on product quality (pellet percentage, durability and inconsistency),

- the absence of production or product tolerance levels or limits and inadequately trained staff (PC: Ender,1999),
- unsubstantiated and different perceptions of the scientific functioning of the pelleting process,
- inadequate Information Technology (IT) and record keeping systems to supply management information on both production processes or product analysis results,
- examples of incorrect steam line arrangement as pointed out during the personnel communication with Steen (2001) and the actual functioning principles of boilers in steam production, as discussed with Visser (PC: Visser, 2000).
- that a general negative sentiment existed amongst employees after the first attempt at an ISO 9002 program by the head office.

The information assembled explained and provided a strong basis for the customer complaints received on the quality and inconsistency of pelleted products delivered.

Considering the increasing demand for quality pelleted rations, the problems identified necessitated that the company implemented programs that:

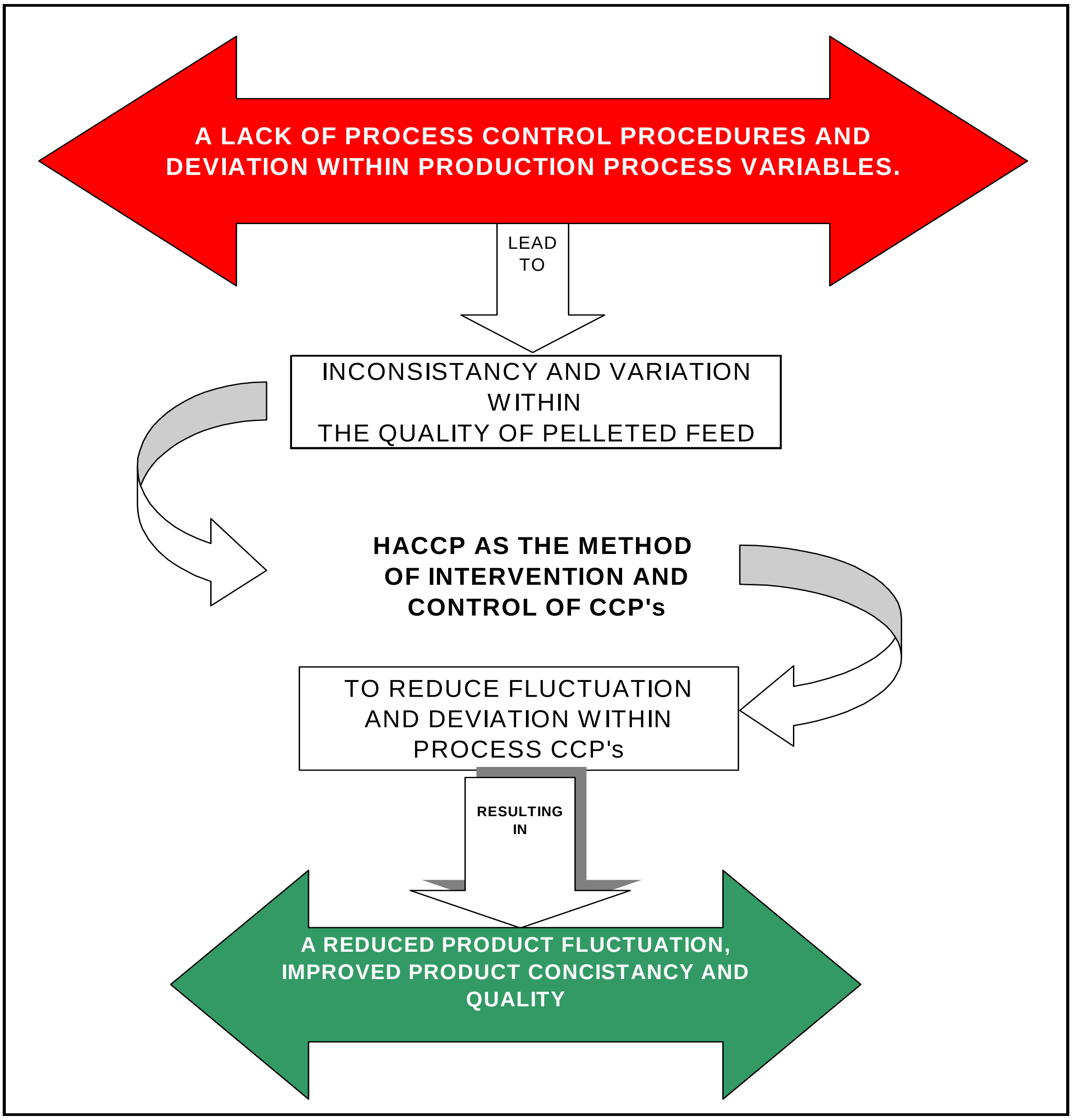
- could address the limitations and risks identified within the previous quality system,
- helped employees understand and take ownership of the pelleting process and the operation of their equipment,
- gave insight into the influence of various pelleting process variables on the pelleting process and the quality of the final end product, and
- educated and empowered personnel.

During the planning of a Total Quality Management (TQM) program it became evident that involvement of personnel from the start was crucial as previous attempts at the ISO 9002 route had only variable degrees of success (McCracken, 1998). This tendency was also observed at other production facilities in South Africa as well and was therefore considered an important issue to address in a new quality program.

It was from this point of view that a Hazard Analysis Critical Control Point (HACCP) program was selected, as it represented a practical and ground level workable quality system with huge financial and quality benefits to an animal feed pelleting plant, while forming an important basis for progress to further quality management systems such as ISO 9001:2000 and Good Manufacturing Practice (GMP). The HACCP system not only addressed nutritional aspects but also those of physical, quality and feed safety (Den Hartog, 2001).

It was therefore postulated that a modified HACCP system could possibly be used as an intervention tool to improve pellet quality and reduce process and product fluctuation (Figure 2).

Figure 2: **Schematic representation of how HACCP was used as the method of intervention to achieve the project objectives**



CHAPTER 2

LITTERATURE REVIEW

2.1 Introduction to HACCP systems

The Campden and Chorleywood Food Reasearch Association (CCFRA,1997) describes HACCP as the acronym for “Hazard Analysis Critical Control Points” and states that it represents a system of food safety assurance based on the prevention of safety problems. The HACCP technique was initially developed by a group of companies that had to develop food for the National Aeronautical Space Association (NASA) space program (CCFRA, 1997). The controls had to be such that it could deal pro-actively with the control of microbiological hazards that might affect product safety. It has increasingly become the accepted technique primarily applicable to issues of product safety associated with biological, chemical or physical hazards. The model has however been increasingly used during recent years in the application of the HACCP technique to identify hazards and control measures associated with product quality defects (e.g. particle size, color, taste, texture etc.)

The term “Hazard” is defined as: “A biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect.” (CCFRA, 1997). In the case of this study the hazard was defined as “poor pellet quality, being a low percentage of pellets at loading with a poor durability” that may have a negative affect on animal health, performance and product quality.

The HACCP concept is a logical cost-effective basis for better decision making with respect to product safety and quality. It has both national and international recognition as the most effective means of controlling food borne disease (and for that matter quality problems) and is promoted by the joint Food and Agricultural Organization (FAO) and World Health Organization (WHO) Codex Alimentarius Commission (Draft Revision 1996; CCFRA, 1997). The integration of GMP, ISO 9001 and HACCP systems are internationally accepted approaches to total quality management, with the HACCP system forming part of the risk assessment and risk management tools within a TQM system (Product Board Animal Feed, Den Haag, 2000 b).

As many quality assurance systems are aimed at known risks, it is often reactive in nature and usually insufficiently tailored to prevent unforeseen problems. The importance of the HACCP system is that its control measures are pro-active in nature and important as a means of preventing quality problems and health risks.

2.2 HACCP system justification

Mortimore (1994), the Campden and Chorleywood Food Research Association (CCFRA, 1997) and Ratcliff (1999) describe HACCP systems as the internationally recognized approach to the prevention of food borne hazards and the assurance of food safety and product quality (Loken,1995 and Pearson, et al 1995). Pearson (1995) describes the use of HACCP systems with great success in the meat, fish and poultry processing industry.

Ratcliff (1999) and the Product Board Animal Feed (2000a) supports the basis of HACCP when referring to the many examples of food scares (conditions of food that might adversely affect human and animal health) despite ISO 9002 registration. He mentions that one of the shortfalls of the ISO 9002 system was that it did not address the issue of risk assessment and due diligence and that this system was often aimed at known risks and is therefore reactive in nature. The HACCP system, however, uses a systematic method of addressing product quality issues and applying appropriate risk controls.

The old ISO 9002:1994 system did indeed have the shortfall of not handling the aspect of risk assessment in the quality system requirements while the new ISO 9001:2000 version has however been upgraded to include the element of “risk assessment and control” in its system requirements. It is exactly in this area that the HACCP system becomes very important as it is extremely well suited for this purpose. It is on this bases that many quality systems work complementary to each other as shown in Figure 3. Some of the advantages of ISO systems to a company and their customers are summarized in Table 1a and 1b.

Table 1a: Advantages of ISO systems to the company

(Taken from the South African Bureau of Standards introduction guide to ISO systems, 1998)

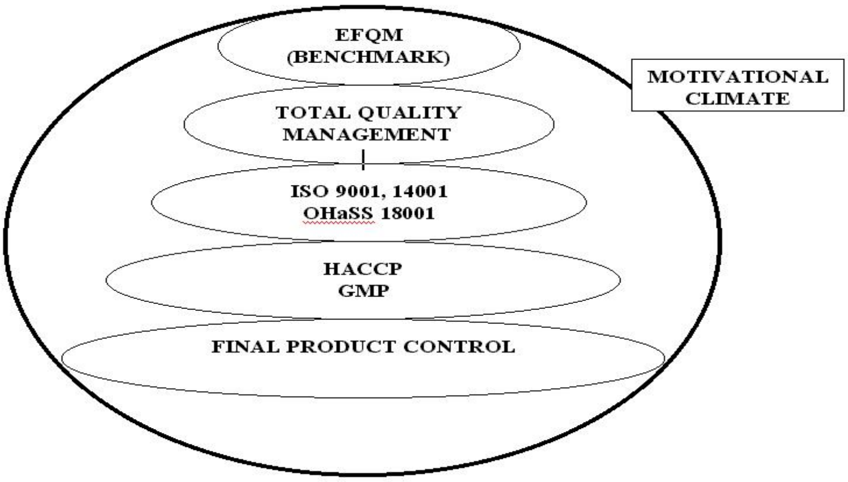
Item	Advantage experienced by personnel	(%)
1	Improved product and service quality	76.08
2	Lowering of products not conforming to standards	57.86
3	Improved image of company in field	71.30
4	Improvement in competitive advantage	56.95
5	Improved internal communication	53.08
6	Better quality awareness	84.05
7	Create a culture of quality awareness	69.70
8	Improved record keeping systems	85.19
9	Improvement in management efficiency	56.04
10	Improvement in customer care and service	72.44
11	Reduction of products returned from customer	58.31

Table 1b: Advantages of ISO systems to the customer

(Taken from the South African Bureau of Standards introduction guide to ISO systems, 1998)

Item	Advantage experienced by the customer	(%)
1	Reduction of time wastage	36.45
2	Reduction in product loss	42.60
3	Reduction of products not conforming to standards	57.86
4	Improved stock control	35.76
5	Improved record keeping	85.19
6	Create quality awareness culture	69.70
7	Improved internal communication	53.08
8	Improvement in customer care and service	72.44
9	Reduction of faulty product returned	58.31

Figure 3: Schematic representation of the various supporting elements in a Total Quality Management program



Douglas (2001) mentions that government policies all over the world are changing in response to consumers demand for safer food especially following food scares (Nitrofuran and salmonella contamination of food as examples) in several countries. He explains that some Canadian mills have opted for, and successfully implemented HACCP systems in their mills and supply chains. Muirhead (2001) supports the value of HACCP systems in the feed industry by stating that the international feed industry is moving more and more towards the use of HACCP systems in their mills.

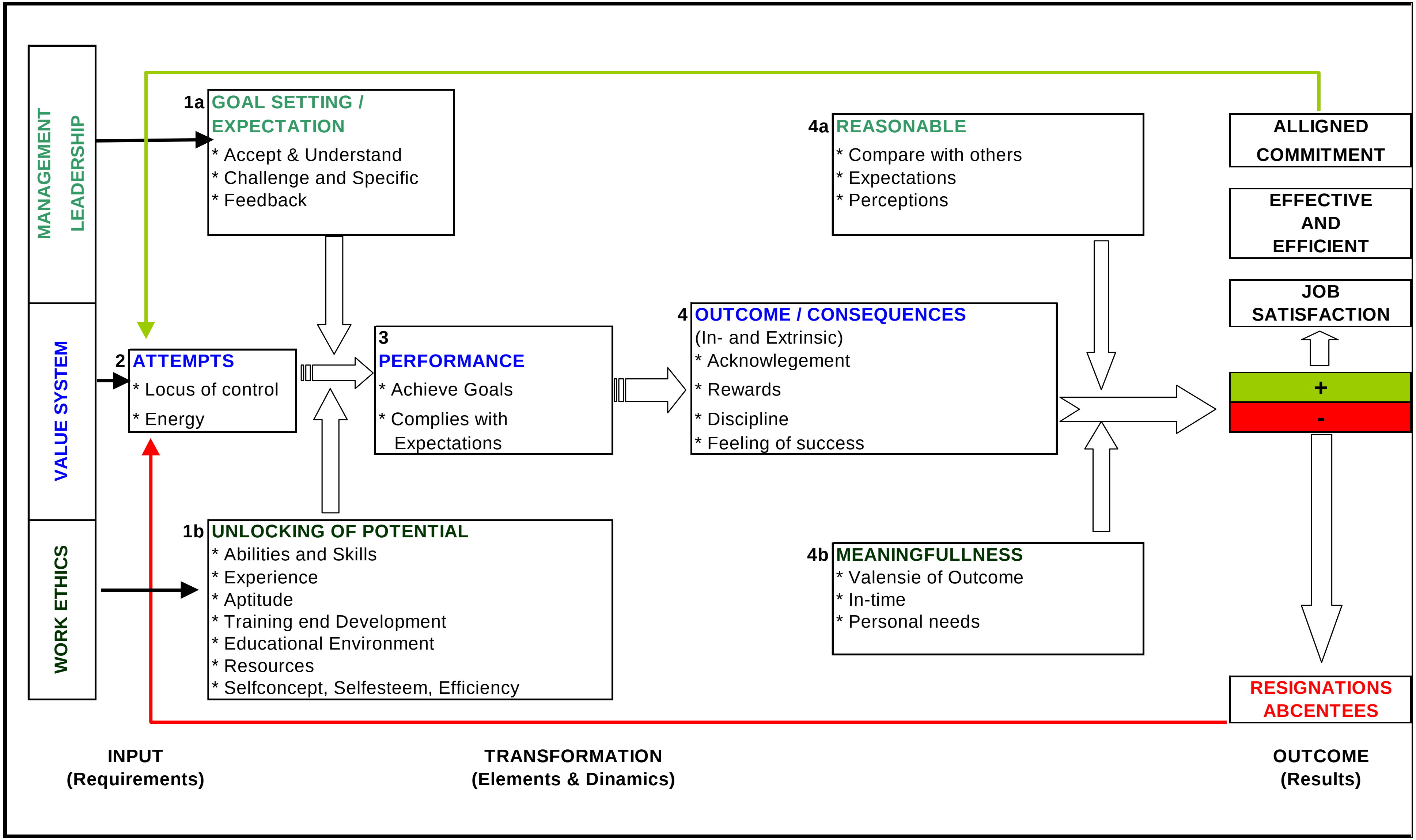
The HACCP model represents an internationally excepted, practical and systematic method of assessing the quality elements of a specific process. It is a system of process control based specifically on the prevention of safety (Thomas, 2001) and in this case, quality problems. Due to its systematic approach this model also forms a good basis for GMP and ISO 9001 system requirements. To achieve the goal of quality pelleted animal feed and reduced product variation it is necessary to identify and understand the different pelleting process variables that influence pellet quality, set parameter specifications and implement systems to monitor these variables to ensure that they are maintained within specified limits. It is on the basis of these requirements that the HACCP system was chosen as the model of choice. The HACCP model can analyze a specific production line with the object of addressing all process variables that might have an influence on product quality, animal health and consumer safety.

In spite of Ratcliff's strong support for HACCP, many authors advocate quality programs that incorporate a combination of ISO, GMP and HACCP as they often supplement one another. This is also the case in the Netherlands where the old GMP system has been changed to include a HACCP system as part of the pro-active approach to quality management (Den Hartog, 2001).

Other supporting elements to consider

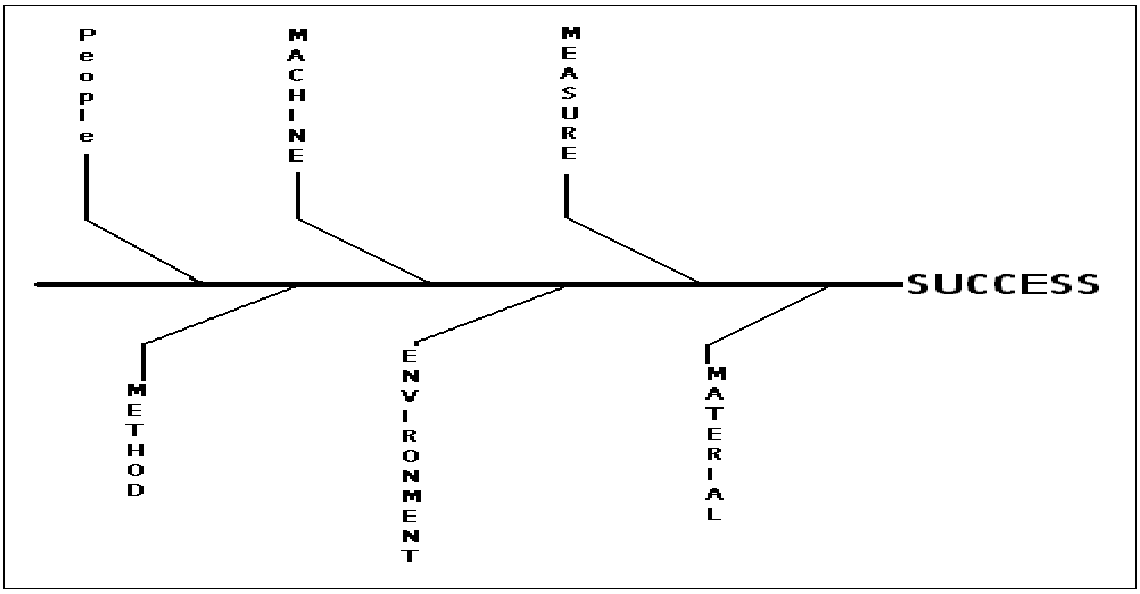
Creating a motivational climate in the working environment is important to the success of many quality programs. The elements and dynamics of a motivational climate formed a supporting basis for achieving success in this area (Coetsee, 1996). The elements and dynamics of a motivational climate are shown in Figure 4.

Figure 4: Elements and dynamics of a motivational climate (Adapted from Coetsee, 1996)



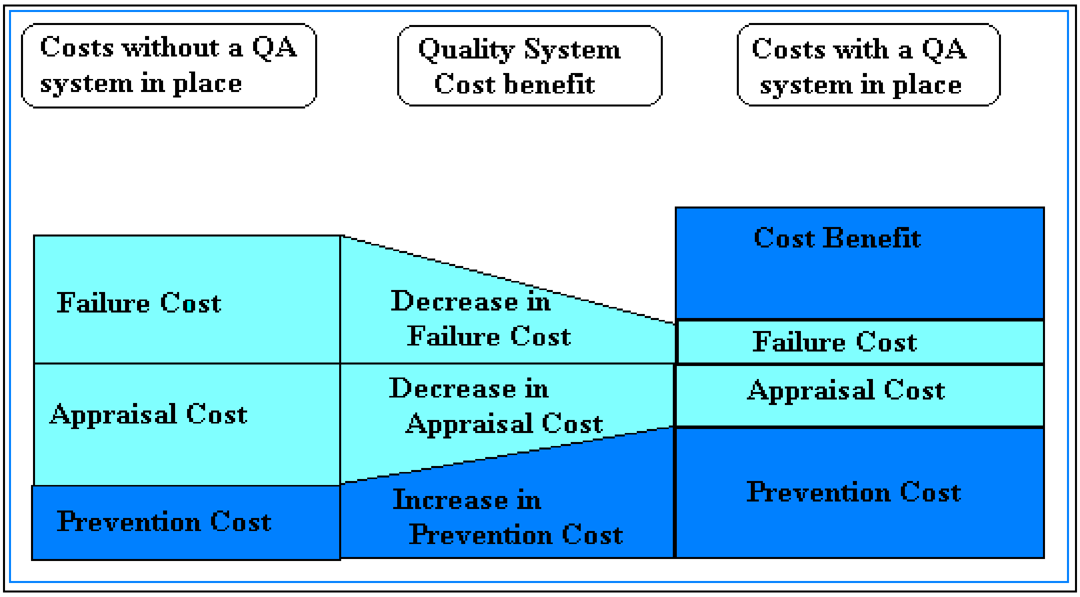
The success of many quality programs is determined by the interaction of various elements including people, equipment, environment, material, method and management. This concept is illustrated in Feed Manufacturing Technology IV (1994), as a “Fishbone diagram” (Figure 5a).

Figure 5a: An example of some of the elements in a Fishbone diagram



Successful programs depend on all the interaction of all these elements with the objective of contributing a cost benefit to a company (Figure 5b), whereas the exclusion of any one of the components may lead to defective products and a rise in the failure cost.

Figure 5b: Schematic representation of the cost benefit derived from a quality management system **(SABS Introduction Guide to ISO Systems, 1998)**



2.3 Formulation and raw material ingredients as factors influencing pellet quality

Reimer (1992), Payne et al. (1998) and Behnke (2001) and, all highlighted the fact that the formulation most probably has the single largest impact on the quality of pellets, approximately 40%, and that it is possible to predict, prior to production, how changes in formulation will affect pellet quality (also referred to as the pelletability index of the formula). They also mention that it is especially important to assess pellet quality data together with the pelletability score and the cost of raw material limitations to determine the best course of action in improving pellet quality.

In order to control the impact of formulation and raw material on pellet quality, two systems are mainly employed, namely:

- The restriction of excessive raw material changes within the formula by applying limits (called bounds and swings) to formulation ingredients that prevent excessive changes in the formula and,
- Incorporation of a pelletability scoring system as described by Borregaard (1993) to aid in assessing the effect of raw material changes on the pellet quality.

The effect of the raw material type and its inclusion level on pellet quality is clearly described by various authors. Behnke (2001) summarizes several articles of Headly & Kerskner (1968) and Richardson & Day (1976) that highlights the work by several authors whom mentions that:

- the addition of fat reduces pellet quality (Headly & Kerskner, 1968),

- the addition of protein and fibrous raw material increases pellet durability (Fahrenholz,1989; Kee, 1988; Lopez, 1993),

- protein has a greater influence on pellet quality compared to starch (Woods, 1987; Briggs *et al.*, 1999),

- pellet quality improves with an increase in protein content (Stevens, 1987; Winowiski, 1998; Briggs *et al*., 1999).

- an increase in moisture improves gelatinisation and reduces the “glass transition” phase temperatures (Zeleznak & Hoseney, 1987), and

- processed raw material is often subjected to heat treatment during pelleting so that the raw material on its own has an impact on the pelleting process and the end product (Qiao, 1998).

- indiscriminate use of temperature during the conditioning or pelleting phase can result in reduced product quality and nutrient destruction (Schwatzer,1999).

- additives such as lignosulphate binders can often be used to aid in improving pellet quality (Friedrich et al,1971). Although these binders do help they do not have any nutritional value and only add to the raw material cost of the ration.

Dozier (2001) highlights the impact and restrictions of formulation on pellet quality as a factor influencing economical poultry meat production. He states that it is often impractical and not cost beneficial to employ such practices as mentioned above since it may impose limits on the least cost formulation system. In his opinion it is far more cost beneficial to optimize and exercise better control on existing production systems without imposing too high restrictions on formulation. This impact was observed in an in-house formulation exercise (Appendix II), where the fat percentage on a specific product group was limited in the formula to a maximum of 6% and the pelletability was set at a minimum of 64.5% with the object of improving the pellet quality through formulation. These formulas had an additional cost of R420 000 per year, demonstrating that restrictions on formulas may have a large financial cost impact. The data supports Dozier’s findings that it is far more cost effective to improve existing equipment with, for instance, a post pelleting fat coating system, instead of imposing restrictions on the least cost formulation system. This demonstrates the cost impact when limiting the fat percentage as a means of correcting pellet quality problems.

2.4 Defining and measuring ideal pellet quality and it's affect on animal performance.

Personal communication with clients and feedback received showed that there is no real consensus amongst producers on what the ideal pellet requirements are, and furthermore, that unrealistic expectations or perceptions of the real contribution of pellet quality to animal performance is not uncommon. This is highlighted by the variety of orders from customers requesting a range of 30 - 100 % pellets in the feed. Poultry producers are also not completely aware of what the statistical probability for success is when considering all the variables involved.

Dale (2000) describes the effect of "common cause" by showing that the probability of a producer reaching the ideal weight and feed conversion rate at a 90% confidence interval and 4 common causes (production process, feed quality, chick quality and broiler production management) is only 66%, highlighting the importance of all role players in achieving success.

The importance of setting standards for the quality of pelleted animal feed is not only important as a means of ensuring quality and safety, but plays an important role as a tool for educating the customer on what can be expected (Ziggers, 1996). Most animals have an acute sense of smell, taste and/or vision (Forbes, 1995), and this places emphasis on the fact that controls need to be in place to prevent feed from being contaminated with substances that might affect feed intake such as odors arising from poor quality or wet raw materials introduced into the feed.

The above shows the importance of involving and training producers. Payne (1998) supports this observation by stating that a company has to determine its own pellet quality based on the current process design, capability and customer needs, and thereafter define quality targets in order to achieve and maintain these requirements.

Quality pelleted animal feed is summarized by Behnke (2001) as feed that :

- consists of the correct nutritional- and physical composition that will ensure optimal performance, maintain health of the animal and ensure complete customer satisfaction.

Pellet quality on the other hand can be defined as:

- the percentage of pellets at any defined stage from pelleting to feeding,
- the durability of the pellet where the durability is an expression of how well the pellets can withstand handling during the production, transport and feeding process, and
- the physical hardness of the pellet.

The pellet percentage is determined by weighing a representative sample from a batch, sifting out the fines and calculating the remaining pellets as a % of the sample. Measuring pellet durability is most often done by the standard Tumbling can method, developed by Young (1970) and described by the ASAE (1987). Other methods such as the Holmen pellet durability tester and the Borregaard LT-III, incorporate a pneumatic recycling mechanism (described by McEllhiney,1988) that also produces consistent results but with lower pellet durability predictions.

The effects of pellet quality on animal performance

The papers by Behnke & Beyer (2001) and Köster (2003) give a good overview on the effect of feed texture and the processing thereof on animal performance. Both overviews emphasize the recognition that feeding poultry pelleted feed could enhance the economics of production by improving feed conversion and growth rates. For this reason, feed for meat birds is usually processed into pellets or crumbles. A survey of various literature sources indicates that pelleting results in improvements in feed conversion from 0 to 12 percent. Because the cost of feed is a substantial portion of producing meat, even small increases in feed conversion can increase economic returns. The cost to mix and manufacture feed must also be considered. These costs must not exceed the performance gains observed in the production of the birds.

Target pellet quality typically varies among the species of birds used for meat production. Pellet quality is especially important with ducks, where the feed mill may seek a Pellet Durability Index (PDI) of 96% to achieve optimum bird performance (Dean, 1986). When ducks consume mash feed, a sticky paste forms on their bill. This caking of feed discourages optimum feed consumption while increasing wastage as ducks wash their bills with water to remove the sticky paste. Because turkeys spend more time on feed, sub-optimum pellet quality can cause more feed wastage. Subsequent research by Dean (1986) demonstrated turkeys to be quite sensitive (even more than broilers) to pellet quality and fines and a PDI of 90% may be targeted.

Pelleted broiler diets generally improve growth performance and feed conversion (Table 2). Hussar and Robblee (1962) reported reground pellets did not affect early bird performance. However, as the birds matured, those fed whole pellets had better growth and feed conversion rates compared with those fed reground pellets. This would suggest that feed form had some influence on performance. Hull *et al*. (1968) reported a 5% better feed conversion for birds fed pelleted diets however, regrinding the pellets resulted in a lower feed conversion than the original mash diet. A field study conducted by Scheider (1991) indicated birds fed 75% whole pellets as compared to 25% whole pellets showed an improved feed conversion (feed:gain = 2.08 vs. 2.13).

Table 2: The effect of different types of feed processing on broiler performance

	Meal		Pellet		
Reference	ADG (g)	F:G	ADG (g)	F:G	Comment
Hussar and Robblee (1962)	18.8	2.17	23.6	1.98	Pellets
			21.2	2.00	Reground pellets
Hull (1968)	18.9	1.56	19.3	1.48	Pellets
			18.3	1.61	Reground pellets
Runnels et al. (1976)	42.0	2.14	47.0	2.10	Pellets (unsifted)
			44.9	2.11	Pellets (sifted)
			44.5	2.12	Crumbles
			44.7	2.12	½ Pellets & ½ Crumbles
Proudfoot and Hulan (1982)					
Experiment 1	34.0	2.10	33.6	2.09	100% fines
			35.3	2.02	45% fines
			35.5	2.02	35% fines
			35.6	2.03	25% fines
			35.8	2.01	15% fines
			36.5	2.04	5% fines
			36.4	2.01	0% fines
Experiment 2	39.2	2.11	38.7	2.11	100% fines
			39.3	2.06	80% fines
			40.5	2.06	60% fines
			40.9	2.05	40% fines
			41.6	2.04	0% fines
Scheider (1991)	—	—	43.3	2.08	25% fines
			42.2	2.13	75% fines

(Adapted from Behnke & Beyer, 2001)

In a study done by van Biljon (2001), birds fed reground pellets did however not perform (weight gain, bodyweight and feed conversion rate (FCR)) as well as the birds fed on pellets, and even performed worse than the birds fed on the mash diet. It is however unsure what percentage of pellets was fed and whether the pellets were subjected to similar heat treatments that could affect digestibility.

From the studies summarized in Table 2, it appears that a lower feed conversion may primarily be a result of selective feeding on the part of the birds, or increased feed consumption or feed disappearance associated with poor quality pellets. Feed wastage and spoilage due to poor feeder management is often a primary contributing factor in feed disappearance and, consequently, decreased feed efficiency. Certain behavioral and anatomical traits of poultry must be considered during feeding. Pelleting reduces feed waste on the farm and this is due partially to avian anatomy. Without teeth and with the need to use gravity to consume feed, broilers and turkeys cannot easily grasp food. Feed with uneven particle size may increase waste since the smaller particles easily fall from the bird's mouth. To fill the crop, a bird consuming fines or mash must spend more time standing to consume food. This decreases feed conversion since more energy must be expended to feed. Even feeder height is important, since setting above or below optimal will influence the amount of feed wasted. Indeed, work has shown that feeder height may need to be lower than recommended if the feed quality is poor. Today's birds are young and heavy compared to birds just a few years ago and thus are able to stand for shorter time periods. As mentioned earlier, there are other practical reasons for pelleting feed. Selection for increased body weight at a younger age has no doubt influenced basic anatomical and physiological traits. For example, the anatomical changes in the bird due to increased growth rate and size means that the oral cavity of birds has changed slightly. At first this may seem trivial, but even this small change may influence feed spillage and feeding time (Behnke & Beyer, 2001; Köster, 2003).

It is also known that the anatomy of the digestive system is affected by feed particle size, which could impact nutrient absorption (Choi *et al*., 1986). This is especially important considering that the digestive system of broilers and turkeys selected for rapid growth is less mature as the birds are forced to market weight faster. Research is limited on the proper pellet sizes required by broilers and turkeys, and this may need to be addressed as feed manufacturing changes are made.

We may have missed the importance of pellet length and size since current manufacturing methods often result in soft feed pellets that may degrade in an experiment or on a farm. It is likely that a refinement of pellet size to age or body weight can be optimized to improve performance. Because birds have a keen sense of sight, feed particle size is also of importance. Studies indicate that birds desire feed in a larger size than mash. If provided a diet with equal portions of pellets and fines, the birds will consume the pelleted feed first (Scheider, 1991).

Poorly manufactured feed with excess fines results in some of the birds consuming only pellets, leaving the smaller fines for less aggressive birds. Because pellet quality affects the rate of growth, the presence of fines in a feed can affect flock uniformity and impact processing. If fines are fed to poultry, a loss in FCR and rate of gain is observed (Brewer & Ferket, 1989; Moran, 1989; Waibel *et al*., 1992). Almost as a rule of thumb, it would appear that older data indicates that with each additional 10% fines, a loss of one conversion point will result. Unfortunately, almost all of the previous literature reported in poultry publications focuses on the number of fines and pellets by weight, not the PDI. Therefore, it is difficult to review contemporary literature concerning the effects of pelleting on bird performance as few studies have been published with sufficient feed processing data to support their hypotheses. This makes it difficult, if not impossible, to interpret much of the available data on poultry feed quality. For example, a diet screened to contain 100% pellets may only contain “soft” pellets that easily break apart during the transport and feeding processes, an observation that was made in research trials by Wilson and Beyer (1998).

Feed pellets are damaged by loading, unloading, storage, conveying and transferring to feed pans. The handling of the feed often results in increased fines and broken pellets, and in some cases, seriously reduces the total percentage of pellets that ultimately reaches the feed pans. Because automated feed transfer and handling systems are necessary, it would seem that the best remedy for this situation is to increase the PDI of the feed using a different manufacturing process. It is important to reiterate that the PDI is a better measure of feed quality, at the feed mill, than the total number of pellets. However, “percentage of fines” is often a more useful measure at the load out, farm and feed pan.

In-house trials and experience in this area indicated that a minimum pellet to fines ratio of 70:30 delivered at the feeder gave the best results (PC: Dunn, 1999). This seems in line with communication with Hancock (2001a) who indicated that there is a significant impact on broiler performance at pellet levels below 60 percent. He also emphasized the importance of setting pellet size specifications for different production stages as the growth performances of, for instance pigs, differ on certain pellet sizes and at various stages of production.

The importance and benefits of pelleting have been well described in the literature. Some of these benefits include enhanced handling, improved animal performance, increased bulk density and flow ability, decreased spillage and wind loss and more important, improved weight gain, FCR's compared to feeding mash, Improved palatability, destruction of pathogenic organisms, decreased segregation of particles and thermal modification of starch and protein (Behnke, 2001; Briggs, 1999).

The difference in intake of pelleted feed compared to mash had already been observed by Heaney as early as 1963 (Forbes, 1995). Previous research has indicated that feeding poor quality pellets reduces the benefits of pelleting, yet, considering the immense increase in pelleted animal feed production, limited published research is available that focuses on understanding and optimizing the pelleting process (Briggs,1999). Hancock (2001b) showed that an increase in fines at the feeder from 20-40% rapidly reduced the benefits of pelleting. As mentioned previously the question still remains : Why pellet if the advantages are diminished by poor quality pellets ?

It is well recognized in the field that the quality of pelleted animal feed plays a significant role in the feeding behavior of animals. This includes behavior such as feed intake by particle size, shape and color, which in turn impacts on energy expenditure needed to feed, and therefore, the production performance and overall health of various animals, particularly poultry (broilers and layers). Excessive fines due to poor quality pellets leads to practical problems in feeder systems leading to blockages and uneven distribution of pellets throughout the house. Chickens, especially layers that receive mostly mash, choose their feed mainly on particle size and to ensure sufficient intake and minimise selective feeding, the feed has to be ground or pelleted to a certain minimum size. This requires special attention in the feed mill (Ziggers, 1999).

Gill (1997) also supports this with findings of Dr. Wiseman from Nottingham University that states that quality pellets causes less fines that will help reduce feed selection and minimise feed wastage.

In addition to the advantages mentioned by Briggs (1999), poultry utilize pelleted diets more efficiently by spending less time eating pellets and hence reduce their energy requirements (Summers & Leeson,1997). Many customers in the marketplace are of opinion that better performance is a result of the pelleted texture alone. This is however not the case as part of the improved performance is brought about by the chemical changes from heat, moisture and pressure during the pelleting process. The need for good quality pellets is often questioned by manufacturers since regrinding of pellets to mash or crumbles produce little apparent difference in performance (Summers & Leeson,1997).

The contribution of pellet quality to improve performance, where high energy diets are concerned, seems of less importance (Summers & Leeson, 1997). It is therefore important to put pellet quality as a component of quality pelleted feed in the right perspective when addressing quality issues at farm level since poor performance figures are often blamed on pellet quality alone and don't take management errors into consideration. Poor quality pelleted feed has various implications to the health of the producing animal. When poor quality pellets restrict feed intake it can impact on general health and may effect the immune response and increase vulnerability to respiratory infections (Afzal, 1999). In contrast to this Van Biljon (2001) reported that the mortalities were highest on broilers fed pellets compared to ground pellets and mash. He does however mention that although the mortalities in chickens on pellets was the highest, the better bodyweight and FCR still contributed to a better overall production efficiency (PEF), proving that the pelleted texture still played the most important role in determining bodyweight and feed efficiency.

2.5 The influence of factory production system parameters on pellet quality and animal performance

The influence and effect of individual processes, process variables or different settings thereof on the quality of the pelleted feed and/or the performance of the animals is well described in the literature. Behnke & Beyer (2001) showed that the processing of feed has pronounced effects on broiler performance.

Investigation of complaints and experience has shown that many companies fail to achieve the optimal level of consistent quality as a result of not monitoring and/or integrating this existing knowledge into a controlled and closely monitored quality program. Behnke (2001) states that our knowledge of how manufacturing practices influence performance has been neglected relative to genetic improvements in broilers.

A large variety of feed processing equipment is available in the market place and Gill (2001b) gives and overview of the different types of equipment that was available at the Victam 2001 show. He emphasizes that it has become important to understand the available processing equipment and the conditions needed for each to perform optimally in the manufacturing plant. Extensive reviews of the pelleting process and methods for reviewing possible pelleting problems are further described by Payne (1998) and Wetzel (1983).

Grinding

Earlier research done by MacBain (1966) indicated that a variation in particle size produces a better pellet than a homogenous particle size. In contrast, other studies (Stevens, 1987) found no effect of particle size on pellet durability index. Cabrera (1994) found no effect of diet particle size (400 to1000µm) on growth performance of broiler chicks fed a complex diet in crumbled form. In a second study, feed efficiency was improved 3% by reducing particle size from 500 to 1000µm in simple diets fed as meal form but not in crumbled form. Therefore the response to reduced particle size (500 to 600 µm) in broiler chicks appear to be the greatest when fed simple (grain-soybean meal) diets in a meal form. Feeding a complex diet in a crumbled form did not appear to require particle size below 1000µm. From the above, it can be concluded that the evaluation of the effect of grind fineness on animal performance continues to be an active area of research. Much needs to be learned regarding other cereals as well as protein meals in this regard.

Reimer (1992) indicated that fineness of grind may control 20% of a pellet’s quality. Decreasing particle size from a coarse to a fine grind exposes more surface area per unit volume for absorption of condensing steam during the conditioning process. This results in a higher feed temperature and more water absorption, which together, within the time available, increases gelatinization of raw starch.

Wondra *et al*. (1995a) studied the effect of a wider range of particle sizes in maize (ranging from 400 - 1000µm) on pigs and observed a 1.3% increase in gain to feed ratio for every 100µm reduction in particle size of the maize.

The importance of measuring and setting standards on ground fractions is emphasized by Hancock (1999a) as it has an impact on pellet quality, animal performance and energy consumption in the mill. Heimann (as quoted by Gill, 1997) supports this further by adding that it is necessary to define terms such as “fine” and ”coarse” as these differ between plants and different equipment, emphasizing the need for quality control systems to closely monitor these variables. Grinding of feed stuffs to different particle sizes influences the digestibility of a ration (Gill, 1997; Hancock, 1999a). Hancock (1999a) showed that by determining and maintaining these fractions feed conversion improved. He also showed that by exceeding the maximum fine portion it could lead to increased stomach ulcers in growing pigs.

Consideration needs to be given to the different applications of equipment and how to utilise this equipment to achieve the best result. This is demonstrated by Anderson (2000) when highlighting some of the differences between conventional hammermills and roller mills. Erickson (as quoted by Gill, 2001a) underlines the importance of particle size by stating that a narrower particle size distribution leads to a more even thermal pressure and other processing effects on the product, promoting quality of both pressed and extruded pellets.

Wassink (2001) supports the importance of particle size control at the hammermill as this is often a problem in plants manufacturing both pellets (needing fine particles) and layer mash (needing coarse particles). Lack of control systems during grinding often lead to incorrect mash fractions that result in reduced pellet quality. Smaller sized particles have greater inter-contact sites and better heat penetration (Behnke, 2001).

Mixing

A coefficient of variation (CV) of 10% has become the accepted degree of variation separating uniform from non-uniform mixes (Duncan, 1973; Beumer, 1991; Wicker & Poole, 1991). This value includes variation from sampling procedures, assay variability, randomness, as well as uniformity of the mix. However, the results also indicate that, depending on the uniformity test used, CV's of up to 20% (twice the current industry recommendation) may be adequate for maximum growth performance in broiler chicks.

Intuitively, nutrient uniformity in a complete diet should be desirable to maximize nutrient utilization. Ensminger *et al*. (1990) state that because baby chicks consume only a few grams of feed each day, it is necessary to have all essential nutrients at the proper level in a very small meal. Thus a standard is needed to indicate adequate, but also minimum mix uniformity. In reality, there is currently no official testing procedure to describe mix uniformity. Beumer (1991) cites uniformity as one of the most important quality aspects in feed production.

In contrast to what McCoy (1994) found with broilers, Holden (1988) states that improper mixing of one batch of feed rarely would cause serious problems in growing pigs because a single batch will be consumed in such a short period of time. Traylor *et al*. (1994) conducted a 21-day growth assay with weanling pigs using chromic (Cr) oxide as the marker with mix time treatments of 0, 0.5, 2, and 4 min in a double-ribbon mixer. When mix time was increased from 0 to 0.5 min the CV for Cr concentration was decreased from 107 to 28%. The CV was further reduced to 12% when mix time was increased to 4 minutes. Efficiency and rate of gain was increased significantly when mix time was increased from 0 to 0.5 min, with little growth response to increasing mixing time further to 4 minutes.

Imbalances in feed due to uncontrolled manufacturing systems may lead to amino acid imbalances and consequently depressed voluntary food intake and animal performance (Forbes, 1995)

Conditioning & Pelleting and temperature control

As early as the sixties several authors showed improved feed conversion and average daily gain following the conditioning of mash and improvement in pellet quality (Hussar, 1962; Hull *et al.*, 1968; Scheideler, 1991). Conditioning temperature variances has an influence on gelatinisation and, or the level of starch damage (Stevens, 1987; Lopez, 1993). Steam conditioning is identified as important in the improvement of pellet quality and production rates (Shoch *et al.*, 1981).

According to Reimer (1992), pellet quality is proportionally dependent on the following factors: 40% diet formulation, 20% particle size, 20% conditioning, 15% die specifications, and 5% cooling and drying. If this is correct, 60% of the influencing factors that may affect pellet quality are determined before the mash enters the actual pelleting system. This increases to 80% after conditioning, but before mash has even entered the die chamber of a pellet mill.

Nielsen (1998) described that production of pellets with high levels of thermal treatment have various factors that need consideration in order to achieve optimum processing. The beneficial effects of increased moisture of mash prior to conditioning is known, emphasizing the importance of precise mixer moisture control (Fairchild, 1999). Harrison (as cited by Gill, 2001c) showed that pressurized conditioning increased throughput and PDI's while lowering energy consumption and temperature at the die.

Boiler water treatment and steam quality

Boiler operations are often neglected as one of the systems influencing pellet or product quality. Systems with excessive amounts of water treatment additives, being carried over to the steam line, might not influence pellet quality but may have a definite influence on the safety of the product (Heidenreich, 1998). Visser (PC: 2000) identified poor boiler water treatment as one of the factors leading to inefficient boiler operation and ultimately the production of poor quality steam (wet instead of dry steam) that negatively impacts on the effectiveness of the steam in transferring heat.

Production control systems and preventive maintenance

The need for accurate control systems to control the processing environment in the plant is becoming more crucial especially with the use and application of liquid micro-ingredients that become more prevalent (Decksheimer, 1998). Pellet quality and optimal mill performance is not only depended on accurate process controls but also on proper scheduled maintenance. Damage to a pellet mill die adversely affects the pelleting process, pellet quality and pelleting costs by limiting the effectiveness of the die in forming and compressing the pellet (Frey, 2001).

Microbiological quality of the feed

The microbiological quality of feed is becoming more and more important. To ensure that the feed complies with these demands, measures need to be in place to closely monitor and optimise these heat treatment processes without damaging nutrients (Gill, 1998). The importance of controlling the temperature/time settings is demonstrated by data from Louw (1999) which shows the influence of time and temperature combinations on the efficiency of killing Enterobacteria and Salmonella. The Product Board Animal Feed (2000a) states that the microbiological control of the final product starts with control of the raw material at receiving and through the correct heat processing thereof. Best (2001) and De Weert (2001) highlights that temperature control systems are essential to control the microbiological quality of feed since the control of raw material as a source of contamination is often not enough or, not in place. In addition to this Richardson (2002) places emphases on several key elements that need to be in place to ensure microbial control in feed.

CHAPTER 3

MATERIALS AND METHODS

The project was implemented at the AFGRI Animal Feeds factory in Isando, Gauteng, South Africa.

3.1 Project design

The project was designed around the 7 principles of HACCP (CCFRA, 1997) namely:

Principle 1 : Conducting a hazard analysis. This means preparing a flow diagram of the steps in the process, identifying and listing the hazards applicable as well as the control measures for each.

Principle 2 : Determine the CCP's in the process using a HACCP decision tree (Figure 6a).

Principle 3 : Establish critical limits which must be met to ensure that the CCP is under control.

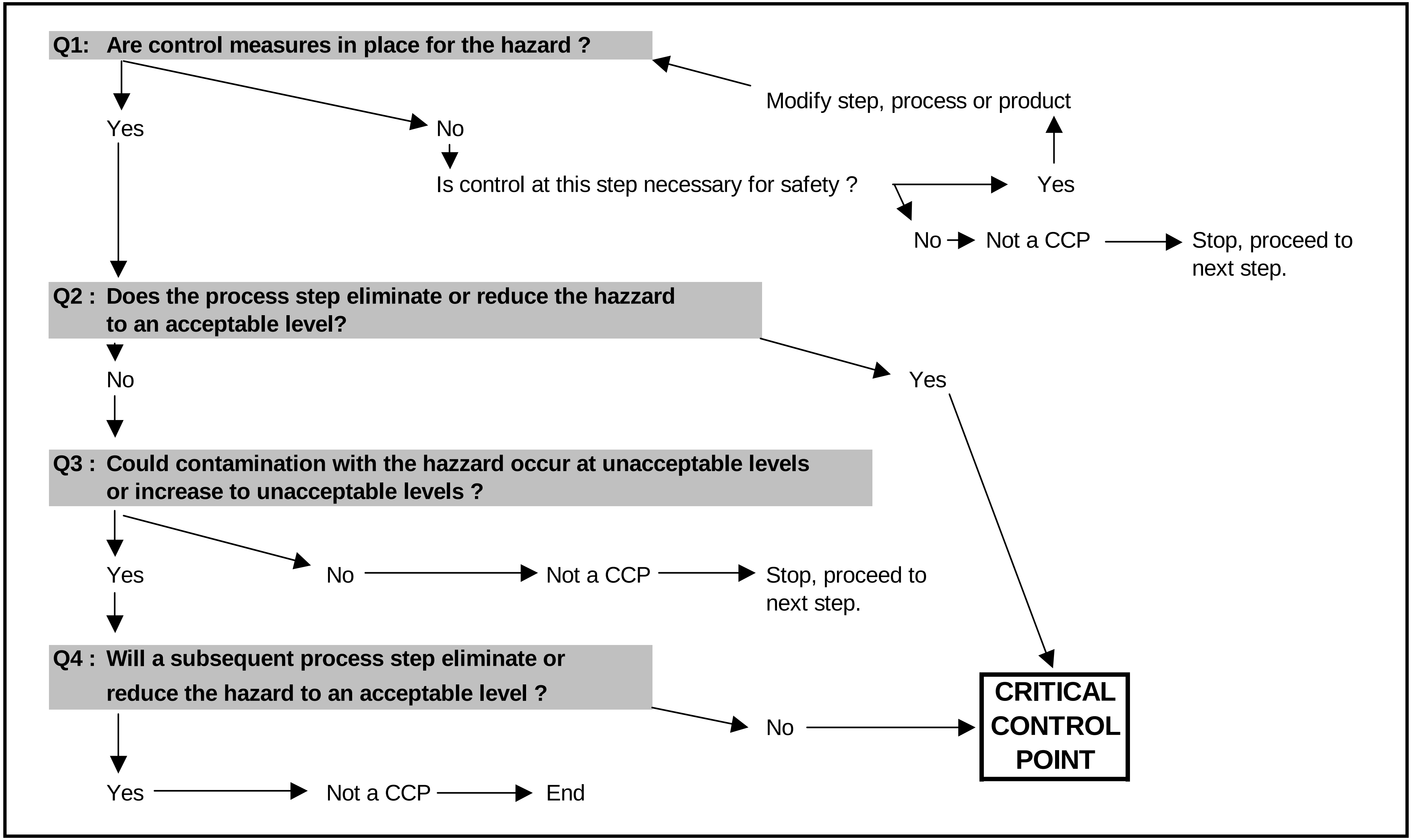
Principle 4 : Establish a system to monitor control of the CCP by scheduled testing or observations (inspections).

Principle 5 : Establish corrective actions to be taken when monitoring indicates that a particular CCP is not under control or is moving out of control.

Principle 6 : Establish procedures for verification to confirm that HACCP is working effectively, which may include appropriate supplementary tests (audits).

Principle 7 : Establish documentation concerning all procedures and records appropriate to these principles and their application.

Figure 6a: A typical example of a HACCP decision tree (CCFRA, 1997)



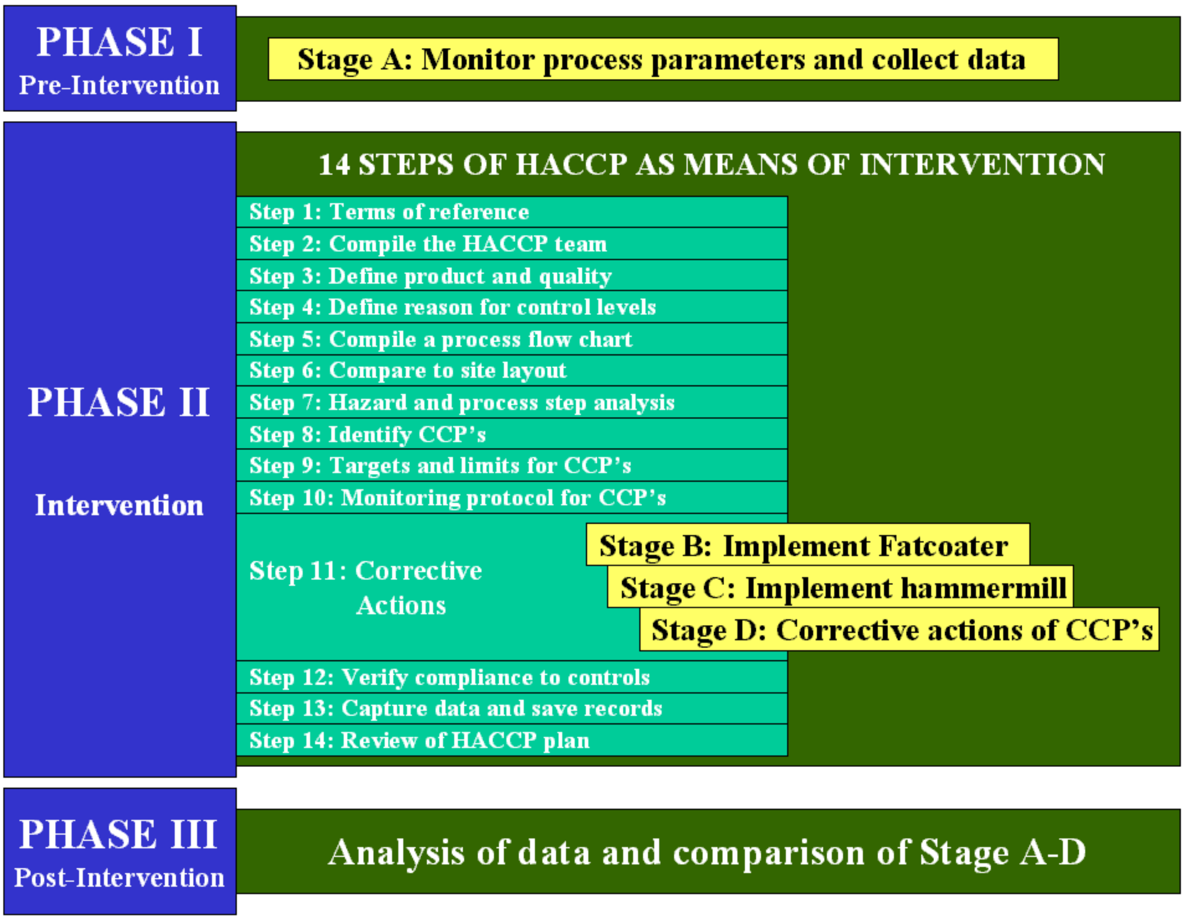
Implementation of the project was divided into three phases (Figure 6b):

Phase I : Set up a monitoring system for the process parameters that has an influence on pellet quality. Measure and determine the degree of fluctuation in pellet quality and CCP's prior to the implementation of the HACCP system.

Phase II : Intervention - reducing the variation of CCP's by means of HACCP implementation. The effect of confounding bias will be reduced by limiting CCP fluctuations through setting target levels, minimum & maximum tolerances and standardizing on measuring techniques and monitoring procedures.

Phase III : Measure and compare the variation in pellet quality and CCP's after intervention to that of phase I.

Figure 6b: Schematic representation of the project to clarify terms and illustrate the layout of the project design



3.2 Project procedures

3.2.1 Phase I

3.2.1.1 Pre-intervention processing layout

The pre-intervention process layout was analysed by compiling a process flow diagram and documenting the various steps involved in the process. This would serve as a reference for later use during Steps 5 and 6 of Phase II.

Formulations were calculated monthly on a linear regression based least-cost formulation program called “Format” (Version 216.5, 1-April-2002. Format International). Only limited restrictions in terms of bounds and swings existed on ingredients and nutrients were present in the formulas at the onset of the project. A pelletability index was used as an indicator of formula (raw material) changes and its impact on pellet quality. The pelletability index was calculated with the Format program using the method described in the Borregaard pelleting handbook (Payne, 1998). Pelletability values were calculated using some of the raw material values for quality as shown in Appendix III and IV. Values for local ingredients not listed in the tables, were based on similar ingredients from the table.

Pre-intervention grinding of maize was achieved by grinding with a roller- and hammermill in combination or separately. The hammermill used mainly a 4-mm screen. The other raw materials were ground on a separate hammermill line using an 8-mm screen. Ground maize was sent to two pre-mixing bins as fine or coarse. Due to low grinding capacity the combination of the two hammermills were often used to keep bins full. No controls for monitoring of this CCP were in place. No post-grinding system was identified. Pre-pelleting samples were collected with an auto-sampler directly after the mixer and the mash fractions determined by standard sieve tests using the combination of a pan with 600, 1440, 2360 and 3550 μm sieves.

Mixing was standard through a 5 ton Bühler paddle mixer, set at 210 seconds mixing time and additional fat was added into the mixer at levels of up to four percent. No post-pelleting fat application systems were in place.

Process control of most processes was handled by a “Sitec Scada” Process Logical Computer (PLC) system. Conditioning and pelleting was done on a Le Mac 930 pellet press with a die configuration of 4.5x95x92.2mm. Conditioner set-point for conditioning was set manually and maintained automatically by the PLC after stabilization. Limited monitoring of pre- and post conditioning parameters existed. Changes to pelleting variables were restricted with only feeder speed, conditioning temperature and steam pressure being active variables. A fairly new die was in place at the onset of the project. Steam layout consisted of an incoming steam line with pressure- and temperature meters and a pressure reducer at approximately 4 meter before the conditioner. The conditioner was fitted with two intra chamber temperature probes at the steam inlet and mash outlet respectively.

A 30 t/hour Geelen counter-flow cooler achieved cooling with a low and high-level discharge mechanism while no intra-cooler temperature sensors were present. The cooling bed level was uneven in distribution with the central part being the highest. Pre- or post cooling monitoring was not actively monitored. No measuring of fines return after pelleting was evident at the onset of the project. No fat coating system was present. Evaluation of the fines percentage took place at loading although the correct methodology was not used and specifications were not in place or actively enforced. Training was provided after the initial assessment, before data collection commenced and at all areas where testing methods were found to be incorrect.

Pellet quality was described as the percentage of pellets on the vehicle after loading and was calculated as the percentage of pellets above a 3550μm sieve. The sieve aperture constituted 79% of the pellet diameter. Samples were collected by cross sectional sampling of compartments with a 2.1m bulk probe, prepared with a sample divider and labeled for testing. Pellet durability was calculated with the tumbling can method (ASAE, 1987). The mash fraction’s mean particle size was determined as the percentage of particles remaining on top of each of the 600, 1440, 2360, and 3550 μm range of sieves (Gill, 1997).

Processing temperatures were taken from inline temperature probes and cross checked by hand held infrared thermometers. Moisture analysis on mash was performed with a standard Precisa HA-300 infrared moisture balance and a standard set-up of 105^{o}C with a 2-decimal/30second-change interval.

Steam supply was evaluated by monitoring the temperature and pressure at the supply and reducing valve, as well as the conditioning temperature via an intra-barrel temperature probe.

3.2.1.2 Stage A: Monitoring of process parameters and collection of data

Baseline data was collected for:

- The percentage of fat included in the mixer and fat coater, the total fat % in the formula, formula pelletability score, and total maize in the formula. Fat inclusion levels were obtained from the Format formula archive and inclusion levels controlled by the PLC.
- Grinding fractions of maize after the hammermill, and pre-pelleting fractions from directly after the mixer were collected via the auto-sampler for sieve analyses.
- Steam supply-pressure and temperature, conditioning temperature and feeder rate were measured via in-line meters. Moisture of conditioned mash was analysed with an infrared moisture balance. Pellet temperature and moisture, during and after cooling, was measured with in-line temperature probes and the infrared moisture balance.
- Loaded pellet % and durability was measured with sieve tests and the tumbling can method respectively.

Identified points were monitored and data capture sheets used to gather process and quality data for the various monitoring points indicated. Data from these sheets were transferred and captured on Microsoft Excel Worksheets where they were analysed.

3.2.1.3 Stage A: Measurement of the degree of fluctuation in pellet quality and monitoring points prior to implementation of the HACCP system

Fluctuation in process parameter data was calculated as the difference of averages between stages, as well as the percentage Standard Deviation (STDEV) and the Coefficient of Variation (CV) of parameters within each stage. An adapted Shewart control chart (Feed Manufacturing Technology IV, 1994) was used to calculate the range (R) and x-bar values for the pellet percentage.

3.2.2 Phase II

The procedure for the intervention section, consisted of the 14 HACCP steps as set out in the Codex Alimentarius Commission, draft revision (1996) namely:

Step 1: Define the terms of reference.

The hazard was defined as: "The poor quality of pellet feed that has the potential to lower product quality and reduce the performance of broilers." In this case the hazard is an excess of fines in the feed fed to broilers. The Hazard analysis entailed the processes of collecting information on the hazard and the conditions leading to its presence.

Step 2: The HACCP team consisted of:

The HACCP team leader (QA manager), the Quality Coordinator (Plant manager), the Hazard specialist (Factory manager), the CCP coordinator (process controller) and one process operator as well as the laboratory operators performing the analysis.

Step 3: The product and its desired quality was defined as:

Pelleted broiler feed, loaded at a minimum of 90% pellets on the truck and a durability (PDI) of 95% for all fat coated formulas.

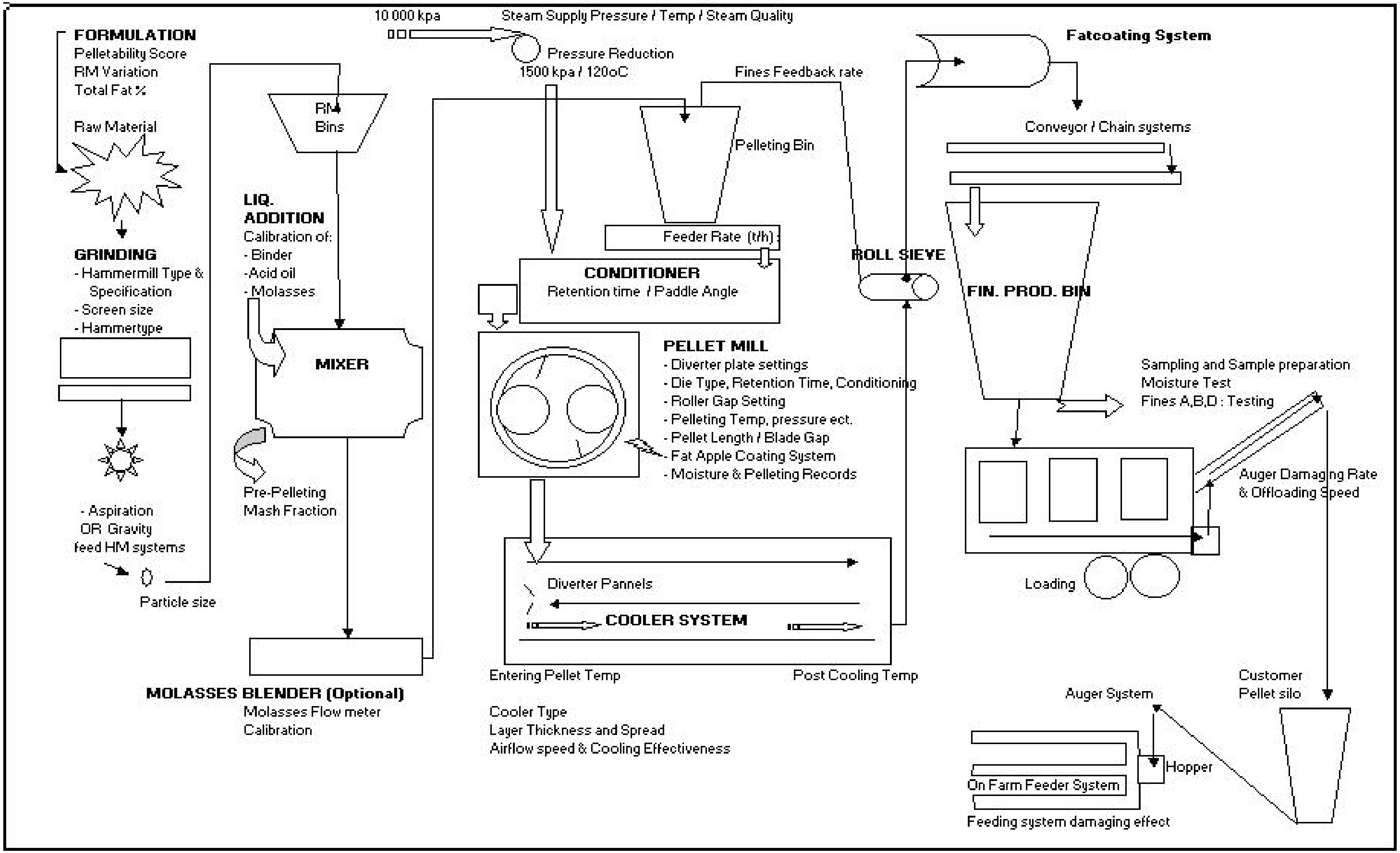
Step 4: The reason for this specification and its intended use was defined as:

A low percentage of pellets on the truck with a poor durability has a negative impact on the product and animal performance as well as customer satisfaction.

Step 5: The process flow diagram:

The process flow diagram is shown in Figure 7

Figure 7: Typical process flow of a pelleting plant to illustrate the location of the CCP's in the process



Step 6: The basic flow diagram was compared to the actual site layout and the detail added for purposes of accuracy.

Step 7: Each process step was listed and a CCP analysis conducted on each:

The main CCP's were defined as those having the greatest contribution to pellet quality and would receive primary focus. These included, formulation (formula fat content and addition area), grinding (mash and pre-pelleting particle size), conditioning of the mash (steam supply and conditioning temperature), "die" condition and drying/cooling (Reimer, 1992 and Behnke, 2001). The hazard and the CCP analysis is listed as Appendix VIII.

Step 8: Based on the outcome of Step 7 six critical control points for the project were identified and defined as:

a) The fat content of formulas, b) ingredient fluctuation of especially starch and protein (formulation), c) maize and pre-pelleting mash particle size (grinding), d) steam supply, e) conditioning temperature (conditioning) and f) the drying/cooling process.

Step 9: Targets and limits for each CCP were defined as:

The target for the fat coater was to reduce the fat addition in the mixer as far as possible and to maximise fat coating levels without adversely affecting the product quality.
Mash fraction targets are shown in Table 3.
Steam supply and conditioner temperature targets are shown in Table 4
Pellet quality targets are shown in Table 5.

Table 3: Pre pelleting mash fraction targets and limits set for broiler pelleted rations at Afgri, Isando

Fraction	>3550 (μm)	3550-2360 (μm)	2360-1440 (μm)	1440-600 (μm)	600-0 (μm)
Target	0	Max. 5%	Max. 20%	Min. 65%	Max.10%
Limits	0	0-10%	10-25%	60-75%	0-10%

Table 4: Targets for steam supply and conditioning temperature at AFGRI, Isando

Reduced Pressure (Bar)	Reduced Temperature (^{o}C)	Conditioning Temperature (^{o}C)
2.5 – 3	Min. 135 – 145	75-(80)-85

Table 5: Pellet quality targets set for the mill at AFGRI, Isando

	QUALITY PARAMETERS			
	Loaded Pellet %	Pellet % Limits	Durability %	Durability % Limits
Target Level	*Min. 90	**Min.80 / Max.97	Min. 95	90-96

* The loaded pellet % of Min. 90 was set as in internal goal

** Lower limit of 80% was set as the point where when exceeded the possibility of delivering less that 65% at the farm was high.

Step 10: The monitoring protocol for each CCP was defined as:

Products from the same product group were randomly selected on a shift basis (2-3 times per day) and all CCP data on these recorded. Results were monitored against targets and compliance to limits.

Step 11: Training and planning of corrective actions:

Data analysed from Phase I and corrective actions required to maintain CCP's within control limits indicated that several key changes to the processing equipment had to be implemented. The two main corrections were done as Stage B (implementation of a fat coating system to reduce the percentage of fat added at the mixer), and Stage C (replacement of the hammer- and roller mills with a single hammermill with enough grinding capacity on a small (3-mm) screen size). Stage D focused on the improved monitoring of CCP's and the timely reaction to corrective protocols for those CCP's that exceeded limits.

Step 12 : Compliance was verified on a daily basis by evaluation and discussion of datasheets.

Step 13 : All records were collected and captured on Microsoft Excel spreadsheets.

Step 14 : Reviews of the HACCP plan and data were held on a monthly basis. Audits were executed at random during the month.

3.2.2 Phase III: Comparison of pellet quality between stages A to D

3.2.3.1 Observations and Analytical procedures

An example of the data capture sheet used is attached as Appendix VI. Process data from the different CCP's were captured on the data sheet or logged directly from process PLC's process display. From here the data was transferred to Excel spreadsheets for analyses purposes. The same data sheet accompanied the in-process samples and final product sample to the laboratory where pellet quality tests and in-process analysis were completed. These results were then also captured on the same data sheets and transferred as above. Where known targets from the literature on CCP's were not available, data collected from phase I, was analysed in order to calculate CCP targets. This data included retrospective data prior to improvements in the manufacturing process and was sufficient to determine target values.

3.2.3.2 Data analysis

Data from electronic in-process monitoring equipment was captured on in-process production data sheets and stored in Microsoft Excel spreadsheets for analyses.

- Increased precision of data was achieved by training, standardising test methods, increasing the number of tests, increasing the number of samples and automation of processes.
- Measurements were taken on a continuous basis and samples were selected at random. No fixed number of samples was specified.

The validity of statistical methods and the significance of results after intervention were evaluated. Statistical significance of average pellet quality results between stages A-D was calculated using a t-Test for two samples assuming equal variances. It is important to note that values from CCP's and parameters in this study may vary from one production unit to another and are not necessarily applicable to a different pelleting plant.

The importance of our model lies in its method of analysing each individual system, determining the parameters applicable to that production unit and then implementing control measures to ensure compliance to those CCP parameters. The degree of improvement resulting from the HACCP system intervention in our factory was considered to be the documented end product.

Results from the data groups were analysed for their Averages, Percentage Standard Deviation (STDEV), Coefficient of Variation (CV) and range (R), where R equaled the maximum deviation of each result from the target less the minimum deviation from the target, and the X-bar value (where X equaled the sum of deviations from the target divided by the number of data points).

CHAPTER 4

RESULTS

4.1 Phase I: Data from monitoring points and pellet quality results

A summary of results from formulation data, fat addition levels and pelletability indexes are shown in Table 6. Pre-intervention levels of added fat in the mixer ranged from 0.28-4% with an average of 2.64%, while the total fat averaged 7.99% with a range of 4.55 – 9.64%. The formula pelletability index was calculated at an average of 36.7 with a range from 23.1 – 48.7. Total maize levels (starch) remained fairly constant at an average of 60-62% throughout with a minimum to maximum range of 22.1% with the minimum being 51.1% and the maximum 73.2%.

Table 6: Formulated fat addition levels prior to the installation of the fatcoater

Name	Fat as a Coating (%)	Fat addition in Mixer (%)	Total Fat In the Formula (%)	Fat from Raw Material (%)	Pelletability Index[1]	Total Maize (%)
Average %	0	2.64	7.99	5.35	36.7	62.0
Min.	-	0.28	4.55	1.55	23.1	51.1
Max.	-	4.00	9.64	8.64	48.7	73.2
Range	-	3.73	5.09	7.09	25.6	22.2
STDEV	-	0.70	0.76	0.98	5.34	4.45
CV	-	26.7	9.46	18.4	14.6	7.18

[1] Pelletability index calculated with Format using the Borregaard raw material table (Appendix IV).
[2] n = 465 for each variable.

Maize and pre-pelleting mash fractions obtained from Stage A are shown in Tables 7a and 7b. Grinding fractions in the target region of 900μm (shown as 1440-600μm) averaged 32.9% for the mash and 21.1% for maize. The larger portion of the pre-pelleting mash fraction, however, was coarser with 34.8% in the 2360-1440μm range.

Table 7a: Summary of maize grinding fractions obtained during Stage A

		Maize Grinding Fraction				
		% >3550 (μm)	% between 3550-2360 (μm)	% between 2360-1440 (μm)	% between 1440-600 (μm)	% between 600-0 (μm)
	Target:	0	5	20	65	10
Stage						
A	Average %	3.25	28.8	41.6	21.1	4.76
A	STDEV	1.76	6.98	3.72	5.96	2.04
A	CV	54.0	24.2	9.0	28.2	42.8

Table 7b: Summary of the pre-pelleting mash grinding fractions during Stage A

		Pre-pelleting fraction				
		% >3550 (µm)	% between 3550-2360 (µm)	% between 2360-1440 (µm)	% between 1440-600 (µm)	% between 600-0 (µm)
	Target:	0	5	20	65	10
Stage	Statistic					
A	Average %	3.57	20.0	34.8	32.9	8.32
A	STDEV	1.85	5.05	3.48	3.38	2.14
A	CV	51.6	25.2	10.0	10.3	25.8

A summary of the steam supply and conditioning values are shown in Table 8. Conditioner temperature probes indicated an average mash temperature of 64.5^{o}C with a reduced pressure of 2.42 Bar and a steam temperature of 92.6^{o}C. Supply pressure averaged 10 Bar. Average pre-conditioning mash moisture was relatively dry at 10.5%. This increased to 12.7% during conditioning and decreased to 10.6% after cooling. The % STDEV and CV of the mash temperature in Stage A was the highest of all stages at 0.67 and 27.9 respectively.

Table 8:Change in steam supply and conditioning temperatures during Stage A

		Reduced Pressure (Bar)	Reduced Steam Temperature (^{o}C)	Conditioner Probe Temperature (^{o}C)	Cooling Difference (^{o}C)
	Target:	2.5-3	135-145	80-85	5
Stage	Statistic				
A	Average	2.42	92.6	64.5	0.99
A	STDEV	0.67	16.6	17.6	1.71
A	CV	27.9	17.9	27.3	173

Moisture values obtained from the conditioner and cooler are listed in Table 9.

Table 9: Moisture data from the conditioner and cooler during Stage A

		Moisture Control							
		Pre Conditioner Moisture (%)	Post Conditioner Moisture (%)	Moisture Gain (%)	Pre Cooler Moisture (%)	Post Cooler Moisture (%)	Moisture Loss (%)	Final Moisture (%)	Moisture Loss / Gain (%)
Stage	Target:	12	15	3	14	13	-1	12	0
A	Average	10.5	12.7	2.20	12.0	10.6	-1.40	10.7	0.19
A	STDEV	0.93	1.51	0.58	1.22	0.86	-0.36	0.78	-0.15
A	CV	8.90	12.0	3.10	10.2	8.12	-2.08	7.31	-1.59

A summary of cooling and drying values are shown in Table 10. The pellet temperature after cooling was on average only 1^{o}C above ambient. In many cases the temperature was well below that of ambient and the cooling difference CV was very high at 173.

Table 10: Cooling temperature values during Stage A

Stage	Target:	Post-Cooler Temperature (^{o}C) 23	Ambient Temperature (^{o}C) 22	Cooling Differences (^{o}C) <5 ^{o}C Above ambient
A	Average %	22.3	21.3	1.00
A	% STDEV	2.85	3.70	1.71
A	CV	12.8	17.4	173

Data on the pellet quality obtained during Stage A is listed in Table 11. The percentage of pellets loaded was 63.1% on average with a durability index of 87.3. The percentage of pellets loaded was on average 27% below the target of 90%.

Table 11: Summary of pellet quality during Stage A

		QUALITY PARAMETERS			
Stage	Statistic	% Pellets Loaded	Pellet % Deviation[1]	Pellet Durability (%)	Deviation from Durability Target
A	Average	63.1	-27.0	87.3	-7.75
A	% STDEV	13.3	-	2.53	-
A	CV	21.14	-	2.90	-

[1] Deviation from target values in Table 3

On completion of defining the process layout and collecting the initial data, Phase I was concluded.

4.2 Phase II: HACCP system as the intervention tool for project structuring

4.2.1 Stage B Results: Formulation (Implementation of the fat coating system to reduce fat percentage in the mixer)

With the fatcoater in place, fat inclusion levels (Table 12) in formulas changed from an average of 2.64% in the mixer during Stage A (Phase I) to 0.53% in the mixer and 3.66% as a coating in Stage B. Pelletability indexes of formulas improved from 36.7 in Stage A (see Table 6) to 45 in Stage B (see Table 12) after installation of the fat coater. Total fat in formulations increased on average by 0.42%. The range between the minimum and maximum values was more stable at 2.03% compared to the 5.09% before the fat coater while the CV for total fat percentage in the formula improved from 9.46 to 4.84. The average fat percentage derived from the raw material itself was reduced from 5.35% to 4.22%.

Table 12: Formulation data, fat addition in the mixer and pelletability index after installation of the fat coater

	Formulation data					
Name	Fat addition as a coating	Fat addition in the mixer	Fat level in the formula	Total fat from raw material	Pelletability Index	Total maize
Average (%)	3.66	0.53	8.41	4.22	45.0	59.9
Nr. of results	358	156	358	358	358	358
Min. (%)	1.40	0.29	7.38	3.23	33.1	53.1
Max. (%)	4.49	1.25	9.40	5.70	49.8	69.3
Range (%)	3.09	0.96	2.03	2.48	16.8	16.2
STDEV	0.47	0.14	0.41	0.36	2.28	3.70
CV	12.9	26.8	4.84	8.07	5.08	6.17

4.2.2 Stage C Results: Maize and pre-pellet mash grinding fractions

Results of the maize and pre-pelleting mash particle fractions are shown in Table 13a and 13b.

Table 13a: Summary of the maize ground particle size (fractions) obtained during stages B to D

		Maize Grinding Fraction				
		Particles >3550 µm	Particles between 3550-2360 µm	Particles between 2360-1440 µm	Particles between 1440-600 µm	Particles between 600-0 µm
	Target %:	0	5	20	65	10
Stage	Statistic					
B	Average %	4.15	29.1	40.9	20.6	4.93
C	Average %	0.13	1.86	35.1	51.4	11.3
D	Average %	0.12	1.24	40.2	50.3	8.17
B	STDEV	3.08	8.90	7.59	7.59	2.17
C	STDEV	0.21	4.48	12.7	8.96	4.78
D	STDEV	0.18	1.18	10.0	8.46	2.18
B	CV	74.0	30.6	18.5	36.9	44.0
C	CV	156	240	36.2	17.4	42.5
D	CV	154	95.6	24.8	16.8	26.7

Table 13b: **Summary of ground particle sizes for the pre-pelleting mash during stages B to D**

		Pre-pelleting fraction				
		Particles >3550 µm	Particles between 3550-2360 µm	Particles between 2360-1440 µm	Particles between 1440-600 µm	Particles between 600-0 µm
	Target %:	0	5	20	65	10
Stage	Statistic					
B	Average %	2.81	18.3	35.0	34.2	8.82
C	Average %	0.96	4.27	27.2	55.3	12.6
D	Average %	0.34	2.64	32.9	54.8	9.15
B	STDEV	1.62	4.97	4.16	7.30	2.97
C	STDEV	1.06	4.71	6.68	6.30	3.96
D	STDEV	0.32	2.77	9.47	8.01	2.94
B	CV	57.7	27.1	11.9	21.4	33.7
C	CV	110	110	24.5	11.4	31.5
D	CV	93.3	104	28.8	14.6	32.1

The shift in the pre- and post intervention grinding fractions during stages A-D is shown for the maize and pre-pelleting mash in Figure 8 and Figure 9 respectively. The shift in the distribution of maize particle fractions is clearly visible during the progress from stage A to D. Particle fraction size during stages A & B ("Before" the new hammermill) is clearly coarser than during stages C & D ("After") when the new hammermill was implemented.

Figure 8: **Shift of the maize particle size (fraction curves) during Stages A to D with the hammermill installed during Stage C**

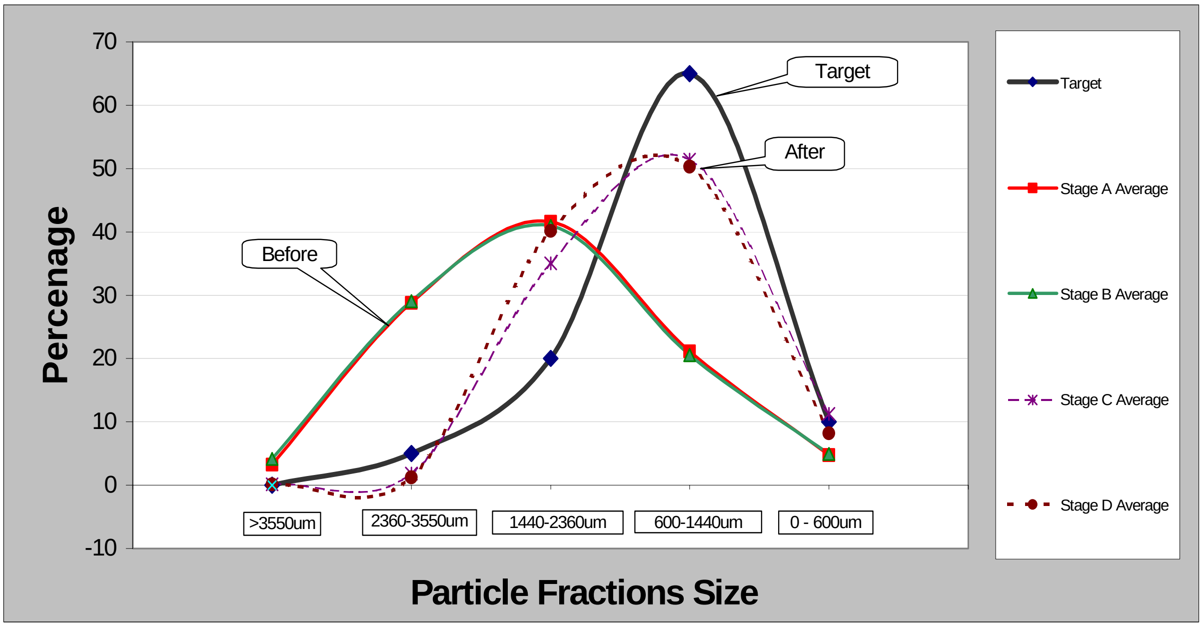


Figure 9: Shift of the pre-pelleting mash particle size curves during Stages A to D, with the new hammermill installed during Stage C

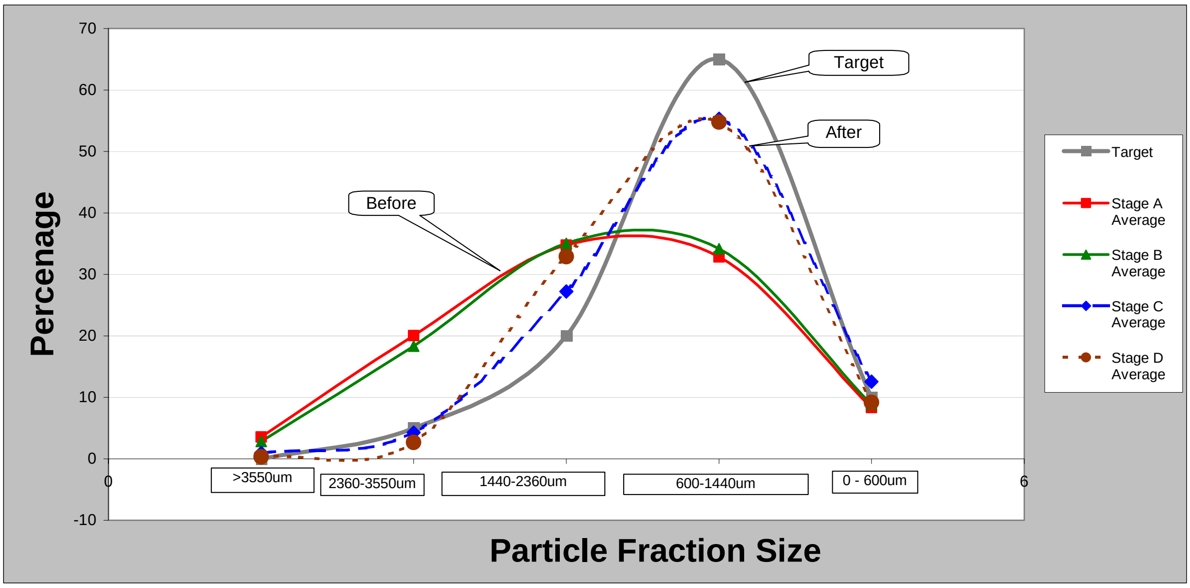


Figure 9 illustrates a smaller difference in the distribution of the pre-pellet mash particle fractions when compared to that of the maize. A slightly higher 1440-600µm mash fraction (+5%) is also observed. It is clear from the maize fraction data that a definite shift occurred in the size of grinding fractions from Stage C, with fractions changing from the coarser 1440µm+ particle size during Stage A to the finer target particle size of 900µm.

The target fraction (1440-600µm) remained constant at 21.1 and 20.6% during Stage A and B. Thereafter it improved by 30.8% from 20.6% in Stage B to 51.4% in Stage C. This. The target fraction achieved during Stage C with the new hammermill was still approximately 20% below the minimum target fraction of 70% in the 1440-600µm range. Values for particle sizes in Stages A and B were on average 40% below the desired minimum of 65% in the 900µm range (Hancock, 2001) and 20% over specification for 2360-1440µm and 3550-2360µm ranges.

4.2.3 Stage D: Improved monitoring and corrective actions

From the data previously listed in Tables 6 and 12 it is evident that the levels of maize in the formulas remained more or less constant at 60-62%.

The fluctuation in fat percentage showed significant improvements with the range improving from 7.09% in Stage A to 2.48% in Stage D. Improvements in the raw material STDEV and CV were also observed for the total fat percentage, pelletability and raw material fat percentage.

The CV values for the target grinding fraction on maize (Table 13a) improved from 28.2 in Stage A and 36.9 in Stage B to a more stable 17.4 and 16.8 in stages C and D. The CV values for the pre-pellet target fraction, however, showed no additional improvement compared to that of the maize. A slight reduction in the average target fraction was observed during Stage D from 51.4% to 50.3%.

Values for steam supply and conditioning temperature are shown in Table 14. Conditioning temperature of the mash did not show an increase in temperature from Stage C to Stage D and remained at approximately 74^{o}C. The STDEV and CV values, however, improved throughout all the stages. Reduced pressure remained more or less constant with improvements in STDEV and CV recorded during all stages. The STDEV of the reduced pressure improved from 0.67 in Stage A to 0.19 in Stage D, while the CV improved from 27.9 to 6.85. The temperature after the reducer showed a significant increase up to 142^{o}C during Stage D, as well as the lowest CV and STDEV values for all stages. Temperature after reduction improved from 92.6^{o}C in Stage A to 142^{o}C in Stage D, which was also within set specifications. Deviation from specifications were also reduced by approximately 30^{o}C.

Table 14: Change of steam supply and conditioning temperature during Stages A to D

		Reduced Pressure (Bar)	Reduced Temperature (^{o}C)	Conditioner Probe Temperature (^{o}C)	Cooling Difference (^{o}C)
	Target:	2.5-3	135-145	80-85	5
Stage	Statistic				
A	Average	2.42	92.6	64.5	0.99
B	Average	1.77	90.6	68.6	1.67
C	Average	2.37	117	74.5	6.36
D	Average	2.71	142	73.8	3.80
A	STDEV	0.67	16.6	17.6	1.71
B	STDEV	0.36	14.2	8.22	2.82
C	STDEV	0.35	32.7	6.79	4.64
D	STDEV	0.19	11.1	5.32	3.67
A	CV	27.9	17.9	27.3	173
B	CV	20.1	15.6	12.0	168
C	CV	14.9	27.7	9.12	773
D	CV	6.85	7.81	7.21	96.3

In Table 15 a slight improvement in the post cooling temperature compared to ambient was observed during Stage C and D.

Table 15: Cooling and drying values during Stages A to D

Stage	Statistic		Post-Cooler Temperature (°C)	Ambient Temperature (°C)	Cooling Difference (°C)
		Target:	23	22	< 5 °C Above Ambient
A	Average		22.3	21.3	0.99
B	Average		22.7	21.0	1.67
C	Average		23.8	17.2	6.36
D	Average		26.4	22.6	3.80
A	STDEV		2.85	3.70	1.71
B	STDEV		3.07	4.22	2.82
C	STDEV		2.16	4.28	4.64
D	STDEV		3.10	4.51	3.67
A	CV		12.8	17.4	173
B	CV		13.5	20.1	168
C	CV		9.08	24.9	73.0
D	CV		11.8	20.0	96.3

Table 16: Conditioning and cooler moisture data during Stages A to D

		Moisture Control							
		Pre Conditioner Moisture (%)	Post Conditioner Moisture (%)	Moisture Gain (%)	Pre Cooler Moisture (%)	Post Cooler Moisture (%)	Moisture Loss (%)	Final Moisture (%)	Moisture Loss / Gain (%)
Stage	Target:	12	15	3	14	13	-1	12	0
A	Average	10.5	12.7	2.19	12.0	10.6	-1.44	10.7	0.19
B	Average	10.8	12.9	2.06	12.4	10.3	-2.15	10.4	-0.42
C	Average	10.4	12.4	1.99	11.8	10.0	-1.81	10.2	-0.22
D	Average	9.9	11.8	1.89	11.4	9.5	-1.83	9.55	-0.35
A	STDEV	0.93	1.51	0.58	1.22	0.86	-0.36	0.78	-0.15
B	STDEV	1.21	1.28	0.07	1.15	0.89	-0.27	1.16	-0.05
C	STDEV	0.64	1.07	0.43	0.85	0.53	-0.32	0.72	0.08
D	STDEV	0.72	0.86	0.15	1.12	0.65	-0.47	0.94	0.22
A	CV	8.90	12.0	3.06	10.2	8.12	-2.03	7.31	-1.59
B	CV	11.2	9.91	-1.27	9.27	8.62	-0.65	11.1	-0.07
C	CV	6.16	8.68	2.52	7.18	5.28	-1.90	7.05	0.89
D	CV	7.25	7.33	0.08	9.84	6.81	-3.03	9.80	2.55

From Table 16 it is evident that moisture values were consistently lower than target values, especially in the conditioner. No significant improvements were observed for moisture during Stage D.

4.3 Phase III: Comparison of pellet quality data observed during Stages A to D

From Table 17 it is evident that Stage A had an average pellet percentage of 63.1%, 27% below the target value while the durability before the intervention was at 87.3%, which is 7.75% below the target value. Both the STDEV and CV were largest pre-intervention and improved from 13.3 to 5.39 and 21.1 to 5.99 respectively after Stage D. This indicates a significant ($p<0.01$ for all stages) improvement in pellet quality between stages A-D as well as a decrease in product variation during all stages.

Improvements from all the stages culminated in a pellet percentage improvement of 26.9% in total and a reduction in the CV of 15.1. The fat coating system contributed 19.1%, the correction of fractions 4.08% and Stage D another 3.95% to the improvement of the pellet percentage. The pellet durability improved by 5.6% from 87.3 to 92.9%, all of which were achieved with Stage C and D. Both the STDEV and CV decreased throughout all the stages.

Table 17: Summary of pellet quality data obtained for the percentage of pellets loaded and loaded pellet durability's

		QUALITY PARAMETERS			
Stage	Statistic	Percentage of Pellets Loaded	Pellet % Deviation[1]	Pellet Durability (%)	Deviation from Durability Target
A	Average	63.1	-27.0	87.3	-7.75
B	Average	82.1	-7.90	90.3	-4.71
C	Average	86.2	-1.30	92.8	-2.33
D	Average	90.0	0.02	92.9	-2.13
A	STDEV	13.3	-	2.53	-
B	STDEV	10.3	-	2.70	-
C	STDEV	9.21	-	1.97	-
D	STDEV	5.39	-	1.57	-
A	CV	21.1	-	2.90	-
B	CV	12.4	-	2.99	-
C	CV	10.7	-	2.12	-
D	CV	5.99	-	1.69	-

[1] Deviation from target values in Table 5

4.3.1 Descriptive statistics

The comparative t-Test data listed in Table 18 shows that there is a significant difference between the mean percentage of pellets loaded between the different stages. In the case of Stage A compared to Stage B the implementation of the fat coater had a significant impact ($p<0.01$) on the average pellet percentage loaded. In Stage B compared to Stage C the correction of the grinding fraction showed a significant ($p<0.1$) improvement on the percentage of pellets loaded. The implementation of the Stage D improvements also resulted in a significant ($p<0.05$) improvement in the pellet percentage loaded, showing that all the stage improvements contributed successfully to the improvement of the pellet percentage loaded.

Table 18: **Descriptive statistics of the mean percentage of pellets loaded between the stages (t-Test: Two-Sample Assuming Equal Variances)**

Comparison of the average pellet percentage between different stages					
	A	**B**		**A**	**C**
Mean	63.05	82.1	Mean	63.05	86.18
Variance	177.73	103.31	Variance	177.732	84.79
Observations	58	44	Observations	58	30
Pooled Variance	145.73		Pooled Variance	146.39	
Hypothesized Mean Difference	0.00		Hypothesized Mean Difference	0.00	
Df	100		Df	86	
t Stat	-7.89		t Stat	-8.50	
P(T<=t) two-tail	**0.00**		**P(T<=t) two-tail**	**0.00**	
t Critical two-tail	1.98		t Critical two-tail	1.99	
	B	**C**		**B**	**D**
Mean	82.1	86.18	Mean	82.1	90.03
Variance	103.313	84.79	Variance	103.31	29.08
Observations	44	30	Observations	44	40
Pooled Variance	95.85		Pooled Variance	68.01	
Hypothesized Mean Difference	0.00		Hypothesized Mean Difference	0.00	
Df	72		Df	82	
t Stat	-1.76		t Stat	-4.40	
P(T<=t) two-tail	**0.08**		**P(T<=t) two-tail**	**0.00**	
t Critical two-tail	1.99		t Critical two-tail	1.99	
	C	**D**		**A**	**D**
Mean	86.18	90.025	Mean	63.05	90.03
Variance	84.79	29.083	Variance	177.73	29.08
Observations	30	40.000	Observations	58	40
Pooled Variance	52.84		Pooled Variance	117.34	
Hypothesized Mean Difference	0.00		Hypothesized Mean Difference	0.00	
Df	68		Df	96	
t Stat	-2.19		t Stat	-12.12	
P(T<=t) two-tail	**0.03**		**P(T<=t) two-tail**	**0.00**	
t Critical two-tail	1.99		t Critical two-tail	1.99	

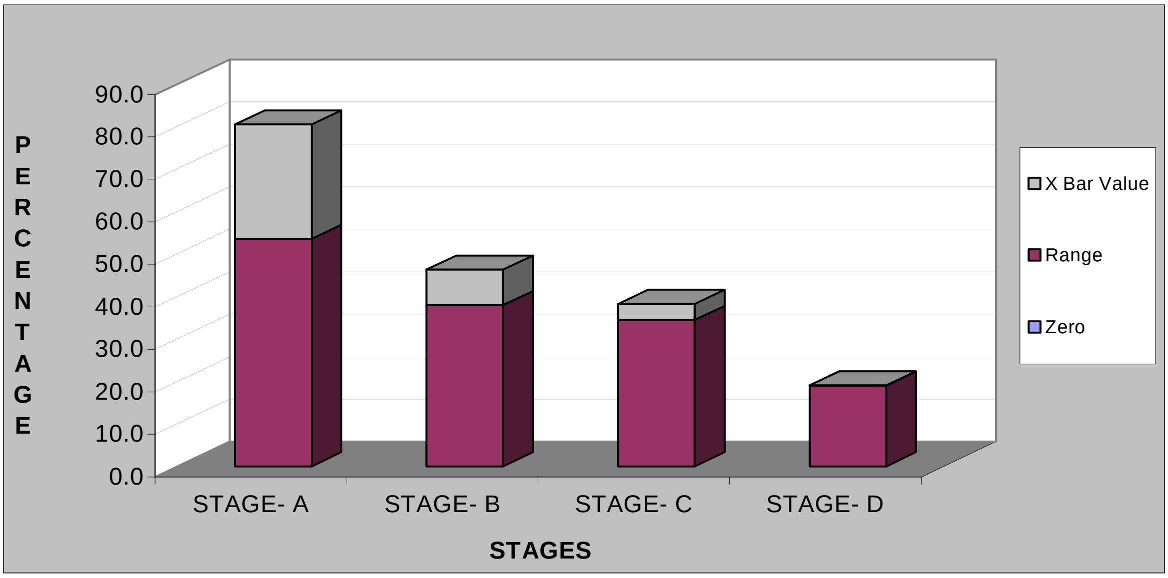
4.3.2 Calculated range and X-Bar values

The improvement in the range and X-bar values is listed in Table 19 and illustrated in Figure 10. The figure clearly shows the reduction in the fluctuation of pellet percentage as expressed by the range and X-bar values.

Table 19: Calculated statistics for range and X-Bar values

	Zero Point	R (Range) Value	X-BAR Value
Stage A	0.0	53.5	27.0
Stage B	0.0	37.9	8.37
Stage C	0.0	34.4	3.82
Stage D	0.0	19.0	0.02

Figure 10: Graphical presentation of the Range and X Bar values



The deviation from targets (R=range) improved by 34.5 points from 53.5 in Stage A s to 19 in Stage D, of which Stage D contributed 15.4 points. This indicates an improvement in product consistency throughout phases B, C and D.

The X-Bar values changed from 27 in Stage A to 0.02 in Stage D. Data from both R- and X-Bar values thus indicate a decline in the product deviations from set targets for Staged A through to D, indicating a reduction in product variability.

CHAPTER 5

DISCUSSION

5.1 Introduction

From all the initial complaints analysed (Appendix VII), approximately 28 percent were related to poor pellet quality while, complaints that resulted from CCP's not being in place, accounted for almost 75 percent. Considering the costs involved and, that the number of complaints on the quality of pelleted feed was less than five percent of total number of orders manufactured, it highlighted the importance of having systems in place to address the root cause of these complaints. Although the original focus of the study was on pellet quality complaints, further investigations into the complaints revealed that the lack of control over CCP's as mentioned above was an even higher financial and quality risk. The cost impact of not controlling such CCP's is illustrated in Appendix VIII. From the data shown it became clear that the cost as a result of complaints, liability claims and corrective measures were financially important to address, and made these issues important to the company to correct. This information underlined the statement made by Herman, (2000) that the three basic pillars of quality assurance needed to be addressed are:

> You can not improve what you do not control,
> You can not control what you do not measure,
> You can not measure what you do not define.

It became clear from original discussion with personnel that the pelleting process variables that influences pellet quality were not exactly known, understood, properly monitored and, that producing a high quality pelleted animal feed was a fine art not yet mastered by pelleting operators. As a wide variety of factors influenced the final end product it also added to the complexity of the process. Although some of the factors influencing the quality of pelleted feed were known to a degree by operators there were no structured CCP monitoring and corrective action systems in place. As training programs were needed to create a culture of quality awareness surrounding product specifications and manufacturing requirements, the HACCP system formed a basis and starting point for the implementation of this TQM program.

5.2 Phase I (Stage A): Processing layout, data from monitoring points and pellet quality results

Due to a lack of grinding capacity with smaller sieves both mills were used in combination to fill two maize bins, one fine and one coarse. Operators contributed to this variation through the use of different (alternating) grinding routines and strategies to keep the fine maize bin filled, which was under continuous pressure due to the low grinding capacity. This practice contributed to the deviation of the mean particle size from target values in the 900μm fraction as shown by the high CV during Stage A. This also explains the 20% above the target in the 2360-1440μm and 3550-2360μm ranges. The below optimum conditioning temperature of 64°C and moisture of 12.6% may also have contributed to this phenomenon as a result of the larger particles and lower temperature leading to a lesser degree of gelatinisation.

The target value for the pre-pelleting mash fraction was somewhat higher than the target of 500-700μm suggested by Wenger's researchers and the optimum values of 650-700μm suggested by Dozier (2001). It should however be remembered that particle sizes of 600μm and below could pose a threat of ulceration in pigs due to compaction and increased gizzard pH in broilers (Hancock, 1999a). Furthermore, the energy required to obtain a 500μm fine size could be as much as twice the normal amount of energy used, thus, impacting on the cost efficiency of the grinding process (McEllhiney,1992). Gill (1998) states that Rokey suggests a rule of thumb maximum particle size of one-third of the pellet diameter, equaling a maximum of 1485μm for the 4.5 mm pellets used in this study. This means that there should in fact be no particles above the 1440μm sieve as used in this study. The target in this study was set at a maximum of 20% above 1440μm and could be explained by the wider particle dispersion obtained with grinding on hammermills compared to roller mills. This also suggests that the use of a 3 mm screen with the larger hammermill might be needed as the 4 mm screen used in this study was still approximately 15% below the target of 65% in the 1440-600μm range. This is noted as an area for future improvement. Maize and pre-pellet mash fractions of Stage A were considerably coarser than target values, which may lead to poor starch particle gelatinisation and subsequently inferior pellet quality due to the slow rise of particle core temperatures expected with coarser particles.

5.3 Phase II: Intervention

5.3.1 HACCP structuring and training

The implementation of the system proved to be a great learning experience for the whole team. From discussions it was clear that much of the process was not fully and equally understood by all. This supports the statement by Behnke (2001) that: "… there is truly still a great deal of art in the science of pelleting and a great deal that we don't understand or perhaps misunderstand about pelleting". The analysis and discussion of the processing system in this study proved to be very important in standardizing procedures and knowledge within operators and the rest of the team.

5.3.2 Stage B: Fat-coater installation to reduce the fat percentage in the mixer

The increase in the pellet quality and durability can be attributed to the implementation of the fatcoater that facilitated the reduction of the average fat % in the mixer from 2.64% to 0.53%. The impact of the change is also reflected by the improved pelletability index of the formulas from 36.7 to 45. This was, however, still slightly lower than the pelletability index of 47-50 suggested by Payne (1998) needed for good pellets.

The lower pre-pellet fat concentration of the mash improved particle binding during the gelatinisation process supporting the improvement in pellet quality. The observed improvement due to the lower fat percentage in the mixer (or formula) was however not as much in this study as observed by Reimer (1992). This may have been due to other contributing factors such as a lower conditioning temperature and coarser mash fractions that were not optimised at the stage of installing the fat coater. Considering that the average maize (starch) and protein levels were fairly stable in this product during the project it stands to reason that the influence of raw material changes as mentioned by Briggs et al. (1999) was minimal. The reduction in the minimum-maximum range of the raw material observed could however explain the positive effect of reducing the variability in pellet quality.

5.3.3 Stage C: Grinding fractions of maize and pre-pellet mash

The new high capacity mill helped to correct the capacity problem and alternating grinding routines used before, explaining the improvement in the maize CV. Correcting the 900μm fraction may have contributed to improved heat penetration (Wondra *et al*., 1995; Behnke, 2001) and hence improved gelatinisation, which may explain ($p<0.1$) part of the increase in pellet quality during Stage C from 82.1% to 86.2%. This increase of 4.08% is however not as significant as the 20% improvement contributed by grinding as reported by Reimer, 1992. Considering that steam temperature was not optimal, the slight increase in mash temperature observed could be explained by the smaller particles leading to a faster increase in core temperature as explained by the graphs in Appendix IX and X.

Although the particle size of the target fraction had improved considerably it was still some 18% below the 1440-2360μm target values. Wassink (2001) suggested that particle size might be altered further by adjusting the hammer tip speed through a variable speed motor and frequency controller. The shift from a coarse to a finer pre-pelleting particle size was mainly due to the contribution of the finer maize and not the raw material as such.

5.3.4 Stage D: CCP system and corrective protocols

With the onset of the initial data being recorded, an increase in pellet percentage from 57.7% to 63.1% was observed – this was however strange as no real intervention had been done. This could possibly be explained by the "Hawthorn" effect (Knapp, 1992) that noted improvement in results just by improving attention, and in this case improved focus on process monitoring and record keeping.

Routine monitoring, calibration and adjustment of steam temperature and pressure meters reduced the variation in pressure reduction and temperature values. The reduced temperature values in stage A-C were low compared to steam tbales possibly due to uncalibrated meters in these stages. Optimization of conditioner set-point as close to 80^{o}C as possible did not show an increase in average temperature in Stage D, possibly due to steam quality not being optimal. A higher set point was, however, achieved during Stage B and C and may be due to the improvement in the mash fraction and the removal of the fat from the formula allowing better conditioning.

Although a higher conditioning temperature could not be reached during Stage D there was a further improvement in the STDEV of 1.47 and the CV of 1.91. The increase in pelleting rate observed may be attributed to the above as well as the introduction of routine pellet mill checks to ensure correct roller gap settings and die condition and cutting blade sharpness. These checks may have contributed to reducing the pellet percentage variability by picking up, and attending to problems earlier during the production process.

The difficulty in reaching the target conditioning temperature of 80^{o}C suggested that conditioning and steam quality was probably still not optimal. The exact reason for this was not clear but it may be explained by the reducer-to-conditioner distance of 4m that is shorter than the minimum of 6m proposed by Payne(1998), leading to a high steam velocity and the reduction of heat transfer to the mash. Lowering the reduced pressure target may also give a positive increase, as the average of 2.5 Bar during conditioning was higher than the 1-2 Bar proposed by Payne (1998) for starchy type rations. Dozier (2001) indicated that with good quality steam one should be able to reach a conditioning temperature of at least 88^{o}C, which supports the author's concerns of a possible steam quality problem in this study.

Possible future improvements include; adding conditioning automation software to reduce set point time, minimizing operator influence and memorizing optimum settings for formulas. Also, optimisation of the pre-conditioning mash moisture up to 14.5% could lead to further improvements in pellet quality (Fairchild & Greer, 1999). Caution is however advised to a possible decrease in nutrient density.

No significant increase in moisture concentration during conditioning was observed. According to the literature (Payne, 1993), the reason for not reaching the ideal level of 15% moisture may be due to a high velocity of steam with a short reducer-to-conditioner distance as expected in our study. Payne (1993) further indicated that the post-reducer steam pipe diameter should be sufficient to carry the increased volume of steam at the required lower velocity. Improving the moisture to between 15-18% can further aid in reaching the glass transition stage (Behnke, 2001) of the mash, aiding further to pellet improvement. Correction of the reducer-to-conditioner length and evaluation of the pipe diameter did not form part of the corrections implemented in this investigation and need further attention.

Temperature of pellets in the cooler was on average 3.8°C below ambient temperature after reducing airflow in Stage D compared to the ambient plus 15°C maximum suggested by Gill, (1998). The target in this study of 5°C was, however, in line with the values suggested in Feed Manufacturing Technology IV (1994). This small “below-ambient” temperature difference also explains the loss of moisture from pellets during cooling, possibly due to an elevated airflow. Reducing the airflow speed above a level that will reduce moisture loss is not advocated by the author as this may lead to an increase in fines settlement in airflow ducting leading to an increased risk of corrosion. The problem after all lies in the moisture that was below target during conditioning. This was not investigated in our study since proper controls for monitoring and adjusting airspeed and temperature were not yet present during Stage D.

Focus on the implementation of inclusion bounds and raw material swings and giving attention to other formulation items such as pelletability index, raw material variation and total fat percentage in the formula further added to improvements. Variation in total dietary fat % was reduced as seen by the decrease of the CV from 9.46 to 4.84.

The pelletability STDEV and CV were better with an improvement from 5.34 to 2.28 and 14.6 to 5.08 respectively. The percentage of fat derived from raw materials were slightly reduced from 5.35 to 4.51%. Due to the reduction of raw material and fat variability in formulas an improvement in the pellet percentage was still achieved despite the average increase in total fat percentage from 7.99 to 8.41%. This could mainly be a result of adding higher levels of fat without affecting the mash fat levels and thus the pellet quality.

The PDI index of 92.9 in the study was slightly lower than the 95% mentioned by Gill (1999). The total fines percentage was however higher at 10% compared to the commercial operation fines of 1-2% mentioned by Gill (1999). This may be attributed to the poorer conditioning and long transport systems prior to loading at this site.
Calibration and monitoring protocols were introduced for fatcoater scales after several errors in the inclusion level of fat were observed during Stage A. This helped in contributing to the reduced CV observed for physical fat inclusion against formula targets. Regular evaluation of fraction data facilitated easier identification of wearing/failing screens and hammers. Slow identification of this problem during

Stage A could also have contributed to the poor pellet quality and high product variability during this phase.

The loss of moisture as reflected between the pre- and post cooler moisture data possibly suggests too high airflow speeds which reflected in the "below-ambient" temperatures and moisture loss patterns observed on the pellets. Flattening and leveling of the cooler bed was achieved by changing diverter flaps and spreaders, and airflow on extraction ducts were slightly reduced to try and reduce the moisture loss. No inline control system was available at the time of the trial to facilitate further process changes and monitoring and this point needs to be assessed in more detail.

Dozier (2001) states that a 10% improvement in the pellet durability is possible if a 5°C increase in conditioning temperature could be achieved. Reduction of particle size from 665 to 500μm may add an additional 14.5% increase to the PDI whereas the increasing of mash moisture in the mixer from 12 to 14.5% may add another 10% to the PDI. Thus, when compared to the data of Dozier (2001), the results of this study suggest that further improvement is quite possible with additional system improvements.

Towards the end of Stage D a slight shift towards the coarser particle fraction was observed. Closer investigation revealed that the sieve and hammers were starting to show signs of wear after a few months of running, proving that the monitoring systems are useful in the early detection of wear and tear changes on equipment.

5.4 Phase III: Comparison of pellet quality observed during stages A to D

It is clear from Figure 14 and the data in Table 16 that both the range (R) and X-Bar values support the decrease of variability of the pellet percentage. The reduced deviation from targets (R=range) indicates an improvement in product consistency throughout Stages B, C and D. The improved R- and X-Bar values both indicate a decline in the product deviations from set targets for Stages A through to D, supporting the reduction in product variability observed.

CHAPTER 6

CONCLUSION

It is clear from the data that the control and corrective measures applied had successfully achieved the goal of reducing product variance and improving the total percentage of pellets loaded. The direct impact of the process parameters on product quality is quite clear and it is also evident that the quality of the final product is indeed the result of a complex interaction between many elements.

Many benefits were achieved during the project and included:

- A reduction of poor pellet quality as a negative factor influencing product quality and animal performance.
- A reduction of customer complaints and ultimately the amount of claims.
- The systematic methodology of the HACCP model contributed to an increased understanding amongst employees of how the various processes contributed to pellet quality. Employees have become more quality aware and fitted with skills to monitor and control the manufacturing and inspection process.
- Increased co-operation between factories and improved manufacturing skills as well as a better knowledge of process operations and the impact of various CCP's on the quality of pelleted animal feed.
- Specifications were established for use during product inspection and testing of pelleted animal feeds.
- Records are available to substantiate compliance to the required CCP's. They were also valuable in demonstrating the risk assessment steps taken for this hazard.
- A positive contribution towards the ISO 9001 certification of the company that was achieved during April 2003.
- Many of the benefits of ISO systems were also experienced.

The project had successfully met the objectives of the study by:

i. Determining the true status of the product before intervention, and measuring the fluctuation of the percentage of pelleted feed loaded and the deviation from target values.
ii. Identifying and measuring the deviation of processing CCP’s from targets. This part of the study was especially important in identifying areas of weakness and future improvement as well.
iii. Measuring the improvement in pellet quality, and the reduction in CCP fluctuation as a result of implementing the HACCP program.
iv. Demonstrating that a system such as this can be implemented in the quality and pelleting environment of a feed mill with benefits to the company and the customer.

From the data presented it can be concluded that the HACCP system, implemented as an intervention tool in this study, had a statistically significant contribution to the improvement in pellet quality (pellet percentage and durability) as well as the reduction of product variability. The improvement in the pellet quality is supported by the total reduction in customer complaints on the issue.

CHAPTER 7

RECOMMENDATIONS AND FUTURE RESEARCH

Due to the nature of the HACCP system several important focus areas were identified that need further attention. One of these areas was that of human resource development and training for process operators. The project relied heavily on the inputs of the production controllers whereas trained operators at the equipment itself can ease the burden on the controller and increase the frequency of CCP monitoring and data collection. The author envisages expanding the program by focusing on training at lower levels to increase the effectiveness of the monitoring process.

It became clear during the project that several processes could be improved even further. A case in point is a system to aid in the management of the cooling process and reduce the loss in revenue due to moisture loss. The installation of inline monitoring equipment such as temperature and moisture probes could also drastically improve process feedback, control and data recording.

As a last recommendation the author has found the data collection process very time consuming due to the lack of proper information management systems for the laboratory and process CCP data collected. Improvements in this area can greatly increase the feedback of data and the reaction time to correct process parameters that exceed target limits. Such information systems will improve the availability of data that is needed to validate processes and demonstrate compliance to specifications.

Due to the unique differences between facilities and production systems the HACCP model represented an important tool in facilitating system analysis, identifying CCP's, setting specifications, training and applying monitoring and corrective protocols. As vehicle augers have a huge influence on pellet destruction during off loading it should be quantified further and form part of the total monitoring and control program.

The data from this study supports the international trend to use HACCP systems pro-actively as a quality assurance tool in the feed manufacturing environment for the improvement of product quality and reduction in the variability thereof.

SUMMARY

IMPROVED PELLET QUALITY FOLLOWING THE IMPLEMENTATION OF A HACCP SYSTEM IN A COMMERCIAL ANIMAL FEED PELLETING PLANT

by

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DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE MASTERS OF SCIENCE
IN PRODUCTION ANIMAL STUDIES

In the

FACULTY OF VETERINARY SCIENCE
DEPARTMENT OF PRODUCTION ANIMAL STUDIES
UNIVERSITY OF PRETORIA

OCTOBER 2003

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An investigation of complaints about the cause of poor product quality and performance pointed to critical control points (CCP's) in the pelleting process that were either absent or not monitored and controlled. The non-conformance cost due to poor pellet quality and product inconsistency is quite significant.

The positive relationship between pellet quality and animal performance is well known. Poor and inconsistent quality of pelleted feed is the consequence of many contributing factors such as formulation, processing variables, people and the manufacturing environment, which affect pellet quality either individually or in combination.

Data collected on the control of some critical elements in the production process revealed that many production parameters are often not closely monitored or controlled, and that quality control limits are often poorly enforced or non-existent, explaining the varying causes for complaints on the quality and inconsistency of pelleted feed.

Production facilities differ in layout and the success of a Hazard Analysis Critical Control Point (HACCP) program exists in its systematic method of process analysis, applying appropriate risk controls and timely corrective protocols. Modified HACCP programs can be utilized to reduce process parameter variation resulting in improved product quality and consistency.

A HACCP system modified for the pelleting environment was used as an intervention tool to address poor pellet quality and product inconsistency in a broiler feed mill. Implementation of the system was achieved by measuring the quality and variability of products and processes prior to implementation. The processing layout was identified, analysed, CCP's and limits set after which the CCP's were measured and compared to ideal targets. Corrective actions and changes to the production process were prioritised in order of each CCP's contribution to pellet quality. Monitoring, control and corrective protocols were introduced for CCP's through consecutive training and work sessions. Re-assessment of the pellet quality and product variation concluded the intervention phase.

Data analysed from the first phase helped to facilitate the restructuring of the production process and the implementation of improvement phases. Systematic analysis identified formulation (fat addition levels and point of addition) and mash grinding fraction as key areas of improvement. This was achieved by lowering the fat percentage in the mixer from 3.50 to 0.5%, thereafter adding the fat by means of a post pelleting fat coater. The coarse pre-pelleting mash fraction (particle size being above 2360μm), was reduced from 28.5 to 1% on average and the ideal target particle size (being from 600μm to 1440μm), was increased from 20.5 to 51% on average. This increase was achieved by correcting and improving grinding operation with a larger capacity hammermill. Conditioning temperature increased from 64.5 to 74.5^{o}C. Correcting the above changes to critical factors contributed to increasing the pellet percentage of the final product at loading from 63.05 to 86.18%.

Improved monitoring of CCP's and timely corrective protocols led to a further improvement in loaded pellet percentage from 86 to 90% and also improved the repeatability in obtaining better pellet quality at loading. The STDEV of the final product pellet percentage showed an improvement of 13.3 to 5.39. Hazard analysis and the collection of data helped in identifying further areas of improvement.

In conclusion, the HACCP system as implemented in this plant, resulted in the improvement of pellet quality (percentage of pellets at loading and pellet durability) as well as a reduction in its variability. It is recommended that HACCP systems should be used more pro-actively as a quality assurance tool for process improvement, assuring product safety, reducing process variation and increasing product quality.

SAMEVATTING

VERBETERDE PIL KWALITEIT NA AFLOOP VAN DIE IMPLEMENTERING VAN 'N HACCP STELSEL IN 'N KOMMERSIËLE VEEVOER VERPILLINGSAANLEG

deur
R.S. VAN ROOYEN

VERHANDELING INGEHANDIG TER GEDEELTELIKE VERVULLING
VAN DIE VEREISTES VIR DIE GRAAD MEESTER VAN NATUURWETENSKAP
IN PRODUKSIEDIER STUDIES

In die

FAKULTEIT VEEARTSENYKUNDE
DEPARTEMENT VAN PRODUKSIE DIER STUDIES
UNIVERSITEIT VAN PRETORIA

OKTOBER 2003

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Ondersoeke na die oorsaak van klanteklagtes oor swak pilkwaliteit en onderprestasie van produkte en diere het aangetoon dat verskeie kritiese beheer punte (KBP'e) in die verpilling proses dikwels nie in plek is, gemonitor word of onder beheer is nie. Die koste as gevolg van hierdie swak pilkwaliteit en produk variasie is noemenswaardig hoog.

Die positiewe verband tussen pilkwaliteit en prestasie by diere is goed bekend. Swak en varierende kwaliteit van die pille is die gevolg van verskeie bydraende faktore soos formulering, prosessering veranderlikes, mense en die omgewing. Hierdie faktore het op hulle eie of in samewerking 'n invloed op die eind resultaat van die produk.

Data wat versamel is oor die beheer van kritiese beheer punte het aangetoon dat verskeie prosesse dikwels nie noukeuring gemonitor en beheer word nie. Limiete vir die beheer van prosesse bestaan in sommige gevalle nie wat dus die variasie en oorsake vir die swak en varierende produk kwaliteit kan verduidelik.

Produksie fasiliteite het verskillende uitlegte, opstellings en apperatuur. Die voordeel van “Gevaar analise kritiese beheer punt stelsels” (HACCP) is geleë in die sistematiese metode waarmee prosesse ontleed word, risikos ge-identifiseer en regstellings en voorkomende optredes in plek geplaas word. HACCP stelsels kan gebruik word om prosessering variasie te verminder met gevolglike verbetering en stabilisering van produk kwaliteit.

‘n HACCP stelsel wat aangepas is vir die verpillingsomgewing is gebruik as metode van intervensie om die wisselvallige en swak pilkwaiteit in ‘n verpillings aanleg aan te spreek. Implementering het ‘n aanvang geneem deur eers die variasie in die pilkwaliteit en die prosesse te meet. Hierna is die verpilling proses deeglik ontleed, kritiese beheer punte ge-identifiseer en limiete vir elk gestel. Data is versamel, ontleed en vergelyk met die ideale teikens vir elke KBP. Regstellings en veranderings is geprioritiseer en aangebring na gelang van elke beheerpunt se bydrae tot die verbetering van pilkwaliteit. Dit is opgevolg deur opleiding oor die monitering, beheer en korrektiewe protokolle vir alle KBP’e. Die projek is afgesluit deur die pilkwaliteit en produk variasie weer te meet en te vergelyk teenoor die data voor die aanvang van die HACCP stelsel.

Analiese van data uit die eerste fase het ‘n belangrike rol gespeel in die identifisering van tekortkomminge in die stelsel asook die strukturering van daaropvolgende verbeteringe. Sistematiese analise het aangetoon dat formulering (of te wel die vet persentasie en area van toediening) asook die regstelling van die maalfraksies sleutel areas vir verbetering was. Verbetering is bereik deur die installasie van ‘n vet opspuitstelsel, na afloop van verpilling, om sodoende die vet persentasie in die menger te verlaag van 3.5% tot 0.5%. Die implementering van ‘n groter hammermeule is aangewend om ‘n tekort aan maalkapasiteit en growwe fraksie probleme aan te spreek. Die growwe fraksie (bo 2360μm) is verlaag van 28.5% tot 1% en die teiken fraksie (600 – 1440μm) is verbeter van 20.5% tot 51%.

Kondisionering temperatuur is verbeter van 64.5^{o}C tot 74.5^{o}C deur herhaaldelike optimalisering van die temperatuur verstelling tot so na aan 80^{o}C as moontlik. Bogenoemde het reeds ‘n groot bydra gelewer in die verbetering van die van die pilkwaliteit van 63.05 tot 86.18%. Verbeterde monitering van KBP’e en tydige regstelling van KBP afwykings het aanleiding gegee tot ‘n verdere verbetering in die pilkwaliteit vanaf 86% tot 90% asook ‘n verbetering in die koeffisient van variasie (CV) vanaf 10.69 tot 5.99 en ‘n verlaging in die standaard afwyking vanaf 13.33 tot 5.39. Gevaar analise en versameling van proses data het ‘n verdere bydraende voordeel gelewer deur toekomstige areas van verbetering uit te wys.

Dit is duidelik uit die studie dat die HACCP stelsel soos ge-implementeer in die aanleg ‘n statisties betekenisvolle bydrae gelewer het tot die verbetering van die pilkwaliteit asook die verlaging in variasie binne die produk. Die data ondersteun die internasionale neiging dat HACCP stelsels meer pro-aktief aangewend kan word as ‘n kwaliteit instrument vir die ontleding en verbetering van prosesse, versekering van produk veiligheid, verlaging van variasie in prosesse en uiteindelike verbetering van produk kwaliteit.

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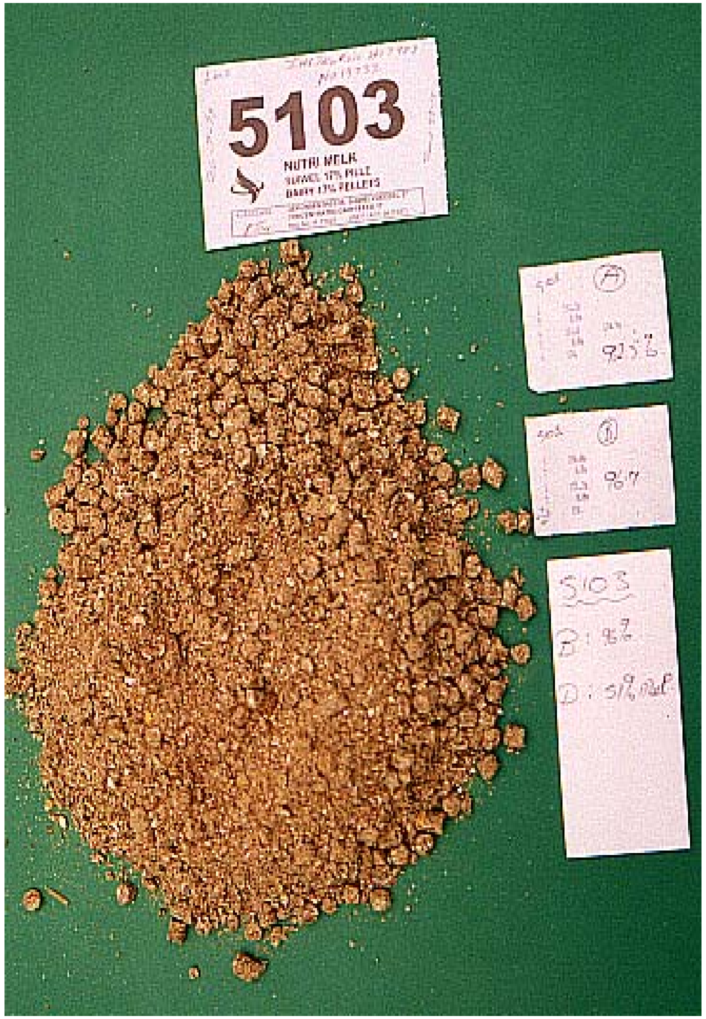
Appendices

Appendix I: Some examples of poor quality pellet feed before implementation of the project.



Appendix II: Cost impact when placing restrictions on the least cost formulations

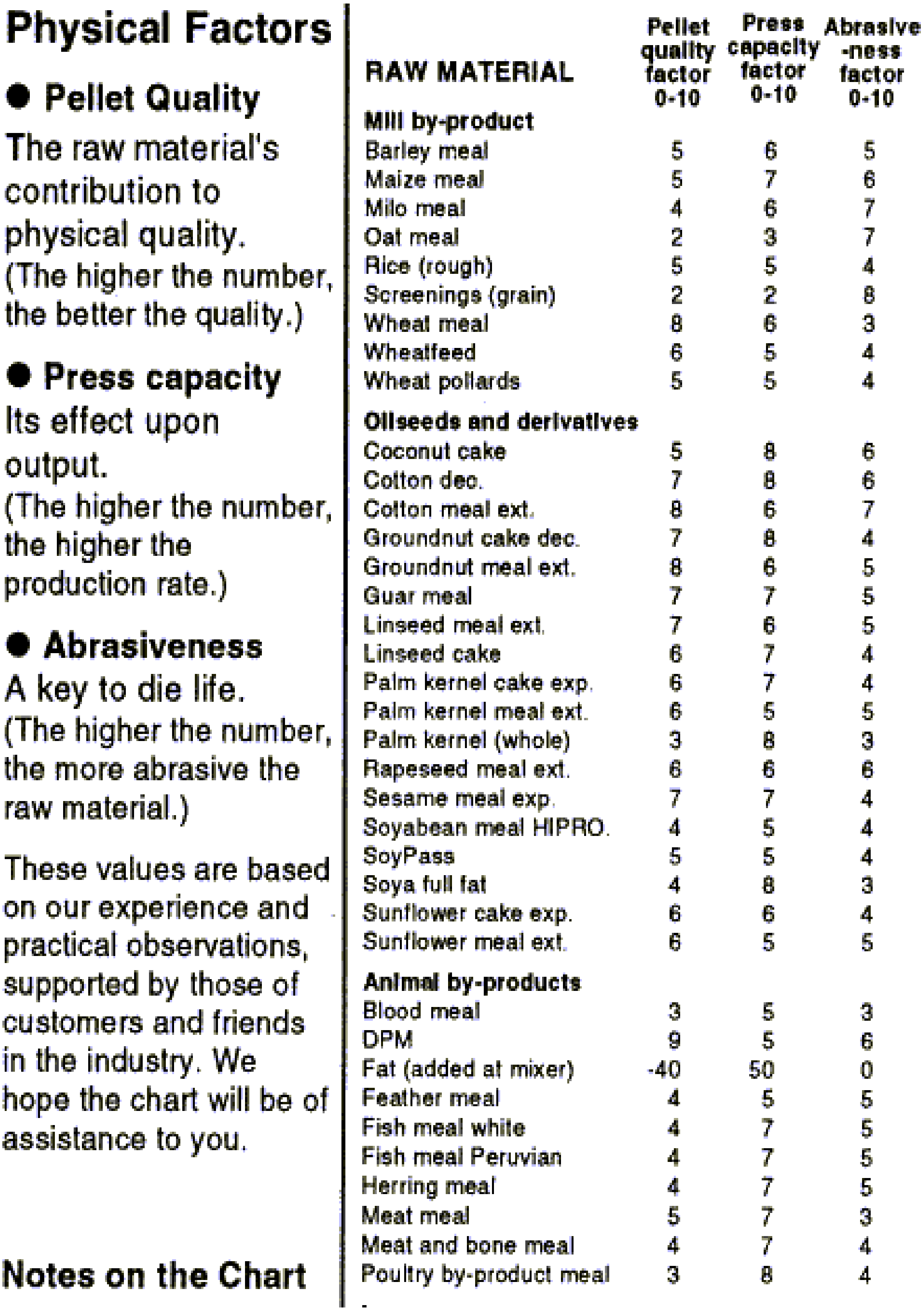
STANDARD		RESTRICTION	COST PER MONTH
Normal average fat % for the group of 22 products:	7.68%	Target Restriction of Maximum 6% fat	R 5 677
Normal Pelletability Score	58%	Minimum Pelletability set at 63%	R 2 440
Average feed cost / ton	R991	Total cost for project formulas	R 8 117
		Cost per Year	**R 97 404**
		Cost per year if restrictions were applied to all pelleted feed	**R 420 000**

The cost impact is clearly illustrated in this exercise where restrictions were placed on the least cost formulations in order to achieve an improvement in pellet quality.

Appendix III: Some raw material quality values listed by Wetzel (1983) to calculate the pelletability score

RAW MATERIAL PELLETABILITY		
Ingredient	**Quality Factor (1-10)**	**Capacity Factor (1-10)**
Alfalfa	7	2-3
Barley	6	6
Bagasse	7	2-3
Citrus Pulp	7	3
Maize	5	7
Corngluten meal	3	4
Cottonseed E-meal	8	6
Feathermeal	4	5
Fishmeal	4	7
Grassmeal	7	2
Guarmeal	7	6
Peanut E-meal	8	6
Maizegerm E-meal	5	5
Tapioca	5	3
Meatmeal	5	7
Minerals	2	4
Palmkernal E-meal	6	5
Ricebran	2	3
Skim milk powder	9	2
Soybean E-meal	6	5
Wheat	8	6
Whey dried	6	3

Appendix IV: Some of the raw material quality values listed in Borregaard (1993) to calculate the pelletability score



Physical Factors

● Pellet Quality

The raw material's contribution to physical quality. (The higher the number, the better the quality.)

● Press capacity

Its effect upon output. (The higher the number, the higher the production rate.)

● Abrasiveness

A key to die life. (The higher the number, the more abrasive the raw material.)

These values are based on our experience and practical observations, supported by those of customers and friends in the industry. We hope the chart will be of assistance to you.

Notes on the Chart

RAW MATERIAL	Pellet quality factor 0-10	Press capacity factor 0-10	Abrasive -ness factor 0-10
Mill by-product			
Barley meal	5	6	5
Maize meal	5	7	6
Milo meal	4	6	7
Oat meal	2	3	7
Rice (rough)	5	5	4
Screenings (grain)	2	2	8
Wheat meal	8	6	3
Wheatfeed	6	5	4
Wheat pollards	5	5	4
Oilseeds and derivatives			
Coconut cake	5	8	6
Cotton dec.	7	8	6
Cotton meal ext.	8	6	7
Groundnut cake dec.	7	8	4
Groundnut meal ext.	8	6	5
Guar meal	7	7	5
Linseed meal ext.	7	6	5
Linseed cake	6	7	4
Palm kernel cake exp.	6	7	4
Palm kernel meal ext.	6	5	5
Palm kernel (whole)	3	8	3
Rapeseed meal ext.	6	6	6
Sesame meal exp.	7	7	4
Soyabean meal HIPRO.	4	5	4
SoyPass	5	5	4
Soya full fat	4	8	3
Sunflower cake exp.	6	6	4
Sunflower meal ext.	6	5	5
Animal by-products			
Blood meal	3	5	3
DPM	9	5	6
Fat (added at mixer)	-40	50	0
Feather meal	4	5	5
Fish meal white	4	7	5
Fish meal Peruvian	4	7	5
Herring meal	4	7	5
Meat meal	5	7	3
Meat and bone meal	4	7	4
Poultry by-product meal	3	8	4

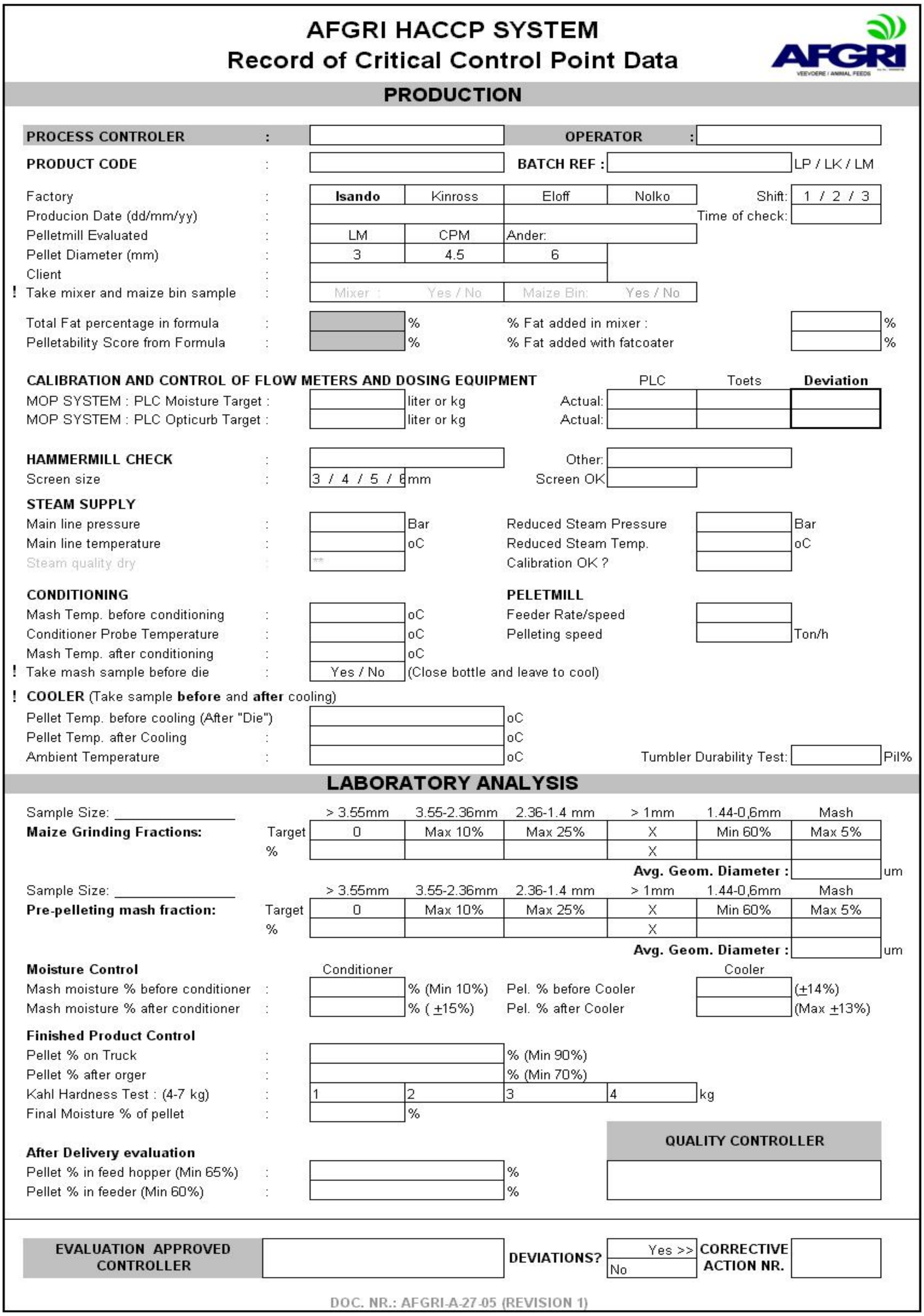
Appendix V: The analysis table compiled for some of the CCP's in the project.

See attached table on next 2 pages

INITIAL HACCP ANALYSIS OF THE PELLETING PROCESS					**CCP QUESTIONS**										
NR	**PROCESS STEP**	**FACTORS CONTRIBUTING TO THE HAZZARDS WITHIN THE PROCESS**	**INFLUENCE ON PELLET QUALITY**	**CONTROL MEASURES**	**Are control Measure that affect the hazard in place at this point ?**	**Does the Process step eliminate the hazard**	**Could deviation within the process contribute to unacceptable levels of the hazard ?**	**Will a subsequent process step correct the hazard (pellet quality)**	**Is this a CCP ?**	**TARGET**	**CRITICAL LIMITS**	**MONITORING PROCEDURES**	**RESPONSIBILITY**	**CORRECTIVE ACTIONS**	**RECORDS**
1	FORMULASIE	High fat %allocated to mixer	Higher fat% in mixer = Lower pellet Quality	Add fat with Fat coater & Maintain Fat in mixer to the minimum	N+Y= Install Fat coater				Y	Reduce Fat to below 1%	Max 1% in mixer	Formulation bound	Nutritionist	Install Fat coater to reduce fat % in mixer	Formulation data
		Pelletability Score differs significantly from previous month (Much lower = High Raw Materia Variation)	Higher fluctuation = larger fluctuation i pelet %	Reduce RM fluctuation with bounds and swings	Y	Y			Y	Maintain Pelletability Score above avg for group	Pelletability score > 40	Formulation bound	Nutritionist	Manage Pelletability index comapred to cost	Formulation data
2	RAW MATERIALS	Product physical structure / coarseness has changed from previous load	Increased coarseness of RM other than maize can increase pre-pellet fraction coarseness and reduce pelletability	Monitor incomming raw material texture fo change	Y	N	Y	Y	N	Grind all RM through RM sieve if texture changes	RM fraction > 65% in 900um range	physical inspection and sieve tests	RM Controller and QA Operator	Report texture change to production amanger, grind if needed.	RM inspection tag and Sieve results
3	STORAGE	Rancidity of high fat products	Increased rancidity = Reduced palatability of feed and reduced intake	Smell and test rancidity levels. Supplier control essential	Y	Y			Y	PW < 1 and VVS < 5	PW < 3 and VVS < 10	Supplier certificate of analysis an physical inspection and Lab results	QA Controller	Report deviations to Production, QA and Procurement managers	Test results and Supplier analysis certificate.
4	GRINDING	Maize Particle Fraction & Size	Increase coarseness = poor gelatinisation, reduced binding, increased breakage and reduced pellet quality	Measure grinding fraction, Routine sieve and hammer inspection	N+Y = New Hammermill				Y	65% in 900um range	Min. 60% in 0-1440um and Max 20% above 1440um	Measure grinding fraction at lease once per shift	Production Controller	If out of spec > check hammermill, screen and adjust screen size	HACCP control sheet
		Pre-pelleting particle fraction & size	Increase coarsenes = poor gelatinisation, reduced binding, increased breakage and reduced pellet quality	Measure grinding fraction, Routine sieve and hammer inspection	N+Y = New Hammermill				Y	65% in 900um range	Min. 60% in 0-1440um and Max 20% above 1440um	Measure grinding fraction at lease once per shift	Production Controller	If out of spec > RM hammermill, screen and adjust screen size	HACCP control sheet
5	MIXING & LIQUID ADDITIONS	Incorrect mixing/batching	Increased variation = increase in pellet% fluctuation	PLC control of scales and batching. Regular calibration of scales.	Y	N	N		N						
		Incorrect liquid/ fat addition volume	Inaccurate fat addition = reduced pellet % and increased fluctuation. Fat levels impacts largely on energy levels and pellet quality	PLC control of scales and batching. Regular calibration of scales.	Y	N	Y	N	Y	Fat addtion in mixer < 1% and = to formula requirement	Within PLC tolerances	PLC alarm system when exceeding tolerances	Production Operator and controller	Stop immediately if tollerance is exceeded > check and correct scales.	Production and Batching reports
		Incorrect Liq temperature	Poor flowing, rancidity if to high	Regular check of liquid tenk temperature	Y	Y			Y	Maintain at 30oC	25-35oC	Check tempertature once per shift	Production Operator and controller	Stop immediately if tollerance is exceeded > check and correct temperture and probes.	Shift control report
6	CONDITIONIN G	Steam supply Pressure/ Temperature is incorrect	Incorect Supply and Pressure, Temperature and steam quality impact negatively on conditioning	Monitor supply and reduce pressure gauges at least on during shift. Check calibration of meters at least once a month.	Y	N	Y	N	Y	Supply at 10Bar and Reduced at 2.3 Bar	Supply Pressure = 8 - 11 and Reduced Pressure = 2.2-2.5	Check Pressure Gauge once during shift	Production Controller	Stop immediately if tollerance is exceeded > check and correct Pressure and probes.	Shift control report
		Conditioning temperature	Low Temp = Poor Gelatinisation while too high temperatures = protein/ nutrien damage.	Monitor temperature probe readings on PLC and check each shift with infra-red thermometer.	Y	Y			Y	Min 80oC	75-85oC	Check Temp Gauge once during shift	Production Controller	Check Tempertaure probes, and steam quality > adjust temperature.	Shift & HACCP control report
		To high conditioning feeder rate	Unsatisfactory conditioning = low gelatinisation = poor pellet quality	Don't exceed product feeder rate recommendation	Y	Y			Y	Feeder rate avg for group	± 3 Above and below target	PLC Feeder rate log	Production Operator	Reduce feeder rate if above limits	PLC log
		Conditioner paddle angle	Improper conditioning, and incorrect filling level	Check settings regularly according to maintenance schedule	Y	Y			Y	Manufacturer guideline	No deviation	Preventive maintenance schedule	Production manager	Correct the angle if out, and increase frequency of checks	Preventive Maintenance Card
7	PELLETING	Pelleting rate	Too high rate= decreased compression/ conditioning	Don’t exceed maximum limits	N	N	Y	N	Y	Maintain optimum setting	Determine	Controls / batch reports	Production Controller	Reduce rate to within limits	Batch reports/ haccp records
		Die condition	Increased die wear = reduced compression = lower pellet quality	Inspect die condition daily, follow preventiv maintenace plan for replacement	Y	N	Y	N	Y	Good die condition	Don’t use longer than the avg tonnes produced for the die type	Daily Die inspection and die change according to preventive maintenance plan	Production manager and maintenance team	Report any die damage or incorrect roller settings immediately, thorough inspection during preventive maintenance	Preventive maintenance and internal non-conformance reports
		Blade setting and sharpness incorrect	Incorrect pellet length and breakage due to blunt blades = increase in fines %	Inspect blade setting and condition once daily	Y	N	Y	Y	Y						
8	COOLING	Cooling is uneven	Uneven cooling = hot pellets = soft pellets	Set spreaders to level bed for even cooling and correct thickness	Y	N	Y	N	Y	Even pellet temperature	< 3oC difference	Monitor pellet temp at several places in cooler during check	Production controller	Report to production manager, set and correct pellet bed levels.	Shift & HACCP control list
		Pellet temperature high	Pellets hot = "bliss"	Change aiflow speed to reduce temperature of pellets. Check discharge settings.	Y	N	Y	N	Y	< 5oc from ambient	Not more than 5oC higer or 1oC lower than ambient.	Measure temperature at least once per shift.	Production controller	Report to production manager, set and correct temperature levels.	Shift & HACCP control list

INITIAL HACCP ANALYSIS OF THE PELLETING PROCESS					CCP QUESTIONS										
NR	**PROCESS STEP**	**FACTORS CONTRIBUTING TO THE HAZZARDS WITHIN THE PROCESS**	**INFLUENCE ON PELLET QUALITY**	**CONTROL MEASURES**	**Are control Measure that affect the hazard in place at this point ?**	**Does the Process step eliminate the hazard**	**Could deviation within the process contribute to unacceptable levels of the hazard ?**	**Will a subsequent process step correct the hazard (pellet quality)**	**Is this a CCP ?**	**TARGET**	**CRITICAL LIMITS**	**MONITORING PROCEDURES**	**RESPONSIBILITY**	**CORRECTIVE ACTIONS**	**RECORDS**
		Pellet moisture very dry	Excessive moisture loss and pellets become brittle	Measure pellet temp and moisture and adjus settings.	N+Y= In process control needed				Y	As close to 12% as possible	Total % < 12 but not lower than pre-conditioning moisture %	Measure moisture % pre-conditioning, pre-cooling and post- cooling at least once per shift.	Production controller	Report to production manager and change settings to reduce moisture loss.	Shift & HACCP control list
9	FINES REMOVAL	In-process fines not removed	Increase fines % at loading	Check effective operation of fines sieve.	Y	Y			Y	< 2 % fines after sieve	Max 5%	Measure fines return % once per month.	Production controller	Inspect sieve condition and blockage if return % increases.	Shift & HACCP control list
10	FAT COATING	Addition accurancy	Uneven coating or fatty pellets	Measure addition accuracy (flow meter calibration)	Y	Y			Y	100% Accurate	± 1%	Measure fat addition accuracy once per day	Production controller	Report incorrect addition levels immediately > recalibrate flowmeters and scales	Shift control list
		Coater Fat temperature	Poor penetration into pellet	Measure coater fat temperture pre coating	Y	Y			Y	Maintain fat temp at a constant 35oC	30-40oC	Check temperature readings at least once per shift	Production controller	Report immediately, check temp probes and element then correct temperature setting.	Shift control list
11	TRANSPORT & STORAGE	Loose chain conveyor belts	Increased damage to pellets = higher fines	Inspect transport system during preventive maintenance	Y	N	Y	N	Y	No additional fines from transport system	Max 3%	Measure fines % prior to storage bins once a month	Production controller	Report to maintenance and set tention on belt and chains	Preventive maintenance cards
12	OUTLOADING	Correct outlouding procedure	Incorrect product loaded or contamination	Maintain outloading procedure and communication	N	N			N	N/A	N/A	Internal Audits and Training records	Production and Dispatch	Retrain if procedures not followed	Training records and non-conformance reports
13	FINAL PRODUCT TESTING	Sample not representative (Technique)	Incorrect test result = inaccurate > problems missed	Training and SOP	Y	Y	-	-	Y	N/A	N/A	Internal Audits	Production and QA Manager	Retrain	Non-conformance and Preventive action reports, Training Capability Matrix
		Testing method not followed	Incorrect test result = inaccurate > problems missed	Training and SOP	Y	Y	-	-	Y	N/A	N/A	Internal Audits	Production and QA Manager	Retrain	Non-conformance and Preventive action reports, Training Capability Matrix
		Physical appearance not monitored	Product variation and foreign material not identified	Training and SOP	Y	N	Y	N	Y	N/A	N/A	Internal Audits	Production and QA Manager	Retrain	Non-conformance and Preventive action reports, Training Capability Matrix
		Out of spec product not rejected	Increase fines delivered to customer	Measure fines % on truck and Durability	Y	Y			Y	Min 85% Loaded, Durability of 95%	Min 80% Loaded, Durability of Min 90%	Deviations reports and Audits	Production and QA Manager	Reject, Preventive and Corrective Actions	Non-conformance and Preventive action reports, Training Capability Matrix
14	TRANSPORT AND OFF LOADING	Increased fines due to auger damage	Increased percentage of fines in feed	Measure fines after aurger, and average offload time per tonne of feed	Y	N	Y	N	Y	Min.70% pellets delivered					

Appendix VI: An example of the CCP data collection form used in the study



AFGRI HACCP SYSTEM
Record of Critical Control Point Data

PRODUCTION

PROCESS CONTROLER : ____ **OPERATOR** : ____
PRODUCT CODE : ____ **BATCH REF :** ____ LP / LK / LM

Factory : **Isando** | Kinross | Eloff | Nolko Shift: 1 / 2 / 3
Producion Date (dd/mm/yy) : ____ Time of check: ____
Pelletmill Evaluated : LM | CPM | Ander:
Pellet Diameter (mm) : 3 | 4.5 | 6
Client : ____
! Take mixer and maize bin sample : Mixer : Yes / No | Maize Bin: Yes / No

Total Fat percentage in formula : ____ % % Fat added in mixer : ____ %
Pelletability Score from Formula : ____ % % Fat added with fatcoater ____ %

			PLC	Toets	**Deviation**
CALIBRATION AND CONTROL OF FLOW METERS AND DOSING EQUIPMENT					
MOP SYSTEM : PLC Moisture Target :	liter or kg	Actual:			
MOP SYSTEM : PLC Opticurb Target :	liter or kg	Actual:			

HAMMERMILL CHECK : ____ Other: ____
Screen size : 3 / 4 / 5 / 6mm Screen OK ____

STEAM SUPPLY
Main line pressure : ____ Bar Reduced Steam Pressure ____ Bar
Main line temperature : ____ oC Reduced Steam Temp. ____ oC
Steam quality dry : ** Calibration OK ? ____

CONDITIONING **PELETMILL**
Mash Temp. before conditioning : ____ oC Feeder Rate/speed ____
Conditioner Probe Temperature : ____ oC Pelleting speed ____ Ton/h
Mash Temp. after conditioning : ____ oC
! Take mash sample before die : Yes / No (Close bottle and leave to cool)

! **COOLER** (Take sample **before** and **after** cooling)
Pellet Temp. before cooling (After "Die") ____ oC
Pellet Temp. after Cooling : ____ oC
Ambient Temperature : ____ oC Tumbler Durability Test: ____ Pil%

LABORATORY ANALYSIS

Sample Size: ____

		> 3.55mm	3.55-2.36mm	2.36-1.4 mm	> 1mm	1.44-0,6mm	Mash	
Maize Grinding Fractions:	Target	0	Max 10%	Max 25%	X	Min 60%	Max 5%	
	%				X			
						Avg. Geom. Diameter :		um

Sample Size: ____

		> 3.55mm	3.55-2.36mm	2.36-1.4 mm	> 1mm	1.44-0,6mm	Mash	
Pre-pelleting mash fraction:	Target	0	Max 10%	Max 25%	X	Min 60%	Max 5%	
	%				X			
						Avg. Geom. Diameter :		um

Moisture Control Conditioner Cooler
Mash moisture % before conditioner : ____ % (Min 10%) Pel. % before Cooler ____ (±14%)
Mash moisture % after conditioner : ____ % (±15%) Pel. % after Cooler ____ (Max ±13%)

Finished Product Control
Pellet % on Truck : ____ % (Min 90%)
Pellet % after orger : ____ % (Min 70%)
Kahl Hardness Test : (4-7 kg) : 1 | 2 | 3 | 4 kg
Final Moisture % of pellet : ____ %

After Delivery evaluation **QUALITY CONTROLLER**
Pellet % in feed hopper (Min 65%) : ____ %
Pellet % in feeder (Min 60%) : ____ %

EVALUATION APPROVED CONTROLLER ____ **DEVIATIONS?** Yes >> / No **CORRECTIVE ACTION NR.** ____

DOC. NR.: AFGRI-A-27-05 (REVISION 1)

Appendix VII: Distribution of complaints and non-conformance costs

(Summary of costs for the period 2001/01/01 – 31/12/01)

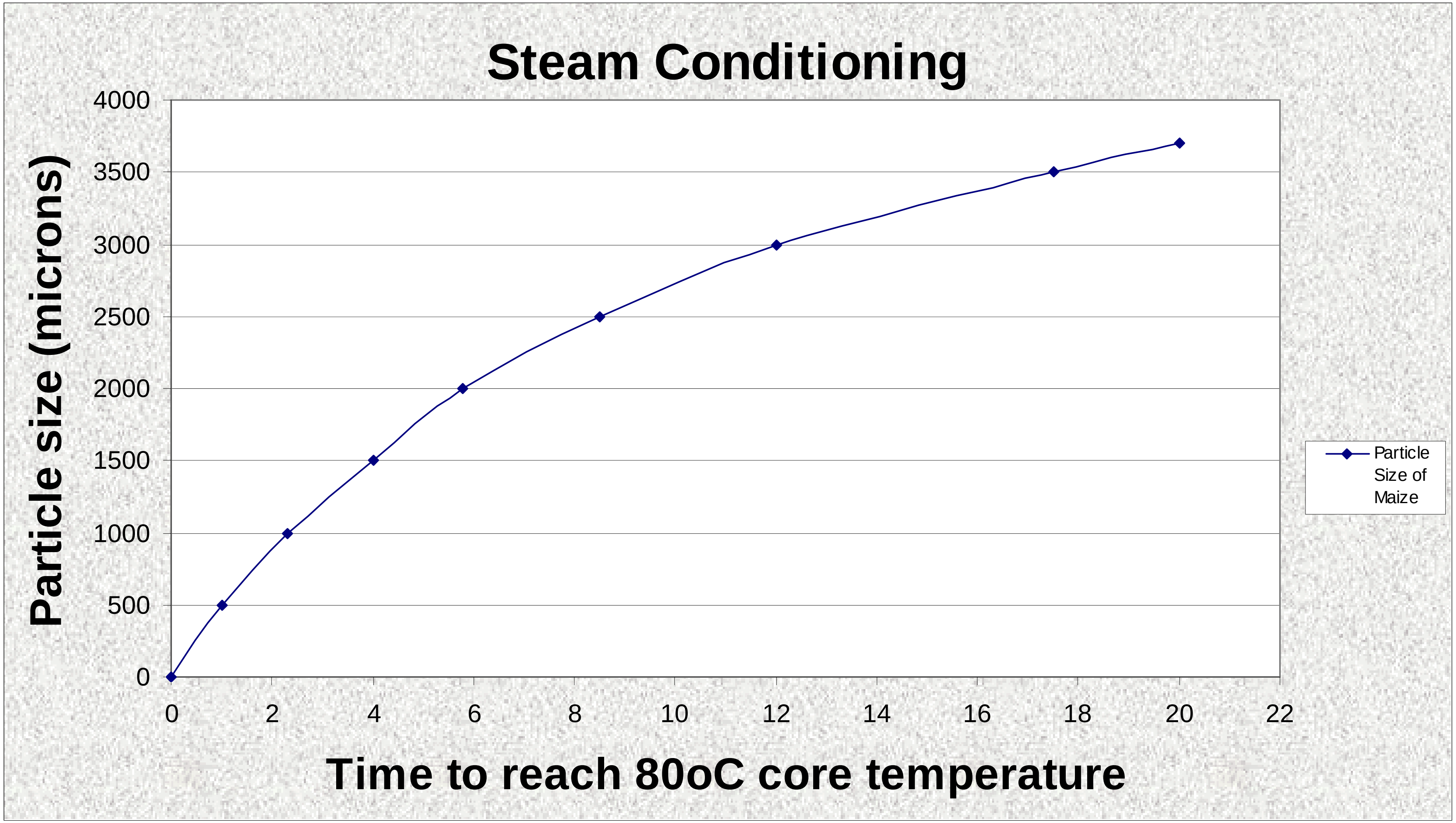
TOTAL NON CONFORMANCE COST : R 274,862.00

	CATHEGORIES OF COMPLAINTS IDENTIFIED										
	PELLET QUALITY	CRUMB QUALITY	TRANSPORT	R/M QUALITY RANSIDITY	PRODUCTION ERRORS	UNKNOWN	MOLASSES	FORMULA (Ca Claim)	PREMIX	ORDERS ADMIN	Total
NR	15	4	3	3	12	1	7	3	1	5	54
%	27.8	7.41	5.56	5.56	22.2	1.85	12.9	5.56	1.85	9.26	
SUM (Rand)	97544.00	11050.00	1180.00	8800.00	45252.00	2880.00	34594.00	66314.00	1373.00	5875.00	
	9500	780	680	3900	4000	2880	500	63914	1373	2011	
	4235	1750	300	4050	2430		3600	1920		1944	
	11550	2520	200	850	1000		985	480		410	
	11303	6000			2160		750			630	
	2070				460		2300			880	
	17960				28902		540				
	5338				330		25919				
	7140				350						
	400				300						
	1540				2740						
	3680				2040						
	9600				540						
	1708										
	1620										
	9900										

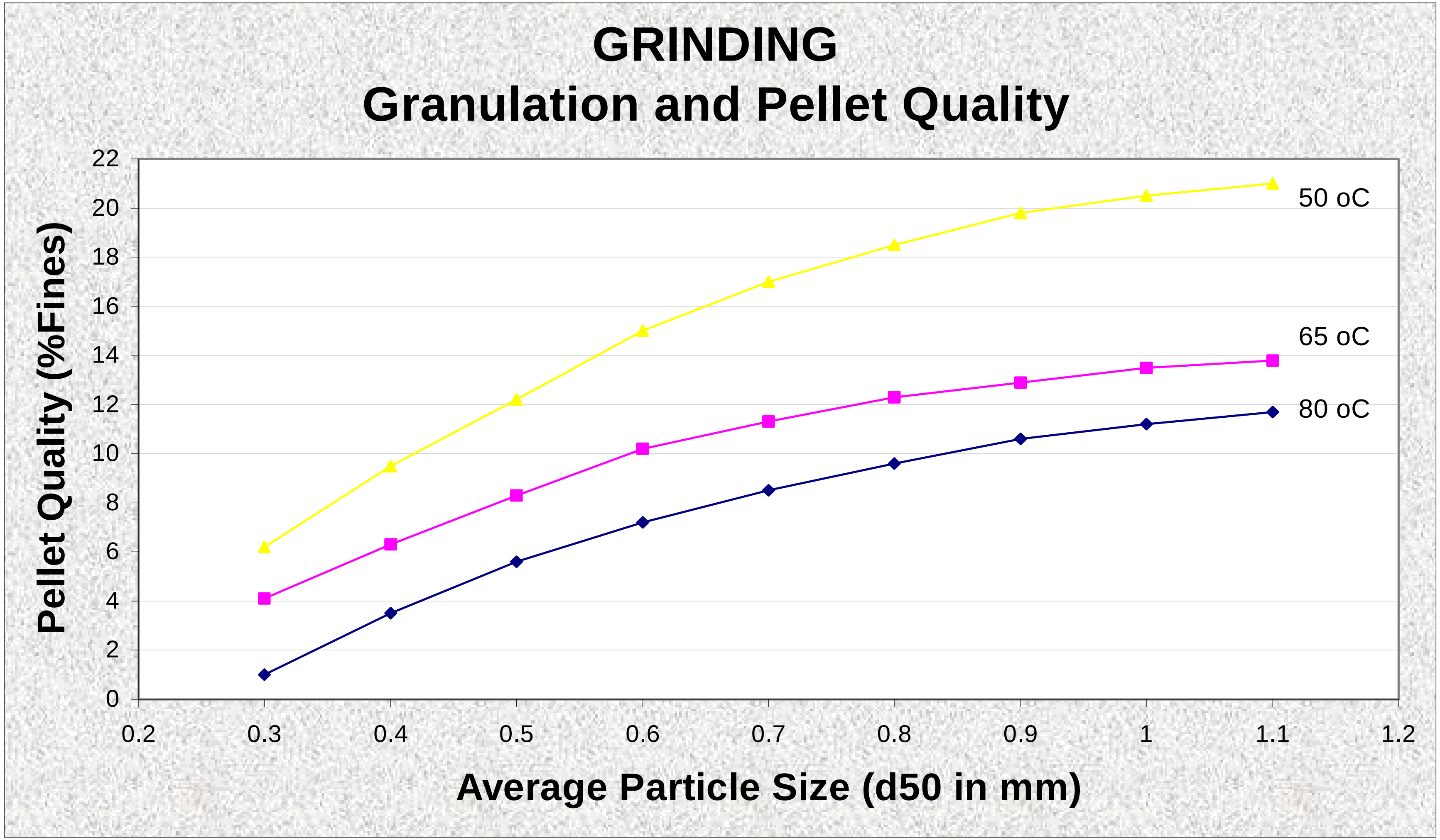
Appendix VIII: Typical example to illustrate the non-conformance cost calculation and hidden cost impact with failure to control one CCP in the pellet manufacturing process

Order Placed for product X :	36 Ton	
HACCP not controlled :	Pellet hardness not monitored	
Complaint from customer :	Poor intake and weight loss, product wastage	
Action taken :	Product collected and replaced with correct quality	
Calculation of Non-conformance Cost for production :	R	7,560.00
Loss of Production cost for 36 T	R	3,600.00
Loss of Transport cost to farm at 100km radius	R	1,980.00
Cost to remove and return pellets to plant	R	1,440.00
Rework cost of product	R	540.00
Cost of CUSTOMER CLAIM due to weight loss and loss of revenue :	R	64,100.75
Total nr of Chickens involved		48430
Weight loss		150 g / Chick
Meat price		7.5 R / kg
Total weight loss		7264.5 kg
Total cost due to weigt loss	R	54,483.75
Loss of bonus for customer	R	9,617.00
Total Cost of Non-conformance to HACCP :	**R**	**71,660.75**

Appendix IX: An example of a time / temperature graph to illustrate the increase in conditioning time to reach 80°C with the increase in particle size. (Adapted from Wetzel, 1983).



Appendix X: **An example of the interaction between conditioning, particle size and pellet quality. (Adapted from Wetzel, 1983).**



Appendix XI: Some examples of the equipment used in the feedmill; A-Roller mill, B-Conditioner and Pellet mill, C-Fatcoater, D-Steam temperature meters

A 	B 
C 	D