

## Possible Genetic Improvement in Dairy Cattle with Improving Reproductive Rates<sup>†</sup>

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### 젖소에 있어서 개량생산 비율에 의한 유전 개량 효과<sup>†</sup>

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### SUMMARY

Genetic changes from improving female's reproductive rate through *in vitro* fertilization of large number of oocytes were studied. The breeding scheme employed was multiple ovulation and embryo transfer of juveniles and adults. Both balanced and unbalanced matings were examined for the four closed progeny population sizes,  $10^3$ ,  $10^4$ ,  $10^5$ ,  $10^6$ . In balanced matings, all selected sires and dams were mated to each other (cross-classified mating) while unbalanced matings allowed selected dams and sires mated partially, eg. unbalanced matings allowed averages of .5 and .25 progeny per each mating. Various numbers of selected sires and dams were also examined in both balanced and unbalanced matings. In all mating schemes, selection of males and females was restricted to be one from each fullsib family to reduce the rate of inbreeding. The model calculations were deterministic and accounted for the effects of selection and inbreeding on loss of the genetic variation in succeeding generations. Balanced rectangular mating schemes, where more donors were selected than sires, resulted in larger selection responses than balanced square mating schemes, where equal numbers of sires and donors were selected, and unbalanced rectangular mating. The first round selection responses from the balanced rectangular matings of juvenile MOET, eg. number of progeny per mating equals 2 with 10 sires selected, were 1.192, 1.406, 1.580 and 1.735 times larger than the first round selection responses from the balanced square mating schemes for the given four progeny population sizes,  $10^3$ ,  $10^4$ ,  $10^5$  and  $10^6$ , respectively. Similar results were obtained in adult MOET breeding schemes. However, balanced square matings gave greater selection responses than the unbalanced rectangular matings.

**Key words** : MOET, dairy cattle, IVF, genetic response

### INTRODUCTION

Traditional genetic improvement has been mainly through artificial insemination (A.I.) breeding schemes. The genetic improvement of most

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livestock animals has a great emphasis on the selection of superior sires due to a wide distribution of their semen. By principle of genetic theory, the superior genes are transmitted through the four pathways of Sire to Sire(SS), Sire to Dam(SD), Dam to Sire(DS), and Dam to Dam(DD), from parent to the next offspring generation. However, the A.I. technique has limitations on its application to Dam to Dam path. Acceleration of genetic improvement could be possible from improving female's reproductive rate such as multiple ovulation and embryo transfer (MOET), *in vitro* fertilization(IVF), and nuclear transfer(NT) by collecting a large number of oocytes. Since the first work of Nicholas and Smith(1983), many studies have reexamined the new breeding technologies utilizing various embryo transfer techniques such as MOET(Jeon *et al.*, 1990; Keller *et al.*, 1989), IVF, and recently nuclear transfer(NT). The success of genetic improvement employing such reproductive techniques largely depends upon the number of quality oocytes from a selected donor. The breeding schemes employing MOET, to date, are typically the ones of juveniles and adults. However, the optimum MOET breeding scheme should be the one with mixture of juvenile and adult schemes. The population on which the improved reproductive techniques are to be used is mainly the nucleus herd with the most superior breeding females, so-called, elite cows. Both open and close breeding schemes are applicable but the open scheme is more preferred. The breeding size should be ideally over 200 donors. And also, the number of transferable embryos should be over 4(Jeon *et al.*, 1990). Unlike MOET, IVF and NT need some cautions that direct distribution of embryos by IVF and NT into cow population may result in undesirable direction of selection objectives due to lower selection accuracy, which is resulted from

the untested progeny, or own performance. The maximum selection accuracy from IVF and IVF breeding schemes theoretically cannot exceed 50%. However, the major advantages are the shorter generation intervals, production of multiple progeny from selected parents, and increased selection intensity of cows to produce cows. The objective of this study was to examine the changes of genetic responses for closed dairy cattle populations employing juvenile and adult MOET breeding schemes possible in the future with improving female's reproductive rate by using IVF.

## MATERIALS AND METHODS

### 1. Breeding structure

To examine the possible genetic gains utilizing the improved reproductive rates, the closed dairy populations were operated solely with MOET, IVF, and NT breeding techniques. The parameters used for the simulation was presented in Table 1. The base populations were at genetic equilibrium state, 2) at the initial selection, estimated breeding values of sires were not included and only dam's record was included, and 3) collection of a large number of oocytes were possible by improving a female's reproductive rate with IVF.

### 2. Model calculations

The model used was the selection index(Rendel and Robertson, 1950) but was modified to account for the loss of genetic variation due to selection and inbreeding. For juvenile MOET, sires and dams were reevaluated when their sibs records were available, which updated and optimized index weights. This is in practice similar to the animal model with BLUP. Even though index equations used in this study ignored the information on distant relatives, this is

**Table 1. Parameters and definitions used in the study**

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Trait : Milk yield  
Heritability : 0.25  
Phenotypic standard deviation : 1  
Repeatability : 0.5  
Selection strategy : Truncation selection  
Mating method :  
1) Balanced square mating(BSM) eg., NS= ND  
2) Balanced rectangular mating(BRM) eg., ND>NS  
3) Unbalanced rectangular mating (UBRM) eg., ND>NS  
Progeny population size : 10<sup>3</sup>, 10<sup>4</sup>, 10<sup>5</sup>, 10<sup>6</sup>  
Number of sires (NS) : 10, 25, 50, 100, 250  
Number of progeny per cell (NPC) : 0.25, 5, 1, 2, 4, 10, 20, 40, 100  
Number of dams (ND) :  
1) Balanced : ND=NPS / (NS×NPC)  
2) Unbalanced : ND=NPS / (NS×NPC×0.5)  
ND=NPS / (NS×NPC×0.25)  
Rate of progeny /donor : NPC×NS

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not a problem due to the small effect on the accuracy of selection. For adult MOET, the index equation also included estimated breeding values of sires(EBVS) and dams(EBVD). The parameters used are listed in Table 1. The outline for the model calculations of juvenile MOET follows:

- 1) Set up a base population and select based on only dams records.
- 2) From second round selection, EBVS and EBVD were updated and selection was based on pedigree index(.5EBVS + .5EBVD).
- 3) Mate all males and females (completely cross-classified) for the balanced mating schemes, or mate partially(incompletely cross-classified).

For adult MOET, males in base population were selected on dams records only but females were selected on their own records. For the pre-

diction of genetic responses, only two pathways(Male and Female) were considered. The asymptotic rate of selection response was not possible if both selection and inbreeding were considered unless no response was achieved due to a complete loss of additive genetic variation from 100 % inbreeding. The inbreeding coefficient at generation t, F<sub>t</sub>, was approximated (Falconer, 1989) as :

$$F_t = dF + (1-dF)F_{t-1} \quad [1]$$

where dF is a rate of inbreeding and approximated as 1 / (2Ne) and Ne is an effective number of parents per generation. The Ne is approximated as (Robertson, 1961):

$$Ne_x = (N_x + i^2_{x\rho_x}) / (1+i^2_{x\rho_x}) \quad [2]$$

where Ne<sub>x</sub> is the effective number of parents of sex x; N<sub>x</sub> is the number of selected parents for sex x; and ρ is the weighted intraclass correlation of estimated breeding values of families (Keller *et al.*, 1990). ρ was approximated as the weighted average intraclass correlation of fullsib(FS), paternal halfsib(PHS), and maternal halfsib(MHS) families. Then, the effective number of parents was approximated as :

$$Ne = (4Ne_m Ne_f) / (Ne_m + Ne_f) \quad [3]$$

where Ne<sub>m</sub> and Ne<sub>f</sub> are effective number of male and female parents, respectively.

## RESULTS AND DISCUSSION

Kinghorn *et al.* (1991) earlier studied juvenile MOET with balanced square mating (BSM), schemes. They found the larger responses were obtained as numbers of selected parents increased within a given population size. This was ma-

**Table 2. Predicted genetic responses and inbreeding coefficients(F) for balanced square mating(BSM) of juvenile MOET**

NPS	$\Delta G$ and F	Number of sires				
		10	25	50	100	250
$10^3$	$\Delta G_1$	.219				
	$\Delta G_{20}$	5.149				
	$F_{20}$	.659				
$10^4$	$\Delta G_1$	.219	.269	.302		
	$\Delta G_{20}$	5.537	7.130	8.111		
	$F_{20}$	.659	.443	.299		
$10^5$	$\Delta G_1$	.219	.269	.302	.333	
	$\Delta G_{20}$	5.651	7.315	8.462	9.465	
	$F_{20}$	.659	.443	.299	.189	
$10^6$	$\Delta G_1$	.219	.269	.302	.333	.370
	$\Delta G_{20}$	5.681	7.374	8.520	9.563	10.771
	$F_{20}$	.659	.433	.299	.189	.096

$G_1$  is a response from the 1st round of selection;  $G_{20}$  and  $F_{20}$  are accumulative response and inbreeding coefficient, respectively, after 20 generations of selection.

**Table 3. Predicted genetic responses and inbreeding coefficients(F) for balanced square mating(BSM) of adult MOET**

NPS	$\Delta G$ and F	Number of sires				
		10	25	50	100	250
$10^3$	$\Delta G_1$	.329				
	$\Delta G_{20}$	4.152				
	$F_{20}$	.222				
$10^4$	$\Delta G_1$	.329	.404	.454		
	$\Delta G_{20}$	4.443	5.487	6.084		
	$F_{20}$	.225	.098	.050		
$10^5$	$\Delta G_1$	.329	.404	.454	.499	
	$\Delta G_{20}$	4.517	5.611	6.330	6.955	
	$F_{20}$	.225	.098	.051	.026	
$10^6$	$\Delta G_1$	.329	.404	.454	.499	.555
	$\Delta G_{20}$	4.536	5.645	6.365	7.020	7.795
	$F_{20}$	.225	.098	.051	.026	.011

$G_1$  is a response from the 1st round of selection;  $G_{20}$  and  $F_{20}$  are accumulative response and inbreeding coefficient, respectively, after 20 generations of selection.

inly due to more cells of cross-classified matings, which increased the selection intensities. The same study was examined in this paper (Table 2) in comparison with adult MOET with BSM scheme (Table 3). As the population sizes

grew larger, selection responses became greater but the difference was not significant in population sizes greater than  $10^5$ . For a given population size, greater selection responses were obtained as the number of sires increased. This

Table 4. Genetic responses from the first round of selection for rectangular Mating schemes of Jevnile  
 MOET: (.) equals rate of embryos per donor

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	.239(10)	.245(25)			
	10 <sup>4</sup>	.285(10)	.297(25)	.301(50)	.302(100)	
	10 <sup>5</sup>	.324(10)	.338(25)	.345(50)	.349(100)	.352(250)
	10 <sup>6</sup>	.358(10)	.374(25)	.382(50)	.388(100)	.393(250)
2	10 <sup>3</sup>	.261(20)				
	10 <sup>4</sup>	.308(20)	.315(50)	.318(100)		
	10 <sup>5</sup>	.346(20)	.357(50)	.361(100)	.364(200)	
	10 <sup>6</sup>	.380(20)	.392(50)	.398(100)	.403(200)	.407(500)
4	10 <sup>3</sup>	.244(40)				
	10 <sup>4</sup>	.295(40)	.301(100)			
	10 <sup>5</sup>	.335(40)	.345(100)	.349(200)	.351(400)	
	10 <sup>6</sup>	.370(40)	.382(100)	.388(200)	.392(400)	.395(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	.276(100)	.281(250)			
	10 <sup>5</sup>	.320(100)	.328(250)	.332(500)		
	10 <sup>6</sup>	.357(100)	.368(250)	.373(500)	.377(1000)	.379(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	.261(200)				
	10 <sup>5</sup>	.308(200)	.315(500)	.318(1000)		
	10 <sup>6</sup>	.346(200)	.357(500)	.361(1000)	.364(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	.244(400)				
	10 <sup>5</sup>	.295(400)	.301(1000)			
	10 <sup>6</sup>	.335(400)	.345(1000)	.349(2000)	.351(4000)	

Table 5. Accumulative genetic responses after 20 generations of selection for rectangular Mating schemes of Juvenile MOET

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	5.915(10)	5.897(25)			
	10 <sup>4</sup>	7.431(10)	8.125(25)	8.270(50)	8.070(100)	
	10 <sup>5</sup>	8.345(10)	9.340(25)	9.828(50)	10.074(100)	10.072(250)
	10 <sup>6</sup>	9.055(10)	10.190(25)	10.829(50)	11.246(100)	11.529(250)
2	10 <sup>3</sup>	6.319(20)				
	10 <sup>4</sup>	7.911(20)	8.547(50)	8.609(100)		
	10 <sup>5</sup>	8.812(20)	9.789(50)	10.253(100)	10.463(200)	
	10 <sup>6</sup>	9.504(20)	10.629(50)	11.256(100)	11.654(200)	11.905(500)
4	10 <sup>3</sup>	5.900(40)				
	10 <sup>4</sup>	7.629(40)	8.163(100)			
	10 <sup>5</sup>	8.587(40)	9.512(100)	9.923(200)	10.073(400)	
	10 <sup>6</sup>	9.309(40)	10.079(100)	10.991(200)	11.353(400)	11.561(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	7.197(100)	7.529(250)			
	10 <sup>5</sup>	8.268(100)	9.106(250)	9.427(500)		
	10 <sup>6</sup>	9.041(100)	10.079(250)	10.616(500)	10.925(1000)	11.059(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	6.806(200)				
	10 <sup>5</sup>	8.005(200)	8.759(500)	8.987(1000)		
	10 <sup>6</sup>	8.828(200)	9.819(500)	10.309(1000)	10.569(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	6.334(400)				
	10 <sup>5</sup>	7.720(400)	8.361(1000)	8.462(2000)		
	10 <sup>6</sup>	8.605(400)	9.541(1000)	9.976(2000)	10.175(4000)	

Table 6. Accumulative inbreeding coefficients after 20 generations of selection for Rectangular Mating schemes for Juvenile MOET

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	.495(10)	.343(25)			
	10 <sup>4</sup>	.571(10)	.323(25)	.200(50)	.168(100)	
	10 <sup>5</sup>	.673(10)	.413(25)	.240(50)	.123(100)	.072(250)
	10 <sup>6</sup>	.719(10)	.477(25)	.293(50)	.147(100)	.061(250)
2	10 <sup>3</sup>	.538(20)				
	10 <sup>4</sup>	.579(20)	.342(50)	.247(100)		
	10 <sup>5</sup>	.637(20)	.390(50)	.231(100)	.136(200)	
	10 <sup>6</sup>	.680(20)	.446(50)	.273(100)	.149(200)	.065(500)
4	10 <sup>3</sup>	.561(40)				
	10 <sup>4</sup>	.561(40)	.346(100)			
	10 <sup>5</sup>	.621(40)	.373(100)	.223(200)	.146(400)	
	10 <sup>6</sup>	.669(40)	.408(100)	.259(200)	.142(400)	.067(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	.544(100)	.392(250)			
	10 <sup>5</sup>	.599(100)	.353(250)	.225(500)		
	10 <sup>6</sup>	.652(100)	.408(250)	.242(500)	.135(1000)	.080(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	.544(200)				
	10 <sup>5</sup>	.581(200)	.345(500)	.247(1000)		
	10 <sup>6</sup>	.637(200)	.390(500)	.231(1000)	.136(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	.569(400)				
	10 <sup>5</sup>	.563(400)	.349(1000)	.299(2000)		
	10 <sup>6</sup>	.622(400)	.373(1000)	.224(2000)	.146(4000)	

Table 7. Genetic responses from the first round of selection for Rectangular Mating schemes of Adult MOET

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	.326(10)	.361(25)			
	10 <sup>4</sup>	.373(10)	.413(25)	.436(50)	.454(100)	
	10 <sup>5</sup>	.412(10)	.454(25)	.479(50)	.500(100)	.523(250)
	10 <sup>6</sup>	.446(10)	.490(25)	.516(50)	.539(100)	.564(250)
2	10 <sup>3</sup>	.370(20)				
	10 <sup>4</sup>	.417(20)	.450(50)	.469(100)		
	10 <sup>5</sup>	.456(20)	.491(50)	.513(100)	.531(200)	
	10 <sup>6</sup>	.490(20)	.527(50)	.550(100)	.570(200)	.592(500)
4	10 <sup>3</sup>	.354(40)				
	10 <sup>4</sup>	.404(40)	.436(100)			
	10 <sup>5</sup>	.445(40)	.479(100)	.500(200)	.518(400)	
	10 <sup>6</sup>	.480(40)	.516(100)	.539(200)	.558(400)	.580(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	.386(100)	.415(250)			
	10 <sup>5</sup>	.430(100)	.463(250)	.483(500)		
	10 <sup>6</sup>	.467(100)	.502(250)	.524(500)	.543(1000)	.564(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	.370(200)				
	10 <sup>5</sup>	.417(200)	.450(500)	.469(1000)		
	10 <sup>6</sup>	.456(200)	.491(500)	.513(1000)	.531(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	.354(400)				
	10 <sup>5</sup>	.404(400)	.436(1000)			
	10 <sup>6</sup>	.445(400)	.479(1000)	.500(2000)	.518(4000)	



Table 8. Accumulative genetic responses after 10 generations of selection for rectangular Mating schemes of Adult MOET

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	4.460(10)	4.398(25)			
	10 <sup>4</sup>	5.672(10)	5.983(25)	6.022(50)	5.912(100)	
	10 <sup>5</sup>	6.442(10)	6.910(25)	7.115(50)	7.229(100)	7.246(250)
	10 <sup>6</sup>	7.060(10)	7.596(25)	7.854(50)	8.039(100)	8.200(250)
2	10 <sup>3</sup>	4.884(20)				
	10 <sup>4</sup>	6.131(20)	6.369(50)	6.365(100)		
	10 <sup>5</sup>	6.905(20)	7.304(50)	7.475(100)	7.560(200)	
	10 <sup>6</sup>	7.526(20)	7.989(50)	8.214(100)	8.372(200)	8.504(500)
4	10 <sup>3</sup>	4.481(40)				
	10 <sup>4</sup>	5.575(40)	5.958(100)			
	10 <sup>5</sup>	6.306(40)	6.834(100)	7.101(200)	7.262(400)	
	10 <sup>6</sup>	6.902(40)	7.507(100)	7.835(200)	8.065(400)	8.249(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	5.393(100)	5.682(250)			
	10 <sup>5</sup>	6.207(100)	6.661(250)	6.859(500)		
	10 <sup>6</sup>	6.859(100)	7.396(250)	7.659(500)	7.832(1000)	7.961(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	5.189(200)				
	10 <sup>5</sup>	6.079(200)	6.467(500)	6.617(1000)		
	10 <sup>6</sup>	6.777(200)	7.252(500)	7.476(1000)	7.618(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	4.917(400)				
	10 <sup>5</sup>	5.901(400)	6.225(1000)	6.330(2000)		
	10 <sup>6</sup>	6.647(400)	7.069(1000)	7.261(2000)	7.377(4000)	

Table 9. Accumulative inbreeding coefficients after 10 generations of selection for Rectangular Mating schemes for Adult MOET

NPS	NPS	Number of sires				
		10	25	50	100	250
1	10 <sup>3</sup>	.140(10)	.078(25)			
	10 <sup>4</sup>	.149(10)	.059(25)	.033(50)	.025(100)	
	10 <sup>5</sup>	.164(10)	.061(25)	.030(50)	.015(100)	.009(250)
	10 <sup>6</sup>	.176(10)	.064(25)	.031(50)	.015(100)	.006(250)
2	10 <sup>3</sup>	.147(20)				
	10 <sup>4</sup>	.141(20)	.060(50)	.039(100)		
	10 <sup>5</sup>	.149(20)	.059(50)	.030(100)	.016(200)	
	10 <sup>6</sup>	.156(20)	.061(50)	.030(100)	.015(200)	.006(500)
4	10 <sup>3</sup>	.164(40)				
	10 <sup>4</sup>	.139(40)	.065(100)			
	10 <sup>5</sup>	.145(40)	.058(100)	.030(200)	.019(400)	
	10 <sup>6</sup>	.152(40)	.060(100)	.030(200)	.015(400)	.007(1000)
10	10 <sup>3</sup>					
	10 <sup>4</sup>	.141(100)	.081(250)			
	10 <sup>5</sup>	.143(100)	.059(250)	.033(500)		
	10 <sup>6</sup>	.150(100)	.059(250)	.030(500)	.015(1000)	.009(2500)
20	10 <sup>3</sup>					
	10 <sup>4</sup>	.149(200)				
	10 <sup>5</sup>	.141(200)	.061(500)	.039(1000)		
	10 <sup>6</sup>	.148(200)	.059(500)	.030(1000)	.016(2000)	
40	10 <sup>3</sup>					
	10 <sup>4</sup>	.167(400)				
	10 <sup>5</sup>	.140(400)	.065(1000)	.051(2000)		
	10 <sup>6</sup>	.146(400)	.059(1000)	.031(2000)	.019(4000)	

result was mainly due to low inbreeding. However, the advantage of selecting more sires were lessened when selecting more than 50 sires. The mating scheme of 10 sires by 10 donors were not practically desirable for juvenile MOET with BSM due to a large accumulation of inbreeding (about 66% after 20 generations).

Considering the genetic responses alone, juvenile MOET with BSM was 25% more efficient than adult MOET with BSM scheme. For the balanced square mating schemes, as large number of parents as possible could be optimum because of more cells to choose animals from, which not only increased the selection intensities but also resulted in much lower inbreeding due to larger number of parents.

Alternative breeding schemes were examined by balanced and unbalanced rectangular mating schemes where more donors than sires were selected for given population sizes (Table 4 to 9). The same numbers of sires were selected as balanced square mating schemes but various numbers of progeny per mating were examined. Since fewer progeny per mating for a given population size were produced, more cells were available for selection of parents in rectangular mating schemes than square mating schemes. This resulted in larger selection responses even with a slightly less selection accuracy while square mating schemes produced more sib-families and increased selection accuracy. Therefore, there was "trade-off" between selection intensity and accuracy. Obviously, rectangular mating schemes gained more benefit from selection intensity than selection accuracy. In rectangular mating schemes, two progeny per cell (NPC=2) overall obtained the largest selection responses. This result was because most cells were filled and consequently achieved highest selection intensities. Unbalanced rectangular mating schemes gave less selection responses than balanced square

mating schemes. In unbalanced matings, selecting more dams lowered the selection intensities, which consequently gave less genetic responses than balanced matings.

## CONCLUSION

For the given sizes of populations, balanced mating schemes were more favorable than unbalanced mating schemes. For balanced mating schemes, rectangular mating schemes showed greater genetic responses than square mating schemes. Among balanced mating schemes, As number of selected sires increased, the selection responses were larger. For a given number of selected sires, as population sizes became larger, the greater selection responses were obtained. The number of 10 selected sires in the four population sizes was not practically recommended due to a high accumulation of inbreeding.

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