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Selection indices for rabbit improvement

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SUMMARY

Records on 884 litters and 3051 bunnies of the Bauscat (B) and Giza White (G) breeds were used to construct different selection indices.

A series of selection indices and subindices were constructed for both B and G does. An index or subindex based on litter size at weaning, mean bunny weight at weaning, litter size at birth and litter weight at birth could be practically applied to improve the productivity of B and G does, under local Egyptian conditions. Preweaning mortality did not contribute significantly to the different selection indices and subindices. Litter weight at birth made a large contribution to the different indices and subindices constructed. Litter size at weaning contributed little in the subindices to be used to select for mean bunny weight at weaning. Mean bunny weight at weaning made a lower contribution to the subindices to be used to select for litter size at weaning. The expected genetic gain in litter size at weaning was slight in all of the selection indices and subindices constructed because of low heritability values for this trait. Considerable genetic improvement for doe productivity of the G breed might be achieved through selection for mean bunny weight at weaning.

Four selection indices and subindices were constructed for B and G rabbits. The index or subindex based on 6-week weight and 8-week weight was the best criterion for selection for the genetic improvement of 6-week weight and 12-week weight. Six- and 8-week weight contributed substantially while 12-week weight contributed little to the value of most of the selection indices and subindices constructed. The highest total genetic gain attributable to 6- and 12-week weight was obtained when the selection indices or subindices including 6-week weight and 8-week weight were used.

INTRODUCTION

When the objective of a breeding programme is to improve several characters, the most efficient way of using the available information is usually to construct a selection index (Hazel, 1943). There are many aspects of genetics, biometry and economics wrapped up in a selection index for any animal improvement programme. The index should be constructed so as to give greatest emphasis to economically important traits and to those which respond to selection.

In most of the advanced and developing countries the use of doe genetic indices in rabbit breeding programmes is yet to be introduced. But from indices applied to other polytocus animals, it can be noticed that litter size at weaning may be the best criterion for the genetic improvement of doe productivity in breeding programmes for rabbits. McReynolds (1974) in the United States constructed selection indices for New Zealand White rabbits where the correlation between the criterion of selection and the genotype of the target trait, r_{IG}'s, estimated indicated that the most efficient criterion was an index involving 21-day weight (P_{21}) and gain from 21 to 56 days of age (P_G). The index was $I = 0{\cdot}875 P_{21} + 0{\cdot}16 P_G$.

The objective of the present study was to construct selection indices for improving some economic litter and growth traits of importance in rabbits.

Table 1. *Increase in net income per unit change in mean bunny weight at weaning*

Trait	Unit	Relative economic value/unit	
		Bauscat	Giza White
Litter size at weaning	Young	90	93
Mean bunny weight at weaning	Gram	1	1

The proposed indices are constructed to try to achieve the genetic improvement of litter size at weaning, mean bunny weight at weaning and growth traits (body weight at 6 and 12 weeks of age) under the prevailing local Egyptian conditions.

MATERIALS AND METHODS

Data for two breeds of rabbits, Bauscat and Giza White, were collected from the experimental farm of the Faculty of Agriculture at Moshtohor, Zagazig, Egypt in the period from October 1975 to September 1983. At the beginning of the breeding season (October), females within each breed were grouped at random into groups ranging from three to five does. For each group of does a buck from the same breed was assigned at random except for the restriction of avoiding full-sib (full sisters) and half-sib (paternal or maternal half-sisters) matings. Each buck was allowed to produce all its litters from the same females, i.e. all litters were produced by each mated pair. A total of 884 litter trait records and 3051 bunny records were included in the study. Mixed model analyses (Harvey, 1977) were performed in order to quantify the average genetic, phenotypic and environmental variation and covariation of litter traits and rabbit's body weight. A mixed model including effects of parity and month of kindling were used for analysing the data of year-adjusted litter traits. Fifty-two sires and 210 daughters (paternal half-sisters) were used for the analysis of litter traits (litter size and weight at birth and weaning, preweaning mortality and mean bunny weight at weaning). Year-corrected records of bunny weights were analysed using a mixed model including the random effects of sire and dam of bunny in addition to parity, month of birth, litter size at birth and at weaning and sex as fixed effects and litter weight at birth and at weaning as a covariate. Sixty-five sires and 289 dams were used for analysis of the data on rabbit's body weight at 6 weeks and up to 12 weeks of age.

Different selection indices and subindices for improving some economic litter and growth traits were constructed.

Selection index for does

Relative economic values. It is assumed here that rabbits are paid for on the basis of live weight only. Total income is therefore considered to be dependent on the number of young per litter at weaning and mean bunny weight at weaning. Other measures such as litter size at birth, litter weight at birth and preweaning mortality should be included in the doe index when the information on them warrants their inclusion. The estimation procedure followed in this study is to compare the increase in net income from a unit change in number of young per litter at weaning age (35 days) with that from a unit change in mean bunny weight at weaning. Therefore, the relative economic importance of these characters can be estimated from comparison of the increase in mean bunny weight at weaning with the increase in litter size at weaning needed to produce a given increase in rabbit meat production. In these data, the ratios used in construction of the indices are shown in Table 1.

Construction. Doe genetic selection indices were constructed for each breed separately by using the general FORTRAN computer program cited by Cunningham (1977). The information required in constructing a doe genetic selection index were specified in the following four vectors and three matrices:

- Y_i A vector of additive genetic values for the two litter traits ($i = 1, 2$) included in the aggregate genotype, i.e. litter size at weaning and mean bunny weight at weaning, respectively.
- a_i A vector of constants, usually representing the relative economic values of these two litter traits in Y_i ($i = 1, 2$).
- X_j A vector of phenotypic measures for the five variables or sources of information ($j = 1, \ldots, 5$) to be included in the index, i.e. litter size at weaning, mean bunny weight at weaning, mortality to weaning, litter size at birth and litter weight at birth, respectively.
- b_j A vector of weighting factors (partial regression coefficients) that are used in the index ($j = 1, \ldots, 5$).
- P A 5×5 matrix of phenotypic variances–covariances of the five variables in X-variates.

Table 2. *Phenotypic and genetic* variances (on diagonal) and covariances (above diagonal) of litter size at weaning (LSW), mean bunny weight at weaning (WBW), preweaning mortality (PM), litter size at birth (LSB) and litter weight at birth (LBW) in Bauscat and Giza White rabbits*

Variates	LSW	WBW	PM	LSB	LWB
			Bauscat		
LSW	3·784 (0·227)	−111·99 (−9·96)	9·97 (0·45)	1·94 (0·16)	68·41 (5·23)
WBW		17454·79 (1256·87)	89·61 (20·10)	−101·45 (−10·83)	−4860·54 (−900·22)
PM			866·51 (†)	3·08 (0·22)	−90·08 (18·63)
LSB				3·17 (0·04)	123·86 (2·83)
LWB					8453·51 (261·05)
			Giza White		
LSW	2·999 (0·198)	−35·42 (3·86)	−19·64 (−1·90)	1·57 (0·07)	40·25 (3·79)
WBW		18·208·62 (2841·75)	−636·20 (−154·54)	−84·49 (−12·20)	−1992·57 (531·22)
PM			622·56 (56·66)	9·79 (0·67)	274·40 (−122·83)
LSB				3·34 (0·20)	126·66 (5·66)
LWB					8067·73 (806·78)

* Genetic variances and covariances are presented in parentheses.
† Negative estimate of sire component of variance set to zero.

G A 5×2 matrix of genotypic covariances between the five variables in *X*-variates and the two litter traits in *Y*.

C A 2×2 matrix of genotypic variances–covariances of *Y*-traits.

The partial regression coefficients (*b*'s) were computed as $b = P^{-1}Ga$, where P^{-1} is the inverse of the variance–covariance matrix of phenotypic values.

Selection index for 6- and 12-week body weight

An estimate of the economic value of 12-week weight (marketing weight) will depend on the sale price of live young per kilogram. According to the 1985 farm price, the average price per kilogram of live weight of broiler rabbits at 12 weeks of age was estimated to be E.P. 3·0. On the other hand, the economic value of 6-week weight was nil because broiler rabbits are not slaughtered at this age in Egypt. Therefore, the relative economic values used in constructing the selection index in this study were 0·0 and 3·0 for a kilogram of live weight of broiler rabbits at 6 and 12 weeks of age, respectively. Using a FORTRAN computer program cited by Cunningham (1977), selection indices for broiler rabbits of each breed were constructed including three variates (6-, 8- and 12-week live weight), two of them (6- and 12-week weight) being for selection criteria.

RESULTS AND DISCUSSION

Selection for doe traits

Indices. Several selection indices for each breed were constructed using phenotypic and genetic variances and covariances given in Table 2. The design of construction was so drawn that on one side there was an index with all the five variates, which was assumed to be 100% efficient (original index) in the genetic sense, then one variate was dropped at a time till only two traits remained. All possible combinations were obtained and listed in Tables 3 and 4 along with other relevant parameters. The efficiences of these indices relative to the original index were calculated as the ratio of the standard deviations of the two indices (Cunningham, 1969).

The actual index weights (*b*'s) for each of the eight indices are given in Tables 3 and 4. It should be noted that there are large differences in index weights for litter size at weaning in index I_1 *v.* I_3 and I_4 *v.* I_6. The reason is that litter size at birth has been measured in indices I_1 and I_4 (not in I_3 or I_6) and it contributes substantially to total genetic gain in aggregate genotype of I_1 and I_4. The *b* values of litter size at weaning were greater than those of other variates in the different indices. This might be attributed to positive genetic correlations between this trait and other traits which appeared in most cases and to its high absolute economic value. However, a trait of low heritability in the index will generally have a low index weight, although this depends partly on what correlated traits are measured too. In addition, the relative responses in the aggregate genotype depend partly on the underlying genetic and phenotypic correlations between traits. In practice, the relative responses in the aggregate genotype are determined by the appropriate choice of selection index weights.

The contribution of each variate to the index can be measured as the percentage reduction in overall rate of genetic progress which results if that variate

Table 3. *Selection indices, standard deviation (σ_I), value of each variate (v), percentage of total gain attributable to each trait ($\triangle_H$), expected change in each trait ($\triangle_G$), correlation of index with total genotype (r_{IH}), correlation of each individual trait with index, and the relative efficiency (RE) in litter size at weaning (X_1), mean bunny weight at weaning (X_2), preweaning mortality (X_3), litter size at birth (X_4) and litter weight at birth (X_5) of Bauscat does*

	I_1			I_2			I_3			I_4		
	b*	v†	$\triangle_H$‡	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$
1. Variates												
X_1	3·6115	13	40	4·1240	41	70	5·0619	48	41	3·5797	13	40
X_2	0·0368	7	60	0·0469	27	30	0·0238	7	59	0·0366	7	60
X_3	−0·0093	0	—	0·0173	0	—	0·0004	0	—	—	—	—
X_4	5·3947	13	—	−0·0134	0	—	—	—	—	5·3819	13	—
X_5	−0·1380	31	—	—	—	—	−0·0729	20	—	−0·1376	31	—
2. σ_I§	11·2			7·82			9·82			11·29		
3. r_{IH}	0·31			0·22			0·27			0·31		
4. $\triangle_G$ in X_1‖	0·05			0·06			0·05			0·05		
5. $\triangle_G$ in X_2‖	6·70			2·30			5·70			6·70		
6. Correlation of X_1 with I	0·11			0·13			0·09			0·11		
7. Correlation of X_2 with I	0·19			0·07			0·16			0·19		
8 RE to I_1	100·0			69·3			86·9			100·0		

	I_5			I_6			I_7			I_8		
	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$
1. Variates												
X_1	4·1867	45	70	5·0633	51	41	4·1183	57	70	4·1780	65	70
X_2	0·0474	28	30	0·0328	8	59	0·0470	30	30	0·0475	31	30
X_3	—	—	—	—	—	—	0·0174	0	—	—	—	—
X_4	−0·0206	0	—	—	—	—	—	—	—	—	—	—
X_5	—	—	—	−0·0729	20	—	—	—	—	—	—	—
2. σ_I§	7·80			9·81			7·82			7·80		
3. r_{IH}	0·22			0·27			0·22			0·22		
4. $\triangle_G$ in X_1‖	0·06			0·05			0·06			0·06		
5. $\triangle_G$ in X_2‖	2·30			5·70			2·30			2·30		
6. Correlation of X_1 with I	0·13			0·09			0·13			0·13		
7. Correlation of X_2 with I	0·06			0·16			0·07			0·06		
8. RE to I_1	69·1			86·9			69·3			69·1		

* b values are the coefficient of the index being in partial regression coefficients.

† Value of each X variate in index (= percentage reduction in rate of genetic gain for aggregate genotype if ariate is omitted).

‡ Percentages of total economic genetic gain accounted for by gain in each trait.

§ This is the value, in economic units, of the genetic gain in aggregate genotype achieved by one standard eviation on the index.

‖ Expected genetic change in each trait achieved by one standard deviation on the index.

The same notation is followed in Tables 4 and 8.

; omitted. The reduction percentages in rate of enetic progress for aggregate genotype indicate hat preweaning mortality did not contribute to he different selection indices and is, of course, time onsuming to measure. The question arises of hether genetic progress from using selection ndices that include preweaning mortality justifies he effort of recording necessary for calculating this rait. On balance, it seems preferable to omit this ariate from the different indices. From the economic point of view, it is preferable also to use the reduced index (I_8) including litter size at weaning and mean bunny weight at weaning instead of I_2 and I_5. The reason is that the inclusion of litter size at birth adds practically nothing to these two indices. On the other hand, litter weight at birth is considered the most important supplementary variate in the different indices constructed because of the high genetic correlation between this variate and the other variates included in the index.

Table 4. *Selection indices, stand deviations* (σ_I), *value of each variate* (v), *percentage of total gain attributable to each trait* ($\triangle_H$), *expected genetic change* ($\triangle_G$) *in each trait, correlation of index with total genotype* (r_{IH}), *correlation of each individual trait with index, and the relative efficiency* (*RE*) *in litter size at weaning* (X_1), *mean bunny weight at weaning* (X_2), *preweaning mortality* (X_3), *litter size at birth* (X_4) *and litter weight at birth* (X_5) *of Giza White does*

	I_1			I_2			I_3			I_4		
	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$
1. Variates												
X_1	14·3031	11	25	11·2225	10	29	6·9318	5	29	13·7352	18	26
X_2	0·1676	21	75	0·1886	41	71	0·1976	42	71	0·1598	18	74
X_3	0·2158	1	—	0·0516	0	—	−0·1683	1	—	—	—	—
X_4	−16·9290	10	—	−2·3331	1	—	—	—	—	−17·6302	12	—
X_5	0·3204	14	—	—	—	—	0·1295	6	—	0·3573	17	—
2. σ_I	34·11			29·6			30·94			35·12		
3. r_{IH}	0·47			0·40			0·43			0·48		
4. $\triangle_G$ in X_1	0·09			0·09			0·10			0·10		
5. $\triangle_G$ in X_2	25·7			20·6			22·1			26·0		
6. Correlation of X_1 with I	0·20			0·21			0·21			0·22		
7. Correlation of X_2 with I	0·48			0·39			0·41			0·49		
8. RE to I_1	100·0			85·5			90·7			10·30		

	I_5			I_6			I_7			I_8		
	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$	b	v	$\triangle_H$
1. Variates												
X_1	10·6722	17	30	8·2619	11	28	9·4874	13	30	9·7387	18	30
X_2	0·1875	42	70	0·2049	53	72	0·1930	47	70	0·1947	56	70
X_3	—	—	—	—	—	—	−0·0353	0	—	—	—	—
X_4	−1·9519	1	—	—	—	—	—	—	—	—	—	—
X_5	—	—	—	0·1190	6	—	—	—	—	—	—	—
2. σ_I	29·14			30·74			29·00			28·99		
3. r_{IH}	0·40			0·42			0·40			0·40		
4. $\triangle_G$ in X_1	0·09			0·09			0·09			0·09		
5. $\triangle_G$ in X_2	20·5			22·0			20·4			20·4		
6. Correlation of X_1 with I	0·21			0·21			0·21			0·21		
7. Correlation of X_2 with I	0·38			0·41			0·38			0·38		
8. RE to I_1	85·4			90·1			85·0			85·0		

The expected genetic change ($\triangle_G$) in any trait achieved by a selection differential of one standard deviation in the index is the product of the genetic standard deviation for the trait and the correlation between the index and the genetic value for such trait. However, the magnitude of the expected genetic change in litter size at weaning was slight in all of the indices used, due to the low heritability values for this trait, all ranging from 0·05 to 0·06 young for the Bauscat and 0·09 to 0·10 young for the Giza White (Tables 3 and 4). Similarly, the estimate of expected genetic change in mean bunny weight at weaning was low in Bauscat rabbits for the same reason. On the other hand, the expected genetic change in mean bunny weight at weaning of Giza White rabbits was high from using the different indices, all ranging from 20·4 to 26 g per bunny. Accordingly, it could be stated that considerable genetic improvement for doe productivity of Giza White rabbits might be achieved through selection for mean bunny weight at weaning.

Correlations between the eight selection indices and individual traits (i.e. litter size at weaning or mean bunny weight at weaning) in the aggregate genotype are shown in Tables 3 and 4. The correlations between each index and litter size at weaning were 0·1 and 0·2 in the Bauscat and the Giza White does, respectively, while the correlations between each index and mean bunny weight at weaning were frequently of 0·1 and 0·4 in the two breeds in the same order. However, the small or moderate sizes of correlations between each index and either litter size at weaning or mean bunny weight at weaning indicates that selection per generation on any index would actually lead to a slight, or may be a moderate, genetic increase in the productivity of does of both breeds.

The chief measure of the utility of an index is its correlation with the aggregate genotype, r_{IH}, where the genetic response to selection is proportional to this correlation. The present results showed that of all the selection indices developed, the index, I_4, which incorporated four variates out of five, had the highest efficiency of the order of 100 and 103% relative to the original index (I_1) in Bauscat and Giza White rabbits, respectively, with corresponding r_{IH} values of 0·31 and 0·48 (Tables 3 and 4). The other index (I_6) which incorporated only three variates was also as efficient as 86·9 and 90·1% relative to I_1 (in the same order of breeds) and with r_{IH} values of 0·27 and 0·42 respectively. When litter weight at birth was dropped, and the indices had incorporated only litter size at weaning, mean bunny weight at weaning and either litter size at birth (I_5) or preweaning mortality (I_7), it resulted in equally efficient selection indices (approximately 69 and 85% in Bauscat and Giza White, respectively), with corresponding r_{IH} values of 0·22 and 0·40. Also, the relative efficiency of the reduced index (I_8) relative to I_1 showed the same magnitude and the same accuracy. Furthermore, selection indices which included mortality to weaning and/or litter size at birth (I_2, I_5 or I_7) are considered the less efficient indices (69 and 85% in Bauscat and Giza White, respectively), and with corresponding r_{IH} values of 0·22 and 0·40 i.e. the inclusion of these traits in selection indices does not appreciably increase efficiency. This might be attributed to the low absolute phenotypic and genetic standard deviations of these traits and consequently low estimates of heritability and genetic and phenotypic correlations. In this respect, Smith (1983) stated that the main factors controlling the efficiency of index selection are largely determined by the values of the factors ah^2, the product of the economic weight (per standard deviation) and the heritability of each trait. If one trait dominates the index, the efficiency will not be sensitive to changes in the economic weight of the other traits, but will be sensitive to the loss or reversal (to negative values) of weights for the originally important trait. Also, any loss in efficiency is affected by both the phenotypic and genetic correlations. The genetic correlations tend to have the more important role in affecting the efficiency, while the phenotypic correlations do have a further effect, and thus have to be considered in estimating efficiency (Smith, 1983). In conclusion and according to the correlation between an index and the aggregate genotype (r_{IH}), the first index (I_1) and the fourth index (I_4) were considered the most accurate while I_2, I_5, I_7, and I_8 were the lowest (Tables 3 and 4). Practically speaking, I_4 is considered the best criterion for selection for the genetic improvement of litter size at weaning and mean bunny weight at weaning in this population of rabbits, under local Egyptian conditions. It could be added that I_3 and I_6 may be used as simple indices with still high precision in estimating the transmitting ability of a doe for its economically important traits.

Subindices. A series of subindices were calculated, each computed as if the five sources of information were to be used to select for just one trait, i.e. to select either for litter size at weaning or for mean bunny weight at weaning. As for the main indices, the design of construction was so drawn that on one side there was a subindex with all the 5 variates, which was assumed to be 100% efficient (original subindex) in the genetic sense, then one variate was dropped at time till only two traits remained. All possible combinations were obtained and listed in Tables 5 and 6 along with other relevant parameters. The efficiences of these subindices, to be used to select just for one trait, relative to the corresponding original subindex (I'_1) were estimated as the ratio of the standard deviations of the two subindices (Cunningham, 1977).

Results given in Tables 5 and 6 indicate that litter size at weaning contributes little in the subindices to be used to select for mean bunny weight at weaning. Also, mean bunny weight at weaning showed lower contribution in the subindices to be used to select for litter size at weaning. These results were expected and it might be due to the existence of negative genetic correlation between the two traits. The percentage reduction in rate of genetic gain for either litter size at weaning or mean bunny weight at weaning presented in Tables 5 and 6 indicated that preweaning mortality did not add to the value of the different selection subindices. At the same time, dropping the less efficient variate (i.e. litter size at birth and litter weight at birth) from the subindices, to be used to select for litter size at weaning, reduces much effort and cost. The selection subindex (I'_8) including litter size at weaning and mean bunny weight at weaning may be useful in this respect. On the other hand, litter weight at birth showed a high contribution to the different subindices to be used to select for mean bunny weight at weaning. This might be due to the high genetic correlation between this variate and the other traits included in the subindex. For such a case, subindices that include litter weight at birth (e.g. I'_1 and I'_4) are considered the most efficient subindices to be used to select for mean bunny weight at weaning. In subindices I'_3 and I'_6, litter weight at birth showed a moderate contribution.

The relative efficiency (RE) in genetic gain, was used also to compare the present subindices (Tables 5 and 6). The subindices of I'_2, I'_3, ..., I'_8 to be used

Table 5. *Selection subindices* (I'), *variances* ($\sigma^2_{I'}$), *value of each variate* (v), *expected genetic gain in each trait* ($\triangle_G$), *correlation of subindex and each trait* ($r_{I'G}$) *and the relative efficiency* (*RE*) *in litter size at weaning* (X_1), *mean bunny weight at weaning* (X_2), *preweaning mortality* (X_3), *litter size at birth* (X_4) *and litter weight at birth* (X_5) *of Bauscat does*

Subindex number for each trait

	I'_1				I'_2				I'_3				I'_4			
	X_1		X_2		X_1		X_2		X_1		X_2		X_1		X_2	
	b*	v†	b	v	b	v	b	v	b	v	b	v	b	v	b	v
1. Variates																
X_1	0·0466	18	−0·5813	0	0·0473	19	−0·1368	0	0·0527	31	0·3222	0	0·0462	19	−0·5818	0
X_2	−0·0002	2	0·0545	14	−0·0002	1	0·0633	33	−0·0002	2	0·0520	14	−0·0002	2	0·0545	14
X_3	−0·0001	0	−0·0002	0	−0·0001	0	0·0230	0	−0·001	0	0·0059	0	—	—	—	—
X_4	−0·0226	2	3·3603	4	−0·0146	1	−1·3296	2	—	—	—	—	0·0225	2	3·3601	4
X_5	−0·0002	0	−0·1197	19	—	—	—	—	0·0001	0	−0·0791	17	−0·0002	0	−0·1197	19
2. $\sigma^2_{I'}$	0·0150		145·62		0·0148		95·76		0·0144		133·51		0·0150		145·62	
3. $\triangle_G$‡	0·12		12·1		0·12		9·8		0·12		11·6		0·12		12·1	
4. $r_{I'G}$	0·26		0·34		0·26		0·28		0·25		0·33		0·26		0·34	
5. RE to I'_1	100		100		99·4		81·1		98·0		95·7		100		100	

	I_5				I_6				I_7				I_8			
	X_1		X_2		X_1		X_2		X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
1. Variates																
X_1	0·0471	20	−0·0538	0	0·0524	33	0·3445	0	0·0536	36	−0·7020	1	0·0533	37	−0·6183	1
X_2	−0·0002	1	0·0639	34	−0·0002	2	0·0521	14	−0·0002	2	0·0674	44	−0·0002	3	0·0680	47
X_3	—	—	—	—	—	—	—	—	−0·0001	0	0·0243	0	—	—	—	—
X_4	0·0146	1	−1·3390	2	—	—	—	—	—	—	—	—	—	—	—	—
X_5	—	—	—	—	0·0001	0	−0·0793	17	—	—	—	—	—	—	—	—
2. $\sigma^2_{I'}$	0·0148		95·33		0·0144		133·48		0·0144		92·17		0·0144		91·68	
3. $\triangle_G$‡	0·12		9·8		0·12		11·6		0·12		9·6		0·12		9·6	
4. $r_{I'G}$	0·25		0·28		0·25		0·33		0·25		0·27		0·25		0·27	
5. RE to I'_1	99·4		80·9		98·0		95·7		98·0		79·5		98·0		79·3	

* b values are the coefficients of the subindex being the partial regression coefficients.
† Value of each X-variate in subindex (= percentage reduction in rate of genetic gain for trait if variate is omitted).
‡ This is the value of the genetic gain in each trait achieved by one standard deviation on the subindex.
The same notation is followed in Tables 6, 9 and 10.

Table 6. *Selection subindices (I'), variances ($\alpha^2_{I'}$), value of each variate (v), expected genetic gain in each trait (Δ_G), correlation of subindex and each trait ($r_{I'G}$) and the relative efficiency (RE) in litter size at weaning (X_1), mean bunny weight at weaning (X_2), preweaning mortality (X_3), litter size at birth (X_4) and litter weight at birth (X_5) of Giza White does*

	Subindex number for each trait															
	I'_1				I'_2				I'_3				I'_4			
	X_1		X_2		X_1		X_2		X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
1. Variates																
X_1	0·0692	20	7·8667	5	0·0652	19	5·1586	4	0·0600	25	1·3527	0	0·0784	54	6·443	6
X_2	0·0003	4	0·1406	24	0·0003	5	0·1590	58	0·0003	6	0·1672	58	0·0003	4	0·134	21
X_3	−0·0005	0	0·2588	1	−0·0007	0	0·1145	0	−0·0009	1	−0·0802	0	—	—	—	—
X_4	−0·0184	1	−15·2133	13	−0·0005	0	−2·3822	1	—	—	—	—	−0·0352	3	−14·357	14
X_5	0·0004	2	0·2816	18	—	—	—	—	0·0003	2	0·1031	7	0·0007	4	0·292	19
2. $\alpha^2_{I'}$	0·0160		725·23		0·0155		483·25		0·0160		547·47		0·0168		735·91	
3. Δ_G	0·013		26·9		0·12		22·0		0·13		23.4		0·13		27·1	
4. $r_{I'G}$	0·28		0·51		0·28		0·41		0·28		0·44		0·29		0·51	
5. RE to I'_1	100		100		98·4		81·61		100		86·9		102·5		100·7	

	I_5				I_6				I_7				I_8			
	X_1		X_2		X_1		X_2		X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
1. Variates																
X_1	0·0724	52	3·9389	4	0·0675	56	1·9862	1	0·0656	38	3·3871	3	0·0703	77	3·2037	3
X_2	0·0003	6	0·1566	58	0·0004	8	0·1707	74	0·0003	5	0·1636	71	0·0003	7	0·1623	90
X_3	—	—	—	—	—	—	—	—	−0·0007	1	0·0257	0	—	—	—	—
X_4	−0·0045	0	−1·5371	1	—	—	—	—	—	—	—	—	—	—	—	—
X_5	—	—	—	—	0·0002	1	0·0981	7	—	—	—	—	—	—	—	—
2. $\alpha^2_{I'}$	0·0153		478·96		0·0157		544·75		0·0155		473·88		0·0153		473·58	
3. Δ_G	0·12		21·9		0·12		23·3		0·12		21·8		0·12		21·8	
4. $r_{I'G}$	0·28		0·41		0·28		0·44		0·28		0.41		0·28		0·41	
5. RE to I'_1	97·8		81·3		99·1		86·7		98·4		80·8		97·8		80·8	

Table 7. *Phenotypic and genetic* variances (on diagonal) and covariances (above diagonal) of 6-, 12- and 8-week weights in Bauscat and Giza White rabbits*

Variates	6-week weight	12-week weight	8-week weight
		Bauscat	
6-week weight	9711·98 (1107·81)	8982·65 (967·58)	8991·12 (1022·70)
12-week weight	—	30896·65 (687·51)	14121·58 (381·87)
8-week weight	—	—	15314·89 (767·40)
		Giza White	
6-week weight	7787·45 (1263·02)	7251·51 (1785·77)	6152·15 (1291·90)
12-week weight	—	24972·66 (2293·64)	11825·34 (2156·69)
8-week weight	—	—	11402·36 (836·26)

* Genetic variances and covariances are presented in parentheses.

to select for litter size at weaning in the Bauscat and Giza White breeds permit 98·0–100% and 97·8–102·5%, respectively, as much gain as could be made with the first subindex (I_1'). These percentages showed that only slight differences were found when using any one of these subindices, and consequently the subindex (I_8') including litter size at weaning and mean bunny weight at weaning may be useful in practice. These results were confirmed by the fact that the correlations of subindices and each trait ($r_{I'G}$) showed generally constant values and the variances of subindices ($\sigma^2_{I'}$) were closely similar in magnitude (Tables 5 and 6). However, changes in the efficiency of selection are more dependent on the genetic correlations among traits than on the phenotypic, but both affect the efficiency (Smith, 1983). On the other hand, the subindices to be used to select for mean bunny weight at weaning revealed a general trend showing that the relative efficiences of the different subindices decreased as preweaning mortality and litter size at birth were included in these subindices. Consequently, I_2', I_5', I_7' and I_8' are considered the less efficient subindices to be used to select for mean bunny weight at weaning. In practice, the fourth subindex (I_4') to be used to select for mean bunny weight at weaning might be considered the most accurate while I_2', I_5' and I_7' and I_8' were the lowest (Tables 5 and 6).

Selection for rabbit body weight

Indices. Four selection indices for each breed were constructed using phenotypic and genetic variances and covariances given in Table 7. The original index was constructed to include all the three variates while the other three indices were included only two variates, i.e. in consequence one of the three variates was dropped. The four indices for each breed were obtained and listed in Table 8 along with other relevant parameters.

Estimates of expected genetic change in 6- and 12-week weight was generally slight in Bauscat and Giza White rabbits (Table 8). Accordingly, it seems that slight genetic improvement for growth traits of both breeds might be achieved through selection for 6-week weight. High values of partial regression coefficients were obtained for 6-week weight in all the indices constructed (Table 8). On the other hand, b values of 12-week weight were lower than those of 6-week weight in the four indices for the two breeds. This might be attributed to heritability of 6-week weight in both breeds being higher than the heritability of 12-week weight. A selection index constructed by McReynolds (1974) to select for 8-week weight in New Zealand White rabbits indicated that the partial regression coefficient for 21-day weight ($b_1 = 0·875$) was higher than the corresponding value for gain from 21 to 56 days of age ($b_2 = 0·169$). These results together with results of the present study indicated that b values measured at earlier ages are higher than those measured at later ages.

Six-week weight contributes substantially to most of the indices constructed (Table 8). Also, 8-week weight appears to be an important supplementary variate in most of the selection indices. On the contrary, 12-week weight did not contribute to the value of most of the selection indices. Whether or not the added information is worth the expense of weighing the rabbits at two ages would determine the choice of selection criteria. Accordingly, it is preferable, for both the present breeds, to use the fourth index (I_4) including 6-week weight and 8-week weight instead of I_2 and I_3.

Correlations (r_{IG}) between the four selection indices and individual growth traits in the aggregate genotype (i.e. 6-week weight and 12-week weight) are shown in Table 8. The correlations between I_2 and 6-week weight in Bauscat and Giza White rabbits were moderate, the estimates being 0·34 and 0·42, respectively. These values indicate that 6-week weight, with its high estimated heritability and the high genetic correlation with 12-week weight, may be a moderately more efficient criterion for selection than would be 12-week weight directly. Similarly, the correlations between either of I_1 or I_4 and 12-

Table 8. *Selection indices, standard deviation (σ_I), value of each variate (v), expected genetic change in each trait (Δ_G), correlation of index with total genotypes (r_{IH}), and correlation of each individual trait with index, and the relative efficiency (RE) in 6-week weight (X_1), 12-week weight (X_2) and 8-week weight (X_3) of Bauscat and Giza rabbits*

	I_1			I_2			I_3			I_4		
Bauscat												
1. Variates	b	v	Δ_G	b	v	Δ_G	b	v	Δ_G	b	v	Δ_G
X_1	0·4973	66	9·4	0·3244	61	11·1	—	—	6·5	0·5030	73	9·5
X_2	0·0370	1	11·7	−0·0275	1	9·9	0·0563	22	4·0	—	—	11·6
X_3	−0·2513	15	—	—	—	—	0·0229	—	—	−0·2205	15	—
2. σ_I		35·10			29·74			11·93			34·75	
3. r_{IH}		0·45			0·38			0·15			0·44	
4. Correlation of X_1 with I		0·28			0·34			0·20			0·29	
5. Correlation of X_2 with I		0·44			0·38			0·15			0·44	
6. RE to I_1		100·0			84·7			34·0			99·0	
Giza White												
1. Variates												
X_1	0·4207	9	14·5	0·5912	30	15·0	—	—	12·2	0·4177	9	14·6
X_2	−0·0154	0	22·2	0·1039	3	20·8	0·0134	0	20·2	—	—	22·1
X_3	0·3563	7	—	—	—	—	0·3426	28	—	0·3420	9	—
2. σ_I		66·73			62·31			60·61			66·71	
3. r_{IH}		0·46			0·43			0·42			0·46	
4. Correlation of X_1 with I		0·41			0·42			0·34			0·41	
5. Correlation of X_2 with I		0·46			0·43			0·42			0·46	
6. RE to I_1		100·0			93·4			90·8			100·0	

week weight were moderate, the estimates being 0·44 and 0·46 in Bauscat and Giza White rabbits, respectively. On the other hand, a lower correlation (0·20) between I_3 and 6-week weight was obtained for Bauscat rabbits. This small correlation between I_3 and 6-week weight indicates that selection on I_3 would actually lead to very slight genetic increase in the growth of Bauscat rabbits. However, the moderate sizes of correlations between each index and either 6-week or 12-week weight indicates that selection per generation on any index (except I_3 in Bauscat rabbits) would lead to a moderate genetic improvement in the overall growth traits of both breeds. For New Zealand White rabbits, McReynolds (1974) estimated the correlations (r_{IG}) between the selection index and genetic value for 21-day weight, 56-day weight and gain from 21 to 56 days of age; the estimates were 0·57, 0·62 and 0·46, respectively. These estimates indicate that 21-day weight may be a slightly more efficient criterion for selection than 56-day weight directly, i.e. improvement of the body weight at later ages through earlier selection for growth traits.

The fourth selection index (I_4), which incorporated 6-week weight and 8-week weight, had the highest efficiency of the order of 99·0 and 100·0% relative to the original index (I_1) in Bauscat and Giza White rabbits, respectively, with corresponding r_{IH} values of 0·44 and 0·46 (Table 8). The third index (I_3) is the less efficient index (34·0 and 90·8% in Bauscat and Giza White rabbits, respectively), and with r_{IH} values of 0·15 and 0·42, respectively. This might be attributed to the dropping of 6-week weight (a highly heritable trait) from the index. Also, the low absolute phenotypic and genetic standard deviations (Table 7) of these traits and consequently low estimate of heritability could be added as other possible causes in this respect. In conclusion, the first index (I_1) and the fourth index (I_4) are considered the most accurate with I_3 the least (Table 8). The index constructed by McReynolds (index involving 21-day weight and gain from 21 to 56 days of age) together with the present indices have led to the conclusion that selection indices based on earlier growth traits are more efficient than those based on later growth traits to select for later body weights of rabbits.

Subindices. Four subindices for each breed were calculated (Tables 9 and 10), each computed as if the three sources of information were to be used to select for just one trait, i.e. to select either for 6-week weight (early age) or for 12-week weight (slaughter age).

The small expected gain in 6-week weight using I_3' relative to the other subindices could be due to the dropping of 6-week weight (highly heritable

Table 9. *Selection subindices (I'), variances ($\sigma^2_{I'}$) value of each variate (v), expected genetic gain in each trait ($\triangle_G$), correlation of subindex and each trait ($r_{I'G}$) and the relative efficiency (RE) in 6-week weight (X_1), 12-week weight (X_2) and 8-week weight (X_3), of Bauscat rabbits*

Subindex number for each trait

	I'_1				I'_2			
	X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v
1. Variates								
X_1	0·1149	26	0·1658	66	0·1164	51	0·1081	61
X_2	−0·0031	0	0·0123	1	−0·0025	0	−0·0092	1
X_3	0·0021	0	−0·0838	15	—	—	—	—
2. σ^2_I	126·53		136·88		126·51		98·30	
3. $\triangle_G$	11·2		11·7		11·2		9·9	
4. $r_{I'G}$	0·34		0·45		0·34		0·38	
5. RE to I'_1	100·0		100·0		100·0		71·8	

	I'_3				I'_4			
	X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v
1. Variates								
X_1	—	—	—	—	0·1144	26	0·1677	73
X_2	0·0014	0	0·0188	22	—	—	—	—
X_3	0·0655	33	0·0076	2	−0·0004	0	−0·0735	15
2. σ^2_I	68·33		15·81		126·36		134·17	
3. $\triangle_G$	8·3		4·0		11·2		11·6	
4. $r_{I'G}$	0·25		0·15		0·34		0·44	
5. RE to I'_1	54·0		11·5		99·9		98·0	

trait) from the subindex. However, these results indicated that using the subindex that included the three variates (I'_1) did not show clear superiority of expected genetic gain in 6-week weight as compared with any of the other subindices (except I'_3) including two variates. Therefore, the subindices (I'_2 or I'_4) including 6-week weight and either of 12-week weight or 8-week weight may be useful to select for 6-week weight in this population of rabbits. The expected genetic gain in 12-week weight was slightly higher when using the first or fourth subindices, while the lowest gain was obtained when using I'_2 and I'_3. This means that the fourth subindex (I'_4), which did not include 12-week weight, gave higher expected genetic gain for 12-week weight than those that did, i.e. selection for 12-week weight (marketing age) is best done by using subindices that do not include this trait.

Values of each X-variate in subindices given in Tables 9 and 10 also indicate that 12-week weight contributes little to the subindices to be used to select either for 6-week weight or for 12-week weight. On the contrary, 6-week weight showed a meaningful and large contribution in the subindices to be used to select either for 6-week weight or for 12-week weight, i.e. selection for body weight at earlier ages should be more efficient.

The subindices of I'_2 and I'_4 to be used to select for 6-week weight in Bauscat and Giza White rabbits permit 100 and 96–99·2%, respectively as much gain as could be made with the first subindex (I'_1). These findings were confirmed by the fact that the correlations of subindices and each trait ($r_{I'G}$) showed similar values and the variances of subindices ($\sigma^2_{I'}$) were generally similar in magnitude (Tables 9 and 10). On the other hand, the subindices of I'_2 and I'_4 to be used to select for 12-week weight showed that the relative efficiences of these subindices relative to I'_1 were increased as 12-week weight was omitted from these subindices, i.e. I'_4 may be useful in practice. In this respect and according to Binet (1965), it is preferable not to use 12-week weight itself as selection criterion, but to use other measurable traits such as 6-week weight and 8-week weight (genetically correlated with 12-week weight) for the purpose of indirect selection.

Table 10. *Selection subindices (I'), variance ($\sigma^2_{I'}$), value of each variate (v), expected genetic gain in each trait ($\triangle_G$), correlation of subindex and each trait ($r_{I'G}$) and the relative efficiency (RE) in 6-week weight (X_1), 12-week weight (X_2) and 8-week weight (X_3), of Giza White rabbits*

	Subindex number for each trait							
	I'_1				I'_2			
	X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v
1. Variates								
X_1	0·1215	15	0·1402	9	0·1310	25	0·1971	30
X_2	0·0268	2	−0·0051	0	0·0335	5	0·0346	3
X_3	0·0200	0	0·1188	7	—	—	—	—
2. $\sigma^2_{I'}$	227·04		494·85		225·24		431·34	
3. $\triangle_G$	15·1		22·2		15·0		20·8	
4. $r_{I'G}$	0·42		0·46		0·42		0·43	
5. RE to I'_1	100·0		100·0		99·2		87·2	
	I'_3				I'_4			
	X_1		X_2		X_1		X_2	
	b	v	b	v	b	v	b	v
1. Variates								
X_1	—	—	—	—	0·1267	18	0·1392	9
X_2	0·0351	5	0·0045	0	—	—	—	—
X_3	0·0769	11	0·1845	28	0·0449	3	0·1140	9
2. $\sigma^2_{I'}$	162·02		408·18		218·05		494·52	
3. $\triangle_G$	12·7		20·2		14·8		22·2	
4. $r_{I'G}$	0·36		0·42		0·42		0·46	
5. RE to I'_1	71·4		82·5		96·0		99·9	

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