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Virág Ács[a], Katalin Szendrő[b] [ID], Hervé Garreau[c], Tamás Donkó[d], Zsolt Matics[a] and István Nagy[a]

[a]Állatnemesítési Intézeti Tanszék, Kaposvár University, Kaposvár, Hungary; [b]Marketing és Kereskedelem Tanszék, Kaposvár University, Kaposvár, Hungary; [c]Egészségügyi Központ Diagnosztikai és Onkoradiológiai Intézet, Kaposvár University, Kaposvár, Hungary; [d]GenPhySE, INRA, INPT ENVT, Tolouse University, Castanet Tolosan, France

ABSTRACT

Genetic parameters for 21-d litter weight (LW21) and thigh muscle volume (TMV) were estimated, and based on these traits a two-trait selection index was created with the purpose of increasing the efficiency of the Pannon White rabbits' breeding programme. Litter weight at 21 d of age (LW21, $n = 22,002$) and thigh muscle volume (TMV, $n = 8124$) measurements (based on computed tomography – CT) were analysed that were recorded between 1992 and 2016. The evaluated animals were reared in 4178 litters and the total number of rabbits involved in the pedigree file was 14,124. LW21 and TMV records were analysed jointly in a two-trait animal model. The estimated heritability for LW21 and TMV were 0.10 ± 0.01 and 0.21 ± 0.02, respectively, and the estimated genetic correlation between these traits was -0.24 ± 0.07. The common environmental effect had the same magnitude (0.10 ± 0.01) as the additive genetic effect. The created selection index constructed to have 50 and 50% contribution of the measured traits. Application possibility of the created index was tested on a given kindling batch. In this case, the first step of the selection procedure was performed either according to the current breeding programme (based on the LW21 breeding values) or based on the two trait selection index. The second step of selection was not changed (based on the TMV breeding values). The consequences of using index scores instead of the regular procedure were obtaining 27.8% higher average breeding value for TMV and 11.4% lower average breeding value for LW21. These results suggest that introduction of the index may improve economic efficiency.

Introduction

In the Pannon rabbit breeding programme of the Kaposvár University, Pannon White breed is one of the dam crossing partners. The breed was selected to average daily gain (ADG) and L-value (defined anatomical points of the surface of the longitudinal cross-section of the long thoracic backbone measured in the interstitial plane of the limbs 2, 3, 4 and 5, respectively) previously with computed tomography (CT). In 2004, the thigh muscle (TMV) rellaced L-value in the selection criteria because its average volume is greater than the volume of the back muscle (*longissimus dorsi*) Thus selection can improve more the muscle volume of the carcase. On the other hand, direct selection for growth and carcase traits led to serious reduction in reproduction. In 2014, ADG was changed by litter weight at day 21 in the breeding programme.

At present, the Pannon White rabbits are pre-selected to litter weight at 21 d of age (LW21) and the second selection step is performed for thigh muscle volume (TMV) (Matics et al. 2014).

Conventional selection for slaughter traits (progeny test) can lengthen the generation interval but at the Kaposvár University, CT-aided rabbit selection is being used since 1992 (Szendrő et al. 1992) thus progeny test can be avoided. Contrary to the favourable results, Szendrő et al. (2010) and Gyovai et al. (2012) pointed out that TMV has a negative correlation with the LW21 (from −0.37 to −0.7). As a result, individuals with the best TMV may not have the best LW21 in the first step of selection. This unfavourable correlation between the two traits increases the difficulty to make simultaneous improvements in LW21 and TMV, and the selection process of the breed needs to make compromises among the selection criteria traits.

CONTACT Miss Virág Ács ✉ acs.virag@ke.hu 📧 Faculty of Agricultural and Environmental Sciences, Kaposvár University, Guba Sándor Str. 40, Kaposvár H7400, Hungary

For the improvement of genetic value of livestock, individuals with the best breeding values have to be chosen as the parents of the next generation. When the information derives from several relatives the breeding values can be estimated with regression theory, but in animal breeding, the multiple regression theory for estimating the breeding values is called selection index.

Application of selection indices may be a good solution to the problem mentioned by Gyovai et al. (2012), since profitability is an appropriate parameter to express the importance of the traits in the final evaluation. TMV is also an interesting parameter in an economic point of view, due to its great amount of muscle it gives more profit with the same input. Selection indices take the genetic and economic values into account and determine the weighting, based on how much profit can be made by increasing the measured trait with one unit. According to Hazel (1943), the aim of the selection index method is to maximise the genetic progress towards a stated economic goal. However, the improvement of the traits in the breeding goal may differ inheritability, variability and profitability. Later, the method was completed with some modifications, such as separating the indexing in two steps by Kyle and Chapman (1953), who added the breeding values for the traits of each individual at the first step and adding the economic values in the second step.

Economic values had been calculated in rabbit breeding previously for prolificacy and growth traits (Armero and Blasco 1992; Prayaga and Eady 2000; Cartuche et al. 2014), but so far no index was developed including reproductive and carcase traits simultaneously.

Pesek and Baker (1969) created a 'desired gain' index by modifying the indexing theory and added substitute desired gains which made it possible to improve the traits in the breeding goal without the exact knowledge of the economic values. Hence, the aim of this study was to develop a selection index for 21-d litter weight and for thigh muscle volume.

Materials and methods

Data collection and production system

This analysis is based on 22,002 LW21 and 8124 TMV measurements from Pannon White rabbit does and growing rabbits, respectively. Records were collected between 1992 and 2016 at the Experimental Rabbit farm of Kaposvár University, Hungary. Animals were reared in 4178 litters and the total number of rabbits involved in the pedigree file was 14,124. The applied reproduction rhythm was 49 d and the generations were overlapping. To avoid inbreeding a circular mating scheme was applied dividing the population into four subgroups. This method was described in detail by Nagy et al. (2010).

In the course of the breeding programme, litter weights were measured at 21 d of age on 122 litters. Besides, TMV data were measured in the Kaposvár University Health Center Institute of Diagnostic Imaging and Radiation Oncology. A Siemens Somatom Cardiac type multidetector CT was used to make the scans with the following settings: tube voltage: 120 kV, current: 140 mAs, data collection mode: spiral. The scanned rabbits were 11 weeks old and fixed with belts in a special plastic container without anaesthesia. During the CT measurement, the scans were taken of the whole body and segmented with *3D Slicer's* automatic segmentation module (Fedorov et al. 2012) between the *crista iliaca* of the *os ilium* and the patella with 2 mm slice thickness. Each CT scan had between 0 and +140 (on HU scale) voxel frequency on the density scale for the muscle tissue.

Animal models

REML and BLUP methods were used to estimate the genetic parameters and breeding values for LW21 and TMV, and these traits were analysed jointly using a two-trait animal model. PEST software (Neustadt, Germany) (Groeneveld, 1990) was used for data coding and the variance components were estimated with VCE 6 (Groeneveld et al. 2008).

The matrix equation of the applied model was as follows:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} X_1 & 0 \\ & X_2 \end{pmatrix}\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} + \begin{pmatrix} Z_1 & 0 \\ & Z_2 \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} + \begin{pmatrix} W_1 & 0 \\ & W_2 \end{pmatrix}\begin{pmatrix} c_1 \\ c_2 \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$$

where y_i = vector of the observations of the ith trait, b_i = vector of the fixed effects of the ith trait, a_i = the vector of random effects for the ith trait, c_i = vector of common litter effects for the ith trait, e_i = vector of random residual effects for the ith trait. X_i, Z_i and W_i are the incidence matrices relating the records of the ith traits to fixed effects.

The descriptive statistics of the examined traits are summarised in Table 1.

The structure of the applied animal model is given in Table 2.

Selection procedure and selection index

The selection procedure of the Pannon White breed is conducted in two consecutive steps for every kindling batch. In the first step, the expected LW21 breeding values of the growing rabbits are predicted based on the ancestors' performances. Based on this prediction whole litters can be ranked within every population subgroup (i.e. all full-sibs have the same expected breeding value). In the first step of selection from a given litter with a high LW21 breeding value generally, 1–2 males and 2–3 females are selected for the second selection step unless the parents of this litter already contributed a sufficient number of breeding animals (2 breeding males per buck and 5 breeding females per doe) to the population. The second step of selection is performed based on the TMV breeding values following CT scans.

In order to test the modification possibility of the breeding programme a two-trait BLUP index (involving LW21 and TMV) was calculated using the software SEL-ACTION (Animal Breeding and Genetics Group, Department of Animal Sciences, Wageningen University, WUR, Wageningen, Netherlands) (Rutten and Bijma 2001). The characteristics of the group of animals which provide information of the selected

Table 1. Descriptive statistics of the measured traits.

Trait	LW21, kg	TMV, cm^3
Number of records	22,002	8124
Maximum	5.51	534
Minimum	0.32	176
Mean	2.64	326
SD	0.65	40.50
CV, %	24.80	12.40

LW21: litter weight at 21 d; TMV: thigh muscle volume.

Table 2. The structure of the applied animal model.

Effect	Type	Levels	Traits	
			LW21	TMV
PARITY	F	4	×	–
YEARMONTH1	F	261	×	–
AGE21	C	1	×	–
LITTERSIZE21	C	1	×	–
PE	R	11,594	×	–
SEX	F	3	–	×
CT_WEIGHT	C	1	–	×
YEARMONTH2	F	94	–	×
PIXEL	F	5	–	×
CE	R	4178	–	×
A	R	14,124	×	×

LW21: litter weight at 21 d; TMV: thigh muscle volume; PARITY: parity number of the doe; YEARMONTH1: year and month of kindling; AGE21: exact age of the kits at 21 day of measurement; LITTERSIZE21: litter size at 21 days; PE: permanent environmental effect; SEX: sex of the growing rabbits; CT_WEIGHT: body weight at CT measurement; YEARMONTH2: year and month of CT measurement; PIXEL: density range of muscle; CE: common environmental effect of the doe; A: additive genetic effect.

candidates are summarised in Table 3. Identical indices were created for both males and females, considering both sexes were selected to the same selection criteria. The contribution of each trait was set to 50% because selection to the carcase traits decreased significantly the reproduction and both traits are necessary to maintain the breed as a successful crossing partner. Besides the targeted improvement of each trait was one additive genetic standard deviation (i.e. 'desired gain' index (Pesek and Baker 1969). The final selection index was transformed to obtain index mean and standard deviation of 100 and 20, respectively, as it is used in the Hungarian pig breeding sector (MFSE 2017).

$$\text{Index} = -244.458 + 522.523 \times \text{LW21} + 6.017 \times \text{TMV}.$$

Testing the efficiency of the selection index

The selection process based on the current breeding programme and on the calculated index scores was compared to a chosen kindling batch where the date of insemination was 29 January 2016. In the kindling batch, 928 kits were born from 121 dams and the number of bucks was 42. Using both selection alternatives in the first step of selection 69 litters (122 individuals) were selected for CT scan based on either on the LW21 expected breeding values or on the calculated BLUP index scores. As the two methods resulted in different rankings, altogether 139 rabbits were sent to CT scan and the proportion of the male and female individuals were 1:1. Regardless of the method of the

Table 3. Characteristics of the group of animals which provide information of the selection candidates.

Population size	
Number of selected male parents	12
Number of selected female parents	28
Number of male selection candidates per dam	100
Number of female selection candidates per dam	40
Total selected proportion female parents	013
Total selected proportion male parents	013
Characteristics of the used groups	
Full sib group 1 with	7 animals
Half-sib group 1 with	1 dam producing 8 animals
Progeny group 1 with	1 dam producing 8 progeny

Number of selected male and female parents: number of selected animals after the final stage of selection; Number of male/female selection candidates per dam: number of male/female offspring born per dam; Total selection proportion male/female parents: the selected proportion among male and female candidates ($0 < p < 1$); Full sib group 1 with 7 animals: 1 full sib group is defined because the male and female selection candidates are both selected to LW21 and TMV; Half-sib group 1 with 1 dam producing 8 animals: number of discint half-sib group; Progeny group 1 with 1 dam producing 8 progeny: number of the progeny group where the proportion of the male/female selection candidates may be full sibs.

first step selection after the CT scans the second step of selection was performed based on TMV breeding values.

Results and discussion

Heritabilities, genetic correlations

The estimated heritabilities (diagonal), genetic correlations (off-diagonal) and standard errors are presented in Table 4.

The estimated heritability for LW21 was low. The heritability of litter traits, such as LW21 were comparable with the previous studies conducted at the Kaposvár University (Gyovai et al. 2012; Nagy et al. 2013) where the heritability for LW21 varied between 0.10 and 0.17. It is also in accordance with the heritability measured by Lukefahr and Hamilton (1997) and Al-Saef et al. (2008) where it ranged between 0.02 and 0.17, which shows that the non-genetic and environmental factors represent the major source of the trait.

TMV showed higher heritability than LW21 but considering that this trait can be defined as a carcase trait, it was lower than expected. On the other hand, looking the results of comparable studies, Gyovai et al. (2008) and Nagy et al. (2013) observed similar results

(0.21 ± 0.03) for the heritability of thigh muscle volume for Pannon White rabbit breed.

The estimated common environmental effect, permanent environmental effect and their standard errors for LW21 and TMV are provided in Table 4.

The magnitude of permanent environmental effect exceeded that of the heritability resulting moderate repeatability of LW21. On the contrary, the common environmental effect had the same magnitude as the additive genetic effect. Rastogi et al. (2000), Gyovai et al. (2008, 2012) and Al-Saef et al. (2008) reported also low magnitude for the permanent environmental effect for litter weight with repeatability animal models.

The estimated correlation between the selection index and the examined traits are provided in Table 5.

Possibilities for selection

The first step of the selection based on the current and alternative methods are presented in Tables 6 and 7. In this stage, the LW21 breeding values decreased significantly with the index selection due to the negative correlation and the weighting to the TMV. The other consequence was that preselecting the rabbits based on the two trait index scores resulted somewhat higher TMV breeding values and higher index scores. The average breeding values for LW21 and TMV by the population subgroups (depending on the method of selection in the first selection step) are presented in Tables 8 and 9. After the CT measurements the estimated breeding values of the LW21 decreased by

Table 4. Estimated heritabilities, permanent environmental effect and genetic correlations between the traits.

Trait	h²	PE	r_g LW21-TMV
LW21	0.10	0.18 ± 0.01	−0.24 ± 0.07
TMV	0.21	–	–

h^2: heritabiliy of the trait; PE: permanent environmental effect; r_g LW21-TMV: measured genetic correlation between the traits in the breeding goal.

Table 5. Correlation coefficients between the selection index and the examined traits.

Trait	LW21	TMV	Index score
LW21	1.00	−0.24	0.28
TMV	–	1.00	0.84
Index score	–	–	1.00

LW21: 21 days litter weight; TMV: Thigh muscle volume.

Table 6. The number of litters and the selected litters in each line, the average of the calculated breeding values of the traits and the index based on regular selection.

BG	NoL	NoSL	LW21_EBV	TMV_EBV	MI
1	39	20	0.23	42.40	100
2	28	17	0.20	44.20	109
3	28	16	0.22	44.20	110
4	26	16	0.22	40	99.30

BG: buck groups; NoL: number of litters; NoSL: number of selected litters; LW21_EBV: estimated breeding values of LW21 in the parental generation; TMV_EBV: estimated breeding values of TMV in the parental generation; MI: mean of index scores.

Table 7. The number of the litters and the selected litters in each line, the average of the calculated breeding values of the traits and the index based on index selection.

BG	NoL	NoSL	LW21_EBV	TMV_EBV	MI
1	39	20	0.17	48.40	104
2	28	17	0.17	47.80	112
3	28	16	0.19	45.10	117
4	26	16	0.15	41.90	113

BG: buck groups; NoL: number of litters; NoSL: number of selected litters; EBV_LW21: mean of the estimated breeding values of LW21 in the parental generation; EBV_TMV: mean of the estimated breeding values of the TMV in the parental generation; MI: mean of index scores.

Table 8. The selected individuals after the computed tomography (CT) measurement based on regular selection.

BG	NI	NSI	LW21_EBV	TMV_EBV	MI
1	39	10	0.18	48.77	102.45
2	34	10	0.16	49.52	120.48
3	35	10	0.19	46.78	120.68
4	31	10	0.17	46.12	101.94

BG: buck group; NI: number of individuals; NSI: number of selected individuals; LW21_EBV: mean of the estimated breeding values of LW21; EBV_TMV: mean of the estimated breeding values of own TMV; MI: mean of the index scores.

Table 9. The selected individuals after the computed tomography (CT) measurement based on index selection.

BG	NI	NSI	LW21_EBV	TMV_EBV	I
1	39	10	0.15	61.46	127.31
2	35	10	0.15	64.81	145.69
3	34	10	0.17	60.29	130.27
4	31	10	0.15	57.88	111.79

BG: buck group; NI: number of individuals; NSI: number of selected individuals; LW21_EBV: mean of the estimated breeding values of LW21; EBV_TMV: mean of the estimated breeding values of own TMV; MI: mean of the index scores.

11.4% with the index selection after the two-stage selection process, on the other hand, own TMV values increased substantially by 27.8%. It can be seen that group 4 showed the worst performance after both selection steps, while groups 2 and 3 were superior. These differences between the subgroups' index scores were originated from the applied selection method which also focuses on maintaining the genetic diversity. In the first step of the selection process, the litters were ranked by the LW21 data and the best bucks in the parental generation were selected which produced the best litters. The main criterion was that the dams of the selected litters had to be the most distant relatives. In some cases, the dams were half-sibs due to the lack of diversity. According to this sorting system, after the CT examinations maximum two female and one male offspring went for further breeding from one sire. The consequences of the different selection strategies can be originated from the negative correlation between LW21 and TMV, which was reported in our study (Table 4) and by Gyovai et al. (2012). Despite of the small reduction of the LW21, the economic efficiency of the selection process can be increased by using indexing LW21 and TMV in the pre-selection stage, since the economic importance of the LW21 is much lower than that of TMV, as reported previously by Szendrő et al. (2016). Prayaga and Eady (2000) and Eady and Garreau (2008) reported the profitability of the price per kg of growing rabbits between 1.6 and 1.75€ in this case the thigh fillet produces 11 €/kg revenue which gives this trait a great economic importance. In an earlier study, Mikó et al. (2010) reported the average weight difference of the thigh fillet based on a divergent selection experiment using Pannon White rabbits. These authors found that the weight of the thigh muscle was 8.5% higher in the positive groups, and there was also a 1.1% increase in the dressing out percentage compared to the negative group. These findings resulted in 0.1 €/kg additional revenue for the meat fillet and 0.03 €/kg for the whole carcase. Thus the benefits achieved by Mikó et al. (2010) and by this study can be substantial through a multiplier level from the aspect of the slaughterhouse.

Considering 1,000,000 slaughtered rabbits per year the increased TMV can result 675,000 EURO profit for the slaughterhouse (Mikó et al. 2010).

Conclusions

Implanting the selection index method in rabbit breeding is reasonable, especially when a special breed is selected for both production and reproduction traits which are not positively correlated. The indexing technique with 'desired gains' can be available for those traits which were not determined before from an economic point of view. For the slaughterhouse, the valuable meat parts represent the main source of the profit, so it is feasible to put a selection index between the thigh muscle volume and one of the reproduction traits, even if the only relevance of this trait is to maintain the breed as a possible crossing partner in the future.

Ethical Approval

Disclosure statement

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ORCID

Katalin Szendrő 🔴 http://orcid.org/0000-0002-0025-1059

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