Breeding Meat Rabbits
Identifying and using disease resistant genes in Crusaders

by Dr Sandra J. Eady

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Foreword

The primary activity of the Crusader project was to continue the development of a leading edge genetic improvement program for meat rabbits, incorporating innovative and new traits that impact on farmer profitability, such as disease resistance, doe health and longevity. An important component of the project was to establish Crusader as an independent industry-based breeding program, supplying rabbit stock to farmers across Australia. Crusader is an important investment for the industry as it applies modern genetic evaluation technologies to improve traits of major economic importance to rabbit farmers, so that the industry has access to a stable and high quality source of breeding stock.

Overall progress in the breeding program, as indicated by the average index value of rabbits, has been substantial with a combination of genetic and management improvements lifting gross margins from an estimated $174 to $242 per doe per annum. The average index value of animals has improved to +$55 per doe per annum, indicating that a significant proportion of the improvement has been from genetic sources. Scientific advances were made in selection for disease traits in grower rabbits, estimating genetic parameters to allow selection for functional traits related to healthy and productive animals, and in identifying the relative balance to place on these traits compared to production traits such as growth rate and number of rabbits weaned per litter. The breeding program was fully commercialised and at the end of the project was being managed independently by Snowy Mountain Gourmet Rabbit Company.

The project sets the industry with a genetically superior source of seed stock that will feed into current production systems, based on natural mating, and new systems where there is an increasing use of advanced technologies such as artificial insemination. Crusader provides an on-going resource that can be used to test and incorporate new selection traits for improved production.

This collaborative project was funded by CSIRO Livestock Industries and RIRDC.

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The project has received on-going support from members of the rabbit industry, in particular Growtec, and the industry association, Farmed Rabbit Industries Australia. The author thanks John Smith, Sue Belson and Jim Flack at CSIRO and Michael and Kathleen Bowerman at SMGRC for technical assistance with experiments. The farmers offering box designs for evaluation are also thanked.

Abbreviations

ADG – average daily liveweight gain of grower rabbits
AI – artificial insemination
AQIS – Australian Quarantine Inspection Service
BLUP – Best Linear Unbiased Prediction
EBV – Estimated Breeding Value
FRIA – Farmed Rabbit Industries of Australia Pty Ltd
h² - heritability
NW – number of kittens weaned per litter
QAFR – Quality Farmed Rabbits Australia
REV – relative economic value
SD – standard deviation
SMGRC – Snowy Mountains Gourmet Rabbit Company
SPF – Specific Pathogen Free
Contents

Foreword ........................................................................................................................................ iii
Acknowledgments................................................................................................................................. iv
Abbreviations...................................................................................................................................... iv
Implications for relevant stakeholders ............................................................................................... x
Recommendations ................................................................................................................................. xi
1. Introduction ..................................................................................................................................... 1
   1.1 Industry background ..................................................................................................................... 1
   1.2 Project outcomes and deliverables ................................................................................................. 2
2. Science advances in the Crusader breeding program ................................................................. 3
   2.1 Heritability of resistance to bacterial infection in meat rabbits ..................................................... 3
   2.1.1. Introduction to breeding for disease resistance ..................................................................... 3
   2.1.2 How the experiment was designed and analysed ...................................................................... 4
   2.1.3 Results of the study ................................................................................................................... 6
   2.1.4 Discussion of results and application in industry ....................................................................... 6
   2.1.5 Conclusions on breeding for resistance to bacterial infection in growers ............................... 9
   2.2 Functional traits – importance and how to measure them ........................................................... 12
   2.2.1 Introduction to functional traits in breeding programs ............................................................ 12
   2.2.2 Finding practical measures and quantifying them .................................................................... 12
   2.2.3 How important are functional traits ......................................................................................... 14
   2.2.4 Conclusions ............................................................................................................................. 14
3. Resources for the industry – database and rabbits .................................................................... 19
   3.1 Transfer of rabbits ....................................................................................................................... 16
   3.2 Training in database operation and estimation of breeding values .............................................. 17
   3.3 Training in allocation of bucks to does ....................................................................................... 17
   3.4 Conclusion on viability of industry-based breeding program ..................................................... 17
4. Meat quality .................................................................................................................................... 40
   4.1 Crusader Enterprise Model and production parameters ............................................................. 19
   4.2 Progress to date in the breeding program ..................................................................................... 19
   4.3 Appropriate adoption of European technology ......................................................................... 39
   4.4 National evaluation for meat rabbits and links with Growtec .................................................... 26
   4.5 Rabbit sales to industry ................................................................................................................ 27
5. Management recommendations ...................................................................................................... 29
   5.1 Evaluation of equipment for breeding does housed under Australian meat rabbit farming conditions ................................................................................................................................................................................................. 29
   5.2 Vulva colour as an indicator of doe receptivity at mating ............................................................ 38
   5.3 New traits and directions for genetic improvement ....................................................................... 39
6. Project summary .............................................................................................................................. 41
7. References for background reading .............................................................................................. 42
Executive Summary

What the report is about
The primary activity of the Crusader project was to continue the development of a leading edge genetic improvement program for meat rabbits, incorporating innovative and new traits that impact on farmer profitability, such as disease resistance, doe health and longevity. An important component of the project was to establish Crusader as an independent industry-based breeding program, supplying rabbit stock to farmers across Australia. Crusader is an important investment for the industry as it applies modern genetic evaluation technologies to improve traits of major economic importance to rabbit farmers, so that the industry has access to a stable and high quality source of breeding stock.

Who is the report targeted at?
The report provides information to a range of stakeholders. The progress in characterising disease resistance is of importance to industry breeding programs and to international research groups working on rabbit genetics. The applied results from the evaluation of equipment for rabbits have direct relevance to commercial farmers. The report on genetic progress with Crusader stock is valuable information for breeders looking for superior rabbits to improve their profitability. The scientific outcomes will guide future R&D investment and the recommendations on new technologies will feed into policy development for the industry in areas such as AQIS importation protocols for rabbits.

Background
The rabbit industry is at the stage of consolidating with the size of farms beginning to increase (>400 breeding does) as individual business become solely focused on rabbit production, including processing, product development and wholesaling. On-farm processing capacity has been a key component of successful enterprises as this removes the expense of transport and provides the opportunity to add to profit margins by processing and wholesaling meat.

Approximately 300 tonne rabbit meat was produced in 2005/06 with a farm gate value of $2.2 – 2.4m. With an average production of 25-30 growers per doe per year, this puts the breeding population at approximately 6,800-8,200 does. The industry appears to be doubling every 3-4 years. Current estimate for gross margin per doe is approximately $174/annum, which is net of variable costs of production excluding labour.

The rabbit industry has tapped into a niche market for high value meat with the majority of rabbit being sold though restaurants and specialty butchers shops for between $15-$20/kg retail. It has a relatively low fat level and is considered to be a healthy white meat. An important challenge for the industry is to maintain the “clean, green and healthy” image of rabbit meat. The application in Australia of some disease control strategies employed in Europe, such as prophylactic feeding of antibiotics, needs to be treated with caution to protect the market position of rabbit meat. The continued emphasis on genetic improvement of disease resistance in the Crusader breeding program is primarily to target this issue.

Aims and objectives
The project was undertaken from June 2004 to July 2007 and its goals were to improve the genetic merit of Crusader rabbits, commercialise the breeding program and provide information on management for increased rabbit production. The specific outcomes and deliverables set for the project are listed below:

- Leading edge genetic improvement program for meat rabbits incorporating innovative and new traits that impact on farmer profitability, such as disease resistance, doe health and longevity.
- Establishment of the 120 doe Crusader herd at Snowy Mountains Gourmet Rabbit Company (SMGRC) facility at Bredbo, NSW, so that it is running independently.
• Improved Crusader breeding stock through the conduct of a selection program based on estimation of estimated breeding values (EBVs), index ranking of animals and appropriate mating allocation.
• Through the regular sale of breeding stock, Crusader rabbits being used in industry and contributing to improvements in farmers’ profits
• Recommendations for industry on improved management options for rabbit farmers, in the first instance recommendations on kit boxes for improved kitten survival
• The establishment of a national meat rabbit genetic evaluation program, with Crusader acting as a hub to provide genetic linkage between breeding herds.

**Methods used and results/key findings**

**Genetic progress for Crusader selection program**

Overall progress in the breeding program, as indicated by the average index value of rabbits, has been substantial with a combination of genetic and management improvements lifting gross margins from an estimated $174 to $242 per doe per annum. The average index value of animals has improved to +$55 per doe per annum, indicating that a significant proportion of the improvement has been from genetic sources.

There has been good progress in the number of kittens weaned given the relatively low heritability for this trait. Given mean starting values of 4 kittens weaned per litter, genetic improvement has been approximately 12.5% for kittens weaned over the 6 years of selection, or approximately 0.4 of kitten per year. Average daily liveweight gain for growers (ADG) has shown a consistent upward trend as expected for a trait that is moderately to highly heritable. Given mean starting value 34 g/head/day for growth rate, genetic improvement has been approximately 29% for growth rate since the breeding program commenced in July 2001. Resistance to bacterial infection in growers is the most recent trait to be introduced to the breeding objective, being included in the selection index in mid-2003. Given a mean starting value for average infection score of 0.50, genetic improvement has been approximately 9% for disease resistance since 2001.

Genetic improvement in litter size and growth rate has been consistent since selection commenced in 2001 and was not interrupted when the rabbits were relocated to SMGRC in 2004. However, progress in improving disease resistance was only evident for the first year after the rabbits were transferred to Bredbo (mid-2004 to mid-2005). This probably reflects a lack of consistency in scoring the rabbits for signs of disease, a subjective assessment that is less well defined than liveweight or number of kittens.

**Transfer to industry and independent operation of Crusader**

The transfer of the Crusader breeding program to industry has been successful and may serve as a useful model for other new animal industries. The critical success factors were:

- identification of a commercial operator that had the capacity to take on the task
- the development of database systems and interface with BLUP software, in a MS Access environment that allowed ease of use by relatively unskilled operators
- the detailed documentation of all activities in Standard Operating Procedures
- flexibility to vary the intensity of data collection to fit a more commercial schedule of production
- a period of support and transition
- access to on-going support as required for occasional auditing and adjustment of procedures

The transfer has also highlighted areas of difficulty that needed to be addressed to ensure efficient operation and data integrity:

- presence of physical card records in the shed to allow shed operators without access to the database the ability to monitor doe performance and flag when anomalies were occurring. This was particularly evident when procedures for generating accurate mating lists failed and does were not being regularly mated.
- timely data collection and entry for a weekly management system that requires data to be up to date to efficiently generate the next weeks’s worksheets
• training of new staff in data collection so that consistency of approach was ensured. This was particularly evident with subjectively assessed traits such as maternal behaviour, body condition and disease incidence scoring.

• timely adjustment of data recording levels where time constraints were impinging on quality and frequency of data collection.

The total time taken to train staff at SMGRC so that the program could be run independently was approximately 12 months. Proficiency was achieved in data collection and entry routines within 2 months, estimation of EBVs and selection of breeding stock within 4 months and buck and doe allocations within 12 months. The program now operates with periodic auditing of mating allocations and genetic trends.

Overall, Crusader has demonstrated that a sophisticated and modern breeding program, estimating breeding values every 3 weeks for index selection of breeding stock every 6 weeks, can be run relatively independently in industry.

Scientific advances for Crusader
Scientific advances were made in selection for disease traits in grower rabbits, estimating genetic parameters to allow selection for functional traits related to healthy and productive animals, and in identifying the relative balance to place on these traits compared to production traits such as growth rate and number of rabbits weaned per litter.

Resistance to bacterial infection
The studies of resistance to bacterial infection in grower rabbits established and refined the parameters required to effectively incorporate this trait into the selection program. Incidence of visual signs of bacterial infection and mortality, from causes related to bacterial infection, was recorded on a weekly basis in growing meat rabbits from 5 to 10 weeks of age. Heritability of weekly incidence of disease was highest in weeks 9 and 10 (0.05±0.02 and 0.06±0.02, respectively with linear model, and 0.10±0.06 and 0.12±0.05, respectively with a threshold model). Common litter effects accounted for 5-20% of the variance of disease incidence, while maternal genetic variance was small (0-3%). Individuals from small litters at weaning had higher disease incidence, and disease incidence reduced as litter parity of the doe increased (P<0.05), when the disease trait was measured at week 9 and 10, but not for earlier weeks.

Genetic correlations between disease incidence and mortality were imprecise and not different from zero. Phenotypic correlations were low to moderate, and positive. Although the mechanism at this stage is unknown, these findings suggest that there are common/shared immunological responses to bacterial challenge that are under genetic control. This study demonstrates that observed signs of bacterial infection in rabbits can be used as an indicator trait for resistance to bacterial infection, and the heritability of the trait is high enough to warrant its inclusion in the breeding program. From one week to the next, rabbits exhibiting disease symptoms were more likely (10 to 50 times depending on week of measurement) to die than those that were healthy. The relative economic value of resistance to bacterial infection was based on the relationship between disease incidence and survival, as well as the direct costs of effective disease control and treatment.

Preliminary estimates of the heritability of resistance to bacterial infection in breeding does and the correlation between the train in the grower rabbit and breeding doe were inconclusive due to too few records for breeding does at this point in time. The heritability estimate for this trait was 0.014±0.10, indicating the data (n=459) is still too sparse for reliable parameter estimation. Once additional records are available, the data require a more rigorous analysis with a repeated measures model or survival analysis approach that accounts for censored records.

For female rabbits, the phenotypic correlation was 0.16±0.05, between signs of infection at growing age (8-9 weeks) and subsequent signs of infection as a breeding doe. Presented as class means, does who were not sick at 8 or 9 weeks of age had an average incidence of sickness of 40% in the 3rd week post-partum. On average does who were sick once at either 8 or 9 weeks of age had a later incidence
of sickness of 59%, and for does who were sick at both 8 and 9 weeks of age the incidence of sickness in the 3rd week post-partum was 67%.

These results are encouraging and highlight the need for more data to be collected so that the overall merit of selection for disease can be assessed in both grower and breeding rabbits.

**Adding functional traits to the breeding objective**

The relative importance of functional traits in a breeding objective can be determined by assessing the financial contribution of one phenotypic standard deviation change in the trait while keeping all other traits constant. For functional traits such as doe longevity (length of productive life), there can be difficulties separating the trait from other traits such as disease incidence or reproductive performance and the risk of double counting needs to be understood.

The relative economic value (REV) was estimated for selection traits for Australian meat rabbits using a gross margin model based on average industry parameters (Eady 2004b) where average returns were $174 per doe per annum. Traits that determine the rate of kitten production have the highest REV, in the order $102-$116 per doe per annum in absolute value, while growth traits including feed conversion efficiency are next in relative importance. Functional traits contribute to profit but are less important, with resistance to bacterial infection in grower rabbits of similar absolute REV to liveweight gain, and doe longevity the lowest at $7.31 per doe per annum.

The financial returns from higher kitten turn-off, reduced feeding costs to meet a target weight and lower mortality of growers are clear. Improving doe longevity reduces the overhead cost of the doe population. Fewer does are needed as replacements, meaning that more are sold for meat income, and maintenance costs from meat turn-off age to first mating are reduced. Given the fecundity of rabbits these are not major costs in a self-replacing breeding unit. In other systems, where replacement does from specialist maternal lines are purchased, the REV for longevity may be higher.

The selection index for the Crusader breeding program contains the traits number weaned/litter, average daily gain and resistance to bacterial infection in grower rabbits. As there are limited resources for introducing new traits, it is likely to be more profitable to focus on improving feed conversion efficiency rather than longevity, in the first instance. The relative contribution to the profit function can be approximated by the product of the heritability and REV, indicating an 8-fold greater contribution from improving feed conversion efficiency compared to doe longevity.

Although there is a clear role for functional traits in a meat rabbit breeding objective, further work is required to complete the picture. Studies are required to determine the genetic relationship between functional traits such as disease resistance, longevity and production traits. With regard to selection for improved longevity, the detrimental impact on generation interval needs to be considered. There also needs to be some method of accounting for the risk that current control measures for disease, such as the prophylactic use of antibiotics in grower feed, may be banned or restricted.

**Equipment for meat rabbits**

Two ancillary experiments yielded practical recommendations on design of cage equipment (mats and nest boxes) that can potentially improve the welfare and productivity of breeding does. The results show that, in the environment experienced by the experimental rabbits, sore hocks (*pododermatitis*) can be reduced in breeding does from an incidence of 4% down to less than 1%, by the provision of suitable pressure mats. The difference between the highest and lowest performing nest boxes, in terms of number of kittens weaned, translates into a difference in enterprise gross margins (Eady 2004) of $58.60 per doe per annum, or an increase of 40% in profit from the use of the best performing nest box compared to the worst. Farmers can use the results as a guide to choosing or constructing nest box equipment, and should be encouraged to objectively compare different designs under their own environmental conditions. Information on cage equipment, productivity levels and gross margins for the industry has been made available for farmers to benchmark their performance.
Industry engagement and transfer of technology
Crusader has contributed to industry events and forums over the duration of the project including field days and meetings held by Farmed Rabbit of Australia (FRIA), a joint Crusader/SMGRC field day and trade display, and various regional activities. Links for industry input into the project have been maintained through the Crusader Advisory Group. A steady stream of enquiries for information has continued through the project from prospective farmers (Australian and overseas) and industry advisors. The Crusader website (www.csiro.au/crusader) was upgraded and moved to the new CSIRO web architecture in March 2006 and information on Crusader was added to the SMGRC website (www.smgrc.com.au).

As an investigation into the provision of a commercial service for genetic evaluation proved too expensive for the industry, genetic links have been built with Growtec (the other major breeding program for meat rabbits in Australia) to allow an across-program evaluation. Constraints have been the logistics of shipping animals but more importantly concern about quarantine, with rabbit operations in Victoria reporting significant occurrence of disease (scouring) with an, as yet, undefined cause. Once progeny have been produced from the more recently exchanged bucks, a joint analysis will be undertaken between the two breeding groups. In the mean time, Crusader bucks have contributed to the Growtec program and vice versa, assisting in the dissemination of superior genes to the industry overall.

The concept of licensing multiplier breeders was investigated but there was not the commercial imperative or business case for investment by SMGRC during the life of the project. This may be an attractive option for breeders in the future as they would yield the benefit (with a lag period) of genetic improvement and increased potential for sale of breeding stock, without the large cost and management expertise to run a full program on-farm. There remains the need to have improved rabbits more geographically dispersed so that breeding stock can be readily accessed.

Sales of Crusader stock to industry have continued over the three years of the project. There is a need for an on-going promotional program to maintain higher levels of breeding stock sales. The response to the FRIA field day in South Australia demonstrated that demand for rabbits is present if logistical constraints can be managed and information on the merit of the rabbits widely distributed. It will be important for the Crusader breeding program to develop the capacity for semen collection, storage and shipment as AI is adopted more widely in industry.

Implications for relevant stakeholders
New traits and directions for genetic improvement
Crusader breeding program has progressed well and it is now prudent to explore new traits that can further improve profit. Traits that have been considered include doe longevity, doe health and litter size, and feed conversion efficiency of grower rabbits. The selection index for the Crusader breeding program already contains the traits number weaned per litter, average daily liveweight gain and resistance to bacterial infection in grower rabbits. As there are limited resources for introducing new traits, it is likely to be more profitable to focus on improving feed conversion efficiency rather than doe longevity, in the first instance. The relative contribution to the profit function can be approximated by the product of the heritability and REV, indicating an 8-fold greater contribution from improving feed conversion efficiency compared to doe longevity.

However, improvement of litter size at weaning still offers the greatest potential for improved financial gain. Progress is steady and encouraging in the Crusader program but could be accelerated considerably by the introduction of European stock. The gap in performance between Crusader stock and rabbit strains in Europe is most evident for prolificacy, with an average of 7 kittens born alive per litter and 5 reared, compared to 9.9 and 8.4 kittens per litter, respectively, for commercial meat rabbits in France.

The difficulty in acquiring rabbits or semen from France is in meeting the quarantine requirements for entry into Australia. The recent establishment of a Specific Pathogen Free (SPF) population of
one of the maternal grand-parent lines in France is an encouraging development, as this potential source of rabbits would meet the in-country quarantine required before the rabbits leave Europe, an expensive component of any importation. It may be worthwhile exploring again the possible importation of rabbits and/or semen with AQIS and industry stakeholders.

**Introduction of artificial insemination (AI)**

A number of industry members have invested in training for their staff and have brought people with expertise from Europe to assist with setting up procedures and laboratories to allow them to undertake AI on-farm. Technical assistance is also available from Mark White, Allied Biotechnology, within Australia.

Along with the introduction of AI, will come the need to upgrade cage equipment, such as nest boxes, as an important part of bio-stimulation to achieve good conception rates is to restrict doe access to kittens for the 10 day period between kindling and AI.

Although genetic gain is satisfactory for the Crusader breeding program, the introduction of AI would allow selection intensity to improve and accelerate rates of gain. It will also be important for the Crusader breeding program to develop the capacity for semen collection, storage and shipment, as AI is adopted more widely in industry.

**Appropriate adoption of European technology**

Rabbit producers have travelled to Europe to observe advanced husbandry systems being employed there. Some technologies, such as AI, offer significant benefits without posing a risk to the industry. However, other practices, while improving rabbit productivity and health, have the potential to be detrimental to the industry's reputation and image. One such practice is the prophylactic feeding of antibiotics to grower rabbits. Genetic resistance to bacterial infection was introduced to the Crusader breeding program with the purpose of assisting the industry to avoid the need to feed antibiotics. Progress needs to be tested to see if antibiotics can be omitted from grower rations for Crusader stock.

**Meat quality**

Initially the rabbit industry's prime concern was to produce the rabbit numbers required by the market. As the industry grows it needs to ensure eating quality is consistent. At some stage the industry should consider investment in research on critical factors for meat quality to help build continued growth in overall demand as well as ensuring a consistent and regular market.

**Recommendations**

The project sets the industry up with a genetically superior source of seed stock that will feed into current production systems, based on natural mating, and new systems where there is an increasing use of advanced technologies such as artificial insemination. Crusader provides an on-going resource that can be used to test and incorporate new selection traits for improved production. The highest priority will be feed efficiency and number of kittens weaned. It would be advantageous to investigate the feasibility of importation of highly prolificacy lines of rabbits from Europe for improving the latter trait.

Scientific advances were made in selection for disease traits in grower rabbits, estimating genetic parameters to allow selection for functional traits related to healthy and productive animals, and in identifying the relative balance to place on these traits compared to production traits such as growth rate and number of rabbits weaned per litter. It is recommended that this type of data collection continue to allow parameters for breeding does to be estimated with increased confidence.

The transfer of the Crusader breeding program to industry has been successful and may serve as a useful model for other new animal industries. Overall, Crusader has demonstrated that a sophisticated and modern breeding program, estimating breeding values every 3 weeks for index selection of breeding stock every 6 weeks, can be run relatively independently in industry.
1. Introduction

1.1 Industry background
Rabbit farming is a relatively young industry in Australia and until the 1990s was banned in most states due to concerns about rabbits escaping and interbreeding with wild rabbits. Farming has now been legalised in the majority of states in Australia, with the exception of Queensland. The industry is small but a viable option for those enterprises have build production units large enough to achieve economies of scale and who have vertically integrated production with processing on-farm and wholesaling and/or retailing of rabbit meat. For smaller producers profit is marginal due to lack of economies of scale, high transport costs to slaughter and lack of participation in down stream profits. Over the last 5 years, the industry has been relatively stable but has demonstrated some periods of mismatch in supply and demand. This has caused problems for some small farmers who have found it difficult to locate processors to take their rabbits over the summer months and in the winter, when demand is greater, processors have not been able to keep up regular supply to their meat wholesalers, retailers and restaurants.

However, the industry has avoided the boom and bust cycle often seen in new animal industries. This has been largely due to an established market for rabbit meat, underpinned by wild rabbit harvesting in the past, the relatively low investment required for entry into the industry and the availability of good quality breeding stock at commercial prices. The industry has a steady level of production by a number of larger enterprises (up to 500 does), with turnover of participants largely amongst those businesses farming less than 100 does.

The rabbit industry is at the stage of consolidating with the size of farms beginning to increase (>400 breeding does) as individual business become solely focused on rabbit production, including processing, product development and wholesaling. On-farm processing capacity has been a key component of successful enterprises as this removes the expense of transport and provides the opportunity to add to profit margins by processing and wholesaling meat.

An industry association has been formed (Farmed Rabbit Industries Australia, FRIA, www.fria.com.au) and is active in recruiting new members and holding industry events such as annual field day. Recent times have seen new entrants to the industry from backgrounds such as poultry farming, and these businesses are actively seeking information and support.

Approximately 300 tonne rabbit meat was produced in 2005/06 with a farm gate value of $2.2 – 2.4m. The industry appears to be doubling every 3-4 years. Current estimate for gross margin per doe is approximately $174/annum.

Snowy Mountains Gourmet Rabbit Company (SMGRC) at Bredbo in southern NSW is a good example of how new enterprises are adding vitality to small regional centres. Bredbo is a town of less than 400 people and SMGRC directly employs 7 people in their rabbit farming and processing operations. There are flow-on business effects with feed mills, veterinary suppliers, equipment manufacturers, meat wholesalers and retailers. The industry also offers flexible employment which assists women with job participation.

The rabbit industry has tapped into a niche market for high value meat with the majority of rabbit being sold though restaurants and specialty butchers shops for between $15-$20/kg retail. It has a relatively low fat level and is considered to be a healthy white meat. An important challenge for the industry is to maintain the “clean, green and healthy” image of rabbit meat. The application in Australia of some disease control strategies employed in Europe, such as prophylactic feeding of antibiotics, needs to be treated with caution to protect the market position of rabbit meat. The continued emphasis on genetic improvement of disease resistance in the Crusader breeding program is primarily to target this issue. An industry, based on rabbits bred to stay healthy, will also improve animal welfare, another public concern associated with intensive farming of livestock.
1.2 Project outcomes and deliverables
The project was undertaken from June 2004 to July 2007 and its goals were to improve the genetic merit of Crusader rabbits, commercialise the breeding program and provide information on management for increased rabbit production. The specific outcomes and deliverables set for the project are listed below:

- Leading edge genetic improvement program for meat rabbits incorporating innovative and new traits that impact on farmer profitability, such as disease resistance, doe health and longevity
- Establishment of the 120 doe Crusader herd at Snowy Mountains Gourmet Rabbit Company (SMGRC) facility at Bredbo, NSW, so that it is running on a weekly management cycle of mating, kindling, weaning and data collection consistent with protocols provided by CSIRO
- Database of information, updated weekly as per protocols, to support research and development for genetic improvement in the meat rabbit industry
- Improved Crusader breeding stock through the conduct of a selection program based on estimation of estimated breeding values (EBVs), index ranking of animals and appropriate mate allocation, as per protocols provided by CSIRO
- Through the regular sale of breeding stock, Crusader rabbits being used in industry and contributing to improvements in farmers’ profits
- High industry awareness of the availability and benefits of Crusader stock by promotion at field days and in the media
- Recommendations for industry on improved management options for rabbit farmers, in the first instance recommendations on kit boxes for improved kitten survival
- The establishment of a national meat rabbit genetic evaluation program, with Crusader acting as a hub to provide genetic linkage between breeding herds.

The following sections cover the advances made in each of the above during the life of this project.
2. Science advances in the Crusader breeding program

The major purpose of the project is to deliver a leading edge genetic improvement program for meat rabbits incorporating innovative and new traits that impact on farmer profitability, such as disease resistance, doe health and longevity. Scientific advances have been made in the area of disease resistance in grower rabbits and breeding does and in understating the context of improvement of function traits in balance with production traits.

2.1 Heritability of resistance to bacterial infection in meat rabbits

The primary disease focus has been improving the resistance of grower rabbits to bacterial infection, as this is the predominant causes of losses in this class of rabbits. Progress has been made in defining traits for selection, estimating genetic parameters and including disease resistance in the breeding objective for Crusader. The results of this work have been published (Eady et al. 2007) and the following sections summarise this paper and give the pertinent references for those who would like more information.

2.1.1. Introduction to breeding for disease resistance

In the intensive meat rabbit industry, control of bacterial disease (largely caused by Pasteurella multocida and Staphylococcus aureus) is a major production challenge (McNitt et al. 1996, Rideaud et al. 1992). In Europe, where rabbit farming is well established, approaches to disease control have relied on environmental hygiene (Lebas et al. 1997), requiring large capital investment in housing and routine inclusion of antibiotics in rabbit feed (Goñi et al. 2004). Even with these controls, Pasteurella multocida infection in meat rabbits still occurs, albeit at low incidence and severity (Rosell 2003).

Management systems with a reliance on the use of antibiotics are under increasing scrutiny due to the risk of microbial antibiotic resistance spreading to human pathogens (Anadon and Martinez-Larranaga 1999, Gnanou and Sanders 2000, Martel et al. 2000). In the general community there is concern about this issue, which is being reflected in a preference for food from livestock that has been produced without the widespread use of antibiotics.

In countries where rabbit farming is less well established, such as Australia, capital investment in the industry has been low compared to industrial rabbit farming in Europe, and sheds have simple ventilation systems and little temperature control (Eady 2003). Scale of production is small, such that batch production of rabbits, using artificial insemination and regular destocking of sheds for cleaning, has yet to be widely adopted.

Improving the genetic resistance of rabbits to bacterial infection has advantages; in Europe, improving rabbit health and survival by breeding for disease resistance is a more sustainable approach than systems that rely on prophylactic use of antibiotics, and in Australia, more resistant breeding stock will be better adapted to the less intensive systems of housing.

To establish a successful industry breeding program to improve disease resistance there are several pre-requisites – there needs to be a well defined and measurable trait that will indicate disease resistance, the indicator trait must have a genetic component of variation (that is it must be heritable), and be genetically correlated with the disease trait of economic importance in the breeding objective. For adoption by industry, it must be practical to measure the trait in a commercial production system.

With disease resistance, identification of a suitable indicator trait is often the most difficult task. Disease expression is often seasonal, difficult to describe quantitatively and incidence is highly variable. These factors, combined with need for feasibility of implementation in an industry breeding program, pose a greater challenge than improving many production traits (such as liveweight gain or number of kits weaned). However, there are successful breeding programs for some major livestock diseases. Selection for mastitis resistance in dairy livestock is one of these, where direct measurement of mastitis is used in Scandinavian cow herds (Heringstad et al. 2001) and indicator traits such as somatic cell count (Shook and Schultz 1994) and type traits (Rogers 2002) are used where there is no direct recording of mastitis. Selection for resistance to gastro-intestinal parasites in sheep, based on
worm egg count in the faeces, is a component of breeding programs in high parasite challenge environments in Australia and New Zealand (Eady et al. 1997).

For a meat rabbit breeding program to improve resistance to bacterial infection, we need to identify a heritable trait that is related to disease incidence and rabbit survival. Genetic variation for bacterial infection has been reported for a range of livestock species (Raadsma 1995; Heringstad et al. 2000) including footrot and fleece rot in sheep, and as mentioned earlier, mastitis in dairy species. There are reports of genetic variation for more general disease expression in pigs (Henryon et al. 2001), Garreau et al. (2006) and Rochambeau et al. (2006) have reported genetic variation for different types of enteropathy in the rabbit. It is anticipated there should be some component of bacterial infection in rabbits that is under genetic control. There is one published estimate of genetic resistance to Pasteurella; Baselga et al. (1988) estimated the heritability of lung damage caused by infection, to be 0.12 to 0.28. This involved post-mortem examination of lung tissue, so this particular trait is not a practical option to measure for a breeding program.

The goal of this study was to determine if the incidence of observable signs of bacterial infection in rabbits has a genetic component, and if so, whether a practical system of scoring rabbits for disease resistance could be devised. It was undertaken with an experimental population set up to establish a national breeding program for meat rabbits in Australia (Eady 2003).

2.1.2 How the experiment was designed and analysed

2.1.2.1 Rabbits and their background

The meat rabbit facility at the FD McMaster Laboratory, Armidale, was established by CSIRO in 1999. After an initial evaluation of the three main meat breeds (Prayaga and Eady 2002, Prayaga and Eady 2003) in Australia (New Zealand White, Californian and Flemish Giant) a selection program began in July 2001. A composite strain of rabbits was established and selection of breeding stock was based on an index of economic return combining estimated breeding values for litter size at weaning and average daily live weight gain from weeks 5 to 10 of age.

This study focused on estimating parameters for disease resistance in grower rabbits from weaning at 5 weeks of age to turn-off. At weaning, the young rabbits were randomly distributed to growing pens, ignoring litter to allow separation of weaning pen and litter effects. Each pen contained 10-12 rabbits which defined the weaning group. During the growing phase, rabbits were weighed and scored for the incidence of disease symptoms each week. The last measurement was made at 10 weeks of age and rabbits slaughtered at 12-13 weeks of age. During the growing period, rabbits had ad libitum access to a commercial pelleted diet (16% protein, 11.5 MJ/kg) and water. Management practices and data collection protocols were approved by the CSIRO McMaster Laboratory Animal Ethics Committee, on an annual basis. It is important to note that the management did not include prophylactic use of antibiotics in the feed to reduce infection levels.

Data were collected from grower rabbits born between 7 March 2000 and 31 March 2004. Rabbits that had incomplete records for the 6 observation times, that is, reappeared after missing a week’s observation, were excluded. The data contained records for 7458 rabbits, representing 366 sires giving an average of 20 progeny per sire. There were 1308 litters giving an average of 3.6 litters per sire. The rabbits were the offspring of 503 dams giving an average of 14.8 offspring per dam.

2.1.2.2 Definition of disease and mortality traits

Rabbits were scored for visible signs (presence or absence) of three kinds of disease – bacterial infection, digestive system upset and other. This paper reports results for bacterial infection; it was the most common ailment observed and accounted for 52% of deaths. Digestive tract disturbance accounted for 30% of deaths leaving 18% to other causes. At the commencement of the breeding program, and at 12 monthly intervals, some dead and sick rabbits were sent to an animal health diagnostic laboratory to confirm the species of bacteria present. Where the signs were abscesses the predominant bacteria was Staphylococcus aureus. Where the signs were nasal discharge (snuffles) the predominant bacteria was Pasteurella multocida. Rabbits sent for post-mortem often showed both signs. The disease signs are described in Table 2.1.1.
Table 2.1.1 Description of disease signs and proportion of deaths, natural or from euthanasia, attributed to bacterial infection

<table>
<thead>
<tr>
<th>Disease</th>
<th>% of total deaths</th>
<th>Signs observed in live rabbits and post-mortem findings for dead rabbits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection</td>
<td>52%</td>
<td>Live rabbits: abscesses usually located in region of lymph nodes; nasal discharge; skin infection; eye \</td>
</tr>
<tr>
<td>i.e. predominantly Pasteurella spp. and Staphylococcus spp.</td>
<td>- comprising 28% dead and 24% euthanased.</td>
<td>infected injuries; infection around ear tag; genital infection; urinary tract infection; middle-ear infection; toe-nail infection. \</td>
</tr>
<tr>
<td></td>
<td></td>
<td>On post-mortem: lung inflammation; abscesses in lungs and abdominal cavity.</td>
</tr>
</tbody>
</table>

Weekly Incidence of disease, a 0 or 1 score for each rabbit, was recorded from week 5 to week 10, giving 6 traits. A composite trait, Overall Incidence, was defined as a 0 or 1, respectively, for the absence or presence of disease at any of the recording times.

Each disease sign was treated independently, that is, if a rabbit had both snuffles and diarrhoea it received a score of 1 for both the infection and digestive tract upset trait for that week. When analysing data for incidence of infection, rabbits that died from a different class of disease were excluded from the analysis. For example, if rabbit died with scouring signs it was completely dropped out of the dataset for bacterial infection.

Five mortality scores were recorded for rabbits indicating whether they lived (0) or died (1, including euthanased) from causes attributed to infection between the six weekly disease assessments. The sum of these defined Overall Mortality indicating whether rabbits survived to 10 weeks of age. Rabbits that died from other causes were excluded from the analysis of mortality.

2.1.2.3 Statistical analysis

The statistical package used for all analyses was ASReml (Gilmour et al. 2006). Although each trait was binary data (0,1), the generalized linear mixed model methodology for binary threshold traits is not reliable under an animal model (see Gilmour et al. 2006, Section 6.9) and it is not possible to estimate genetic correlations between two binary traits using a threshold model in ASReml. Therefore, Weekly Incidence and Overall Incidence were initially analysed using a linear model for the observed data, to investigate the presence of maternal effects and the genetic correlations between disease incidence measurements made from one week to the next and between disease traits and mortality traits. Subsequently, a threshold model, fitting sire rather than animal, was employed to estimate heritability on the underlying normal scale, using a logit transformation for data.

Given the mixed breed origin of the composite strain of rabbits, a genetic groups model was used. Parity of the doe (number of litters produced by an individual doe) and number weaned per litter were fitted as fixed effects. Initial investigation of the fixed effects of parity and number weaned showed they were not linear but groups of sequential values were similar so these effects were fitted as multilevel factors rather than as covariates. Parity which ranged from 1 to 18 was fitted as six classes – parity 1, 2, 3, 4-6, 7-10, and greater than 10. Number weaned which ranged from 1 to 13 was fitted as three classes – 1-5, 6-9 and greater than 9. Sex was not fitted as it was recorded at 10 weeks of age and not available for all animals. Level of heterosis, expressed as a proportion from 0 to 1, was fitted as a covariate. Year/month of birth was fitted as a random effect. Weaning group (defined by the date of weaning and pen number) was also fitted as a random effect. The significance of the fixed effects and their first order interactions were estimated for each trait. Where fixed effects, heterosis and weaning contemporary group were not significant (P<0.05) they were omitted from final models. First order interactions were not significant.

Once significant fixed effects were determined, the model was expanded to include an additional random maternal genetic component. The following animal model was used to estimate direct and maternal genetic components of variance for the disease traits:

$$Y_{ijklmno} = \mu + A_i + M_j + L_k + R_l + W_m + E_n + u_o + v_{cov} + e_{ijklmno}$$
where $Y$ is the trait; $\mu$ is the common mean; $A_i$ is the random effect of the $i$th animal; $M_j$ is the random effect of the $j$th dam; $L_k$ is the random effect of the $k$th litter; $R_l$ is the random effect of the $l$th year/month; $W_m$ is the random effect of the $m$th weaning group; $t_n$ is the effect of $n$th parity class; $u_o$ is the effect of the $o$th number weaned class; $v_{cov}$ is the covariate for level of heterosis and $e_{ijklmno}$ is the random error.

Variance components were estimated by the restricted maximum likelihood procedure. The heritability of each trait was estimated from the ratio of the additive genetic variance to the total phenotypic variance. Correlations between weekly measures and between disease and mortality traits were estimated from bivariate analyses, fitting significant fixed effects independently for each trait. Approximate standard errors for heritabilities and correlations are calculated from the inverse of the Average Information matrix (ASReml, Gilmour et al. 2006).

The following threshold sire model was used to estimate the accumulative effects of Weekly Incidence on mortality in any one week:

$$Y_{ijklmnop} = \mu + S_i + L_k + R_l + W_m + t_n + u_o + v_{cov} + w_p + e_{ijklmno}$$

where $Y$ is a weekly mortality trait; $\mu$ is the common mean; $S_i$ is the random effect of the $i$th sire; $L_k$ is the random effect of the $k$th litter; $R_l$ is the random effect of the $l$th year/month; $W_m$ is the random effect of the $m$th weaning group; $t_n$ is the effect of $n$th parity class; $u_o$ is the effect of the $o$th number weaned class; $v_{cov}$ is the covariate for level of heterosis; $w_p$ is the $p$th Weekly Incidence score and $e_{ijklmno}$ is the random error. For example, for the trait of mortality between week 5 and 6, the Weekly Incidence score for Week 5 was fitted; for mortality between week 6 and 7, the Weekly Incidence score for Week 5 and Week 6 is fitted, plus the first order interaction. Models for subsequent mortality traits include the Weekly Incidence scores for all the preceding weeks recorded.

### 2.1.3 Results of the study

#### 2.1.3.1 Disease incidence

Disease incidence at each measurement time is given in Table 2.1.2. Incidence of infection (number of animals showing symptoms of infection as a proportion of animals examined that week) increased steadily with age from a minimum of 1.9% at 5 weeks of age to maximum of 14% at 10 weeks of age. The mortality (dead and euthanased) due to infection increased from 1% at week 5 to a peak of 1.8% at week 9. A total of 7% of rabbits present at weaning died of infection (or were euthanased) during the growing period.

The chances of dying in week 6 or 7 was up to 50 times greater if the rabbit showed signs of bacterial infection in the preceding week, with the risk decreasing to about a 10 times greater chance of dying 1.for rabbits sick in week 9 and 10 (Table 2.1.2).

**Table 2.1.2 Proportion of animals exhibiting disease symptoms at weekly measurement intervals from 5 to 10 weeks of age (numbers below), weekly mortality from infection (numbers in brackets), and percentage of rabbits with a 0 or 1 score dying in the next week**

<table>
<thead>
<tr>
<th>Trait</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection (%)</td>
<td>1.9</td>
<td>4.7</td>
<td>7.4</td>
<td>10.4</td>
<td>12.2</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>142/7458</td>
<td>344/7387</td>
<td>537/7291</td>
<td>747/7204</td>
<td>860/7075</td>
<td>976/6965</td>
</tr>
<tr>
<td>Mortality from infection</td>
<td>1.0</td>
<td>1.3</td>
<td>1.2</td>
<td>1.8</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>71/7458</td>
<td>96/7387</td>
<td>87/7291</td>
<td>129/7204</td>
<td>110/7075</td>
<td></td>
</tr>
<tr>
<td>% rabbits with “0” score</td>
<td>0.5</td>
<td>0.4</td>
<td>0.5</td>
<td>1.0</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>that died in the next week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% rabbits with “1” score</td>
<td>24.7</td>
<td>20.1</td>
<td>10.4</td>
<td>9.0</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>that died in the next week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase risk$^1$ of</td>
<td>49</td>
<td>50</td>
<td>21</td>
<td>9</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>dying if score is “1”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Risk calculated as the increase rate of deaths observed for rabbits with “0” versus “1” score.

The significance levels for fixed effects are shown in Table 2.1.3 and least squares means for disease incidence are given in Table 2.1.4. Number weaned class was significant for each Weekly Incidence and Overall Incidence with rabbits from small litters exhibiting a higher incidence of disease symptoms than rabbits in larger litters. Parity of the dam was significant only for Week 9 and 10, with rabbits from litters of higher parity tending to have lower disease scores. Heterosis was significant for only one measure, at Week 8, where the incidence of disease reduced as level of heterosis increased.

Year/month of birth accounted for 9-17% of the phenotypic variance for Weekly Incidence of disease while weaning group (pen) did not account for any variance in any trait.

Table 2.1.3 Number of animals, mean and standard deviation (SD) on the observed scale for disease traits and rabbit mortality with significance levels for fixed effects

<table>
<thead>
<tr>
<th>Trait</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Parity Number</th>
<th>Weaned</th>
<th>Level of Heterosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly Incidence of bacterial infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 5</td>
<td>7458</td>
<td>0.019</td>
<td>0.137</td>
<td>ns **</td>
<td>Ns</td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td>7387</td>
<td>0.047</td>
<td>0.211</td>
<td>ns **</td>
<td>Ns</td>
<td></td>
</tr>
<tr>
<td>Week 7</td>
<td>7291</td>
<td>0.074</td>
<td>0.261</td>
<td>ns **</td>
<td>Ns</td>
<td></td>
</tr>
<tr>
<td>Week 8</td>
<td>7204</td>
<td>0.104</td>
<td>0.305</td>
<td>ns **</td>
<td>** -ve</td>
<td></td>
</tr>
<tr>
<td>Week 9</td>
<td>7075</td>
<td>0.122</td>
<td>0.327</td>
<td>** **</td>
<td>Ns</td>
<td></td>
</tr>
<tr>
<td>Week 10</td>
<td>6965</td>
<td>0.140</td>
<td>0.347</td>
<td>* *</td>
<td>Ns</td>
<td></td>
</tr>
<tr>
<td>Overall Incidence</td>
<td>7458</td>
<td>0.316</td>
<td>0.465</td>
<td>** **</td>
<td>Ns</td>
<td></td>
</tr>
</tbody>
</table>

ns – not significant (P>0.05); * P<0.05; **P<0.01.

Maternal genetic effect accounted for only 0-3% of the phenotypic variance in the Weekly Incidence traits, while 5-20% of the variance was attributed to common litter environment. Based on this result, subsequent analyses included a litter effect but not a maternal genetic component. Heritability (on the observed scale) ranged from 0 to 0.06 when maternal genetic effects were fitted (Table 2.1.5) and 0.01 to 0.07 without fitting this effect (Table 2.1.6). The heritability of Overall Incidence on the observed scale was 0.062±0.017.

The genetic correlations among disease incidences at the various weeks were difficult to estimate being very high except for those involving Week 5. The values in Table 2.1.6 were obtained after fitting an Antedependence lag 1 model to the genetic, litter and year-month components. Phenotypic correlations were positive and in the order of 0.01 to 0.28.

Table 2.1.4 Predicted means for disease traits (retransformed from logit scale) for significant fixed effects

<table>
<thead>
<tr>
<th>Disease trait</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
<th>Overall Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litter parity of dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.095</td>
<td>0.113</td>
<td>0.305</td>
</tr>
<tr>
<td>2nd</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.107</td>
<td>0.103</td>
<td>0.315</td>
</tr>
<tr>
<td>3rd</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.066</td>
<td>0.081</td>
<td>0.252</td>
</tr>
<tr>
<td>4-6th</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.084</td>
<td>0.108</td>
<td>0.283</td>
</tr>
<tr>
<td>7-10th</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.068</td>
<td>0.076</td>
<td>0.238</td>
</tr>
<tr>
<td>&gt;10th</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.048</td>
<td>0.074</td>
<td>0.251</td>
</tr>
</tbody>
</table>

Litter size at weaning (number of kittens)

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>0.024</td>
<td>0.056</td>
<td>0.065</td>
<td>0.084</td>
<td>0.091</td>
<td>0.106</td>
<td>0.331</td>
</tr>
<tr>
<td>6-9</td>
<td>0.010</td>
<td>0.029</td>
<td>0.048</td>
<td>0.059</td>
<td>0.065</td>
<td>0.082</td>
<td>0.252</td>
</tr>
<tr>
<td>&gt;9</td>
<td>0.008</td>
<td>0.021</td>
<td>0.042</td>
<td>0.056</td>
<td>0.073</td>
<td>0.087</td>
<td>0.238</td>
</tr>
</tbody>
</table>

ns – not significant (P>0.05).
Table 2.1.5 Heritability (direct genetic, \( h^2 \)) and proportions of maternal genetic (\( m^2 \)), maternal environment (\( M^2 \)) and common litter effects (\( c^2 \)) for disease traits using animal model and data on the observed scale. Asymptotic standard errors are given for estimates.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct additive genetic variance (( h^2 ))</td>
<td>0.021 ± 0.016</td>
<td>0.01 ± 0.008</td>
<td>0.024 ± 0.013</td>
<td>0.042 ± 0.023</td>
<td>0.062 ± 0.018</td>
<td>0.059 ± 0.026</td>
</tr>
<tr>
<td>Maternal genetic variance (( m^2 ))</td>
<td>0.0 ± 0.006</td>
<td>0.012 ± 0.010</td>
<td>0.006 ± 0.007</td>
<td>0.002 ± 0.012</td>
<td>0.0 ± 0.001</td>
<td>0.029 ± 0.018</td>
</tr>
<tr>
<td>Maternal environment variance (( M^2 ))</td>
<td>0.002 ± 0.010</td>
<td>0.0 ± 0.008</td>
<td>0.047 ± 0.011</td>
<td>0.063 ± 0.012</td>
<td>0.063 ± 0.011</td>
<td>0.054 ± 0.012</td>
</tr>
<tr>
<td>Litter variance (( c^2 ))</td>
<td>0.209 ± 0.017</td>
<td>0.078 ± 0.012</td>
<td>0.047 ± 0.011</td>
<td>0.063 ± 0.012</td>
<td>0.063 ± 0.011</td>
<td>0.054 ± 0.012</td>
</tr>
</tbody>
</table>

1 Values without a standard error were estimated on the boundary of the parameter space.

Table 2.1.6 Heritability (on diagonal) and genetic (above diagonal) and phenotypic (below diagonal) correlations for incidence of bacterial infection from week 5 to 10 of age in grower rabbits using an animal model for data on the observed scale.

<table>
<thead>
<tr>
<th>Week</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.023</td>
<td>-0.037</td>
<td>-0.037</td>
<td>-0.037</td>
<td>-0.037</td>
<td>-0.032</td>
</tr>
<tr>
<td>6</td>
<td>0.153</td>
<td>0.007</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.872</td>
</tr>
<tr>
<td>7</td>
<td>0.101</td>
<td>0.237</td>
<td>0.028</td>
<td>1.000</td>
<td>1.000</td>
<td>0.872</td>
</tr>
<tr>
<td>8</td>
<td>0.046</td>
<td>0.166</td>
<td>0.249</td>
<td>0.038</td>
<td>1.000</td>
<td>0.872</td>
</tr>
<tr>
<td>9</td>
<td>0.045</td>
<td>0.146</td>
<td>0.215</td>
<td>0.316</td>
<td>0.070</td>
<td>0.872</td>
</tr>
<tr>
<td>10</td>
<td>0.033</td>
<td>0.133</td>
<td>0.180</td>
<td>0.246</td>
<td>0.322</td>
<td>0.047</td>
</tr>
</tbody>
</table>

Variance components for sire, litter and year/month effects were also estimated using a threshold model. There was a reasonably consistent result from the two approaches. As predicted (Falconer 1981), the estimates for variance components (and error of measurement) were higher when a threshold model was used (Table 2.1.7) because they relate to an underlying scale.

Table 2.1.7 Variance parameters and standard errors for direct genetic (heritability), common litter effects and year/month of birth for Weekly Incidence and Overall Incidence using a threshold model with an assumed underlying normal distribution of liability.

<table>
<thead>
<tr>
<th>Weekly Incidence</th>
<th>Heritability</th>
<th>Common Litter</th>
<th>Year/Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 5</td>
<td>0.12±0.15</td>
<td>0.24±0.06</td>
<td>0.17±0.04</td>
</tr>
<tr>
<td>Week 6</td>
<td>0.00±0.00</td>
<td>0.16±0.03</td>
<td>0.10±0.03</td>
</tr>
<tr>
<td>Week 7</td>
<td>0.09±0.07</td>
<td>0.09±0.03</td>
<td>0.09±0.03</td>
</tr>
<tr>
<td>Week 8</td>
<td>0.06±0.05</td>
<td>0.10±0.02</td>
<td>0.13±0.03</td>
</tr>
<tr>
<td>Week 9</td>
<td>0.10±0.06</td>
<td>0.10±0.02</td>
<td>0.12±0.03</td>
</tr>
<tr>
<td>Week 10</td>
<td>0.12±0.05</td>
<td>0.08±0.02</td>
<td>0.09±0.02</td>
</tr>
<tr>
<td>Overall Incidence</td>
<td>0.05±0.03</td>
<td>0.08±0.01</td>
<td>0.08±0.02</td>
</tr>
</tbody>
</table>

2.1.3.2 Disease incidence relationship with mortality

The combined effects of individual Weekly Incidence on mortality are presented in Table 2.1.8. In most cases disease incidence scores recorded more than one week prior to mortality had no significant bearing on a rabbit surviving or not. However, Weekly Incidence score the week prior to death had a significant effect on mortality in every case, with rabbits showing signs of disease being much more likely to die the following week. These results indicate that the most important disease score is the one in the week immediately prior to death and it would be inappropriate to add together weekly scores, into an aggregate index of disease, to predict mortality.
Table 2.1.8 The percentage and standard error of rabbits from each Weekly Incidence score category (0 negative, 1 positive for bacterial infection) that died at a subsequent date from an infection related cause

<table>
<thead>
<tr>
<th>Time of Death</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-6</td>
<td>0.3</td>
<td>±0.1</td>
<td>0.3</td>
<td>19.3</td>
<td>±3.6</td>
</tr>
<tr>
<td>6-7</td>
<td>0.5</td>
<td>±0.1</td>
<td>0.4</td>
<td>10.0</td>
<td>±1.6</td>
</tr>
<tr>
<td>7-8</td>
<td>0.5</td>
<td>±0.7</td>
<td>±0.1</td>
<td>±0.1</td>
<td>±1.3</td>
</tr>
<tr>
<td>8-9</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.9</td>
<td>9.9</td>
</tr>
<tr>
<td>9-10</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The heritability of Overall Mortality was 0.02±0.05. The genetic and phenotypic correlations between Overall Mortality and Overall Incidence of bacterial infection were -0.11±0.29 and 0.17±0.01, respectively. The genetic and phenotypic correlations between Weekly Incidence of infection and mortality in the next week are given in Table 2.1.9. The large standard errors and the inconsistent size and sign of the genetic correlations mean that no conclusions can be drawn as to the genetic relationship between these two traits. Phenotypic correlations indicate rabbits with positive disease signs are more likely to die of infection related causes.

2.1.4 Discussion of results and application in industry

This study demonstrates that observed signs of bacterial infection in rabbits can be used as an indicator trait for resistance to bacterial infection, and the heritability of the trait (0.06±0.02 with linear model and 0.12±0.05 with a threshold model for disease signs at 10 weeks of age) is high enough to warrant further evaluation of the merit of including it in a breeding program.

Table 2.1.9 Genetic (rg) and phenotypic (rp) correlations between Weekly Incidence of bacterial infection and mortality in the week following the measure of incidence

<table>
<thead>
<tr>
<th>Week 5 and Dead 5-6</th>
<th>Week 6 and Dead 6-7</th>
<th>Week 7 and Dead 7-8</th>
<th>Week 8 and Dead 8-9</th>
<th>Week 9 and Dead 9-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>rg</td>
<td>rp</td>
<td>rg</td>
<td>rp</td>
<td>rg</td>
</tr>
<tr>
<td>0.47 ±0.36</td>
<td>0.37 ±0.03</td>
<td>-0.47 ±0.36</td>
<td>0.38 ±0.01</td>
<td>-0.42 ±0.51</td>
</tr>
<tr>
<td>0.38 ±0.01</td>
<td>0.24 ±0.01</td>
<td>0.03 ±0.32</td>
<td>0.18 ±0.01</td>
<td>-0.61 ±0.18</td>
</tr>
<tr>
<td>±0.03</td>
<td>±0.01</td>
<td>±0.01</td>
<td>±0.01</td>
<td>±0.01</td>
</tr>
</tbody>
</table>

Although the mechanism at this stage is unknown, these findings suggest that there are common/shared immunological responses to bacterial challenge that are under genetic control. If this is the case, the responses are more likely to be innate rather than acquired (i.e. specific antibodies), given the spectrum of bacteria that could have caused infection. Possible innate responses are phagocytosis, complement-mediated acute inflammatory reaction and humoral mechanisms (Roitt 1994). For instance, polymorphonuclear neutrophils provide a major innate defense against pyogenic (pus-forming) bacteria such as Pasteurella multocida and Staphylococcus aureus.

To make genetic improvement in resistance to bacterial infection, it appears that a precise diagnosis of the causative agent, or assay of a specific antibody response, is not required. This is not to say such additional information would not improve prediction of estimated breeding values, but the result demonstrates that simple and inexpensive measures can be used, in the first instance, to breed for disease resistance.

Heritability of mortality (dead and euthanased due to infection) in this study was not significantly different from zero (0.02±0.05). The low genetic variability of mortality could be explained by the low proportion of dead animals and, consequently, by the low variance of mortality. No significant sire effect was found for mortality in two experiments aiming to investigate the genetic variability of resistance to epizootic rabbit enteropathy from a sample of inoculated rabbits (Rochambeau et al. 2006, Garreau et al. 2006).
The genetic relationship between weekly disease incidence and mortality was not well estimated with this dataset, with correlations inconsistent in size and sign, and with large standard errors. However, the results show a phenotypic relationship between observed disease signs and subsequent death, with the risk of dying being increased between 10 and 50 fold if the rabbit had a positive disease score in the prior week. Earlier weekly measures of disease incidence were not useful predictors of mortality so the urge to combine these in an attempt to better define the disease resistance of an animal should be avoided. Rabbits with repeated signs of disease may be mounting an appropriate immune response and surviving.

Selection for reduced disease incidence may not result in a genetic improvement in mortality but still has an economic value in a breeding program as it appears that mortality will be phenotypically reduced with an improvement in disease resistance. One way of quantifying this could be to predict the difference in likelihood of survival from one week to the next between animals that exhibit disease symptoms and those that are healthy. An economic value could then be ascribed to a difference in disease incidence as it relates to a difference in predicted survival. So although there may be no genetic improvement in mortality, there may be a phenotypic improvement resulting in improved economic return.

Measuring disease incidence every week is a very time consuming task and would not be feasible in most industry improvement programs. The heritability of the disease trait was highest and most reliable at later ages (week 9 and 10) when the incidence was also highest. The genetic correlation between weekly incidences was high for weeks 7 to 10 with incidence in week 5 appearing to be under different genetic control. This is probably not surprising as rabbits at week 5 are freshly weaned and would have some carryover resistance from their dams. Therefore, choosing incidence in week 10 as the selection trait should result in a correlated response for other weeks, with the exception of week 5. This would provide improvements in the weeks of highest disease incidence.

Previous estimates of heritability for a single measure of bacterial infection, from two commercial populations of meat rabbits in France, suggested useful genetic variation (0.04±0.01 and 0.03±0.01) but heritability estimates were lower (Eady et al. 2004). The lower heritability estimates between the two studies may be due to a difference in recording systems. In those commercial populations, the purpose of data collection was not specifically to score for the presence or absence of disease and the predominant symptom was recorded, rather than all symptoms. In the present study incidence of bacterial infection was scored more systematically.

Given the binary nature of the trait, consideration would need to be given to the statistical model used to estimate heritability. Analysing traits that are recorded as an incidence (0 or 1) causes statistical challenges because the variance of the trait will be dependent on the incidence. For analysis of variance, the assumption is that mean and variance are independent. The closer the incidence is to 50% the less of a problem is created by this relationship but where incidences are outside 10-90%, a non-linear approach using a threshold model may be preferable (Falconer 1981). In this instance the heritability estimates, using a threshold model, were up to two times higher. An increase in heritability is expected, as transformation to the underlying liability scale reduces the variance of measurement error (Falconer 1981). The use of simulation to investigate the optimum model could be warranted, but would need to be followed by confirmation of realised heritability, via selection experiments to have confidence in the heritability estimate. Using a threshold model has the practical disadvantage that individual animal solutions (EBVs) cannot be directly estimated. The transformation issues are of less importance for the latter disease incidence traits where the incidence exceeded 10%.

For later measures of disease incidence (week 9 and 10) litter parity of the dam had a significant effect. As parity increased the trend was for off-spring to show reduced incidence of infection. This may be explained by the culling practice for breeding does, which was primarily based on disease incidence. Does that stayed longer in the population (and produced more litters) were generally healthier, providing a better maternal environment for kittens. The most consistent fixed effect influencing disease incidence was litter size at weaning, with rabbits from smaller litters showing a
higher incidence of disease. Many of these litters had already lost kittens pre-weaning from disease, indicating a higher level of environmental exposure and/or susceptibility. Contemporary weaning group, representing the individual pen environment for weaned rabbits, did not account for any variation in disease incidence. This result suggests that the distribution of bacteria and/or exposure of animals was reasonably even throughout the shed housing the growers, unlike the pre-weaning environment in the nesting box.

Significant heterosis effects have been reported for disease traits in beef cattle where *Bos indicus* and *Bos taurus* cattle were crossed (tick and worm resistance, Prayaga 2003). The general lack of influence of heterosis on disease incidence in this study may be due to less genetic isolation between the breeds of rabbits or simply because there is no consistent heterosis effect for this trait. There was no significant heterosis observed in the breed crosses in this population (Prayaga and Eady 2003) for individual growth and slaughter traits but significant levels of heterosis were observed for doe reproductive traits in one breed cross (Prayaga and Eady 2002).

How selection for reduced incidence of disease will impact on farm profit needs to be defined so that the relative economic weighting given to this trait in the breeding objective can be established. Disease has a direct cost associated with prophylactic and therapeutic treatment, lost production and mortality. Number of growers turned off per doe per annum is a key economic indicator which is directly affected by grower mortality. Bacterial infection was the largest cause of mortality in this population, with 52% of rabbit losses (dead and euthanased) attributed to this type of disease. The challenge is to link our proposed measure of disease resistance with a reduction in mortality.

The worth of a unit improvement in disease resistance is going to depend on the prevalence and hence importance of the disease. In the Australian environment it is clear that improvement in genetic resistance to disease will have relatively high economic returns given current production levels; a 5% improvement in survival of growers would increase gross margin ($AUS/doi/year) in the order of 10% (Eady 2004).

For production systems where the incidence of disease is much lower, the risk that current control strategies (such as prophylactic use of antibiotics) may not be available in the future needs to be considered when estimating an economic value. A similar dilemma exists with breeding sheep for resistance to internal parasites where pending anthelmintic failure due to drug resistance in the parasite needs to be factored into the estimate (Woolaston and Baker 1996).

In addition to the direct benefits of reduced disease, the genetic correlations with other important production traits need to be accounted for. These include growth rate of grower rabbits, kitten survival pre-weaning and health and longevity of breeding does (traits that contribute to annual turn-off of weaned kittens). Once these factors are better defined and understood a more comprehensive value for improved disease resistance can be derived.

### 2.1.5 Conclusions on breeding for resistance to bacterial infection in growers

This study demonstrates that visible signs of bacterial infection in rabbits have a genetic component of variance. Heritability of the trait (0.06±0.02 with linear model and 0.12±0.05 with a threshold model) is high enough to warrant further evaluation of the merit of including it in a breeding program. These findings suggest that there are common/shared immunological responses to bacterial challenge that are under genetic control. Weekly incidence score at week 10 could be used as the selection trait and genetic correlations between the weekly scores indicate improvement in disease resistance should occur from week 7 to 9. From one week to the next, rabbits exhibiting signs of disease were more likely to die than those that were healthy. As there was little evidence of genetic variation for mortality, selection for reduced disease incidence may not result in a genetic improvement in mortality but still has an economic value in a breeding program as it appears that mortality will be phenotypically reduced with an improvement in disease resistance. The relative economic value of resistance to bacterial infection could be based on the relationship between disease incidence and survival, as well as the direct costs of effective disease control and treatment.
2.2 Functional traits – importance and how to measure them

Many livestock breeding programs in the past have concentrated almost solely on improving production traits such as growth rate, litter size, milk production or fleece weight. There have been dramatic instances of how this focus on greater output has detrimentally affected fitness and ability to function. Fitness traits are those associated with overall reproductive rate while functional traits are associated with the animal’s ability to remain healthy. We have seen examples such as poultry bred for high growth rate unable to support their body mass and dairy cows that cannot conceive because of poor body condition and lameness. Now the shift towards including functional traits in breeding programs is well established, and for rabbits this includes traits such as doe longevity and disease resistance. The following section examines the potential contribution of functional traits in a rabbit breeding program and can be found as a published paper by Eady and Garreau (2007).

2.2.1 Introduction to functional traits in breeding programs

To establish a successful industry breeding program to improve functional traits there are several pre-requisites – there needs to be a well defined and measurable trait that will indicate good animal function, the indicator trait must have a genetic component of variation, and be genetically correlated with the trait of economic importance in the breeding objective. For adoption by industry, the trait must be practical to measure in a commercial production system. With functional traits, identification of a suitable indicator trait is often the most difficult task. Expression is often seasonal, difficult to describe quantitatively and incidence is highly variable. These factors, combined with need for feasibility of implementation in an industry breeding program, pose a greater challenge than improving many production traits. Ignoring functional traits that are of economic importance can be costly in terms of lost selection opportunity for the trait itself, less efficient selection for correlated traits, and from an ethical point of view, lower animal welfare (Kadarmideen and Simm 2002). These issues are examined for disease resistance in grower rabbits and doe longevity, using the national meat rabbit breeding program in Australia (Crusader; Eady 2004a) as a case study.

2.2.2 Finding practical measures and quantifying them

2.2.2.1 Disease resistance

The target trait in the breeding objective is mortality of grower rabbits from bacterial infection, with 52% of grower rabbit deaths attributed to this cause (Eady et al. 2007). Using direct selection for mortality has difficulties in that the low and variable incidence of death often results in heritability of zero (Eady et al. 2007; Garreau et al. 2006; Rochambeau et al. 2006). Although recording mortality is relatively straightforward, it is difficult to collect accurate information on cause of death amongst grower rabbits in an industry breeding program because it requires a skilled technician in the shed daily to record cause of death.

Eady et al. (2007) investigated the use of incidence of bacterial infection as an indicator trait for likelihood of mortality. Incidence measures can be easily and systematically undertaken at the same time as routine liveweight measurement, thus facilitating consistency of data collection and ease of data capture. Grower rabbits were scored on a weekly basis from 5 to 10 weeks of age for incidence of infection (0 or 1 on a binary scale). Incidence in the previous week was found to be a significant predictor of likelihood of death for the following week, between 6 and 9 weeks of age, but not for the measurement made immediately post-weaning at 5 weeks of age. Measurements made more than one week prior to death had no power for predicting mortality and the trait was analysed independently for each time. The genetic correlation between incidence of disease at 9 weeks of age and incidence at 6, 7 and 8 weeks of age was not different from 1 (Eady et al. 2007). Therefore, one measurement at 9 weeks of age should give a correlated response for the prior 3 weeks and improve survival over the 6-9 week period. The change in mortality, from a one phenotypic standard deviation reduction in the incidence of infected animals, can be predicted based on the likelihood of survival for the proportion of animals in the 0 or 1 category. Using the results from Eady et al. (2007), the predicted change in mortality was -5% for grower rabbits post-weaning.
2.2.2.2 Doe longevity

The interest in improving longevity is due to the high death and culling rate for breeding does, in the order of 120% per annum, with about 50% of does being replaced in the first three reproductive cycles (Piles et al. 2006). Defining longevity (period from first mating to death or culling) is relatively easy and recording this information for breeding does is practical to undertake in an industry breeding program. Records of doe reproductive performance are routinely kept and this will include date of first mating and date of last mating or litter produced. However, trying to clearly determine the cause of culling or death becomes problematic. In practice does may be culled for poor reproductive performance (failure to mate, conceive, give birth to live kittens, rear kittens) or for disease, or a combination of both. They will die from a range of causes, the majority related to disease and kindling complications. By selecting for longevity one is not sure of what underlying traits are being influenced and longevity may not be heritable.

The heritability for doe longevity was in the order of 10% in research populations where the reason for culling was controlled, that is, no does were removed for poor reproductive performance, with the exception of complete failure to conceive after a number of matings (Sánchez et al. 2004; Piles et al. 2006). Survival analysis methods were used to estimate hazard functions. The majority of deaths and reasons for culling were attributed to disease (not specified) which suggests that a genetic component to disease incidence may exist. In the Crusader population where does were culled for low reproductive performance as well as disease, a preliminary estimate of heritability for longevity was zero (Table 2.2.1, Eady unpublished data).

To ensure longevity is heritable it may be necessary to define reasons for culling before estimating breeding values, although this would mean censoring of records where does were culled for poor reproduction which may create bias. An alternative may be to select for the primary reason for death/culling, i.e. resistance to disease. In countries where the industry uses a structured three-way crossing system, Sánchez et al. (2004) suggests establishing a highly selected maternal strain with improved longevity. Historically in Europe, development of specialist maternal lines for industry has been done in the public research sector by organisations such as INRA and University of Valencia.

While measuring longevity, it is important to ensure all does are given equal opportunity to conceive and produce kittens. With artificial insemination programs this is readily achieved as all does are prepared and inseminated on a set date. In a continuous natural mating system, which is the most common practice in the Australian industry presently, the regularity of mating is not as systematic. Does may be held back from mating if in poor condition and supporting a large litter from the previous mating and time constraints with natural mating may mean some does are not mated the week they are due. It would not be appropriate to use data in this situation to estimate parameters for longevity, kindling interval or kittens produced per doe per year.

Table 2.2.1 Phenotypic standard deviation, heritability and relative economic value (in Australian commercial industry) for production and functional traits of meat rabbits.
Parameters drawn from a range of sources.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Standard deviation</th>
<th>Heritability</th>
<th>Relative economic value ($/doe/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Component reproduction traits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kittens weaned (number/litter)</td>
<td>3.0</td>
<td>0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$115.62</td>
</tr>
<tr>
<td>Kindling interval (days)</td>
<td>19.8</td>
<td>0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-$115.09</td>
</tr>
<tr>
<td><strong>Composite reproduction trait</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of kits weaned/doe/year</td>
<td>9.6</td>
<td>0.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$102.14</td>
</tr>
<tr>
<td><strong>Growth traits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily liveweight gain (g/d)</td>
<td>5.7</td>
<td>0.31&lt;sup&gt;c&lt;/sup&gt;</td>
<td>$14.69</td>
</tr>
<tr>
<td>Ratio feed:liveweight gain in growers&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.2</td>
<td>0.27&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-$21.38</td>
</tr>
<tr>
<td><strong>Functional traits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incidence of bacterial infection at 9 wks of age (&lt;5% change) in mortality)</td>
<td>0.347&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.10&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-$13.70</td>
</tr>
<tr>
<td>Longevity (weeks)</td>
<td>26</td>
<td>0.0&lt;sup&gt;e&lt;/sup&gt;-0.1&lt;sup&gt;e&lt;/sup&gt;</td>
<td>$7.31</td>
</tr>
</tbody>
</table>

<sup>a</sup> Eady unpublished data from Crusader meat rabbit breeding program in Australia; <sup>b</sup> Eady 2004; <sup>c</sup>Larzul et al. 2004; <sup>d</sup> Eady et al. 2007; <sup>e</sup>Sánchez et al. 2004 and Piles et al. 2006.
2.2.3 How important are functional traits
The relative importance of functional traits in a breeding objective can be determined by assessing the financial contribution of one phenotypic standard deviation change in the trait while keeping all other traits constant. For functional traits such as longevity, there can be difficulties separating the trait from other traits such as disease incidence or reproductive performance and the risk of double counting needs to be understood.

The relative economic value (REV) was estimated for selection traits for Australian meat rabbits (Table 2.2.1) using a gross margin model based on average industry parameters (Eady 2004b) where average returns were $174 per doe per annum. Traits that determine the rate of kitten production have the highest (REV), in the order $102-$116 per doe per annum in absolute value, while growth traits including feed conversion efficiency are next in relative importance. Functional traits contribute to profit but are less important, with resistance to bacterial infection in grower rabbits of similar absolute REV to liveweight gain, and doe longevity the lowest at $0.31 per doe per annum.

The financial returns from higher kitten turn-off, reduced feeding costs to meet a target weight and lower mortality of growers are clear. Improving doe longevity reduces the overhead cost of the doe population. Fewer does are needed as replacements, meaning that more are sold for meat income, and maintenance costs from meat turn-off age to first mating are reduced. Given the fecundity of rabbits these are not major costs in a self-replacing breeding unit. In other systems, where replacement does from specialist maternal lines are purchased, the REV for longevity may be higher.

The selection index for the Crusader breeding program contains the traits number weaned/litter, average daily gain and resistance to bacterial infection in grower rabbits. As there are limited resources for introducing new traits, it is likely to be more profitable to focus on improving feed conversion efficiency rather than longevity, in the first instance. The relative contribution to the profit function can be approximated by the product of the heritability and REV, indicating an 8-fold greater contribution from improving feed conversion efficiency compared to doe longevity.

Although there is a clear role for functional traits in a meat rabbit breeding objective, further work is required to complete the picture. Studies are required to determine the genetic relationship between functional traits such as disease resistance, longevity and production traits. With regard to selection for improved longevity, the detrimental impact on generation interval needs to be considered. There also needs to be some method of accounting for the risk that current control measures for disease, such as the prophylactic use of antibiotics in grower feed, may be banned or restricted.

2.2.4 Conclusions
When considering the introduction of functional traits into a breeding program we need to carefully define the traits so that it is clear what selection will achieve both in terms of underlying traits that the functional traits may represent as well as the contribution to profit. When adding new traits to a breeding program, where there are limited resources, the relative contribution of functional traits should be balanced against production traits to ensure an optimum profit function.

2.3 Relationship between grower health and doe health
The Crusader database is not yet to the stage of having a useful amount of data on the health of breeding does to allow parameter estimation for this trait. The trait chosen for analysis was health of the doe in the 3rd week post-partum and included does that lost all kittens at birth. The 3rd week post-partum was chosen as it allows time for infections, such as mastitis, to manifest themselves with visible signs. A simple proportion was calculated for each doe from the ratio of the number of times sickness from infection was observed and the number of parities recorded for the doe.

The initial heritability estimate for this trait was 0.014±0.10, indicating the data (n=459) is still too sparse for reliable parameter estimation. Once additional records are available, the data requires a more rigorous analysis with a repeated measures model or a survival analysis approach that accounts for censored records.
For female rabbits, the phenotypic correlation was 0.16±0.05, between signs of infection at growing age (8-9 weeks) and subsequent signs of infection as a breeding doe. Presented as class means, does who were not sick at 8 or 9 weeks of age had an average incidence of sickness of 40% in the 3rd week post-partum, on average does who were sick once at either 8 or 9 weeks of age had a later incidence of sickness of 59%, and for does who were sick at both 8 and 9 weeks of age the incidence of sickness in the 3rd week post-partum was 67%.

These results are encouraging and highlight the need for more data to be collected so that the overall merit of selection for disease can be assessed in both grower and breeding rabbits.

2.4 Relationship between resistance to bacterial infection and scouring in grower rabbits

Digestive upset causing diarrhoea was the second most prevalent cause of death amongst growing rabbits, accounting for 31% of deaths in Crusader stock. Scouring can be caused by a range of conditions – some related to disease such as coccidiosis but more often associated with digestive upset caused by a change of feed or feed formulations without sufficient fibre content.

Heritability of scouring was estimated for growing rabbits using Crusader data collected from 2000 to 2005. The heritability estimate for scouring in grower rabbits from 5 to 10 weeks of age was 0.03±0.015, with a common litter effect of 0.09±0.011. However, this model does not partition the genetic maternal effect and the common environmental effect of being born in the same litter. When using an animal model for estimating variance components, variance due to maternal genetic effects may end up in the animal effect, thus inflating heritability estimates. Therefore, additional analysis were undertaken to estimate the maternal genetic effect.

When a maternal genetic effect was added to the model the heritability dropped to 0.022±0.019, with a maternal genetic effect of 0.028±0.015 and a maternal environmental effect of 0.083±0.011. This result suggests that a maternal genetic effect should be fitted when estimating variance parameters for scouring, as by not fitting it one runs the risk of inflating heritability estimates for the trait.

Using a simple genetic model for both traits (animal and common litter effect) a bivariate analysis gave an estimate of 0.05±0.24 for the genetic correlation between infection index score and scouring index score. More complex multi-variate models, including a maternal genetic effect for scouring, need to be investigated. However, the high standard error for the estimates indicates that the data, both in quantity and structure, is not adequate to give a reliable estimate and further data is required for reliable prediction. The phenotypic correlation between scouring and bacterial infection was opposite in sign and close zero, being -0.027±0.012.

Given the low heritability of scouring (0.022±0.019) and no indication of a genetic correlation with bacterial infection, it is not recommended that scouring be included as a selection criterion in the Crusader breeding program at this time.
3. Establishment of an independent industry-based breeding program

3.1 Transfer of rabbits

An objective of the previous RIRDC funded project (CSA-23A) was to transfer the Crusader breeding program, including the rabbits, to an experienced industry enterprise under appropriate and agreed commercial arrangements. The breeding program had reached the stage where its management was largely routine. Research was continuing with the introduction of novel traits such as disease resistance but the day-to-day operation of the program was procedural and well documented, and the database maintenance and estimation of breeding values largely automated. This coincided with the industry reaching a stage of development where there were a number of commercial farmers capable of managing the breeding program.

Expressions of interest were invited from members of the industry with established enterprises who potentially could manage Crusader. Snowy Mountains Gourmet Rabbit Company (SMGRC) was selected based on an assessment against a range of selection criteria. A full description can be found in the Final Report for CSA-23A.

The breeding nucleus of bucks and does was subsequently transferred to SMGRC in three batches on 21 April, 2 June and 30 June 2004. Rabbits were transferred at 12-18 weeks of age with the exception of approximately 10 superior mature does who were sent in a non-pregnant state with the last consignment, after weaning their litters. The rabbits were transported on a stock truck fitted with decking suitable for sheep. The does were placed in two large compartments accommodating approximately 60-70 rabbits. The floor of the compartment was covered with 15-20 cm of straw. Bucks were transported in banks of individual cages taken directly from the rabbit sheds. The truck was covered with a tarpaulin. The trip from Chiswick to Bredbo took approximately 16 hours of travelling time with an overnight break en route. In total approximately 500 rabbits were transferred and there were 5 deaths in transit.

Upon arrival at SMGRC facility the rabbits were allocated to cages in the newly constructed shed. Mating in the new facility commenced on 29 April 2004, with the young does that were shipped on the 21 April. Receptivity of does was low to begin with due to season effects on fertility (decreasing hours of sunlight) and the reproductive status of the does (young maiden does). By September 2004 the mating pattern was returning to normal. The proportion mated also dropped in the allocation prior to transporting when mating was paused for 3 weeks to give time for rabbits to be moved.

Weekly management routines have remained similar to those used at the CSIRO facility at Chiswick. Weaning and weighing are done on Monday and Tuesday, and mating on Thursday, Friday and Saturday. The age of estimating EBVs was reduced by one week to 9 weeks of ages to give more flexibility for slaughtering rabbits when they reach the target weight of >2.6 kg liveweight. Data collection protocols were established for all the traits of interest. Initially doe health was not recorded on a weekly basis due to the high number of dry does. In October 2004 this remaining trait was reintroduced to the weekly routine.

Over the life of the project the data collection routine has been modified as more information came to hand on the optimum selection strategy for disease resistance. In mid-2004, the age at last weighing was reduced from 10 weeks to 9 weeks, as with improved growth rates rabbits were ready for turn-off earlier. Disease incidence in growers is now assessed at week 5 (weaning) and week 8 and 9, rather than weekly from week 5 to 10, thereby reducing the number of times the rabbits are both scored for disease and weighed. This decision was made when additional data analysis demonstrated that the heritability of an overall index (sum of 6 weekly observations) is similar to that of a simplified index based on measurement at week 8 and 9 (0.12±0.04 versus 0.10±0.02, respectively). In order to reduce the recording required for the breeding program, the decision was made to weigh and score for disease at week 5 (weaning), week 8 and week 9. This was implemented in the breeding program in early...
November 2005. This is an important change in protocol as it makes the inclusion of disease resistance a more practical measure for breeders to adopt. The frequency of measuring doe health was also reduced and is now assessed once per kindling, at 3 weeks post-partum, rather than weekly. Apart from these changes, the level of data collection remains similar to that undertaken at Chiswick.

3.2 Training in database operation and estimation of breeding values
In April 2004, Kathleen Bowerman, SMGRC, spent a week training in the Crusader facility. During this time Kathleen participated in each of the weekly routines such as weaning, weighing growers and scoring for disease, recording new litters, checking nest boxes and recording deaths, doe health checks and mating. She gained initial experience of data entry and structure of the Crusader database.

Staff training in Standard Operating Procedures, data collection and entry and EBV calculation continued on site at SMGRC with Sandra Eady travelling to Bredbo regularly (3-4 months) during the project. Standard Operating Procedures (SOP) for data entry and estimating breeding values (EBVs) were updated by Kathleen Bowerman, with additional detail to assist with the understanding of procedures.

Weekly data updates were undertaken jointly at CSIRO and SMGRC until July 2004. After that time, updates were undertaken independently by Kathleen Bowerman. Three-weekly calculations for EBVs were undertaken jointly until September 2004 and were then independently undertaken with occasional checks on procedures. Back-up copies of the master database were initially lodged with the Database Manager at CSIRO on a bi-monthly basis but are now sent weekly.

3.3 Training in allocation of bucks to does
Allocation of bucks to does for mating is the most complicated procedure in running the breeding program, as the procedure requires does to be randomly allocated to bucks, with adjustments for inbreeding so that close relatives are not mated. New mating allocations are done every 6 weeks with bucks being replaced by younger males.

The structure of the database to integrate and apply this information is complex and proved to be the most difficult component to merge with the routine management of the rabbits. It took until mid-2005 for this activity to be independently undertaken at SMGRC, and it still requires periodic checking and support. The complexity resulted in sub-performance in the breeding program until a number of error checks were put in place. The main difficulty was ensuring correct updates for each doe to so that she appeared on the mating list in a timely manner. The data integrity for the matings was not compromised (which bucks was mated with which doe) but many does remained un-mated for extended periods of time. This resulted in reproduction data that was not suitable for estimation of parameters related to doe longevity and production of kittens per unit of time. It also substantially reduced the selection intensity for the breeding program as fewer off-spring were produced.

These challenges highlighted the importance of having an in-shed system for checking the reproduction history for does; at this point in time a card displayed on each does’ cage that gives her mating and kindling history. There also needs to be a strong line of communication between the shed staff and database staff, so that anomalies are effectively communicated.

3.4 Conclusion on viability of industry-based breeding program
The transfer of the Crusader breeding program to industry has been successful and may serve as a useful model for other new animal industries. The critical success factors were:
- identification of a commercial operator that had the capacity to take on the task
- the development of database systems and interface with BLUP software, in a MS Access environment that allowed ease of use by relatively unskilled operators
- the detailed documentation of all activities in Standard Operating Procedures
- flexibility to vary the intensity of data collection to fit a more commercial schedule of production
- a period of support and transition
- access to on-going support as required for occasional auditing and adjustment of procedures

The transfer has also highlighted areas of difficulty that needed to be addressed to ensure efficient operation and data integrity:
- presence of physical card records in the shed to allow shed operators without access to the database the ability to monitor doe performance and flag when anomalies were occurring. This was particularly evident when procedures for generating accurate mating lists failed and does were not being regularly mated.
- timely data collection and entry for a weekly management system that requires data to be up to date to efficiently generate the next week’s worksheets
- training of new staff in data collection so that consistency of approach was ensured. This was particularly evident with subjectively assessed traits such maternal behaviour, body condition and disease incidence scoring.
- timely adjustment of data recording levels where time constraints were impinging on quality and frequency of data collection.

Overall, Crusader has demonstrated that a sophisticated and modern breeding program, estimating breeding values every 3 weeks for index selection of breeding stock every 6 weeks, can be run relatively independently in industry.
4. Resources for the industry – database and rabbits

4.1 Crusader Enterprise Model and production parameters

The Crusader Enterprise Model allows farmers to estimate the gross margin (net of variable costs excluding labour) for meat rabbit farming. This tool has various applications – preparing a business plan for investment a rabbit enterprise, assessing the relative economic value to be applied to each trait in the Crusader selection index, assessing the economic return from investment in a better design of nest boxes, and predicting the impact of change in one variable, such as re-mating interval, on other key factors that determine profit. The Enterprise Model is available for download on the Crusader website (www.csiro.au/crusader) and contains default values that represent a best guess at industry averages for costs and returns.

The Crusader database itself can provide useful information on likely production under low capital farming conditions in Australia (Table 4.1.1). Low capital facilities are defined as a shed with dirt floor with natural ventilation and basic cages construction and equipment. The following parameters are drawn from the Crusader database and are averages for the 12 months from April 2006 to March 2007. These figures should be viewed as only one example of levels of production in the industry, although, they equate reasonable well with informal comparisons with other enterprises where data is systematically collected.

Table 4.1.1 An example of average production parameters for meat rabbits farmed under low capital conditions in Australia for the year April 2006 to March 2007

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at first mating (weeks)</td>
<td>22.2±7.0</td>
</tr>
<tr>
<td>Number of kittens born per litter</td>
<td>9.35±0.62</td>
</tr>
<tr>
<td>Number of kittens born alive per litter</td>
<td>8.16±0.86</td>
</tr>
<tr>
<td>Number of kittens weaned per litter*</td>
<td>4.90±0.88</td>
</tr>
<tr>
<td>Weight of litter born (g)</td>
<td>575±38</td>
</tr>
<tr>
<td>Weight of litter born alive (g)</td>
<td>513±55</td>
</tr>
<tr>
<td>Mortality rate of grower rabbits (%)</td>
<td>14</td>
</tr>
<tr>
<td>Weaning weight 5 weeks (kg)</td>
<td>0.907±0.215</td>
</tr>
<tr>
<td>Growth rate of grower rabbits 5-9 weeks (g/hd/d)</td>
<td>37.0±8.0</td>
</tr>
<tr>
<td>9 week liveweight (kg)</td>
<td>1.967±0.322</td>
</tr>
<tr>
<td>Pregnancy rate for does mated (%)</td>
<td>72</td>
</tr>
<tr>
<td>Average life of doe (weeks)</td>
<td>55.4±33.6</td>
</tr>
</tbody>
</table>

* The average for number of kittens weaned per litter includes litters where all kittens die at birth. Many farmers overlook these litters when estimating the average for this trait.

Information on productivity levels and gross margins is important for the industry as it allows potential farmers to develop a sound business case for investment in the industry and existing farmers to bench-mark their performance.

4.2 Progress to date in the breeding program

4.2.1 Selection history and key dates for Crusader

The Crusader breeding program commenced in May 2001 with the first progeny of selected rabbits being born in July 2001. From May 2001 to April 2003 the rabbits were selected on an index combining estimated breeding value (EBV) for average daily liveweight gain (ADG, g/head/day) from 5 to 10 week of age and litter size at weaning or number weaned (NW). The relative economic weight for each trait was a function of the extra profit derived from one standard phenotypic deviation improvement in that trait. In May 2003, a disease resistance trait was introduced to the index and the
first offspring of rabbits selected with the expanded index were born in August 2003. The trait was incidence of bacterial infection in grower rabbits from 5 to 10 weeks of age. The economic weight for the disease EBV was calculated using the Crusader Enterprise Model to predict increased returns from one phenotypic standard deviation change in the trait and the predicted flow-on effect on survival and improved growth rate.

Index ($/doe/year) = (Number Weaned EBV x $33.71) + (Average Daily Gain EBV x $10.61) + (Disease Resistance EBV x -$28.81)

Genetic parameters used to estimate breeding values are based on values from literature for ADG and NW and on estimates from Crusader data and are given in Table 4.2.1

Table 4.2.1 Heritability estimates for traits in the Crusader Index drawn from published literature and Crusader data.

<table>
<thead>
<tr>
<th>Trait</th>
<th>No. of estimates</th>
<th>Range</th>
<th>Heritability used for Crusader EBVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number born alive (NBA)</td>
<td>11</td>
<td>0.05-0.33</td>
<td>0.1</td>
</tr>
<tr>
<td>Number weaned (NW)</td>
<td>10</td>
<td>0.02-0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>Average daily gain (ADG)</td>
<td>9</td>
<td>0.17-0.48</td>
<td>0.3</td>
</tr>
<tr>
<td>Disease resistance</td>
<td>1</td>
<td>na</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Genetic, phenotypic and environmental trends for each trait in the index are given in Figures 4.2.1 (litter size at weaning), Figure 4.2.2 (average daily liveweight gain) and Figure 4.2.3 (disease resistance).

To aid in interpretation the following definitions apply for each trend:

i. **Genetic trend** is the change in estimated breeding values over time, reflecting the underlying change in genes for each trait and the genetic merit of the animal for improving that trait in their offspring.

ii. **Environmental trend** is the way in which the environment has changed over time to affect the trait, reflecting changes in management, housing, nutrition and exposure to such things as disease or stress.

iii. **Phenotypic trend** is the observed performance of the animals, reflecting the combination of genetic and environmental trends on the expression of the trait.

**4.2.2 Number of kittens weaned**

Their has been good progress in the number of kittens weaned given the relativity low heritability for this trait. Progress has continued at Bredbo indicating the data is being accurately recorded and appropriate animals being selected as replacement breeders. Given mean starting values of 4 kittens weaned per litter, genetic improvement has been approximately 12.5% for kittens weaned over the 6 years of selection, or approximately 0.4 of kitten per year. The environmental trend for litter size at weaning improved over the period the rabbits were housed at Chiswick (associated with improved nest boxes, heating during cold weather and hygiene), but was highly variable with no obvious trend after they were transferred to SMGRC at Bredbo. The nest box trial conducted at Bredbo may have contributed to the variation in environmental effects. Combining genetic and environmental trends for this trait gave an overall improvement in phenotypic performance of approximately 60% since selection commenced.
4.2.3 Average daily liveweight gain in growers
The pattern for the genetic trend for average daily liveweight gain (ADG) is as expected for a trait that is moderately to highly heritable. It has shown a consistent upward trend at both locations. Given mean starting value 34 g/head/day for growth rate, genetic improvement has been approximately 29% for growth rate since the breeding program commenced in July 2001. The environmental trend for growth rate overall has been negative at both locations, the improvement in September 2001 being associated with the rabbits moving into a new shed that was initially very clean. Although the effect of this negative environmental trend has largely countered the genetic gain, there has been a slight positive phenotypic trend for ADG.

4.2.4 Resistance to bacterial infection in growers – disease resistance
This trait is the most recent to be introduced to the breeding objective, being included in the selection index in mid-2003. Prior to direct selection there may have been a slight correlated response to selection for production traits (Figure 4.2.3), although the highly variable nature of the trait makes it difficult to clearly see trends over short periods. However, it does appear that there has been little genetic improvement in disease resistance since mid-2005. This requires investigation and may be related to the consistency with which signs of disease incidence is being recorded. Given a mean starting value for average infection score of 0.50, genetic improvement has been approximately 9% for disease resistance since 2001. The environmental trend for disease was unfavourable at Chiswick. When the rabbits were moved to Bredbo there was a marked reduction in disease incidence but over time a similarly unfavourable trend has been evident. The phenotypic trend for disease score has shown the same pattern, with little overall improvement.

The phenotypic trend in mortality rate (Figure 4.2.4) showed improvement while rabbits were at Chiswick, dropping from approximately 14% to 7%. However, on transfer to Bredbo mortality rose to approximately 14% with high variability over time. As there has been little genetic improvement in disease resistance while the rabbits have been at Bredbo it is difficult to draw any conclusions about the relationship between improved disease resistance and mortality in this environment. In the environment at Chiswick there appeared to be a positive association between improved disease resistance and lower mortality.

4.2.5 Conclusions
In conclusion, genetic improvement in litter size and growth rate has been consistent over the 6 years of selection but improvement in disease resistance was evident only until mid-2005.

Overall progress in the breeding program, as indicated by the average index value of rabbits, has been substantial with a combination of genetic and management improvements lifting gross margins from an estimated $174 to $242 per doe per annum. The average index value of animals has improved to +$55 per doe per annum (Figure 4.2.5), indicating that a significant proportion of the improvement has been from genetic sources.
Figure 4.2.1 Genetic, phenotypic and environmental trends for rabbits selected for improved litter size at weaning (number of kittens/litter). Base data point represents the base population prior to selection and y-axis scale varies for each trend.
Figure 4.2.2 Genetic, phenotypic and environmental trends for rabbits selected for average daily liveweight gain (ADG, g/head/day). Base data point represents the base population prior to selection and y-axis scale varies for each trend.
Figure 4.2.3 Genetic, phenotypic and environmental trends for rabbits selected for disease resistance. Base data point represents the base population prior to selection and y-axis scale varies for each trend.
Figure 4.2.4 Phenotypic trend for mortality rate (%) in grower rabbits.

Figure 4.2.5 Crusader Index for base population prior to selection commencing in July 2001 and over subsequent years.
4.3 Industry engagement
Crusader has contributed to industry events and forums over the duration of the project.

4.3.1 Farmed Rabbit Industries of Australia (FRIA)
The inaugural Annual General Meeting of Farmed Rabbit Industries of Australia was attended in Sydney on 30 July 2004, and subsequently in September 2005. Regular contributions from the Crusader project were prepared for the FRIA website and newsletters.

The annual FRIA national field day was attended in April 2006 in South Australia. The event was very well attended with in excess of 120 people. Preliminary results for the nest box trial were presented along with information on the breeding program, disease diagnosis and the Crusader Enterprise Model for estimating gross margins from rabbit production.

4.3.2. Crusader Project Activities
The Crusader project in conjunction with SMGRC held a field day at Bredbo in April 2005 and was attended by 125 people and 8-10 trade exhibits. Presentations were made on breeding program design for rabbit farming and preliminary results from the nest box trial.

The Crusader Advisory Committee met on 15 July 2004 and 16 September 2005. At the 2005 meeting, the committee decided that Kathleen Bowerman would participate as a management member, opening up a position for another industry member to join the Committee. As the two year period of service was up for all members, the decision was made to call for expressions of interest via the major rural newspapers and an advertisement was placed in papers in WA, Victoria and NSW the first week of November 2005, with applications closing mid-November 2005. There were no expressions of interest submitted, possible due to the time and energy of key industry participants being directed to FRIA. The current member agreed to an extension of their appointment until the end of the project. The Crusader Advisory Committee did not formally meet in 2006 but three was individual consultation with members on strategic direction for the project, particularly in reference to the introduction of AI.

4.3.3 Additional Activities
Project results were presented at the Elders Rural Bank Seminar Series Royal Adelaide Show, 6 September 2004 and a Rabbit Industry Workshop, 13 November 2004, Bendigo. A steady stream of enquiries for information has continued through the year from prospective farmers (Australian and overseas) and industry advisors. The Crusader web site was upgraded and moved to the new CSIRO web architecture in March 2006, an undertaking that required the rewriting and formatting of all documents and files.

4.4 National evaluation for meat rabbits and links with Growtec
One of the project objectives was the establishment of a national meat rabbit genetic evaluation program, with Crusader acting as a hub to provide genetic linkage between breeding herds.

The first step to meet this goal was to investigate the provision of a data service and on-going provider for the genetic evaluation. Livestock Recoding Systems in Armidale were approached to provide a tender for establishing, operating and maintaining software and database facility for estimating across-farm breeding vales. The tender was $12,000-$15,000 for development work and $1000/month for on-going operation. The estimated number of users of this service would be 4-5 each producing 3000-3500 rabbits per year. This would make the cost per rabbit of using the system approximately $0.86-$1.00, which is well over the price that would give a reasonable return on investment of participating (approximately $0.10/rabbit).

The national genetic evaluation program was discussed with industry members through the Crusader Advisory group, the interviews for management of Crusader rabbits early in 2004 and various industry meetings. Interest has been expressed by 2-3 rabbit farmers but it has not been high in priority given other development activities being undertaken (expansion of production units, move to batch management, use of AI).
An alternative approach was followed given the commercial cost of a national service and level of industry capacity to participate. Currently there are two dedicated breeding programs – Crusader and GROWTEC that use systematic evaluation of rabbits and advanced genetic approaches. The proposal was to build genetic links between these programs by use of common bucks, commence across-herd evaluation on a regular basis and select superior sires within both herds for on-going improvement. The opportunity for additional breeders to join the core breeding program would remain open for those breeders who wish to make the investment in data collection and pedigree recording.

The concept of licensing multiplier breeders was investigated but there was not the commercial imperative or business case for investment by SMGRC during the life of the project. This may be an attractive option for breeders in the future as they would yield the benefit (with a lag period) of genetic improvement and increased potential for sale of breeding stock, without the large cost and management expertise to run a full program on-farm. There remains the need to have improved rabbits more geographically dispersed so that breeding stock can be readily accessed.

To date, building genetics links between Crusader and GROWTEC has been progressing with the exchange of bucks. Constraints have been the logistics of shipping animals but more importantly concern about quarantine, with rabbit operations in Victoria reporting significant occurrence of disease (scouring) with an, as yet, undefined cause. Once progeny have been produced from the more recently exchanged bucks, a joint analysis will be undertaken between the two breeding groups. In the mean time, Crusader bucks have contributed to the Growtec program and vice versa, assisting in the dissemination of superior genes to the industry overall.

4.5 Rabbit sales to industry

Rabbit sales since the Crusader population was established are shown in Figure 4.5.1. After transferring to Bredbo in April-June 2004 sales dropped as the breeding facility was established at the new site.

Figure 4.5.1 Rabbit sales since the Crusader population was established in July 2001

Breeder sales were strong for rabbits born in the first half of 2005 but scaled back in the second half 2005 until (Figure 4.5.1). This may have been related to a lower media profile for the project and/or industry trends for consolidation rather than growth in number of farms. Most of the growth during this period appeared to be coming from established breeders building up numbers, which they did largely by retaining females bred on-farm rather than purchasing does. This flags the need to concentrate on promoting to industry the genetic merit of Crusader stock and the importance of regularly purchasing improved bucks or semen.
Breeder sales continued to be low in late 2005 and the first half of 2006 but picked up in August, September and October 2006. Most of the sales were to new clients largely as a result of SMGRC promoting Crusader stock at the FRIA field day and following up with assistance from FRIA to co-ordinate shipping of rabbits in bulk orders to a central location for dispersal. Current sales have been for smaller orders of rabbits going to existing farmers in NSW.

There is a need for an on-going promotional program to maintain higher levels of breeding stock sales. The response to the field day in SA demonstrates demand for the rabbits is present if logistical constraints can be managed and information on the merit of the rabbits widely distributed. It will be important for the Crusader breeding program to develop the capacity for semen collection, storage and shipment as AI is adopted more widely in industry.
5. Management recommendations

5.1 Evaluation of equipment for breeding does housed under Australian meat rabbit farming conditions

5.1.1 Introduction to housing issues for Australian farmed rabbits
Meat rabbits in Australia are predominantly housed indoors and the quality and design of these facilities have a large impact on both welfare and productivity. Defining optimal housing conditions for rabbits has received much attention in countries where rabbit production is a well established livestock industry and sophisticated systems of climate control, rabbit accommodation and waste removal have been developed (McNitt et al. 1996). Current international research is examining the effects on productivity and welfare of stocking density of grower rabbits per cage (Maertens 2004, Rashwan et al. 2004), daily lighting program for breeding does (Theau-Clément and Mercier 2004) and effect of restricted sucking time on performance of kittens (Eiben et al. 2004). These are issues that are more advanced than the ones currently being faced in Australia.

Generally the sophistication of housing for rabbits in Australia has not yet reached that found in Europe, largely due to the early stage of industry development and the capital cost of importing equipment and constructing highly specialised facilities. During the industry’s establishment phase in Australia, the most common cages used for housing rabbits have been a basic wire cage to which farmers have added equipment such as feeders, nest boxes for kittens and mats (Eady 2004a). This equipment has often been designed and manufactured on-farm. The experiments described here were undertaken to provide rabbit farmers with practical information on equipment design to improve welfare and productivity of breeding does.

Sore hocks (pododermatitis) is a common ailment of heavy rabbits, rabbits that fluctuate in body condition such as breeding does and those that lack dense fur on the feet pads. The type of cage floor can also influence the incidence of this disease (McNitt et al. 1996). Rabbits housed in wire cages or pens are prone to pressure sores on their hocks from sitting on wire. This condition can be alleviated by providing a mat on which the rabbits can rest. In European rabbit sheds it is common for plastic moulded mats, with space for waste to drop through, to form part of the cage floor. The gauge of wire used in floor mesh can also influence the level of hock sore and Australian code of housing for rabbits specifies a gauge of not less than 2.5 mm (SCARM 1998). The aim of the first experiment was to assess the effectiveness of different cage mats and gauge of floor wire at reducing the incidence of sore hocks in breeding does.

One of the major traits driving profitability of rabbit farming is number of kittens weaned (Eady and Garreau 2007). Newborn kittens are susceptible to cold and require prompt maternal attention to survive, factors that are influenced by nest box design. The aim of the second experiment was to compare different nest box designs in terms of doe behaviour, kitten survival and kitten growth, as well as ease of checking kittens and cleaning of boxes between litters.

5.1.2 Description of equipment evaluation

5.1.2.1 Location and animals
The experiments were conducted using meat rabbits from the Crusader® project, Crusader being an industry breeding program set up by CSIRO to develop a strain of rabbit for Australian conditions (Eady 2004a). The first experiment with cage mats was conducted at CSIRO Livestock Industries McMaster Laboratory, Armidale NSW, in a purpose-built rabbit facility (Prayaga and Eady 2002) during the period 2001 to 2004. Rabbits were housed under commercial conditions similar to those found in industry. The second experiment evaluating nest boxes was conducted at Snowy Mountains Gourmet Rabbit Company (SMGRC) facilities at Bredbo NSW, from 2004 to 2006, where the rabbits moved to after commercialisation of the breeding program in 2004. Shed design and cage construction was similar to that in the CSIRO facility. All activities with the rabbits at both sites were approved by the CSIRO McMaster Laboratory Animal Ethics Committee.
### 5.1.2.2 Cage mat experiment

The experiment was conducted in the Crusader facility at Armidale where the cages had floors of 2.5 mm mesh. The incidence of hocksore prior to the experiment ranged from 5-8% of breeding does in the shed, at any one time. The majority of does recovered from hocksore but reoccurrence was high. The first type of mats provided for does were Animat® (Tepomark International Inc, Evanston, US), a specifically designed animal mat of extruded rubber. However, the rubber was soft enough for the rabbits to chew and the mats quickly disintegrated into small pieces. The next style of mat used was cement board, which provided a smooth surface for resting that was hard enough to resist chewing. However, the level of hocksore did not appear to be significantly improved, and alternatives needed to be investigated. In addition to mats, the standard gauge of wire (2.5 mm) for floors was increased to 3 mm to determine if this change alone could reduce incidence of hocksore.

The six treatments investigated were:

1. “Cement” board mats (300 x 300 mm) on 2.5 mm gauge wire floors
2. “Coreflute” plastic mats (300 x 375 mm) with circular 12 mm diameter drainage holes on 2.5 mm gauge wire floors. Coreflute is a light-weight corrugated plastic material used for making signs.
3. “Cement” board mats on 3 mm gauge wire floors
4. No mat and 3 mm gauge wire floors
5. “Moulded Plastic” plastic mats (300 x 375 mm) produced in Europe by Extrona (Extrona®, Barcelona, Spain) on 2.5 mm gauge wire floor
6. “Rubber Tyre” domestic door mats made from strips of tyre rubber (330 x 590 mm) on 2.5 mm gauge wire floor

Due to animal welfare concerns the 2.5 mm floor with no mat was not included as a treatment. Each of the mats is pictured in Photograph 5.1.

The trial commenced in April 2003 and continued until March 2004. Health of the does in each treatment was monitored weekly and incidence of hocksore was recorded. Data from the initial 3 weeks of the trial period were omitted from analysis to remove the effect of does with existing hocksore at the commencement of the trial. Observations were expressed in two ways; the first being the number of times hocksore was observed over the trial period (incidence) which combines the number of does and the period for which they were affected; and the second being the proportion of individual does affected by hocksore over the trial period (does affected). The base level of incidence in the two weeks pre-experiment was 5.8%.

The assessment period varied for treatments. Within 3 months it was clear that the incidence of hocksore was not improved by the use of coreflute mats and, as the mats were easily chewed and were light enough for the does to move around the cage, they were replaced with two more alternatives - the Moulded Plastic and Rubber Tyre mats. This confounds treatment effect with time but the assumption was made that incidence of hocksore was unlikely to change over time as the shed environment remained stable, there was no active selection for improved reduced hocksore and the level of the disease remained stable in the treatments that spanned the full experimental period. Details the period of the treatment, the number of weekly observations, the number of does populating the cages are given in Table 5.1.
Photograph 5.1 Pressure mats assessed for effectiveness in reducing incidence of hocksore in breeding does – Cement mat (top L), Coreflute mat (top R), Moulded Plastic mat (bottom L) and Rubber Tyre mat (bottom R)

Table 5.1 Number of cages allocated to each treatment, measurement period, number of rabbits and number of observations made during the experiment

<table>
<thead>
<tr>
<th>Type of mat</th>
<th>Number of cages</th>
<th>Measurement period (excluding 1st 3 weeks of data)</th>
<th>Number of weekly observations</th>
<th>Number of does resident in cages</th>
<th>Number of hocksore observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement mat + 2.5 mm wire floor</td>
<td>48</td>
<td>15/05/03 to 14/08/03 for 24 cages, then replaced by Extrona 15/05/03 to 17/09/03 for 24 cages then replaced by Rubber Tyre</td>
<td>2005</td>
<td>120</td>
<td>62</td>
</tr>
<tr>
<td>Coreflute mat + 2.5 mm wire floor</td>
<td>48</td>
<td>15/05/03 to 13/03/04</td>
<td>744</td>
<td>68</td>
<td>35</td>
</tr>
<tr>
<td>Cement mat + 3mm wire floor</td>
<td>12</td>
<td>15/05/03 to 13/03/04</td>
<td>485</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>No mat + 3mm wire floor</td>
<td>12</td>
<td>15/05/03 to 13/03/04</td>
<td>508</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>Extrona mat + 2.5 mm wire floor</td>
<td>24</td>
<td>04/09/03 to 13/03/04</td>
<td>505</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td>Rubber Tyre mat + 2.5 mm wire floor</td>
<td>24</td>
<td>08/10/03 to 13/03/04</td>
<td>494</td>
<td>34</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.2.3 Nest box experiment

5.1.2.3.1 Description of the boxes
Five box designs were evaluated (Photo 5.2); four of them being designs developed by Australian rabbit farmers and the 5th being an imported box from established rabbit farming equipment manufacturers in Spain. Where the boxes were commercially available they were bought from the supplier. Boxes not commercially available were constructed as per the plans supplied by the farmers who designed them.
The box designs evaluated were:

1. Crusader®: plastic nest boxes with and without infrared heat lamps suspended above the box + wood shavings for nesting material. The boxes were open at the top and were 300mm wide x 375mm long x 180mm deep in dimension with the floor of the box perforated with a close grid of holes. A hole was cut in the base of the cage so that the boxes dropped down below floor height. Due to the shallow open nature of the boxes, the recommended installation is to include a heat lamp for use in the winter.

2. Extrona®: metal nest boxes and plastic trays + wood shavings for nesting material. The boxes had a flip-back metal lid to access to the kittens. The dimensions of the box were 270mm wide x 400 mm long x 320 mm deep. The boxes were attached to the front of the cage with a hole cut in the wire to give access. Although fitted with sliding door, these were not closed at any stage.

3. QAFR: nest boxes of timber construction with cut back lid, the floor formed by a plant nursery seedling tray with drainage holes + wood shavings for nesting material. The dimensions of the box were 325 mm wide x 385 x 315 mm deep, with the front edge where the doe entered 160 mm high from the base and the lid cut back to cover one third of the box.

4. Growtec: plastic coreflute nest boxes fitted with plastic trays with drill holes for drainage + wood shavings for nesting material. Box dimensions were 300 mm wide x 400 mm long x 300 mm deep with an entrance on one face. The boxes were closed at the top with flaps that could be opened for kitten inspection. Wood shavings were used between the floor of the box and the plastic tray as well as in the tray.

5. SMGRC: nest boxes constructed of ply wood with an open top + shredded paper for nesting material. The boxes were 420 mm wide x 280 mm long  x 320 mm deep with a U-shaped entrance cut from one face down to a height of 160 mm.

Photograph 5.2 Nest box designs evaluated in terms of litter productivity traits. From top left Crusader, Extrona, QAFR, Growtec and SMGRC.
Nest boxes were inspected daily and nesting material replaced as required to keep the kittens dry and clean. All nest boxes were used as per manufacturer’s recommendations for construction, use and nesting material. With the addition of heating lamps to half of the Crusader boxes, there were 6 treatments in all. In the Crusader plus heat treatment, the lamps were turned on prior to the litter being born and remained on until the litter was 2 weeks of age. The lamps were used for the period from mid-May to late October.

5.1.2.3.2 Treatment allocation.
The doe cages were of commercial design commonly used in Australia (Harrison International, Sydney, Australia). The basic cage, which was 1000 mm wide x 600 mm long x 450 mm deep with a 2.5mm gauge wire mesh floor, was modified to accommodate each style of box. The breeding cages were set up in banks of 42 cages, 21 per side.

Each style of nest box was randomly allocated to a row of 21 cages in the breeding shed to allow the recording of the time required to inspect kits as part of the daily management routine. This meant that row effects could not be estimated. However, preliminary examination of litter data prior to the experiment indicated no significant differences between rows. Data collection commenced on 15 December 2004 and was completed on 29 July 2006. Delays in obtaining the Extrona boxes from Spain meant that this box was evaluated for a shorter period, from 29 March 2005 to 29 July 2006. Until the boxes arrived, the cages were furnished with SMGRC nest boxes, hence, the number of cages with SMGRC boxes was 42 until March 2005, and then reduced to 21 as the Extrona boxes were installed. The experiment commenced with the does currently resident in each cage. Does remained in the one cage for their productive life. Maiden does were randomly allocated to cages as replacements were required. Details on period of measurement, number of cages in each treatment, number of litter produced and number of individual does resident in the cages allocated to each treatment are given in Table 5.2.

5.1.2.3.3 Measurements recorded
Litter traits recorded were total number born, number born alive and number weaned. Total weight of the litter at weaning was also recorded. Doe behavioural traits such as site of birth of litter (in the nest box or on the wire cage floor) and nesting behaviour (plucking fur to prepare nest for birth of kittens) were recorded for each litter.

The time taken to check the row of cages allocated to each treatment was recorded on 26 separate days spaced throughout the experimental period. The time required to wash and disinfect each type of box, once removed from the cage, was recorded on 5 separate days during the experimental period.

5.1.2.3.4 Statistical analysis
For the cage mat experiment, Chi squared statistics and significance of treatment effects were calculated (Minitab Statistical Software 2000), contrasting the frequency of hocksore in each treatment. For the nest box experiment, a generalised linear mixed model (ASREML, Gilmour et al. 2006) was used for analysis of variance. Fixed effects of box design, parity of the doe (number of litters produced by an individual doe), location born (in box or on wire cage floor) and nesting behaviour (fur plucked or not) were fitted for the traits number born, number born alive, number weaned and weight of weaned litter. Number born was fitted as a co-variate for the traits number born alive, number weaned and litter weight at weaning. Week of birth and dam identity were fitted as random effects. First order interactions were fitted but were not significant and were removed from the final models. Chi squared statistics and significance of maternal nesting behaviour effects were calculated, contrasting the frequency of each behaviour. Chi squared statistics and significance of nest box treatment effects were calculated, contrasting the frequency of cause of kitten death in each treatment. Analysis of variance (Minitab Statistical Software 2000) was used to determine nest box effects on time to check litters and time to wash boxes.
Table 5.2 Period of data collection, number of cages, litters and does for each nest box treatment

<table>
<thead>
<tr>
<th>Type of nest box</th>
<th>Crusader</th>
<th>Crusader + Heat</th>
<th>Exatrona</th>
<th>QAFLR</th>
<th>Growtec</th>
<th>SMGRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of cages with nest box</strong></td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>42 until 28/03/2005 21 from 29/03/2005</td>
</tr>
<tr>
<td><strong>Number of litters recorded</strong></td>
<td>114</td>
<td>119</td>
<td>85</td>
<td>113</td>
<td>104</td>
<td>121</td>
</tr>
<tr>
<td><strong>Number of does resident in cages</strong></td>
<td>35</td>
<td>48</td>
<td>35</td>
<td>40</td>
<td>37</td>
<td>47</td>
</tr>
</tbody>
</table>

5.1.3 Results of the evaluation

5.1.3.1 Cage mat experiment

There was a significant difference (P<0.05) between mat types in their ability to reduce the incidence of hock sore; with the incidence being lower in the treatments with no mat+3mm floor (1.2%), Moulded Plastic (1.0%) and Rubber Tyre (0.2%) and the incidence of hock sore higher for Cement (3.1%), Coreflute (4.7%) and Cement+3mm floor (4.7%) treatments. Results are presented graphically in Figure 5.1. The proportion of does affected by hock sore followed a similar pattern, with the highest proportion in the Cement, Coreflute, Cement+3mm groups, a reduced proportion in the no mat+3mm group and the lowest proportion in the ® and Rubber Tyre groups (Figure 5.1).

The use of 3 mm gauge wire for floor construction showed some advantage in reducing hock sore but not when combined with the cement mats. This may have been due to difficulties in keeping the mats clean and dry because of their solid construction with no drainage holes. In retrospect, a comparison of 2.5 mm gauge wire floor with and without Cement mats would have been useful in interpreting this effect. However, a no mat + 2.5mm wire treatment was not deemed to be acceptable on welfare grounds, as it was already established that there was a problem with hock sore and some additional controls were required.

Figure 5.1 Incidence of hock sore observations and proportion of does showing hock sore symptoms when housed in cages with differing pressure mats and gauge of wire in the floor. Within measurement trait different data labels denote significant differences (P<0.05).
5.1.3.2 Nest box experiment

Factors affecting the litter traits recorded for different nest box treatments are given in Table 5.3. Type of box did not affect the total number of kittens born per litter or the number born alive, but did significantly affect the number weaned per litter, and the weight of the weaned litter. Doe behaviour had a significant effect on all litter traits except total number born. There was no significant interaction between doe behaviour and design of nest box. Week of birth did not affect any of the traits and indicates the difference in period of evaluation for the Extrona boxes should not have biased the group means.

Table 5.3 Factors affecting the litter traits recorded for different nest box treatments

<table>
<thead>
<tr>
<th>Litter trait</th>
<th>Number born (kittens/litter)</th>
<th>Number born alive (kittens/litter)</th>
<th>Number weaned (kittens/litter)</th>
<th>Weight of weaned litter (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of box</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Parity of doe</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>Ns</td>
</tr>
<tr>
<td>Location born (box or wire)</td>
<td>ns</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Fur plucked (Y or N)</td>
<td>ns</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Week of birth</td>
<td>ns</td>
<td>na</td>
<td>**</td>
<td>na</td>
</tr>
<tr>
<td>Doe identity</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>Ns</td>
</tr>
<tr>
<td>Number born in litter</td>
<td>na</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

ns – not significant; * P<0.05; ** P<0.001; na – not applicable.

Total number born is determined by ovulation rate, fertilisation and foetal mortality, traits that should not be influenced by the type of nest box provided to the doe. As there was no difference in total number born between nest box treatments, it appears that there were no biases introduced by different treatments starting out with different total litter size at birth. Total number of kittens born per litter was significantly influenced by the permanent maternal effect of the doe (Table 5.3); repeat litters for some does allowed a measure of this effect. This effect could be environmental or genetic or a combination of both. Number born was fitted as covariate for subsequent litter traits and was highly significant (P<0.01). Once number born was accounted for, the remaining variance attributed to the doe was not significant for any of the traits.

Design of the nest box did not have an effect on number of kittens born alive (Table 5.4) but did affect later survival. Kittens had a greater chance of surviving to weaning if they were born in the Crusader plus heat treatment compared to the Growtec and SMGRC treatments. Performance of the Extrona, QAFR and Crusader (without heat) treatments was intermediate. The same pattern of results was observed for the weight of the litter at weaning.

Table 5.4 Mean and standard error (±se) for number of kittens born, born alive, and weaned per litter and total weight of litter for litters born and raised in a range of nest box designs

<table>
<thead>
<tr>
<th>Type of box</th>
<th>Number of litters</th>
<th>Number born (kits/litter)</th>
<th>Number born alive (kits/litter)</th>
<th>Number weaned (kits/litter)</th>
<th>Weight of weaned litter (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crusader</td>
<td>114</td>
<td>8.5±0.27</td>
<td>7.7±0.33</td>
<td>5.0±0.31</td>
<td>3.95±0.24</td>
</tr>
<tr>
<td>Crusader + Heat</td>
<td>119</td>
<td>8.8±0.26</td>
<td>8.2±0.32</td>
<td>5.8±0.30</td>
<td>4.64±0.23</td>
</tr>
<tr>
<td>Extrona</td>
<td>85</td>
<td>9.1±0.31</td>
<td>8.0±0.38</td>
<td>5.3±0.35</td>
<td>3.82±0.27</td>
</tr>
<tr>
<td>QAFR</td>
<td>113</td>
<td>9.0±0.27</td>
<td>7.4±0.33</td>
<td>5.1±0.35</td>
<td>3.62±0.24</td>
</tr>
<tr>
<td>Growtec</td>
<td>104</td>
<td>8.7±0.28</td>
<td>7.5±0.34</td>
<td>4.3±0.32</td>
<td>3.47±0.25</td>
</tr>
<tr>
<td>SMGRC</td>
<td>121</td>
<td>8.8±0.26</td>
<td>7.6±0.32</td>
<td>4.6±0.31</td>
<td>3.54±0.23</td>
</tr>
</tbody>
</table>

*Superscripts with different letter indicate significant differences (P<0.05).

Whether the doe plucked fur to prepare a nest and the location where the kittens were born had a highly significant effect on the number of kittens born alive, which flowed on to number weaned and the weight of the weaned litter (Table 5.5). Three times as many kittens survived if their dam plucked fur to prepare a nest and 10-times as many survived if they were born in the nest rather than on the wire of the cage floor. There was no significant interaction of these effects.
Table 5.5 Mean and standard error (±se) for number of kittens born alive and weaned per litter and total weight of litter for litters born to dams showing different maternal behaviour for nest preparation and site of birth

<table>
<thead>
<tr>
<th>Trait</th>
<th>Number born alive (kits/litter)</th>
<th>Number weaned (kits/litter)</th>
<th>Weight of weaned litter (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fur plucked to make nest</td>
<td>Yes 8.0±0.13</td>
<td>5.1±0.13</td>
<td>4.01±0.10</td>
</tr>
<tr>
<td></td>
<td>No 2.5±0.53</td>
<td>1.6±0.52</td>
<td>1.22±0.40</td>
</tr>
<tr>
<td>Location of kits at birth</td>
<td>Box 7.9±0.13</td>
<td>5.0±0.13</td>
<td>3.95±0.10</td>
</tr>
<tr>
<td></td>
<td>Wire 0.8±0.75</td>
<td>0.5±0.73</td>
<td>0.48±0.57</td>
</tr>
</tbody>
</table>

*aSuperscripts with different letter indicate significant differences (P<0.05).

Although the incidence of litters born on the wire was significantly less (P<0.001) for the drop down Crusader boxes versus the other designs (Table 5.6), this was not a large enough effect to translate into a significantly higher survival rate of kittens at birth for this style of box compared to the other style where the does had to negotiate the lip of the box. Similarly for fur plucking the statistically higher incidence of fur plucking (P<0.05) for the does using Crusader boxes did not translate into a greater number of kittens born alive. However, across all boxes the effect of site of birth and fur plucking had an overwhelming effect on kitten survival at birth (Table 5.5).

Maternal behaviour such as plucking fur for nest building is stimulated by changes in hormone levels prior to parturition (McNitt et al. 1996; EFSA 2005). In the days prior to parturition the fur loosens on the belly, legs and neck allowing the doe to easily pluck fur and mix it with nesting material provided in the box. Does generally improve in nesting behaviour with subsequent litters. The reasons for giving birth outside the nest are undetermined but there is an association with poor nest making and failure to give birth in the nest box. In this experiment, the proportion of does having kittens on the wire that failed to build a nest was 68%, which means that does failing to build a nest had twice the rate of births on the wire compared to does who did build a nest.

Table 5.6 Incidence of favourable maternal behaviour of does allocated to various next box designs

<table>
<thead>
<tr>
<th>Type of box</th>
<th>Number of litters</th>
<th>% born in box</th>
<th>% with fur plucked by doe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crusader</td>
<td>114</td>
<td>100.0%</td>
<td>97.4%</td>
</tr>
<tr>
<td>Crusader + Heat</td>
<td>119</td>
<td>100.0%</td>
<td>96.6%</td>
</tr>
<tr>
<td>Extrona</td>
<td>85</td>
<td>96.5%</td>
<td>92.9%</td>
</tr>
<tr>
<td>QAFR</td>
<td>113</td>
<td>94.7%</td>
<td>93.8%</td>
</tr>
<tr>
<td>Growtec</td>
<td>104</td>
<td>96.2%</td>
<td>90.4%</td>
</tr>
<tr>
<td>SMGRC</td>
<td>121</td>
<td>95.0%</td>
<td>93.4%</td>
</tr>
</tbody>
</table>

The primary causes of kitten death were poor maternal behaviour and the kittens failing to feed. Failure to feed could also be a reflection of poor maternal behaviour if caused by behaviour of the dam but could also be the result of low kitten viability (Table 5.7). The next most common causes of death were lung infection and scouring, both related to levels of bacterial infection.

Table 5.7 Attributed likely cause of kitten deaths as a percentage of total deaths

<table>
<thead>
<tr>
<th>Cause of kitten mortality</th>
<th>Poor maternal behaviour (hypothermia, cannibalism, smothering)</th>
<th>Lung infection</th>
<th>Not fed</th>
<th>Scouring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crusader</td>
<td>29%</td>
<td>11%</td>
<td>34%</td>
<td>14%</td>
</tr>
<tr>
<td>Crusader + Heat</td>
<td>24%</td>
<td>12%</td>
<td>23%</td>
<td>16%</td>
</tr>
<tr>
<td>Extrona</td>
<td>30%</td>
<td>14%</td>
<td>33%</td>
<td>9%</td>
</tr>
<tr>
<td>QAFR</td>
<td>56%</td>
<td>16%</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>Growtec</td>
<td>89%</td>
<td>20%</td>
<td>39%</td>
<td>16%</td>
</tr>
<tr>
<td>SMGRC</td>
<td>59%</td>
<td>15%</td>
<td>56%</td>
<td>13%</td>
</tr>
</tbody>
</table>
The differences in cause of death between the treatments are not generally significant except for the higher proportion of kittens dying from poor maternal behaviour in the Growtec treatment compared to others (P<0.05). In this treatment, the incidence of death from hypothermia was elevated compared to the other treatments.

In addition to kitten survival, the time taken to inspect litters and clean boxes is also important in assessing nest box design, as labour is a significant component of variable expenses. The time taken to inspect nest boxes for dead kittens and replace soiled bedding was significantly different for some designs, with Growtec taking the longest and Crusader the shortest time, and Extrona intermediate (Table 5.8). This is largely related to how visible the kittens are and ease of access to replace bedding; boxes with lids taking more time to look after. The absolute time taken to inspect the nest boxes is probably greater in this experiment than in a fully commercial operation due to the requirement to record dead kittens. However, the relative differences are likely to remain even if the average time is reduced for a commercial operation. When the boxes were removed from the cages for cleaning and disinfecting, there was also a significant difference in the time taken for this job. Once again Growtec boxes took the longest and Crusader the shortest time, and Extrona intermediate. These times would vary with the fastidious of the cleaner but would not be different for a fully commercial operation unless automated washing systems were used.

Table 5.8 Least squares means (±se) for time to check kittens and change bedding and time to clean nest boxes of different design

<table>
<thead>
<tr>
<th>Type of Box</th>
<th>Time to check kittens and change bedding in each nest box (minutes)</th>
<th>Time to disinfect and clean boxes between uses (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crusader</td>
<td>0.92±0.11</td>
<td>1.16±0.13</td>
</tr>
<tr>
<td>Extrona</td>
<td>1.79±0.13</td>
<td>1.68±0.18</td>
</tr>
<tr>
<td>QAFR</td>
<td>1.07±0.11</td>
<td>1.18±0.13</td>
</tr>
<tr>
<td>Growtec</td>
<td>2.30±0.11</td>
<td>1.90±0.12</td>
</tr>
<tr>
<td>SMGRC</td>
<td>0.98±0.11</td>
<td>1.35±0.16</td>
</tr>
</tbody>
</table>

5.1.4 Conclusion and application in industry
The two experiments yielded practical recommendations on design of cage equipment that can potentially improve the welfare and productivity of breeding does. The results show that, in the environment experienced by the experimental rabbits, hocksore can be reduced in breeding does by the provision of suitable pressure mats and that kitten survival can be improved by the use of nest boxes of a particular design.

The Moulded Plastic and Rubber Tyre mats showed the greatest improvement over Cement or Coreflute mats in terms of reduced incidence of sore hocks. The Moulded Plastic mats are imported from Spain (www.extrona.com) and retail for between $12 and $16. The Rubber Tyre mats are readily available from hardware stores for around $10. Based on the results from this experiment the recommendation is for mats, similar to the Moulded Plastic and Rubber Tyre mats, to be used to alleviate problems of hocksore in breeders. Mats constructed from cement board or coreflute should be avoided.

The maximum difference between treatment means for litter size at weaning was 1.5 kittens per litter, with the Crusader plus heat boxes performing the best. Some of the other designs may have benefited from the addition of heat lamps given the significant losses from hypothermia but as the designers of the boxes did not recommend heating for their commercial use this was not evaluated in the experiment. The difference between the highest and lowest performing boxes translates into a difference in enterprise gross margins (Eady 2004b) of $52.35 per doe per annum including the cost of heating, or an increase of 36% in profit from the use of the best performing nest box compared to the worst. This is a highly significant difference and highlights the impact that improvement in kitten survival has on profit.

This experiment evaluates the performance of does provided with different nest box designs in only one environment. The SMGRC facility is located at Bredbo, in an environment where minimum
winter temperatures are below 0°C and summer maximums above 30°C. Both cold and heat stress are experienced by rabbits at these temperatures. Differences in climate should be kept in mind when extrapolating results to different regions. For instance, the advantages of providing a heat source may not be manifest in coastal regions of northern NSW where minimum temperatures are much higher. In such an environment it is possible that the differences in kitten survival between nest box designs may be moderated.

It is a reasonably straightforward task to evaluate different box designs given performance records are electronically kept for the production unit. Many rabbit farmers have attempted comparisons in a less formal way to arrive at their current box design, evolving the design to improve on historic performance. However, in many instances there has been no systematic recording of outcomes and “improvement” is based on subjective assessment rather than data. Accounting for time trends is also impossible using this system. The results of this experiment show that there can be significant differences in enterprise profit depending on the type of nest box used. Farmers can use the results presented here as a guide to choosing or constructing nest boxes and should be encouraged to objectively compare different designs under their own environmental conditions.

As an outcome of this experiment, SMGRC have commenced converting their commercial breeding shed to Crusader boxes with heat lamps, due to the improvement in kitten survival. QAFR have also moved to replace all their boxes with the Extrona design.

5.2 Vulva colour as an indicator of doe receptivity at mating

Natural mating is a labour intensive activity and most of the time is taken up trying to mate non-receptive does. The routine is for all does scheduled for mating to be put with a buck and the two rabbits observed until there is either a successful mating or it is evident that no mating is going to occur. The latter of these takes up the most time.

In an attempt to develop an indicator of a doe’s receptivity, scoring of vulva colour was undertaken for a 12 month period from March 2006 to April 2007, to determine if this trait could be used to predict doe receptivity. The colour of the vulva was scored just prior to mating. Four classifications were used – white, pink, red and purple. Table 5.9 gives the mating outcomes for each colour classification.

The results show that vulva colour is a reasonably good indicator of receptivity with does showing a dark purple colour the most likely to complete a successful mating (81.8%) while does showing little colour have a low success rate (11.1%). Does exhibiting a pink, or intermediate colour, show an intermediate result of 56.7% successful matings. However, does exhibiting a red vulva do not appear to be highly receptive (21.1%), indicating the relationship is not linear. Does with a red vulva may be exhibiting colour related to infection or irritation, predisposing them to a lower mating success rate.

Table 5.9 Proportion of does and mating outcomes for does exhibiting each vulva colour classification

<table>
<thead>
<tr>
<th>Vulva Colour</th>
<th>Attempted matings in each class (%)</th>
<th>Number of successful matings</th>
<th>Number of unsuccessful matings</th>
<th>Percentage of successful matings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>9.6</td>
<td>6</td>
<td>48</td>
<td>11.1</td>
</tr>
<tr>
<td>Pink</td>
<td>63.5</td>
<td>203</td>
<td>155</td>
<td>56.7</td>
</tr>
<tr>
<td>Red</td>
<td>3.4</td>
<td>4</td>
<td>15</td>
<td>21.1</td>
</tr>
<tr>
<td>Purple</td>
<td>23.5</td>
<td>108</td>
<td>24</td>
<td>81.8</td>
</tr>
</tbody>
</table>

From a practical perspective, vulva colour can be used to prioritise the mating of does so that those that are most likely to be receptive to the buck are mated first. Does showing no sign of colour may be better left, with no attempt to mate them until they show a change.
6. New challenges for the industry

6.1 New traits and directions for genetic improvement
Crusader breeding program has progressed well and it is now prudent to explore new traits that can further improve profit. Traits that have been considered include doe longevity, doe health and litter size, and feed conversion efficiency of grower rabbits. The selection index for the Crusader breeding program already contains the traits number weaned per litter, average daily liveweight gain and resistance to bacterial infection in grower rabbits. As there are limited resources for introducing new traits, it is likely to be more profitable to focus on improving feed conversion efficiency rather than doe longevity, in the first instance. The relative contribution to the profit function can be approximated by the product of the heritability and REV, indicating an 8-fold greater contribution from improving feed conversion efficiency compared to doe longevity.

However, improvement of litter size at weaning still offers the greatest potential for improved financial gain. Progress is steady and encouraging in the Crusader program but could be accelerated considerably by the introduction of European stock. The gap in performance between Crusader stock and rabbit strains in Europe is most evident for prolificacy. The comparison between Crusader does and commercial does in France is 72% versus 81% of does conceiving after mating, 8 versus 10 kittens born alive per litter and 5 versus 8.5 kittens reared per litter, respectively.

The difficulty in acquiring rabbits or semen from France is in meeting the quarantine requirements for entry into Australia. The recent establishment of a Specific Pathogen Free (SPF) population of one of the maternal grand-parent lines in France is an encouraging development, as this potential source of rabbits would meet the in-country quarantine required before the rabbits leave Europe, an expensive component of any importation. It may be worthwhile exploring again the possible importation of rabbits and/or semen with AQIS and industry stakeholders.

6.2 Introduction of artificial insemination (AI)
A number of industry members have invested in training for their staff and have brought people with expertise from Europe to assist with setting up procedures and laboratories to allow them to undertake AI on-farm. Technical assistance is also available from Mark White, Allied Biotechnology, within Australia.

Along with the introduction of AI, will come the need to upgrade cage equipment, such as nest boxes, as an important part of bio-stimulation to achieve good conception rates is to restrict doe access to kittens for the 10 day period between kindling and AI.

Although genetic gain is satisfactory for the Crusader breeding program, the introduction of AI would allow selection intensity to improve and accelerate rates of gain. It will also be important for the Crusader breeding program to develop the capacity for semen collection, storage and shipment, as AI is adopted more widely in industry.

6.3 Appropriate adoption of European technology
Rabbit producers have travelled to Europe to observe advanced husbandry systems being employed there. Some technologies, such as AI, offer significant benefits without posing a risk to the industry. However, other practices, while improving rabbit productivity and health, have the potential to be detrimental to the industry's reputation and image. One such practice is the prophylactic feeding of antibiotics to grower rabbits. Genetic resistance to bacterial infection was introduced to the Crusader breeding program with the purpose of assisting the industry to avoid the need to feed antibiotics. Progress needs to be tested to see if antibiotics can be omitted from grower rations for Crusader stock.
6.4 Meat quality
Initially the rabbit industry's prime concern was to produce the rabbit numbers required by the market. As the industry grows it needs to ensure eating quality is consistent. At some stage the industry should consider investment in research on critical factors for meat quality to help build continued growth in overall demand as well as ensuring a consistent and regular market.
7. Project summary

The project sets the industry with a genetically superior source of seed stock that will feed into current production systems, based on natural mating, and new systems where there is an increasing use of advanced technologies such as artificial insemination. Crusader provides an on-going resource that can be used to test and incorporate new selection traits for improved production. The highest priority will be feed efficiency and number of kittens weaned. It would be advantageous to investigate the feasibility of importation of highly prolificacy lines of rabbits from Europe for improving the latter trait.

Scientific advances were made in selection for disease traits in grower rabbits, estimating genetic parameters to allow selection for functional traits related to healthy and productive animals, and in identifying the relative balance to place on these traits compared to production traits such as growth rate and number of rabbits weaned per litter.

The transfer of the Crusader breeding program to industry has been successful and may serve as a useful model for other new animal industries. Overall, Crusader has demonstrated that a sophisticated and modern breeding program, estimating breeding values every 3 weeks for index selection of breeding stock every 6 weeks, can be run relatively independently in industry.
8. References for background reading


Eady, S.J., 2004a. Farmed rabbits in Australia – RIRDC Publication No 02/144. Rural Industries Research and Development Corporation, Canberra, ACT.


Eady, S.J., Garreau, H., 2007. Functional traits – can we find practical measures to quantify them and how important are they? Proceedings of the Association for Advancement of Animal Breeding and Genetics, Armidale, Australia, 17, 495-498.


