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Importance of Heterosis in Animals: A Review

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ABSTRACT

Hybrid vigor or heterocyst is the phenomenon in which progeny of crosses between inbred lines or purebred populations are better than the expected average of the two populations or lines for a particular trait. Utilization of heterocyst (hybrid vigor) is the exclusive goal of crossbreeding. The amount of heterosis maintained in a herd depends on the type of crossbreeding system selected. Hybrid vigor includes greater viability, faster growth rate, greater milk, egg and wool production in animals. Heterocyst is an unexpected deviation from the average of the two parental lines. The cause of heterosis the non-additive gene action (dominance, Overdominance and epistasis).No heterosis is observed for traits governed by additive gene action. Heterosis can occur for a wide variety of performance traits. The traits showing heterosis are called as heterotic traits. However, it tends to be greatest for traits with low heritability and least for traits with high heritability. Traits of low heritability (reproductive traits) are generally most benefited from heterosis. They can be improved through the adequate use of crossbreeding systems.

Keywords: crossbreeding, heterosis, crossbred

INTRODUCTION:

In 1914 Professor Shull proposed for the first time the word 'heterosis' (Shull, 1914). The term used to measure crossbred performance compared to the parental average is hybrid vigour also known as heterosis. Hybrid Vigour measures the ability of crossbred offspring to outperform the expected abilities transmitted by their parents. Since the goal of crossbreeding is to combine two, three or four different breeds in order to achieve some desirable trait from each different breed, Heterosis refers to the superiority of the crossbred animal relative to the average of its straightbred parents. Heterosis may be positive or negative depending upon the trait. Positive heterosis is called as hybrid vigour. Heterosis is typically expressed in percentage improvement in the trait of interest. Heterosis results from the increase in the heterozygosity of a crossbred animal's genetic makeup. Heterosis is the result of gene dominance, overdominance and epistasis. Heterosis dependent on an animal having two different copies of a gene. The level of heterozygosity an animal has depends on the random inheritance of copies of genes from its parents. The exploitation of heterosis most important reason for utilising cross breeding in animals along with the exploitation of additive effects from improved purebred animals. Heterosis arises from the effects of gene combinations means effects of pairs of genes (Cassell, 2007). Heterotic effects in the crossbred progeny depends upon the differences in the frequencies of the different alleles at each locus that contributes to the trait (McAllister, 2002), larger these differences greater the heterozygosity and the heterosis effects. Crossbred animals often show increased vitality and performance. This is known as heterosis or hybrid effect. The Sahiwal - Friesian cross resistant to most of the common cattle diseases and has a good milk production. A criss-cross breeding programme is suggested to maintain the hybrid vigour in the offspring of crossbred animals. In general, animals that are crosses of unrelated breeds, such as Angus and Brahman exhibit higher levels of heterosis due to more heterozygosity than crosses of more genetically similar breeds such as a cross of Angus and Hereford. The genetic basis for heterosis is the opposite of the origin of inbreeding depression. Crossbreeding cause more gene pairs to be heterozygous. Breeds that are genetically diverse tend to cause more heterozygosity and more heterosis when crossed. Heterozygosity will result in better performance if there is non-additive gene action (dominance, overdominance and epistasis). Crossbreeding has been shown to be an efficient method to improve reproductive efficiency and productivity and fitness in beef cattle. Crossbred (F_1, F_2 and F_3) females had calves that weighed an average of approximately 5.5 lb. more than purebred calves at birth(Gregory *et al*., 1991).Cross-breeding within species leads to offspring that are genetically fitter than their parents (Darwin, 1876).

Lippman and Zamir (2006) described offspring from parents with greater genetic diversity are genetically fitter than offspring of parents with less diversity. Cross breeds dogs are faster learners than pure breeds (Ennik *et al*., 2006). The increase in corn production (Duvick, 2001), milk production (Ahlborn-Breier and Hokenboken,1991) and meat production (Sellier, 1976) possible with cross-breeding. 16% increase in the pounds of calf weaning weight per cow exposed above the average of the parent breeds (Ritchie *et al*., 1999). Crossbreeding as a mating system optimizes the additive genetic and non-additive (heterotic) breed effects of *Bos taurus* and *Bos indicus* cattle in sustainable breeding systems (Gregory and Cundiff, 1980). The reason for crossbreeding is to increase the dairy cattle production through new combinations of genes in different breeds (Simm, 2000). Heterosis is a result of the non-additive gene effect, dominance and epitasis along with differences in the frequencies of the different alleles at each locus. The total genetic makeup of crossbreds can include additive effects, dominance, maternal effects, maternal heterosis and recombination effects. Which effect that may be present is dependent of the particular kinds of crosses involved (McAllister, 2002). The amount of heterosis expressed for a given trait is inversely related to the heritability of the trait. Generally, heterosis generates the largest improvement in lowly heritable traits. Moderate improvements due to heterosis in moderately heritable traits. Little or no heterosis is observed in highly heritable traits. The highest level of heterosis is most commonly seen in functional traits affecting reproduction, survival and overall fitness. These traits often show at least 10% heterosis and low heritability .Production traits affecting milk yield and growth show about 5% heterosis and a moderately high heritability (Hansen, 2006). The expected level of heterosis is difficult to predict and it differs depending on the type and number of breeds in the crossbreeding system (Sorensen *et al*., 2008). Crossbreeding can also cause negative effects and one of them is recombination loss. It is caused by separation of favorable gene combinations that are accumulated in the parental breeds. Recombination loss can be difficult to estimate although it has been seen to reduce the level of heterosis (Cassell and McAllister, 2009). The highest level of individual heterosis is always seen in the F_1 generation, but unfortunately the level always decreases in subsequent generations. If F_1 cattle are crossed to produce the second generation (F_2), heterosis is halved compared to the level in the F_1. It continues to be halved in every following generation of backcrossing to the parent breeds (Simm, 2000). An alternative to maintain the level of heterosis after creating a two way cross is to produce a three way cross because in the third generation (F_3) or fourth generation (F_4) there is no further decrease in heterosis, as long as no inbreeding exists. The level of heterosis changes depending on the number of breeds in the cross (Sorensen *et al*., 2008). Heins (2007) reported that the Brown-Swiss-Holstein crossbreds had only a slightly reduced milk yield along with a significantly higher yield of milk components, fewer days open and a low number of somatic cells compared to purebred Holstein. Due to heterosis, crossbred Jersey-Holsteins had superior performance compared with purebred Holsteins for milk yield, fat and protein (Bryant *et al*., 2007). Jersey-Holstein crossbred cows maintained body condition score and hence had lower levels of live weight loss after calving (Heins *et al.*, 2008). Cattle and Swine species dependant heavily on heterosis to improve productivity and efficiency of production (Hansen, 2006). In temperate countries, crossbreeding has been widely used in pigs and poultry to exploit both breed differences and heterosis . Crosses between temperate and tropical breeds have often shown large amounts of heterosis, because of the large genetic distance between them. Heterosis is more important under a suboptimal (poor) than in optimal (good) environment. Thus, heterosis is the complement of inbreeding depression and usually appears in traits that show depression of performance under inbreeding. Reproductive traits in dairy cattle are usually very sensitive to inbreeding depression and thus cross breeding or out-crossing can show large heterotic effects. F_1 crosses probably take the advantage of hybrid vigor that arises by crossing two genetically distant populations. Second-generation crosses suffer reduction in hybrid vigor by half than first generation crosses due to segregation and recombination losses (Sendros, 2002). Loss of hybrid vigor is the genetic factor for reduced performances in F_2 crosses, poor selection standards to select F_1 bulls for inter se mating greatly contributed drop in the lifetime performances. F_1 crosses yielded more milk (147%), were milked for more days and had shorter calving interval (McDowell, 1988). Studies in France have shown that the F_1 crosses tend to be above median average of the two breeds for milk but closer to the Normande for components (Hansen, 2010). A three way cross will maintain hybrid vigor in later generations at 86%, while a 2 way cross will at 67% and a 4 way cross at 93% (Hansen, 2006). Three way crosses offer an increased heterosis along with longevity, protein and fat components, and calving ease (Snowdon, 2010). In a three way cross program the F_1 and F_2 generations are both able to maintain 100 % hybrid vigor compared to a two way cross program where hybrid vigor drops to 50 % in the F_2 generation (Pro Cross, 2009). Heterosis is utilized most commonly in beef cattle through crossbreeding. Heterosis in beef cattle can produce calves with enhanced reproductive, survival, longevity (Dhuyvetter, 1998), fertility, growth, meat quality (Peck, 2009) and disease

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resistance traits (Dandapat, 2009). The benefits of heterosis on beef herd quality and consequently profitability (Anderson, 1990) and herd management programs (Brown, 2010). Heterosis achieved through continuous crossbreeding can be used to increase weight of calf weaned per cow exposed to breeding by 20 % (Gregory and Cundiff, 1980). Heterosis can also increase longevity of cows by 1.3 yr and can increase the total calf weight weaned per cow by 30 % over the life span of a dam (Cundiff *et al.*, 1992). Loss of heterozygosity in inter se mated populations does not occur if inbreeding is evaded (Dickerson, 1973). Cows exhibit more hybrid vigour in first and second parities than at later parities (Cundiff *et al.*, 1974). Herefords (Gregory and Cundiff, 1980) among the beef breeds and Holstein (McDowell, 1982) among the dairy breeds appear to have slightly higher than average heterosis (Sorensen *et al.*, 2008). Heterosis has been utilized in beef production to enhance fertility, longevity, growth and meat quality traits in commercial herds through various cross-breeding systems. Application of crossing systems such as three or four-breed crosses would be very difficult, so rotational crossbreeding systems are required to exploit breed and heterotic effects. These schemes allow commercial farmers to produce crossbred female replacements from their own herds. Holstein-Friesian x Jersey crosses show higher net income than purebred HF and Jersey cows, so that dairy farmers mate their cows to bulls from another breed to generate crossbred replacements with the aim of exploiting the effects of breed and heterosis (Lopez-Villalobos, 1998). In rotational systems heterosis is retained at high levels, 66% in two–breed rotation, 86% in three–breed rotation (Handley, 2001)

Measurement of Heterosis:

Percent heterosis can be calculated as:

$$\% \text{ Heterosis} = \frac{[\text{Mean of } F_1 \text{ progeny- mean of parent breed}] \times 100}{\text{Mean of parent breed}}$$

Heterosis in F_1= Mean of F_1 progeny- mean of parent breed

Heterosis in F_2 =1/2 heterosis in F_1

Types of heterosis

There are three main types of heterosis

1) Individual heterosis: The improvement in performance by the individual crossbred animal above average of its parents. Examples of individual heterosis are increased weaning weight, yearling weight and carcass traits.

2) Maternal heterosis: Maternal heterosis is the advantage of the crossbred mother over the average of purebred mothers. Examples of maternal heterosis are younger age at puberty, increased calving rate, increased survival of her calf to weaning, pounds of calf produced in her lifetime higher weaning weights, greater longevity in the dam and other reproductive traits.

3) Paternal heterosis: Paternal heterosis is the advantage of a crossbred sire over the average of purebred sires (Buchanan, 2011). The improvement in productive and reproductive characteristics of the bull. Examples of paternal heterosis are reduced age at puberty, improvements in scrotal circumference, improved sperm concentration, increased pregnancy rate and weaning rate when mated to cows.

Genetic basis of heterosis

There are three theories of heterosis. 1. Dominant theory 2. Over Dominance theory

3. Epistasis theory

1. Dominant theory: Superiority of hybrids to the suppression of undesirable recessive alleles from one parent by dominant alleles from the other parent. The dominance hypothesis was first expressed by the geneticist Charles Davenport (1908)
2. Over Dominance theory: Heterozygote advantage to the survival of many alleles those are recessive and harmful in homozygotes. The overdominance hypothesis was developed independently by East (1908) and Shull (1908).
3. Epistasis theory: It postulates that gene interactions are responsible for heterosis. The epistasis is a phenomenon of interacting genes which are not alleles.

Conclusion

The main benefit of crossbreeding is heterosis, which is the improvement in genetic level in a hybrid offspring above the average of the parent breeds. Crossbreeding schemes is most profitable breeding strategy can assist improve

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growth, reproduction, production and maternal traits, health and overall fitness by taking advantage of heterosis, which results when animals from diverse backgrounds are crossed. Inbreeding must be avoided to retain high levels of heterozygosity and heterosis in composite breeds. The challenge of maintaining heterosis and minimizing inbreeding can only be met using large populations of cattle. If no inbreeding is practiced, the heterosis is retained in composites for several generations. F_2 crosses are not appropriate genotype of choice for dairy production because continuous reduction in hybrid vigor. Traits of low heritability such as fertility, milk yield and longevity are difficult to enhance through pure breeding but are greatly enhanced through crossbreeding leading to improvements in survival, reproductive efficiency and growth rates. The successful exploitation of heterosis depends upon how superior the crosses are over the purebreds and cost of replacement of purebred stock, therefore it is normally practiced in poultry, swine and sheep where the fertility is high and the cost of replacement of purebred stock is essential.

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