Composite Breeding

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Introduction
Breeders can improve their breeding stock genetically by utilising variation that exists within our livestock species. In beef cattle, within and between breed variation and crossbreeding effects are resources that can be used to breed animals that have outstanding performance in a large number of traits that determine productivity and profitability. Therefore the critical question for a breeder is **where are you going** ?

Once this has been established, the next question is **how do you 'best' get there?** Straightbreeding, crossbreeding and composite breeding, or combinations of these are all methods of using these genetic resources to achieve your breeding objective or goal. The speed, risk and cost at which this goal is achieved differs. However the basic premise of knowing where you are going is paramount. Composites are simply a form of crossbreeding that is used to develop a stabilised 'breed' and is one of the tools available to breeders to meet their breeding objective.

The development of composites is not a new technique to many livestock species, however recent changes in the beef industry are forcing breeders to access different options for breeding cattle. If the development or use of a composite is deemed the most appropriate means by which to meet your objectives there are several underlying genetic principles that need to be understood.

Composite breed theory
The aim of most beef cattle breeders is to breed or use a population of animals that better meet market requirements and/or environmental conditions. This is done by selection within breeds or by crossing breeds. However in some situations breeders have found limitations with existing breeds or crossbreeding systems and have considered the option of composite breeding. Composites are developed by crossing two or more pre-existing breeds in a specific design to develop a new stabilised 'breed'. The design aims to utilise the same genetic resources used in straightbreeding and traditional crossing but in a slightly different way.

Firstly, large differences exist between breeds for major bioeconomic traits. For example, the milk production of Holstein, the growth of a Charolais and the tick resistance of a Brahman. These types of differences have been used to choose a breed for a particular region or suitability to a specific market. Between breed variation can be used in the development of a composite by choosing breeds that possess the desired traits and combining them. Characterising breed differences requires comprehensive breed comparisons. One such experiment is the Germplasm Evaluation Program at Clay Centre Nebraska. To date a total of 26 sire breeds have been evaluated in their F_1 progeny out of Hereford, Angus or crossbred dams. This research has characterised these sire breeds for a large number of production, reproduction and quality traits.

Secondly, within breed variation is the genetic resource used to improve straightbreds. This resource can also be exploited in crossbreeding and in the development of composites by selecting superior animals within each of the parent breeds. Most Australian beef breeds are publishing Sire Summaries of the estimated breeding values (EBVs) on a large number of animals for several traits. For some breeds these include growth, carcase and fertility traits. This information is very important when choosing animals within a breed to best meet your breeding objectives.

Lastly, the effects of heterosis (or hybrid vigour) and complementarity are used in crossbreeding systems including composites. Heterosis is discussed in detail below. Complementarity refers to the advantage of one particular cross or straightbred over another (excluding heterosis) resulting from the manner in which two or more traits combine or complement each other. That is, marrying breeds together in a particular way so that they complement each other to produce the desired offspring. Therefore, complementarity is achieved by choosing combinations of breeds that not only maximise *productivity* but also *profitability*. Certain crossbreeding systems, such as a terminal sire system, can achieve complementarity by mating a relatively small, low cost, easy calving and fertile female to a large, fast growing, good carcase quality sire. For example, a system that uses this kind of complementarity is a three-way cross calf resulting from a Charolais sire over Angus x Hereford cows. Composite breed development can use complementarity when choosing the foundation breeds that when married together will complement each other for a wide range of traits. However under the definition, a composite when stabilised can't exploit complementarity because replacements will contain the genetics of both the sire and dam breeds.

In summary, composite breeding is nothing magic it simply uses the genetic resources that are available to a straightbreeder and a crossbreeder in a slightly different way. I like to define a composite breed as:

A population stabilised by at least one intra-generational mating following the initial crossing of two or more breeds. The design aims to use breed differences and retained heterosis in future generations without crossbreeding

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Note: Although only one intra-generational mating is required to stabilise the genetic composition several further matings are advised. Also a composite can be developed that does not retain heterosis. However the likelihood of success will be limited especially if reproductive and fitness traits are important, particularly in a stressful type environment.

Beef producers have two ways to take advantage of composite breed theory. The first is to develop your own composite and the second is to use an existing composite.

Developing a composite

For any beef breeder considering developing a composite the following recommendations should be considered. Variations and modifications exist to the recommended procedure but in doing so there is an increased chance of developing a composite inferior to existing breeds.

Recommendations:

- know your biological objectives in terms of desired performance, product and markets - with a well defined direction it is more likely of developing a useful composite.
- Determine and describe your environment, management and economic requirements for production - this will determine which breeds and animals within breeds to consider.
- carefully select breeds with known differences and characteristics for as many traits that will match the first two points above. This may require using results from well designed research trials or from experience.
- choose animals within breeds with known performance for as many important traits as possible.
- an appropriate crossing design will need to be determined to combine the breeds in the desired proportions. If the proportions of breeds are equal then a *balanced* composite is formed. If unequal proportions then what is termed an *optimal* composite is developed.
- research suggests that in the initial crossing of the straightbreds you should use a large number of sires per breed (15 to 20) - this will help avoid inbreeding in the composite and ensure adequate sampling of genes.
- during the development of the composite it is advised to use around 25 sires/generation. This will require a large number of cows (about 500 cows/generation) - this is to slow the accumulated inbreeding in the composite over time.
- perform at least **two** *inter se* matings (random mating within the cross) after the initial crossing to stabilise the breed proportions and both individual and maternal heterosis (see Figure 1) - if not stabilised the foundation breed's contributions and heterosis will vary between generations resulting in variation in performance.
- have lots of money, time and patience especially if several breeds are used in the composite. This is primarily because maintaining a number of breeds and breed combinations is very demanding on management. Also get good technical advice to help ensure everything is designed correctly.

after development (stabilised):

- avoid/manage inbreeding - hybrid vigour will be lost and may lead to the appearance of detrimental traits.
- like any straight breed, further improvement will depend on being performance recorded and the information used to select genetically superior animals.

Figure 1: Example design for the development of a 2-breed balanced composite

Breed A x Breed B	**Parent breeds**
⇓	
1/2A 1/2B x 1/2A 1/2B	F_1 GENERATION
⇓	
1/2A 1/2B x 1/2A 1/2B	F_2 GENERATION
⇓	
1/2A 1/2B x 1/2A 1/2B	F_3 GENERATION
⇓	
.	
⇓	
1/2 A 1/2B	F_n GENERATION

Using a Composite

The other way beef producers can take advantage of composites is to use existing ones (someone else has developed). Choosing a particular composite for your production/marketing environment will involve the same types of decisions as if you were considering a particular straightbreeding or crossbreeding system. That is, the composite under consideration must meet your breeding objectives and production system. If this is the case then using a composite will have the following characteristics:

- the composite can be managed as a straightbred herd.
- the composite can be used in any crossbreeding system.
- it will be possible to become a seedstock supplier of the composite.

For a commercial producer, composite bulls could be used in their herd. Once again the reason for choosing a composite bull would be the same as selecting a bull from any existing breed or a crossbred bull. The composite bull must possess the genetics you require in your breeding program.

Importance of heterosis

One of the genetic resources mentioned that is important in the development of a composite is taking advantage of heterosis. Heterosis or hybrid vigour is defined as the increased performance of the crossbreds relative to the straightbred parents. In genetic terminology, it is the result of increased heterozygosity in the crossbred, commonly a result of recovery from inbreeding in the foundation straightbreds. Simply the crossbred animal has genes sampled from more than one breed and this allows the individual to perform better, particularly under stressful conditions.

Designed studies allows the amount of heterosis exhibited by crossbreds to be measured relative to contemporarily reared straightbreds. Two ways of reporting the amount of heterosis are either as the units of the trait or as a percentage.

Heterosis (units) = mean *performance of crossbreds - mean performance of straightbreds*

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or

$$\textbf{Heterosis \%} = \frac{\text{(mean performance of crossbreds) - (mean performance of straightbreds)}}{\text{(mean performance of straightbreds)}} \times 100$$

Example: heterosis calculation for weaning weight.

Data*:	mean weaning weight of crossbreds		= 208 kg
	mean weaning weight of straightbreds		= 200 kg
Calculation:	a) heterosis (in kg)	= 208 - 200	= 8kg
	b) heterosis (%)	= (208 - 200)/200	= 4%

In this simple example the crossbreds exhibited 8kg or 4% heterosis for weaning weight. An example of this type of system would be a 2-breed cross between Hereford and Angus breeds producing the Hereford x Angus crossbreds.

* These types of results must come from designed studies to ensure valid estimates. Firstly, the crossbreds and straightbreds must be raised together to avoid confounding of environmental effects. Secondly, the sires used to generate the crossbreds must also be used to generate the straightbreds. Lastly, maternal effects need to be considered usually by having reciprocal crosses.

World-wide results from designed studies have estimated heterosis for many crosses and traits. In general heterosis for production type traits such as growth and carcase is usually in the range of 0-10%. Whereas for lowly heritable traits, such as those associated with reproduction, heterosis is usually in the range of 5-25%. In addition, the more genetically diverse the breeds in the cross the higher is the expected level of heterosis (eg. Bos taurus x Bos indicus). The various crossbreeding systems achieve different amounts of heterosis. That maximum amount always occurs in the F_1 cross and therefore is the basis for comparing other systems.

Retention of heterosis in composites

One of the aims of a composite is to retain the benefit in performance due to heterosis without requiring an ongoing crossbreeding program. Heterosis expressed in a stabilised composite (F_3 generation or later) originated from the initial crossing of the straightbreds but the amount is only a proportion of that expressed in the F_1. The *expected* amount of heterosis retained for a combination of individual and maternal traits in a stabilised composite can be calculated as follows:

Retention of heterosis = 1 - sum of (*p*²)

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where *p* is the proportion of each breeds that contributed to the composite i.e. retention of heterosis is the squared breed contributions, summed and subtracted from 1.

For example, if we use the previous example from Figure 1 where two breeds were used in equal proportions (ie. 1/2 Angus and 1/2 Hereford) the expected retention of heterosis is:

$$\text{retention of heterosis} = 1 - [\,(1/2)^2 + (1/2)^2]$$
$$= 1 - 0.5$$
$$= 0.5 \text{ or } 50\%$$

That is, the balanced two-breed composite (when stabilised) will have 50% retention of the heterosis expressed in the F_1. Using our previous weaning weight example, where heterosis was 8 kg in the F_1, the composite will be expected to retain 50% of this or 4 kg of weaning weight.

To maximise the retention of heterosis in a stabilised composite more than four breeds are recommended in equal proportions. A composite with equal proportions of four foundation breeds would theoretically retain 75 % of the heterosis expressed in the mean F_1 (see Table 1). More than four breeds will theoretically retain higher levels of heterosis but the complexity of the initial mating systems usually precludes such designs in practice.

Table 1. Expected retention of heterosis (%) and estimated increase in performance as a result of heterosis for various crossbreeding systems (at stabilisation).

Crossbreeding system	% of maximum heterosis	Estimated increase in calf weight weaned per cow exposed
Straightbreds	0	0
3-breed cross	100.0	23.3
2-breed rotation	66.7	15.5
3-breed rotation	85.7	20.0
Two-breed composite:		
1/2A, 1/2B	50.0	11.6
5/8A, 3/8B	46.9	10.9
3/4A, 1/4B	37.5	8.7
Four-breed composite:		
1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Six-breed composite:		
1/4A, 1/4B, 1/8C, 1/81D, 1/8E, 1/8F	81.3	18.9

Source: Gregory and Cundiff (1980). Journal of Animal Science 51:1124.

United States and New Zealand research has shown that for the majority of traits the actual retention of heterosis in their experimental composites is as expected (using previous equation), however some exceptions do exist. The retention of heterosis is based on retaining heterozygosity, if through selection or inbreeding this is decreased then retention of heterosis in the composite will be reduced and may approach zero.

Note: The expression of heterosis from Bos taurus breeds with Bos indicus breeds is considerably greater than among Bos taurus breeds. Research to date on retention of heterosis in composites is from Bos taurus breeds and it is unknown if the theory will hold under advanced generations of composites with Bos taurus and Bos indicus breeds. Preliminary research indicate possible reduced retention of heterosis for fertility traits.

Advantages of composites

1) Ease of running: a composite can be run as a straightbred (after stabilisation) and therefore is less complicated than many crossbreeding systems such as rotations and therefore reduces management.

2) Faster progress: composites can marry the attributes of several breeds relatively rapidly, particularly lowly heritable traits such as reproduction (but a time lag still exists in development eg. greater than 10 years for a four-breed composite).

3) Heterosis expressed: a composite will express hybrid vigour (not maximum), and is simpler than most crossbreeding systems once stabilised.

4) Small herds: a composite can be used in small commercial herds that are too small to undertake an effectively crossbreeding program.

5) More variation: some composites may exhibit greater genetic variation compared to their foundation straightbreds due do differences in gene frequencies. On one hand this may be seen as a disadvantage, however from a selection point of view it will mean potentially greater response to selection. Research however is showing little evidence of increased in variation in the traits recorded, possibly due to the usual practice of developing composite from similar biological types. For example Clay Centre has not observed any increased variation for the many traits measured in their three composites relative to the straightbred populations.

Limitations of composite development

1) Breed characterisation: the major limitation in the planning stages of a composite is the ability to accurately characterise existing breeds for expected performance for all important traits. The problem is usually compounded if new or exotic breeds are being considered. The risk is that an uncharacterised breed may bring along some unfavourable characteristics that will severely limit the success of the composite. It should be noted that successful composite breeding requires a continually improving straightbred seedstock sector.

2) Within breed differences: large variation between animals exists within a breed or strain. In developing a composite it is very important that the expected performance of breeding animals is known for as many traits as possible. Breeds with an national genetic evaluation system provide genetic information (EBVs) on sires (and dams) however the number of traits available are limited for some breed.

3) Obtaining breeding values: during the development of the composite in the F_1, F_2 and F_3 generations it will important to start selecting superior animals for the next generation (beware of inbreeding and single trait selection). The existing genetic evaluation procedures could be used to identify superior animals within a generation but would need to be modified if selection occurred across F_1, F_2 and F_3 generations. Once stabilised it is important to improve the composite by selecting superior animals as replacements. The problem is that to compute EBVs a database needs to be established to collect pedigree and performance data (traditionally a service provided in straightbreds by the Society). A flow on problem is then the absence of EBVs for sale composite breeding stock to industry.

4) Small population size: initial problem of a new composite is the small population size which may create problems in avoiding inbreeding and also may limit selection for a particular trait especially if little variation exists for the trait(s) of interest. If inbreeding occurs then the initial advantage of the composite due to retention of heterosis will be lost.

5) Heterosis not maximised: as illustrated in Table 1 heterosis is not maximising in a composite compared to certain crossbreeding systems eg. 3-way cross.

6) Maternal and individual effects: for a composite under development it is difficult to exploit breed differences in individual versus maternal performance. Unfortunately when developing a composite it is difficult to pick only the desirable characteristics from an animal. For example a sire may possess desirable growth characteristics but may have too much milk which will also be included in the composite.

7) **Loss of favourable, gene interactions:** during the development of a composite the several generation of crossing may result in the loss of favourable joint effects of genes that were fixed within a straightbreed. This loss of performance is referred to in genetics as recombination or epistatic loss. Research has shown that over a large number of generations straightbred animals have developed genes that in combination have allowed the long term success of the breed. Upon crossing some of these combinations can be lost and have a negative effect on performance (but maybe favourable). Loss of performance due to this effect is very difficult to measure however current knowledge suggests that crosses involving several breeds suffer more loss and composites developed over several generations may also suffer more loss.

8) Increased variability: increased variability for some traits may be a limiting factor in composite breed development, especially for traits under the control of a single gene eg. horns and coat colour. Avoiding this kind of variation appears important for marketing but will restrict the use of valuable breeds and animals if for example only red animals are used in developing a composite.

9) No valid comparisons: one of the greatest limitations of a composite is determining just how good it is. The true test is to compare it with the original straightbreds and intermediate crossbreds, however these would need to be unselected replicates maintained with the developing composite under the same environment. This is only feasible in research herds and therefore in industry it is difficult to determine if a composite is superior to the original foundation breeds.

Open composites

The other variation on the composite theory (and definition presented) is that of an open composite. This is a population developed by mating of two or more pre-existing breeds and genetics from any source can be added at any time. For this type of program to work the breeder must select animals based on a clearly defined breeding objective. Only superior stock should be used for progress to be maintained. Also it is important to consider the possibility of complete breed substitution rather than a slow infusion. Theoretically the open composite could be another efficient way to breed cattle but several limitations exist. Open composites can suffer from large fluctuations in performance between generations and currently the ability to determine superiority of animals (particularly sires) across breeds and crossbreds is difficult primarily due to a lack of suitable data. Also one of the features of the closed composite discussed earlier was the reduced management (after stabilisation), an open composite may have increased management, similar to other crossbreeding systems.

Examples of composites

Listed in Table 2 are some examples of composites. This is by no means an exhaustive list but it should give some idea of the types of composites developed (recently). Distinction is made between who developed the composite: industry or research organisations.

Table 2: Some composite breeds developed by research organisations and industry in Australia and overseas.

Research	**Industry**
Overseas	Overseas
MARC I	Santa Gertrudis
MARC III	Brangus
CGC	Braford
CASH	Beefmaster
RX3	Simbrah
Bonsmara	Shaver Beefblend
New Zealand (6 two-breed)	Leachman Range Maker
	Ankina
Australia	Santa Cruz
Belmont Reds	Luing
Adaptors	
BX	Australia
Wokalups	Beefmakers
Grafton (BxH)	Charbray
AFS	Droughtmaster
AMZ	Mandalong Specials
	Simford

Conclusions

Composites are developed using the various genetic resources. If retained heterosis is an important component of the performance of your composite then it is crucial to avoid inbreeding. Alternatively, if it is particular breed characters and complementarity that will give the composite its edge then selection of animals within and between foundation breeds will be important.

The bottom line is if you are considering developing a composite you should have good reasons for doing so, have clear directions, be large scale and committed to a long term project. The likelihood of success will depend on how well the various recommendations are addressed and probably a good dose of luck. Composites are just another method available to beef producers to improve the efficiency of production.

Glossary of terms

breed: a population in which its members can be identified by performance or pedigree.
composite breed (closed): a population developed by *inter se* (random mating within a cross) mating of two or more existing breeds.
composite breed (open): a population developed by mating of two or more existing breeds and new breeds can be added at any time at any percentage.
EBV: estimated breeding value. An estimate of the genetic merit of an individual for a given trait.
epistasis: interaction between non-paired genes.
F_1: the first filial generation.
F_2: offspring of F_1 x F_1 matings of the same genotype.
F_3: offspring of F_2 x F_2 matings of the same genotype.
heritability: the proportion of the observed variance of a trait that is due to genes transmitted from the parents.
heterosis: differences in the performance of crossbreds compared to the average of the parental breeds or types.
heterozygosity: the frequency of loci in an individual that carries unlike members of a pair of allelles.
hybrid vigour: same as heterosis but usually if increased performance is observed.
inbreeding: mating of individuals that are related to each other by ancestry.
retained heterosis: the amount of heterosis retained at stabilisation as a proportion of that expressed in the F_1
rotation: a crossbreeding system in which two or more breeds are rotated into the population in alternate generations.
specific crossing: crossbreeding systems that simply cross a number of breeds eg. 2-, 3-, 4-breed crosses, backcross.
synthetic: same as composite, however US now using it to describe *open* composites.

* AGBU is a joint institute of the NSW Agriculture and the University of New England.