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Possibilities of Preventing Deterioration in Reproductive Performance while Improving Milk Production Traits in Holstein Friesian Cattle, Via Using Restricted Selection Indexes

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ABSTRACT

Genetic and phenotypic parameters of productive (305-day yields of milk, MY; fat, FY and protein, PY) and reproductive (days open, DO; number of service per conception, NSC and age at first calving, AFC) traits were estimated from 1180 first lactation records on Holstein dairy cows, daughters of 93 sires and 650 dams, using multi-trait animal model. Seven selection indexes aiming to improve 305-day yields of milk, fat and protein were considered using various combinations of these three traits as sources of information. The full index (I_1), being the most accurate index, had the highest correlation with the true breeding value (r_{TI} = 0.629). Comparable accuracy (r_{TI} = 0.607) would be expected from the single trait index involving milk yield alone. At each round of selection, such a single trait index is expected to result in advantageous productive traits in terms of higher yields of milk (+727.24 kg), fat (+22.10 kg) and protein (+20.68 kg), and disadvantageous reproductive performance in terms of DO (+4.41 day), NSC (+0.01 service) and AFC (+0.15 month). To prevent deterioration in DO, NSC and AFC, separate restrictions were imposed to the full index ($I_{8(DO)}$, $I_{9(NSC)}$ and $I_{10(AFC)}$ respectively). The optimum balance between production and fertility was obtainable via using ($I_{9(NSC)}$) instead of I_1 with slight reduction in accuracy of selection (r_{TI} = 0.590 vs. 0.629) and in expected gain in yields of fat (20.60 vs. 25.12 kg) and protein (19.36 vs. 23.63 kg) but with seemingly tolerable sacrifice in milk yield gain (709.13 vs. 774.07 kg).

Keywords: Holstein Friesian, first lactation, selection indices, milk production traits, reproductive traits.

INTRODUCTION

The enormous increase in cattle milk yield achieved due to selective breeding has been reported (Carthy *et al*., 2015; Oltenacu and Broo, 2010; Oltenacu and Algers, 2005) to be accompanied by declining ability to reproduce, increasing incidence of health problems, and declining longevity in modern dairy cows.

Since antagonistic phenotypic and genetic relationship between milk production and fertility (Zink *et al*., 2012; Riecka and Candrák, 2011) makes improvement of fertility rather difficult, optimum balance between production and fertility must be pursued to maximize profitability.

The objective of this study was to construct selection indexes using first lactation traits, aiming to simultaneously improve the productive traits with restricted genetic changes in days open or number of services per conception or age at first calving.

MATERIALS AND METHODS

Source of Animals:

A total of 1180 first lactation records of Holstein Friesian cows, progeny of 93 sires and 651 dams were used in present work. The data were collected from the private dairy farm Alexandria-Copenhagen located about 76 km from Alexandria using Cairo-Alexandria desert road. The obtained data represented the period from 1998 to 2010 of productive and reproductive records.

Management:

Cows were reared under normal environmental conditions and fed on a commercial ration containing 51.0% yellow corn, 15.5% wheat bran and 29.5% soybean meal and providing 19.7% crude protein and 2567 kcal/kg.

Traits considered:

The productive traits were 305-day milk yield (MY, kg), fat yield (FY, kg) and protein yield (PY, kg), while the reproductive traits were days open (DO, day), number of services per conception (NSC, service) and age at first calving (AFC, month).

Statistical analysis:

VCE-6 software program package (Kovač *et al*., 2002) was applied in this study using multitrait-animal model to estimate the genetic and phenotypic parameters. In matrix notation, the animal model was:

$$\mathbf{y = Xb + Za + e},$$

where:

y = the vector of observations traits,

b = the vector of fixed effects (year and month of birth),

a = the vector of random additive genetic direct effects,

X and Z = known incidence matrices relating observations to the respective fixed and random effects with Z augmented with columns of zeros for animals without records, and

e = the vector of random residual effects.

Definition of the aggregate genotype:

The breeding objective was to maximize the revenue of dairy producers through the selection for higher 305-day milk yield, fat yield and protein yield. The aggregate genotype (T) was defined as:

$$\mathbf{T = a_1\, g_{MY} + a_2\, g_{FY} + a_3\, g_{PY}},$$

where:

g_{MY} = the additive genetic value for 305-day milk yield,

g_{FY} = the additive genetic value for fat yield,

g_{PY} = the additive genetic value for protein yield and

a_1, a_2 and a_3 = the relative economic weights for MY, FY and PY, respectively.

Economic values:

The economic values for MY, FY and PY were assumed using the method described by Lamont (1991) using the following equation:

$$a_i = \frac{\sum_i^n h_i^2}{h_i^2},$$

where: h_i^2 = the heritability estimates of the ith trait included in the aggregate genotype.

Selection indexes:

The traits studied were used in various combinations to construct ten selection indexes (Cunningham *et al.*, 1970) grouped under two strategies as follows:

Strategy i: selection based on productive traits (MY, FY and PY) ignoring the genetic changes in the reproductive traits; and

Strategy ii: selection based on the most accurate index, given no genetic change would occur in one of the reproductive traits (DO, NSC or AFC).

RESULTS AND DISCUSSION

Means and heritabilities

Descriptive analysis with heritability estimates of productive and reproductive traits are shown in Table 1. Means of the first lactation 305-day milk yield (8761.3 kg.) was within the range of other commercial herds of Holstein cows in Egypt (9038 kg, Salem *et al.* 2006; 10847 kg, Abou-Bakr *et al.,* 2006; 8237 kg, Salem and Hammoud, 2016). The mean of AFC (26.5 month) was lower than the value of 29.2 month reported by Salem *et al.* (2006) and the value of 27.1 month reported by Salem and Hammoud (2016). The number of days of 165.8 recorded in the present study for DO was much lower than that of 255 found by Abou-Bakr *et al.* (2000) and greater than the value of 154 obtained by Abou-Bakr *et al.* (2006) and 114 obtained by Salem and Hammoud (2016). The mean of NSC of 2.3 was lower than the value of 2.9 reported by Abou-Bakr *et al.* (2000) and much higher than the value of 1.9 found by Salem and Hammoud (2016). The DO and NSC were found to be much more variable (63.8 to 76.9%, respectively) than AFC (16.8%).

The heritability estimates of MY, FY and PY were moderate (0.37, 0.26 and 0.28, respectively). The present heritability estimate of MY was comparable with previous estimates obtained on Holstein Friesian of 0.36 by Güler *et al.* (2010) and on Dutch Friesian of 0.35 by Van Arendonk *et al.* (1989). However, the present estimate was higher than previous estimates in the range of 0.09 to 0.27 published on other populations of Holstein Friesian cows (Rushdi *et al*., 2014; Toghiani, 2012; Boujenane and Hilal, 2012; Tekerli and Koçak, 2009; Salem *et al*., 2006; Tuna, 2004; Tawfik *et al*. 2000).

The heritability estimates for fat yield of 0.26, Table 1; 0.22, VanRaden *et al.,* 2004; 0.21, Zink *et al*., 2012; 0.21, Kadarmideen *et al*., 2003 were higher than the value of 0.15 reported by Toghiani (2012) and lower than the range of estimates of 0.32 to 0.41 reported by Boujenane (2002), Hoekstra *et al.* (1994) and Van Arendok *et al*. (1989). The present h^2-value for PY (0.28) was higher than literature estimates (e.g. 0.22, VanRaden *et al*., 2004; 0.24, Toghiani, 2012; 0.24, Zink *et al*., 2012).

The heritability estimates for reproductive traits were found to be very low either for DO (0.08, Table 1; 0.04, VanRaden *et al*., 2004; 0.06, Toghiani, 2012; 0.08, Zambrano and Echeverri, 2014), or NSC (0.04, Table 1; 0.04, Kadarmideen *et al*., 2003; 0.04, Zambrano and Echeverri, 2014) or AFC (0.12, Table 1; 0.23, Salem *et al*., 2006). The low heritability estimates of fertility traits may be attributed to the fact that they are influenced by many physiological and environmental factors. On the other hand, continuous improvement in milk production capacity is known to lead to deterioration of reproductive traits which are negatively correlated with productive traits (Cassandro, 2014). Thus, enhancement of management systems and environmental conditions can be a cornerstone in improvement of fecundity traits together with using breeding programs that prevent any deterioration in these traits due to continuous improvement in milk production traits.

Table 1. Trait means ($\bar{X}$), coefficients of variation (CV %), heritability estimates with standard errors (h^2±SE) and economic values of the traits considered

Trait	Emblem	$\bar{X}$	CV%	h^2± SE	Economic value
i. Productive traits					
Milk yield, kg	MY	8761.2	26.80	0.37 ±0.013	2.46
Fat yield, kg	FY	260.4	35.20	0.26 ±0.009	3.50
Protein yield, kg	PY	216.8	37.20	0.28 ±0.011	3.25
ii. Reproductive traits					
Days open, day	DO	165.8	63.80	0.08 ±0.041	…
Services per conception, service	NSC	2.3	76.99	0.04 ±0.097	…
Age at first calving, month	AFC	26.5	16.88	0.12 ±0.012	…

Genetic and phenotypic correlations:

The genetic (r_G) and phenotypic (r_P) correlations between productive and reproductive traits are shown in Table 2. The high lactating cows are expected to produce milk with high yields of fat and protein. This is indicated from the strong positive genetic correlations between MY on one hand and FY (r_G = 0.80, Table 2; 0.96, Boujenane, 2002) and PY (r_G = 0.83, Table 2; 0.81, VanRaden *et al*., 2004) on the other. If fat yield is high due to genotype, cows tend to have milk with moderately high protein yield (r_G= 0.59, Table 2; 0.58, VanRaden *et al*., 2004).

Moderate to high genetic interrelationships were reported in the present study among the reproductive traits (r_G = 0.45 to 0.61). Similar high genetic correlation (0.98) was reported between days open and number of services per conception by Zambrano and Echeverri (2014) on Holstein Frisian.

Unfavorable genetic relationship was observed between days open on one hand and yields of milk (0.24, Table 2), fat (0.13, Table 2, 0.40, Zink *et al.*, 2012) and protein (0.18, Table 2; 0.49, Zink *et al.*, 2012) on the other. The present results showed that cows with the poorest genetic potential for reproductive performance (longer days open, older age at first calving and higher NSC) are those having high genetic potential for milk production (milk yield) and milk components (fat yield and protein yield). Since genetic improvement in milk production traits is expected to produce cows with moderately longer DO (r_G = 0.24), slightly higher NSC (r_G = 0.05) and older AFC (r_G = 0.11) restricting changes in reproductive traits to zero, through selection indexes, would be justifiable.

Table 2. Genetic (above diagonal) and phenotypic (below diagonal) correlations between productive and reproductive traits

Trait	Productive traits			Reproductive traits		
	MY	FY	PY	DO	NSC	AFC
i. Productive:						
Milk yield, MY	…	0.80	0.83	0.24	0.05	0.11
Fat yield, FY	0.48	…	0.59	0.13	0.51	0.04
Protein yield, PY	0.50	0.92	…	0.18	0.47	0.11
ii. Reproductive:						
Days open, DO	0.02	0.21	0.25	…	0.61	0.45
Services per conception, NSC	0.07	0.14	0.13	0.13	…	0.46
Age at first calving, AFC	0.05	0.03	0.02	0.02	0.04	…

Selection Indexes:

Index coefficients, index accuracy (r_{TI}), and relative efficiency (RE) for unrestricted and restricted indices are shown in Table 3.

The maximum accuracy of selection (r_{TI}= 0.629) was obtained using the full index (I_1) including all sources of information. This is due to the higher genetic inter-correlation among them. In terms of accuracy of selection, selection based on an index involving MY with either FY (I_2) or PY (I_3) would be as efficient as the full index (r_{TI} = 0.619 and 0.620, respectively). However, using an index including FY and PY together (I_4) would reduce the accuracy of selection by 30%. On the other hand, use of MY alone in an index (I_5) would be 97% as efficient as the full index and more efficient than use of either FY (I_6) or PY (I_7) alone by 35 and 27%, respectively. From the economic point of view, I_5 including MY alone is obviously the best and the simplest index in improving milk production and its components of fat and protein.

Restricting the full index to result in zero genetic change in DO or NSC or AFC were 35%, 94% and 72%, respectively as efficient as the unrestricted form (I_1). These results indicated the possibility of preventing the expected deterioration in NSC with slight sacrifice in accuracy of selection (6%). Applying the same procedure to prevent the expected genetic deterioration in DO and AFC would cause drastic reduction (65% and 28%, respectively) in accuracy of selection.

Table 3. Index coefficients, indexes standard deviation (σ_I) and accuracy of selection (r_{TI}) estimated from each index (I)

Selection strategy*	index	Index coefficients†			σ_I	r_{TI}	RE
		MY	FY	PY			
Strategy I	I_1	0.840	-3.478	10.995	2002.54	0.629	100
	I_2	0.881	4.420	…	1970.14	0.619	98
	I_3	0.830	…	6,651	1975.30	0.620	99
	I_4	…	-1.991	19.640	1403.80	0.441	70
	I_5	0.984	…	…	1933.57	0.607	97
	I_6	…	12.828	…	1242.25	0.390	62
	I_7	…	…	17.460	1401.52	0.440	70
Strategy II	$I_{8\ (DO)}$	0.052	15.706	-14.088	709.15	0.223	35
	$I_{9\ (NSC)}$	1.003	-5.727	3.643	1879.48	0.590	94
	$I_{10\ (AFC)}$	0.493	22.870	-22.750	1436.15	0.451	72

***: Strategy I: Ignoring genetic change in the reproductive traits; Strategy II: Restricting genetic change in the reproductive traits to zero.**
†: MY= 305-day milk yield; FY= fat yield; PY = protein yield.

Expected genetic change:

Results of expected genetic changes in individual traits of aggregate genotype and related traits are presented in Table 4.

At each round of selection, applying first strategy by selection based on unrestricted indexes (I_1 to I_7) is expected to produce cows with advantageous productive traits in terms of higher yields of milk (448.6 to 747.1 kg), fat (21.3 to 25.1 kg) and protein (19.7 to 23.6 kg), and disadvantageous productive performance in terms of longer DO (+1.8 to 4.6), higher NSC (+0.01 to 0.09) and older AFC (+0.04 to 0.15 month).

Selection based on the most accurate single trait index (I_5) is expected to result in developing cows having higher yields of milk (+727.24 kg), fat (+22.10 kg) and protein (+20.68 kg), but with slightly longer DO (+4.41), higher NSC (+0.01) and older AFC (+0.15 month).

Table 4. Expected genetic changes per generation in aggregate genotype and related traits when using selection indices.

Selection Strategy*	Index	Source of information†	Expected genetic change (Δ_g) in: Productive traits			Reproductive traits		
			MY (kg)	FY (kg)	PY (kg)	DO (day)	NSC (service)	AFC (month)
Strategy I	I_1	MY, FY, PY	747.07	25.12	23.63	4.59	0.03	0.18
	I_2	MY, FY	736.95	24.06	22.47	4.28	0.03	0.14
	I_3	MY, PY	737.27	24.68	23.15	4.42	0.03	0.16
	I_4	FY, PY	507.00	23.81	22.55	2.98	0.09	0.14
	I_5	MY	727.24	22.10	20.68	4.41	0.01	0.15
	I_6	FY	448.60	21.30	19.73	1.84	0.08	0.04
	I_7	PY	506.17	23.80	22.48	2.88	0.09	0.13
Strategy II	$I_{8\,(DO)}$	MY, FY, PY	260.21	10.94	9.45	0.00	0.04	-0.10
	$I_{9\,(NSC)}$	MY, FY, PY	709.13	20.60	19.36	4.53	0.00	0.17
	$I_{10\,(AFC)}$	MY, FY, PY	538.10	17.48	15.77	2.15	0.03	0.00

***: Strategy I: Ignoring Δ_g in the reproductive traits; Strategy II: Restricting Δ_g in the reproductive traits to zero.**

†: MY= 305-day milk yield; FY= fat yield; PY = protein yield; DO = days open; NSC = number of services per conception; AFC = age at first calving.

As compared with its unrestricted form, the full index restricted to zero change in days open ($I_{8(DO)}$) or in age at fist calving ($I_{10(AFC)}$) would result in drastic decline in accuracy of selection by 64.5% and 28.3%, respectively, (Table 3) and in the expected genetic gain in yields of milk (65.20 and 27.97%, respectively), fat (56.45 and 30.41%, respectively) and protein (60.01 and 33.26%, respectively) (Table 4). From the genetic point of view, this result indicates the difficulty of maintaining the present level of DO and AFC of high yielding cows. However, it is possible to prevent the genetic deterioration in NSC via using ($I_{9(NSC)}$) instead of I_1 with slight reduction in accuracy of selection (r_{TI} = 0.590 vs. 0.629, Table 3) and in the expected gain (Table 4) in yields of milk (709.13 vs. 774.07 kg), fat (20.60 vs. 25.12 kg) and protein (19.36 vs. 23.63 kg). The expected genetic improvement in the yields of milk, fat and protein was higher than those reported, using similar indices, on Australian Braunvieh cows by Khalil and Sliman (1989).

CONCLUSION

1-It could be concluded that in case of accepting the idea that the increase in income due to the gain in production could compensate the increase in cost due to the loss in fertility, the use of 305-day milk yield (MY) as a single source of information in the following selection index:

$$\mathbf{I_5 = 0.984\ MY; \quad (r_{TI} = 0.607)}$$

would be recommended to optimize selection for the given aggregate genotype.

2-It would be possible to stop the expected increase in number of services per conception (NSC) by using the following restricted form of the most accurate selection index:

$$\mathbf{I_{9(NSC)} = 1.003\ MY - 5.727\ FY + 3.643\ PY; \quad (r_{TI} = 0.590).}$$

3-It is excluded to envisage restricting I_1 to result in zero genetic change in days open ($I_{8(Do)}$) or in age at first calving ($I_{10(AFC)}$) as it is expected that this would result in huge reduction in both accuracy of selection and expected genetic gain in productive traits.

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إمكانية منع التدهور في الأداء التناسلي الحادث أثناء تحسين صفات إنتاج اللبن في ماشية الهولشتين فريزيان باستخدام أدلة الانتخاب المقيدة

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قُدرت المعالم الوراثية والمظهرية لكل من الصفات الإنتاجية (إنتاج اللبن عند ٣٠٥ يوم، MY؛ كمية الدهن، FY؛ كمية البروتين، PY) والتناسلية (طول الفترة المفتوحة، DO؛ عدد التلقيحات اللازمة للإخصاب، NSC؛ العمر عند أول ولادة، AFC) على عدد ١١٨٠ سجل خاص بالحلبة الأولى على أبقار الهولشتين الحلابة، من نسل ٩٣ طلوقة و ٦٥٠ أم، باستخدام النموذج الإحصائي الحيواني متعدد الصفات. تم بناء سبعة أدلة انتخابية لتحسين صفات إنتاج اللبن عند ٣٠٥ يوم وكمية الدهن والبروتين معتمدة في ذلك على هذه الصفات الثلاث كمصادر للمعلومات. أظهرت النتائج أن الدليل الكامل (I_1) المعتمد على الثلاثة صفات إنتاجية كان الأكثر دقة وارتباطاً بصفات القيمة الوراثية الحقيقة (r_{TI} = ٠.٦٢٩). في حين أن الاعتماد على الدليل الفردي المحتوى على صفى إنتاج اللبن عند ٣٠٥ يوم فقط أظهرت دقة متقاربة للدليل الكامل (r_{TI} = ٠.٦٠٧). مع كل جولة انتخاب بشدة انتخاب = ١ ، فإن هذا الدليل الفردي يتوقع أن يحسن في الصفات الإنتاجية بدرجة مفيدة معبرا عنها في صورة زيادة في كمية إنتاج اللبن عند ٣٠٥ يوم (+٧٢٧.٢٤ كجم) ، كمية الدهن (+ ٢٢.١٠ كجم) وكمية البروتين (+٢٠.٦٨ كجم) مع تأثيرا غير مرغوبة في الأداء التناسلي معبراً عنها في صورة زيادة في طول الفترة المفتوحة (+٤.٤١ يوم)، عدد التلقيحات اللازمة للإخصاب (+٠.٠١ تلقيحه)، والعمر عند أول ولادة (+٠.١٥ شهر). ولمنع التدهور في الصفات التناسلية DO و NSC و AFG تم عمل أدلة انتخابية مقيدة لكل صفة تناسلية بصورة منفردة على الدليل الكامل ($I_{8 (DO)}$ و $I_{9 (NSC)}$ و $I_{10 (AFC)}$، على الترتيب). تم الحصول على التوازن المثالي بين الإنتاج والخصوبة باستخدام الدليل المقيد ($I_{9 (NSC)}$) بدلا من الدليل الكامل I_1 مع انخفاض ضئيل في دقة الانتخاب (r_{TI} = ٠.٥٩١ مقارنة بـ ٠.٦٢٩) وفى الزيادة المتوقعة في كمية الدهن (٢٠.٦٠ مقارنة بـ ٢٥.١٢ كجم) وكمية البروتين (١٩.٣٦ مقارنة بـ ٢٣.٦٣ كجم) مع تضحية يمكن تحملها على ما يبدو في زيادة إنتاج اللبن (٧٠٩.١٣ مقارنة ٧٤٧.٠٧ كجم).