

## GERMPLASM UTILIZATION IN BEEF CATTLE

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### SUMMARY

- 1) Generally, high levels of heterosis were observed for growth rate, reproductive, and maternal traits including milk production in  $F_1$  through  $F_4$  generations of three composite populations.
- 2) Heterosis differed among composite populations for some major bioeconomic traits. Results suggest that specific cross heterosis is important; i.e., level of heterosis for some traits may vary among specific breed combinations.
- 3) Generally, retained heterosis in advanced generations of composite populations was equal to, or greater than, expectation based on retained heterozygosity in the three composite populations.
- 4) Results suggest that although there is, generally, a high relationship between retained heterosis and retained heterozygosity the relationship is not linear for all situations; i.e., for some traits and in some breed combinations, retained heterosis may be greater or may be less than expectation based on retained heterozygosity.
- 5) Even though results suggest that specific cross heterosis may be of some importance, it is not feasible to have estimates of  $F_1$  heterosis and of heterosis retained in advanced generations of a large number of specific breed combinations in order to choose breeds as contributors to specific composite populations (breeds). Thus, use of average values for  $F_1$  heterosis and of retained heterosis in advanced generations of *inter se* mated composite populations is suggested for *Bos taurus* breeds.
- 6) These results, generally, support the hypothesis that heterosis in cattle is primarily due to dominance effects of genes. Thus, heterosis in breed crosses can likely be accounted for as recovery of accumulated inbreeding depression that has occurred in breeds since their formation.
- 7) Estimates of genetic standard deviations and of phenotypic coefficients of variation were similar for parental purebreds combined and for composite populations combined for most bioeconomic traits.
- 8) Composite populations (breeds) offer an alternative breeding system that is generally competitive with crossbreeding for using heterosis and is easier to manage regardless of size of herd.
- 9) Composite populations (breeds) offer a procedure that is more effective than continuous crossbreeding for using genetic differences among breeds to achieve and maintain optimum performance levels for major bioeconomic traits on a continuing basis. This includes traits such as: (a) growth rate and size, (b) carcass composition, (c) milk yield, (d) climatic and nutritive adaptability, and (e) age at puberty.

- 10) Large differences among parental breeds were observed for: (a) growth rate and size, (b) age at puberty and scrotal circumference, (c) maternal traits including milk production, and (d) carcass and meat traits.
- 11) Composites were generally intermediate to parental breeds for carcass composition and more closely approached the optimum carcass composition; e.g., Hereford, Angus, and Red Poll (British breeds) had more carcass fat than is optimum, whereas the continental breeds tended to have less carcass fat than is optimum to meet current market requirements in U.S. beef production systems. After adjusting for the effects of carcass weight, composites and contributing purebreds did not differ in carcass composition.

## INTRODUCTION

Heterosis achieved through continuous crossbreeding can be used to increase weight of calf weaned per cow exposed to breeding by 20%. Retention of heterosis was equal to, or greater than, retention of heterozygosity in rotational crossbreeding systems (Gregory and Cundiff, 1980). Comprehensive programs of breed characterization have revealed large differences among breeds for most bioeconomic traits (Gregory et al., 1982; Cundiff et al., 1986). Fluctuation in breed composition between generations in rotational crossbreeding systems can result in considerable variation among both cows and calves in level of performance for major bioeconomic traits unless breeds used in the rotation are of a similar biological type. Use of breeds with similar performance characteristics restricts the use that can be made of breed differences in average genetic merit to meet requirements for specific production and marketing situations (Gregory and Cundiff, 1980). Retention of initial ( $F_1$ ) heterozygosity after crossing and subsequent random (*inter se*) mating within the crosses is proportional to  $(n-1)/n$  where  $n$  breeds contribute equally to the foundation. When breeds used do not contribute equally to the foundation of a composite breed, percentage of mean ( $F_1$ ) heterozygosity retained is proportional to  $1 - \sum P_i^2$ , where  $P_i$  is the fraction of each of  $n$  contributing breeds. This loss of heterozygosity occurs between the  $F_1$  and  $F_2$  generations, and if inbreeding is avoided, further loss of heterozygosity in *inter se* mated populations does not occur (Wright, 1922; Dickerson, 1969, 1973). The primary objectives of this experiment were: 1) to estimate retention of combined individual and maternal heterosis in advanced generations of composite populations mated *inter se* to determine the potential of composite breeds as a more simple procedure than continuous crossbreeding for using heterosis and as a more effective procedure than continuous crossbreeding for using genetic differences among breeds to achieve and maintain optimum additive genetic (breed) composition for major bioeconomic traits; and 2) to evaluate differences among parental breeds for production, carcass, and meat traits.

## MATERIALS AND METHODS

**Populations.** Contributing purebreds and matings to establish three composite populations and their breed composition are shown in Table 1. In this experiment the  $F_1$  is defined as the first generation that reflects the final breed composition of a composite population. As indicated by Table 1,  $F_1$ ,  $F_2$ , and  $F_3$  generations were mated *inter se* to produce, respectively,  $F_2$ ,  $F_3$ , and  $F_4$  generation progeny in the three composite populations. Composite populations were formed from the same sires and dams represented in the nine contributing purebreds. This experiment was conducted over a period of 14 yr (1978-1992). A total of 21,530 animals by 832 sires (12,612 purebreds by 523 sires and 8,918 composites by 309 sires) were produced in the 21 populations in the experiment; e.g., nine purebreds and  $F_1$ ,  $F_2$ ,  $F_3$ , and  $F_4$  generations in each of the three composite populations. Linear functions of least squares means of parental breeds and for the  $F_1$ ,  $F_2$ , and combined  $F_3/F_4$  generations of each composite were computed to estimate heterosis for  $F_1$ ,  $F_2$ , and combined  $F_3/F_4$  progeny; e.g., heterosis = value of composite population minus value for contributing purebreds weighted by their contribution (1/4 or 1/8) to a composite population. Values presented are means

for the three composite populations.

**Experimental Protocol.** All females produced in the experiment were exposed to breeding except all  $F_4$  generation progeny were removed from the experiment at an age of one yr. Excess animals were removed from the experiment based on non-performance criteria. Extremes in regard to growth and size, fat, and skeletal and muscular anatomy were avoided in identifying sires in all purebred and composite populations. A broad pedigree base was maintained in all breed groups. Matings were random except half-sib or closer matings were avoided. Except for the last four years (1988 through 1991), all males were retained intact to an age of one yr. In 1988-1991, except for males needed for replacement, all males from the nine purebreds and from the  $F_3$  generation of the three composite populations were castrated at an average age of 203 d and fed by breed group for an average of 235 d and serially slaughtered (4 slaughter groups at intervals of 20 to 22 d) at an average age of 438 d to obtain information on growth, feed efficiency, carcass, and meat traits.

## RESULTS AND DISCUSSION

Heterozygosity in  $F_1$ ,  $F_2$ , and  $F_3$  generations is provided in Table 1. Genetic expectations for individual ( $H^i$ ) and maternal ( $H^m$ ) heterosis in each generation of each composite are shown in Table 1 assuming that retention of heterosis is proportional to retention of heterozygosity.

### Heterosis and Heterosis Retention

Mean estimates of combined individual ( $H^i$ ) and maternal ( $H^m$ ) heterosis for the three composites for major bioeconomic traits for  $F_1$ ,  $F_2$ , and combined  $F_3/F_4$  generations and deviations from expectation based on retained heterozygosity are presented in Table 2.

**Intact Males- Growth and Size Traits.** Mean heterosis was significant in each generation for all traits evaluated. Retained heterosis in the combined  $F_3/F_4$  generation was greater ( $P < .05$ ) than expectation for birth weight and 368-d weight, but did not differ ( $P > .05$ ) from expectation for other traits.

**Females- Growth and Size Traits.** Mean heterosis was significant in each generation for all traits evaluated. Retained heterosis was greater ( $P < .05$ ) than expectation for birth weight, 368-d weight, 522-d weight, and adult height, but did not differ ( $P > .05$ ) from expectation for other traits.

**Reproductive and Maternal Traits.** Mean heterosis was significant for all traits evaluated in all generations except percentage calf crop weaned in  $F_1$  generation of 2 yr old females and combined  $F_2/F_3$  generations among females of all ages. Retained heterosis was greater ( $P < .01$ ) than expectation based on retained heterozygosity for 200-d calf weight in females of all ages and was less ( $P < .05$ ) than expectation for percentage calf crop weaned in females of all ages. This result on percentage calf crop weaned in females of all ages was caused by a high fetal death loss between pregnancy diagnosis and parturition in Composite MARC III. This is a trait for which combined individual ( $H^i$ ) and maternal ( $H^m$ )  $F_1$  heterosis was not observed in this experiment, nor has individual ( $H^i$ ) nor maternal ( $H^m$ ) heterosis been observed for this trait in other experiments. For our interpretation of this result, see Gregory et al. (1992a). Retained heterosis did not differ ( $P > .05$ ) from expectation for other reproductive traits. Mean retained heterosis was significant for estimated 12 hr milk yield using the weigh/nurse/weigh procedure in  $F_2$  generation dams nursing  $F_3$  generation progeny.

**Growth and Carcass Traits of Castrate Males.** Mean retained heterosis was significant in  $F_3$  generation castrate males for weight at 203 d (initial), 438 d (slaughter), for carcass weight, and for weight of carcass lean, fat and bone. Carcass and meat data were not obtained on  $F_1$  and  $F_2$  generation castrate males.

### Differences Among Breed Groups of Castrate Males

Least squares means for the nine parental breeds and for the  $F_3$  generation of the three composite populations of castrate males are presented in Table 3 for: 1) growth rate and size; 2) percentage longissimus muscle fat; 3) percentage of carcass lean, fat, and bone; and 4) carcass lean, fat, and bone weight. Results for this series of traits are presented to provide an example of the magnitude of breed differences for most bioeconomic traits observed in the experiment. Composites were generally intermediate to parental breeds for carcass composition and more closely approached the optimum for the U.S. marketing system; e.g., Hereford, Angus, and Red Poll purebreds (British breeds) had more carcass fat than is optimum, whereas the continental purebreds tended to have less carcass fat than is optimum to meet current market requirements. After adjusting for the effects of carcass weight, composites and contributing purebreds did not differ in carcass composition.

### Genetic and Phenotypic Variation

Genetic ( $\sigma_g$ ) and phenotypic ( $\sigma_p$ ) standard deviations and phenotypic coefficients of variation (CV) for composites and contributing purebreds are presented in Table 4 for growth and size traits of intact males and for females, some reproductive and maternal traits, and for some growth and carcass traits of castrate males. There were no consistent differences between composites and contributing purebreds in  $\sigma_g$ 's and phenotypic CV's. For traits associated with weight,  $\sigma_p$ 's tended to be slightly larger in composites. This difference in  $\sigma_p$ 's is expected because of the heavier weight of composites (Gregory et al. 1991a,b,c,d; 1992a,b,c; 1994).

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Table 1. Matings to establish composites, retention of heterozygosity and expected retention of heterosis

	Composite Populations			Mean	
	MARC I	MARC II	MARC III		
Parents of F <sub>1</sub> generation <sup>a</sup>	(C x LH) x (B x LA) OR (C x LA) x (B x LH) Reciprocals	(GH) x (SA) OR (GA) x (SH)	(PA) x (RH) OR (PA) x (HR) Reciprocals		
Breed composition of F <sub>1</sub> and subsequent generations	.25B, .25C, .25L .125H, .125A	.25G, .25S .25H, .25A	.25P, .25R .25H, .25A		
F <sub>1</sub> Heterozygosity <sup>b</sup>	.94 <sup>d</sup>	1	1	.98	
F <sub>2</sub> Heterozygosity	.78	.75	.75	.76	
F <sub>3</sub> Heterozygosity	.78	.75	.75	.76	
	<u>Dam</u> <u>Progeny</u>				
Heterosis <sup>c</sup>	F <sub>1</sub> F <sub>2</sub>	.78 H <sup>i</sup> + .94 H <sup>m</sup>	.75 H <sup>i</sup> + 1 H <sup>m</sup>	.75 H <sup>i</sup> + 1 H <sup>m</sup>	.76 H <sup>i</sup> + .98 H <sup>m</sup>
Heterosis	F <sub>2</sub> F <sub>3</sub>	.78 H <sup>i</sup> + .78 H <sup>m</sup>	.75 H <sup>i</sup> + .75 H <sup>m</sup>	.75 H <sup>i</sup> + .75 H <sup>m</sup>	.76 H <sup>i</sup> + .76 H <sup>m</sup>
Heterosis	F <sub>3</sub> F <sub>4</sub>	.78 H <sup>i</sup> + .78 H <sup>m</sup>	.75 H <sup>i</sup> + .75 H <sup>m</sup>	.75 H <sup>i</sup> + .75 H <sup>m</sup>	.76 H <sup>i</sup> + .76 H <sup>m</sup>

<sup>a</sup>Composite populations were established from same animals used in purebred foundation where C = Charolais, L = Limousin, H = Hereford, B = Braunvieh, A = Angus, G = Gelbvieh, S = Simmental, P = Pinzgauer, and R = Red Poll.

<sup>b</sup>Retention of initial (F<sub>1</sub>) heterozygosity following crossing and subsequent random mating within the crosses (*inter se*) is proportional to  $1 - \sum P_i^2$ , where P<sub>i</sub> is the fraction of each of *n* breeds contributing to the foundation of a composite population. Loss of heterozygosity occurs between the F<sub>1</sub> and F<sub>2</sub> generations. If inbreeding is avoided, further loss of heterozygosity is not expected.

<sup>c</sup>H<sup>i</sup> denotes individual heterosis expressed by progeny of a given generation and H<sup>m</sup> denotes maternal heterosis expressed by their dams assuming that retention of heterosis is proportional to retention of heterozygosity.

<sup>d</sup>.94 instead of 1 because both sires and dams of F<sub>1</sub> generation were one-fourth Limousin.

Table 2. Mean heterosis in  $F_1$ ,  $F_2$ , and combined  $F_3/F_4$  generations and deviations from expectation in composite populations of beef cattle

Traits	$F_1$ minus Purebreeds	$F_2$ minus Purebreeds	Combined $F_3/F_4$ minus Purebreeds	Deviation from expectation in $F_1/F_4$ generations <sup>a</sup>
<u>Intact males-growth and size traits</u>				
Birth wt, kg	1.4**	2.3**	2.3**	1.2**
200-d wt, kg	20.4**	15.5**	15.3**	-.2
368-d wt, kg	28.8**	26.6**	27.1**	5.2*
368-d ht, cm	2.4**	1.6**	1.9**	.1
368-d cond. score <sup>b</sup>	.4**	.4**	.2**	-.1
368-d scrotal cir., cm	1.3**	.9**	1.1**	.1
<u>Females-growth and size traits</u>				
Birth wt, kg	1.8**	2.2**	2.3**	9**
200-d wt, kg	18.0**	14.8**	14.7**	1.0
368-d wt, kg	26.0**	23.3**	23.6**	3.8*
368-d ht, cm	2.0**	1.5**	1.8**	.3
368-d cond. score <sup>b</sup>	.7**	.5**	.4**	-.1
522-d wt, kg	20.5**	22.2**	20.7**	5.1**
522-d ht, cm	1.7**	1.5**	1.5**	.2
Adult wt, kg	21.2**	17.3**	18.4**	2.3
Adult ht, cm	.8**	.9**	1.3**	.7**
Adult cond. score <sup>b</sup>	.4**	.3**	.2**	-.1
<u>Reproductive and maternal traits<sup>c</sup></u>				
Age at puberty, d	-21**	-18**	-17**	1.0
Pregnant - 1 yr, %	3.4 <sup>†</sup>	6.2**		3.4 <sup>†</sup>
Calf crop wnd. - 2 yr., %	3.6	4.6**		1.6
200-d calf wt - 2 yr., kg	15.0**	15.4**		2.5
200-d calf wt/ female exposed - 2 yr., kg	15.5**	18.1**		5.2
<u>All ages</u>				
Pregnant, %	5.5**	3.4**		-1.2
Calf crop wnd., %	6.3**	2.1		-3.1*
200-d calf wt., kg	15.1**	16.3**		3.3**
200-d calf wt./ female exposed, kg	25.1**	16.6**		-4.2
12 hr milk yield, kg		.7**		
<u>Growth and carcass traits - castrate males</u>				
Initial wt, 203 d, kg			15.8**	
Slaughter wt, 438 d, kg			22.8**	
Carcass wt, kg			14.8**	
Carcass lean wt, kg			5.6**	
Carcass fat wt, kg			8.2**	
Carcass bone wt, kg			1.2**	

<sup>†</sup>P < .10. \*P < .05. \*\*P < .01.

<sup>a</sup>+ = greater heterosis than expectation; - = less heterosis than expectation, based on retained heterozygosity.

<sup>b</sup>9 = high, 1 = low.

<sup>c</sup>F<sub>1</sub> and combined F<sub>2</sub>/F<sub>3</sub> generation females producing, respectively, F<sub>2</sub> and combined F<sub>3</sub>/F<sub>4</sub> generation progeny.

Table 3. Least squares breed group means for growth and carcass traits of castrate males

Breed group	N	Initial	Slaughter	Carcass	Longiss.	Carcass lean		Carcass fat		Carcass bone	
		wt, 203 d, kg	wt, 438 d, kg		wt, kg	fat, %	%	kg	%	kg	%
μ	1,596	258	549	333	4.0	58.8	186	26.0	83	15.2	48
Red Poll	114	250	525	315	4.6	56.0	167	29.1	88	14.9	44
Hereford	132	217	507	306	4.5	53.8	156	31.8	94	14.4	42
Angus	117	233	515	316	4.8	54.9	164	31.0	94	14.1	42
Limousin	138	241	519	330	2.8	64.6	202	21.1	67	14.3	45
Braunvieh	137	273	567	339	3.7	60.1	194	23.3	76	16.5	53
Pinzgauer	119	276	557	331	4.2	59.8	188	24.1	76	16.1	51
Gelbvieh	147	277	567	340	3.2	62.4	202	21.8	72	15.8	51
Simmental	126	274	581	348	3.7	61.1	201	22.8	76	16.1	53
Charolais	124	266	573	348	3.4	61.2	202	22.5	75	16.2	53
D.05 <sup>a</sup>		10.7	19.2	12.4	.5	1.3	7.1	1.5	6.3	.4	2.0
MARC I, F <sub>3</sub>	157	265	563	345	3.6	60.0	197	25.1	83	14.9	49
MARC II, F <sub>3</sub>	146	274	573	347	4.3	56.4	186	29.0	97	14.7	48
MARC III, F <sub>3</sub>	139	254	543	329	4.6	55.3	173	29.9	95	14.8	46
D.05 <sup>b</sup>		11.0	19.7	12.7	.5	1.4	7.3	1.5	6.6	.4	2.1

<sup>a</sup>D.05 is the approximate difference between means of parental breeds required for significance.

<sup>b</sup>D.05 is the approximate difference between means of all breed groups required for significance.

Table 4. Genetic ( $\sigma_g$ ) and phenotypic ( $\sigma_p$ ) standard deviations and phenotypic coefficients of variation (CV) for contributing purebreds and composites

	Purebreds				Composites			
	$\sigma_g$	$\sigma_p$	$\bar{X}$	CV	$\sigma_g$	$\sigma_p$	$\bar{X}$	CV
<u>Intact males-growth and size traits</u>								
	N = 4,115				N = 3,421			
Birth wt, kg	3.5	4.7	42.6	.11	3.2	5.3	43.3	.12
200-d wt, kg	11.0	21.0	234	.09	11.8	22.5	241	.09
368-d wt, kg	21.4	34.1	443	.08	20.0	37.4	453	.08
368-d ht, cm	2.1	3.2	125	.03	2.4	3.6	124	.03
368-d cond. score <sup>a</sup>	.5	.8	4.6	.17	.4	.8	5.2	.15
368-d scrotal cir., cm	1.5	2.4	32.4	.07	1.6	2.5	33.2	.08
<u>Females-growth and size traits</u>								
	N = 4,674				N = 3,106			
Birth wt, kg	3.1	4.4	39.5	.11	2.9	4.9	40.5	.12
200-d wt, kg	12.2	20.0	218	.09	9.5	20.7	227	.09
368-d wt, kg	18.9	28.8	333	.09	16.7	30.2	351	.09
368-d ht, cm	2.1	3.2	120	.03	2.3	3.6	120	.03
368-d cond. score <sup>a</sup>	.6	.9	4.9	.18	.5	.8	5.6	.14
522-d wt, kg	22.5	29.3	390	.08	17.2	31.6	404	.08
522-d ht, cm	2.4	3.4	127	.03	2.3	3.6	127	.03
<u>Reproductive and maternal traits</u>								
<u>One/two yr old</u>								
	N = 3,847				N = 2,766			
Age at puberty, d	17.8	29.0	370	.08	14.9	25.4	360	.07
	N = 2,488				N = 1,625			
200-d calf wt, - 2 yr, kg	12.2	21.7	206	.105	10.7	22.6	215	.105
<u>All ages</u>								
	N = 9,619				N = 6,296			
200-d calf wt, kg	12.1	23.2	222	.104	13.6	24.5	232	.106
<u>Growth and carcasss traits-castrate males</u>								
	N = 1,153				N = 441			
Initial wt, 203 d, kg	13.3	23.1	236	.10	14.2	25.5	241	.11
Slaughter wt, 438 d, kg	21.7	42.3	547	.08	28.7	47.2	559	.08
Carcass wt, 438 d, kg	12.4	27.6	331	.08	17.9	30.8	340	.09
Carcass lean wt, kg	8.1	16.1	190	.08	10.7	17.2	188	.09
Carcass fat wt, kg	8.6	13.6	76	.18	6.3	16.2	86	.19
Carcass bone wt, kg	2.8	4.1	48	.08	2.1	4.9	48	.10

<sup>a</sup>9 = high, 1 = low.