

Feed and reproductive efficiency differences between divergently selected lines for birthweight environmental variability in mice

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Abstract

Sustainability has come to play an important role in agricultural production. A way to combine efficiency with sustainability might be by searching for robust animals that can be selected for the homogeneity of certain traits. Furthermore, the optimization of feed efficiency is one of the challenges to improve livestock genetics programmes, but this might compromise reproductive efficiency. Animals from two divergent mouse lines, regarding variability of birthweight, were used to check whether homogeneity was also related to both feed and reproductive efficiency. The objective of this study was to use these divergent lines of mice to compare them with their feed efficiency and the reproductive capacity. Animal weight, weight gain, feed intake, relative intake and cumulated transformation index were considered as feed efficiency traits. Animals from the low line had both lower weight and feed intake from 21 to 56 days. They had a worse transforming index in the three last weeks when litter size was fitted as an effect of the model, but the lines become similar if the higher litter size of the low line was not included. Reproductively, the low line performed better considering the number of females having parturitions, the number of parturitions, and with higher litter size and survival in both parturitions. Hence, the low variability line was preferred because of reproductive efficiency without seriously affecting its feed efficiency. Homogeneity seemed to be related to robustness with similar feed efficiency but higher reproductive efficiency.

KEYWORDS

efficiency, homogeneity, mice, robustness

1 | INTRODUCTION

Animal breeding is one of the tools employed to address the challenges faced by animal production farms (Gilbert et al., 2017), which also demands an efficient use of resources, increased robustness of animals and more efficient production under possible changing circumstances at the same time (Sánchez, Ragab, Quintanilla, Rothschild, & Piles, 2017). Feed currently represents the main production cost that has a direct impact on the financial results of the farm, for instance: 70%–80% in rabbits (Moura, Kaps,

Vogt, & Lamberson, 1997), 75% in pigs (Whittemore & Kyriazakis, 2006) and nearly 70% in dairy cattle (Lawrence, Mintert, Anderson, & Anderson, 2008). In addition, the rising human population requires searching for efficient ways to breed livestock for meat rich in protein (Sell-Kubiak, Wimmers, Reyer, & Szwaczkowski, 2017).

Moreover, sustainability plays an important role in agricultural production (Gamborg & Sandøe, 2005; Olesen, Groen, & Gjerde, 2000), with breeding goals that include production traits and functional traits, such as longevity, health and animal welfare (Kanis, de Greef, Hiemstra, &

van Arendonk, 2005). Therefore, breeding strategies have to improve feed efficiency, welfare and reduce the environmental impact of meat production, but improving feed efficiency might compromise reproductive efficiency. Genetic selection in animal breeding has a substantial impact on knowledge progress and its application in animal production. In addition, feed efficiency is not usually considered as a direct selection criterion in animal breeding programmes in prolific species (Sánchez et al., 2017). This is mainly due to the high financial costs and the difficulty in obtaining individual consumption measures, including accounting for the indirect effects from social interaction amongst animals (Carmelink, Duijvesteijn, Ursinus, Bolhuis, & Bijma, 2014). A way to overcome these disadvantages might be to search for the homogeneity of certain traits. Homogeneous animal production would decrease handling and production costs that should result in better profits for the farm (Bolet et al., 2007) and better animal welfare (Mormede & Terenina, 2012). Therefore, considering the selection for homogeneity and feed efficiency may improve productivity and animal welfare.

Most authors address how management factors affect animal welfare, health, productivity and product quality, but little is known about the relationship between animal nutrition and animal welfare (FAO 2013). This knowledge is required for livestock production systems that need to be efficient, environmentally friendly and socially acceptable. Farmers usually find it difficult to adopt practices which promote animal welfare without having information on the impact on animal productivity and income. It is unlikely that farmers follow these strategies in developing countries unless their income increases. Therefore, it is important to know whether selecting for efficient use of feed can have negative consequences on other aspects of productivity, especially under farming conditions. Summarizing, there is a need for researching animal welfare to understand the impact on income by certain farming activities. These studies could eventually pave the way to develop guidelines and policy options to promote sustainable animal feeding practices that enhance animal welfare, productivity, product quality and profitability (Food and Agriculture Organization of the United Nations (FAO), 2013).

Sustainability is related to robustness, and robustness is then related to homogeneity, but it is unusual to check for robustness or homogeneity with experimental material. The definition of robustness has also become controversial. Knap (2005) defined robustness as the capacity of achieving a high level of productive potential supporting at the same time a certain level of stress, in other words, expressing high productive level in different environmental conditions. Bodin et al. (2010) defined it as the sensitivity to some variations in the environment in which a phenotype is expressed. Mormede and Terenina (2012) suggested that

it is the combination of a high production potential with a low sensitivity towards environmental changes. Overall, across this study, robust animals will be considered as those expected to have higher survival rate and better reproduction.

Improving a trait level and reducing variability are desirable in animal production because significant variation around the optimal value of a trait can have a negative impact on performance (Mulder, Bijma, & Hill, 2008; Pun et al., 2013). In aquaculture, Marjanovic, Mulder, Khaw, and Bijma (2016) obtained substantial genetic variation in uniformity of harvest weight and body size traits, resulting in expected genetic improvement of homogeneity by selective breeding of the GIFT strain in Nile tilapia. Formoso-Rafferty, Cervantes, Ibáñez-Escriche, and Gutiérrez (2016a) developed in mice a divergent selection experiment for birthweight environmental variability and they concluded that genetic control of the birthweight environmental variability was possible. Furthermore, they showed that this selection criterion had direct implications in other interesting traits in livestock. These are related not only to productivity traits but also with animal welfare (Formoso-Rafferty, Cervantes, Ibáñez-Escriche, & Gutiérrez, 2016b). As a result of that experiment, two divergent lines for birthweight environmental variability were created (Formoso-Rafferty et al., 2016a), where low line presented more benefits in production, welfare, heritability and robustness-related traits. Consequently, these two divergent lines presented the opportunity to prove whether homogeneity is also related to both feed and reproductive efficiency. The objective of this study was to compare the low and high birthweight variability lines of mice, for their fertility, and their feed efficiency assessed through the transformation index, and to explore the possible benefits in robustness derived from the selection for homogeneity.

2 | MATERIAL AND METHODS

The used data were registered in mice from two lines divergently selected for birthweight environmental variability. All the details of the selection process can be found in Formoso-Rafferty et al. (2016a). These lines will be referred to as “low” and “high” line in the rest of this study. For the feed efficiency analysis specific information on weights and intake was registered during five consecutive generations of the selection experiment (from generation 10 to 14), but for the reproductive efficiency analysis the reproductive information was obtained across the 16 generations of the selection experiment.

The experimental feed efficiency design consisted of 40 female mice weaned at 21 days taken from each of 2 generations, and an additional 20 from 3 other generations,

(two full-sib females from half number of random litters) within high and low lines of the divergent selection experiment, totalling 271 animals with useful records after editing. All females were individually housed and fed to appetite (ad libitum) after weaning. Body weight (W) measurements in grams of each animal were taken every week during 6 weeks after weaning. Feed intake of each animal (FI) was registered in grams as the difference between offered feed and leftovers. Other traits were then analysed such as relative intake (RI), as the rate between FI and W at the beginning of the week, weight gain in grams (WG) and cumulated transformation index (TI) as the rate between FI and WG from weaning up to the end of each considered week. For all these traits a subindex w from 0 to 5 was added to specify the week after weaning in which they were recorded (Table 1).

Mice were considered mature at 42 days of age (Silver, 1995), but it was decided to start mating from 56 days onwards. All the females were housed in cages, each with one male from the same line, cohabiting for 31 days to have the opportunity to become pregnant up to two times. To know the differences in reproductive efficiency between lines, fertility was studied through several traits. First, the percentage of females having at least one parturition (P1) was recorded, as well as the percentage of females attaining two parturitions (P2) in each generation. Fertility was also expressed as the number of parturitions per female (NP) and generation. Litter size at birth (LSB) and at weaning (LSW), and the number of pups stillborn (MB) and deaths at weaning (MW) were also registered in both first and second parturitions. Records from different parturitions were considered independent as first parturition could condition the second one. The experience of a first parturition may affect the outcome of a second parturition, but this effect is expected to be different from one line to another. Therefore, first and second parturitions were independently analysed between lines. The mean, standard deviation and number of records for reproductive traits are shown in Table 2. There were 1,436 females registered, 1,343 having

at least a first parturition and 851 performing two parturitions.

Statistical analyses were performed using Statistical Analysis System software (SAS 1990). W, FI, RI, WG and TI were feed efficiency traits, and reproductive traits were NP, LSB, LSW, MB and MW in the first and second parities. These were analysed under a model with the specific line, generation and its interaction as class effects, and litter size (LS) as a linear and quadratic covariate as sources of variation, and using a general linear model procedure. The statistical model for the feed efficiency traits was also defined by removing LS covariate as genetic differences in LS exist between lines. The means were compared by the Tukey's test under different significance levels ($p < 0.05$, $p < 0.01$ and $p < 0.001$). Least square means were computed to show the observed differences between levels of relevant effects. The percentage of females having one or two parturitions was compared based on single statistical chi-square tests.

3 | RESULTS

3.1 | Feed efficiency

Table 3 includes the significance level of line, generation, interaction between line and generation, and linear and quadratic litter size covariates when fitted, on W_w , WG_w , FI_w , RI_w and TI_w in week w 0 (weaning) and 1, 2, 3, 4 and 5 (after weaning), when litter size was fitted or not fitted.

It is shown in Table 3 that the litter size only had an influence on female weight at weaning (W_0 and W_1) but not in WG, FI and RI. However, there were important differences in TI from the first week after weaning until the end of the experiment. Apparently, the evolution of TI was very similar between lines (Figure 1). When comparing fitting or not fitting litter size in the models, its inclusion only slightly changed the significance of TI during the last 3 weeks of the experiment thus becoming

TABLE 1 Mean and standard deviation for feed efficiency analysed traits ($n = 271$)

	Weight	Feed intake	Relative intake	Weight gain	Transformation index					
Weaning	W_0	11.47 ± 2.12								
1	W_1	18.76 ± 2.38	FI_1	26.45 ± 3.38	RI_1	2.36 ± 0.41	WG_1	7.29 ± 1.51	TI_1	3.90 ± 2.14
2	W_2	22.61 ± 2.19	FI_2	28.97 ± 3.07	RI_2	1.56 ± 0.21	WG_2	3.85 ± 1.41	TI_2	5.08 ± 0.92
3	W_3	23.83 ± 2.47	FI_3	28.78 ± 3.39	RI_3	1.28 ± 0.15	WG_3	1.22 ± 1.10	TI_3	6.94 ± 1.14
4	W_4	24.65 ± 2.51	FI_4	28.36 ± 3.55	RI_4	1.20 ± 0.15	WG_4	0.82 ± 1.00	TI_4	8.70 ± 1.36
5	W_5	25.43 ± 2.67	FI_5	28.37 ± 3.73	RI_5	1.16 ± 0.16	WG_5	0.77 ± 1.03	TI_5	10.32 ± 1.71

W_w : live weight (g); FI_w : feed intake (g); RI_w : relative intake; WG_w : weight gain (g); TI_w : cumulated transformation index (in week w after weaning).

TABLE 2 Number of records, means and standard deviations for fertility analysed traits

Trait	n	Mean	SD
NP	1436	1.53	0.62
First parturition			
LSB	1343	9.37	2.78
LSW	1343	8.32	3.06
MB	1343	0.18	0.68
MW	1343	1.05	2.02
Second parturition			
LSB	851	9.56	3.17
LSW	851	8.42	3.41
MB	851	0.24	0.92
MW	851	1.14	2.02

NP: number of parturitions; LSB: litter size at birth (newborns); LSW: litter size at weaning (pups); MB: mortality at birth (pups stillborn); MW: mortality at weaning (pups).

the line with highly significant effect ($p < 0.001$). When the litter size effect was not fitted, TI was slightly different between lines ($p < 0.05$) only in the third and last weeks. However, regarding TI it can be noted that the lines become similar if the higher litter size of the low line was assumed by not fitting this effect in the model.

When litter size was fitted, there was a significant influence of the line across the whole period for W, FI and RI ($p < 0.001$ or $p < 0.01$), but not consistently across the experiment for WG and TI. The line influence was neither significant for WG during the last 2 weeks, nor for TI in the first 2 weeks. Generation affected mainly intake (FI and RI) and TI ($p < 0.001$), but much less for W and WG. The generation effect ensured fitting only the common environmental influence on the performances in both lines by checking residual plots and not finding abnormalities in their distributions. Histograms of the different traits are shown as an Appendix 1. Interaction tended to be nonsignificant, which was expected as animals shared the same environment within generation, probably affecting both lines in the same manner. Differences in W between lines are shown in Figure 2a, in which female weight was always lower in the low line. Meanwhile, Figure 2b shows the evolution of WG with no differences between lines with the exception of WG₃ in which the low line was significantly lower ($p < 0.001$).

Regarding FI, Figure 3a (also in Table 3) shows that the low line was significantly lower than the high line across the experiment, but RI was significantly higher in the low line than in the high line during the experiment (Table 3, Figure 3b).

TABLE 3 Significance of the difference between lines, generations, interaction lines*generation, and linear and quadratic litter size covariate when fitted, for the feed efficiency analysed traits, fitting or not fitting litter size (LS)

	Live weight					Weight gain					Feed intake					Relative intake					Transformation index						
	W ₀	W ₁	W ₂	W ₃	W ₄	W ₅	WG ₁	WG ₂	WG ₃	WG ₄	WG ₅	FI ₁	FI ₂	FI ₃	FI ₄	FI ₅	RI ₁	RI ₂	RI ₃	RI ₄	RI ₅	TI ₁	TI ₂	TI ₃	TI ₄	TI ₅	
With LS as covariate	***	***	***	***	***	***	*	*	***	n.s.	n.s.	**	***	***	**	**	**	**	**	**	**	n.s.	n.s.	***	***	***	***
Line	***	***	***	***	***	***	*	*	***	n.s.	n.s.	**	***	***	**	**	**	**	**	**	**	n.s.	n.s.	***	***	***	***
Generation	n.s.	*	n.s.	**	*	***	**	***	n.s.	*	*	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Line*Generation	n.s.	n.s.	*	**	***	***	n.s.	***	n.s.	n.s.	n.s.	n.s.	**	n.s.	**	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	**	**	**
LS	***	**	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	***	***	***	**
LS*LS	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	*	n.s.	*						
Without LS as covariate	***	***	***	***	***	***	n.s.	n.s.	n.s.	n.s.	n.s.	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Line	***	***	***	***	***	***	n.s.	n.s.	n.s.	n.s.	n.s.	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	n.s.
Generation	**	*	n.s.	*	*	***	**	***	*	*	*	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Line*Generation	n.s.	n.s.	n.s.	*	***	***	n.s.	***	n.s.	*	n.s.	n.s.	*	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	***

Notes. W_w: live weight (g); WG_w: weight gain (g); FI_w: feed intake (g); RI_w: relative intake; TI_w: cumulated transformation index (in week w after weaning as a subindex). n.s. not significant. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

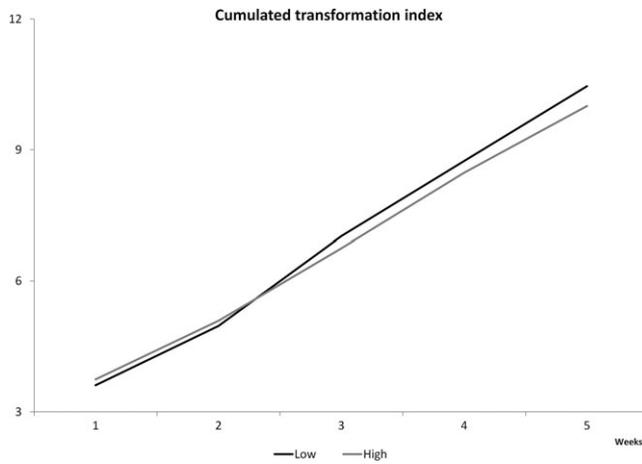


FIGURE 1 Phenotypic evolution of the cumulated transformation index in both variability lines after weaning during the experiment period (5 weeks)

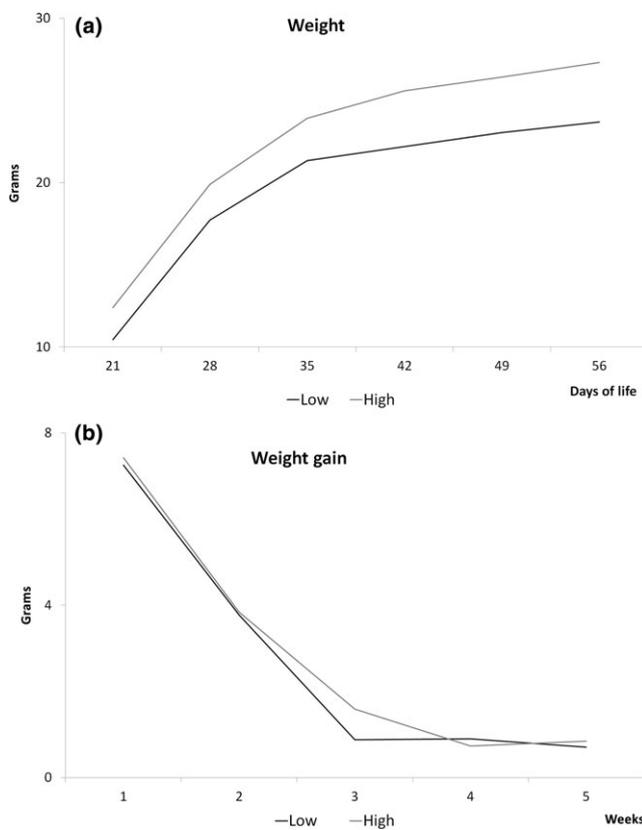


FIGURE 2 Phenotypic evolution of female weekly weight (a) and weight gain (b) in both variability lines from weaning at 21–56 days of life (5 weeks)

3.2 | Reproductive efficiency

The percentage of females having at least one (P1) or two parturitions (P2) across the 16 generations of selection in both low and high lines are shown in Figure 4. Despite the fact that both selected lines had a good level of mean

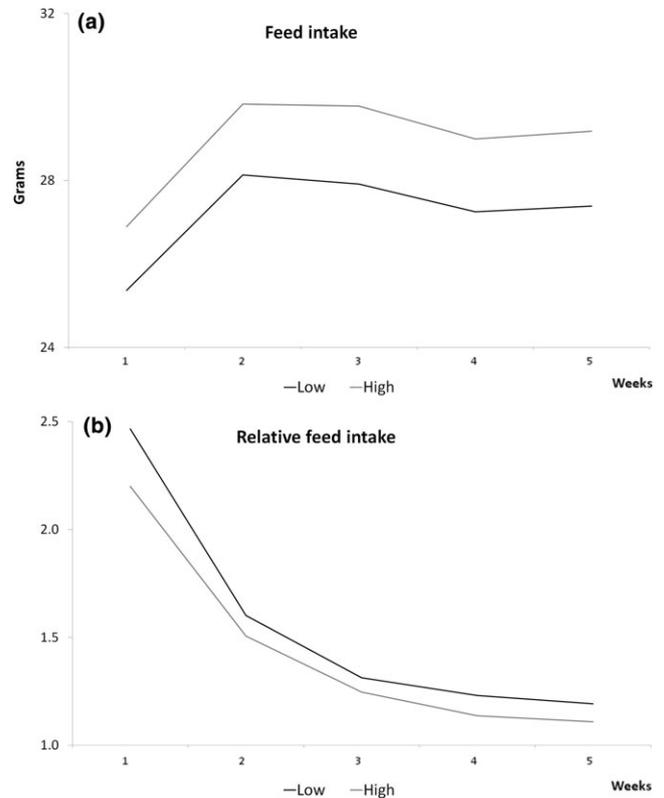


FIGURE 3 Phenotypic evolution of weekly feed intake (a) and relative feed intake (b) in both variability lines after weaning (5 weeks)

fertility, regarding P1, the low line was 95.26% versus 91.78% of the high line ($p < 0.01$), and regarding P2, the low line reproductive performance was 64.76% versus 53.62% of the high line ($p < 0.001$). As a consequence, the number of females with no parturition was higher in the high line. However, significance within generation tended to be less apparent because of the low number of records, showing in addition the expected lower difference in the former generations of selection than the latter. Thus, the low line performed significantly better than the high line in both fertility indicators, and specifically in the second parturition the low line was consistently and significantly better than the high line in generations 12–16, the last five generations of selection.

The least square means and the standard error of the rest of reproductive traits in both lines and the significance between them are shown in Table 4. The LSB and LSW were significantly higher ($p < 0.001$) in the low line in both parturitions. There was a high level of survival in both lines, but with MB significantly lower in the low line in the first parturition ($p < 0.001$). There were no significant differences in MW in the first parturition or in MB and MW in the second one. The number of dead pups was always lower in the low line even when there was a significantly higher litter size. Thus, translating this result into

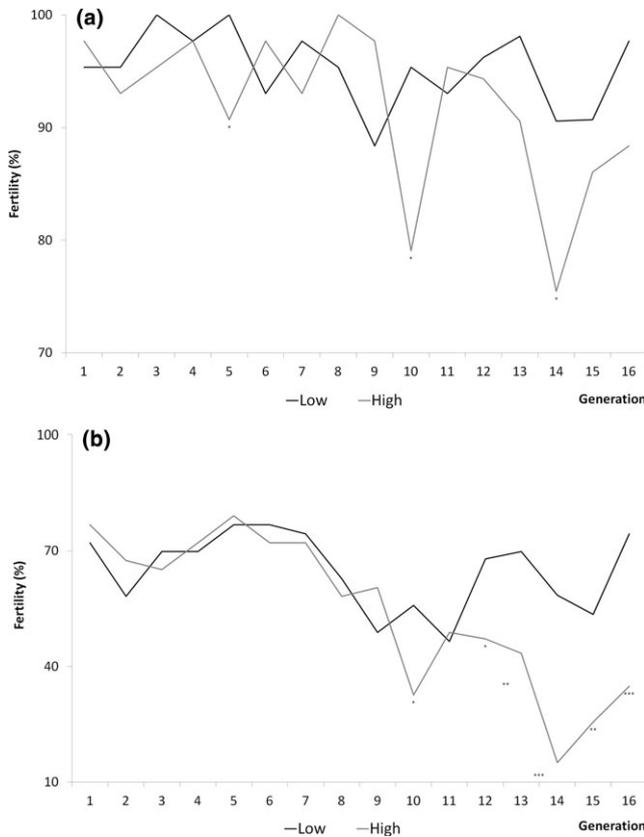


FIGURE 4 Fertility (%) in the first (a) and second (b) parturition and its degree of significance in both variability lines across generations (1–16). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

survival percentage at birth across parturitions, for the low line it was 98.4% versus 97.0% of the high line, and 87.6% versus 83.8% for the high line. This result suggests an improvement in robustness in the low line even though pups were smaller at birth (Formoso-Rafferty et al., 2016a) and at weaning.

4 | DISCUSSION

This research was a study of the differences in feed efficiency, and reproduction ability, between two mice lines diverging in birthweight variability. One of the main findings of the present paper was related to robustness as defined by Mormede and Terenina (2012) of being less sensitive to the environment as indicated by a low variation benefitting animal welfare. Under this definition, a sound relationship between homogeneity and robustness seemed to be present. Formoso-Rafferty et al. (2016b) had already suggested that the low line presented higher robustness and welfare, but not yet demonstrated for a worsening productivity. It was, therefore, necessary to broaden the investigation to include this issue.

TABLE 4 Least square means and standard error (in brackets) of reproductive traits in both variability lines and its degree of significance (p) in the first and second parturition computed using the Tukey's range test

	NP	First birth			Second birth		
		LSB	LSW	MW	LSB	MSB	MW
Low	1.600 (0.022)	9.984 (0.103)	9.046 (0.112)	0.955 (0.076)	10.090 (0.144)	9.132 (0.153)	1.039 (0.094)
High	1.464 (0.022)	8.764 (0.105)	7.607 (0.114)	1.158 (0.077)	8.683 (0.171)	7.459 (0.181)	1.266 (0.111)
p	***	***	***	n.s.	***	***	n.s.

Notes: NP: number of parturitions; LSB: litter size at birth (newborns); LSW: litter size at weaning (pups); MW: mortality at birth (pups stillborn); MSB: mortality at weaning (pups); n.s.: not significant. *** $p < 0.001$.

Feed efficiency depends on the relationship between the feed intake and the growth of an animal. While growth is a trait rather easy to register by weighing the animals at certain points in their life, feed intake is a more complex measurement to obtain. So, feed intake can be collected at an individual level by providing automatic feeding stations, in chickens (Howie, Avendano, Tolkamp, & Kyriazakis, 2011; Howie, Tolkamp, Avendano, & Kyriazakis, 2009) and in pigs (Sánchez et al., 2017) or individually. Feed efficiency, mostly expressed as feed conversion ratio (FCR) or residual feed intake (RFI), is an indicator to judge the financial and environmental performance of a farming system (Barea et al., 2010; Gidenne, Garreau, Drouilhet, Aubert, & Maertens, 2017). Byerly (1941) proposed feed efficiency as such an indicator and shown to have a genetic variability and, therefore, Hess, Byerly, and Jull (1941) proposed it as a selection criterion. In this study both live weight and feed intake were studied as components of the feed conversion ratio, as well as weight gain and relative intake to finally analyse FCR as cumulated transformation ratio.

Regarding feed efficiency, the results showed that lines did not substantially differ in productivity. All animal weights in the low line were significantly lower than in the high line but there were minor differences between lines in weight gain (Figure 2). Differences in body weight were the consequence of lower birth and weaning weight in low line from the genetically correlated response with the selection criterion (Formoso-Rafferty et al., 2016b). In addition, the low line had lower weights due to higher litter size at birth and at weaning. Despite the fact that during the experiment the low line presented lower weights (Figure 2a) and feed intake was also significantly lower than in the high line (Figure 3a). In the end, there were no important differences between lines in the cumulated transformation index (Figure 1) when litter size influence was not fitted in the model. Even though there were no differences in TI between lines in the first 2 weeks when litter size was fitted, they were highly significant in the last 3 weeks of the experiment, with the low line having a worse transformation index, suggesting that adult weight was achieved earlier in the low line than in high line. However, the significance of the line effect on TI almost disappeared when litter size was not considered in the model. Therefore, the high line would not be preferred as differences in litter size have been proved to be genetic.

This higher litter size of the low line appeared as a result of the correlated response to select for environmental variability (Formoso-Rafferty et al., 2016b). The genetic relationship between homogeneity and litter size was unknown when designing the selection experiment. Hence, the applied genetic evaluation model included litter size as a systematic effect in both the mean and variability levels

of the model. However, the results could still be affected by litter size. For example, if the litter size is small for a female tending to give high variability litters, all animals can be of similar size by chance. However, if the litter size was larger, the animals will tend to be born with different weights (Formoso-Rafferty et al., 2016a). Even though predicted breeding values used in the selection were adjusted for litter size there was a substantial correlated response, showing a close genetic relationship between litter size and homogeneity. In our study, this effect was also observed as the high line had smaller litter sizes than the low line (Table 4).

These results for the low line could be good indicators of a similar performance than the high line in terms of feed efficiency. However, the low line presented higher litter size and survival without additional energy cost. Feed efficiency has been shown not to be affected by the lower size of the animal originating from an increase in the homogeneity, but it has also been shown here the reproductive advantages of the low line. Regarding reproduction ability, and according to the results of this study, selecting to reduce variability would be an objective as the animals would increase reproductive efficiency without loss of feed efficiency. Differences between lines were more significant throughout generations with the result of higher number of second parturitions in low line than in high line which was a correlated effect of the selection (Formoso-Rafferty et al., 2016b). Furthermore, mortality at birth and at weaning in the first and second parturitions was higher in the high line. Overall the low line had more litters with higher LS and survival at birth and at weaning with the consequent benefits in production and welfare.

The suitable use of the metabolic resources sustains the animal needs such as maintenance, growth, reproduction and other metabolic functions during its life (Glazier, 1999). Williams and Jenkins (2003) argued that decreasing feed intake without affecting growth or production would reduce maintenance energy thus improving feed efficiency. Reducing maintenance energy requirements in livestock is an appealing goal since up to 70% of feed intake may be consumed to meet these requirements (Bhatnagar & Nielsen, 2014a,b). It was interesting to see that animal weights in the low line were 15% lower, but only consumed 6% less than those in the high line showing that the maintenance cost is expensive in terms of feed intake. According to the Resource Allocation Theory developed by Beilharz, Luxford, and Wilkinson (1993), fitness components, number of parturitions, litter size and survival of progeny were connected because the required metabolic resources for their function are interrelated, as resources used for one function are no longer available for any other function. There may be some exceptions for this assumption, which are termed "resource association" by Glazier (1999) and

Rauw (2009). For example, energy used to aid digestion, locomotion and production may be used again for thermoregulation. An important assumption is that energy budgets that are for the duration of an animal lifespan are limited and must be allocated amongst competing demands. Despite this fact, there were no differences between lines in the economic balance of the total growth but the reproductive efficiency might have been affected.

Improving feed efficiency with reproductive performance is important to ensure profitability of animal production systems (Fontoura et al., 2016). An approach to select for fertility along with feed efficiency is likely to be successful, as fertility traits (Cammack, Thomas, & Enns, 2009) and feed efficiency (Fontoura et al., 2016) are heritable and consequently bring economic benefits through genetic improvement (Herd, Archer, & Arthur, 2003). Studies relating feed and reproductive efficiency are scarce. But it was demonstrated that fertility is usually affected by body composition, environmental and genetic factors. These factors influence the reproductive process at ovulation, fertilization or implantation or during gestation and parturition (Rodríguez et al., 2018). Not only is there a need for animals with low feed intake but they also have to perform properly in both weight and reproduction. The objective for livestock producers is to achieve both excellent feed and reproductive efficiency without compromising either one of them. In other words, a female with an appropriate feed efficiency is of no importance if it cannot reproduce and provide a litter. On the other hand, animals properly reproducing will not be willed if they consume a large amount of feed but given that income for producers comes mainly from the weight of animals the key expense would be feed intake. In addition, less feed efficiency could result in delayed parturitions (Arthur, Herd, Wilkins, & Archer, 2005; Basarab, McCartney, Okine, & Baron, 2007).

The development of prolific breeds increased the number of pups born per female. Consequently, this led to wider birthweight variability within the same litter, which will probably have negative consequences. Selection to reduce environmental variance can lead to more uniform products without compromising future genetic progress, as genetic variance of the trait is not affected (Mulder et al., 2008). On the other hand, genetic uniformity can be overall useful for production traits (Bodin et al., 2010). For example, homogeneity of birthweight within litters in rabbits is related to higher viability of the kits, and also in mice (Formoso-Rafferty et al., 2016b). Females with less adaptable genotypes would be more susceptible to diseases and to stress, showing a higher degree of variability, as shown in rabbit litter sizes (Argente et al., 2014; García et al., 2016). Moreover, selection to reduce environmental variance would have other advantages, leading to animals that cope

better within their environment, something frequently used to define animal welfare (Blasco, Martínez-Álvarez, García, Ibáñez-Escriche, & Argente, 2017; Broom, 2008). In addition, this type of selection process would affect the heritability of the birthweight (Formoso-Rafferty, Cervantes, Ibáñez-Escriche, & Gutiérrez, 2017). This type of experiment has been useful because the establishment of experimental lines is considered a common strategy to evaluate the direct and the correlated responses to a particular selection criterion and to study the impact of the selection on animal physiology (Gilbert et al., 2017). Well-structured information such as that provided by divergent selection experiments is very useful, because methodologies using direct phenotyping and genomic selection could be the key for future efficient breeding programmes, particularly for feed efficiency, because no genomic or blood biomarker has been identified (Gilbert et al., 2017). In the future, it will be necessary to look at the overall feed efficiency, and also at the genes that affect the use of different nutrients (Reyer, Hawken, Murani, Ponsuksili, & Wimmers, 2015).

Benefits in production and welfare were already reported by García et al. (2016) who proved that selecting for LS residual variance affected welfare in rabbits. It is worth noting that the unwilling effect of LS on mortality and growth can be reduced in homogeneous litters which results in more efficient growth in rabbits with low birthweight (Poignier, Szendrő, Levai, Radnai, & Biro-Nemeth, 2000). The health inferiority accompanying the heterogeneity was similarly shown in rabbits, with heterogeneous litters being prone to suffer from diseases (Poignier et al., 2000).

Therefore, the homogeneity in animal production can be highly important for animal production as it influences the efficient use of resources and facilities, thus providing extra value for fattening farms. However, some possible shortcomings of this study have to be mentioned. The study presented here might have been limited by the difficulty in obtaining a higher number of records. For example, it remains unclear whether the superiority of the high line in TI, as shown here, could be dependent on the litter size. Conclusions are also restricted to the fact that both populations stayed in the same common and single environment.

It would be interesting to investigate this analysis in other farming species from different populations, to establish whether the phenomenon is useful at selecting animals with higher inherent fertility with better survival, litter size and robustness. We need to improve our understanding of the genetic and phenotypic relationships between feed intake and production at different phases of the animal's productive life to optimally improve the efficiency of the whole production system (Herd & Arthur, 2009). This research is a contribution to this understanding.

Summarizing, there were no significant differences between lines in the case of feed efficiency. However,

the low line performed much better for reproduction, with higher litter size and survival, which are clear welfare indicators, and, therefore, considered more robust. The present study concurs with Mormede and Terenina (2012) that the low line seems to be more robust and is less sensitive to environmental effects with a low variation, better welfare and higher profits. However, it is true that the environment experimental conditions were controlled and the ability of the animals to react to environmental challenges was not studied. It still remains necessary to prove whether the low line would be more robust in a stressful environment.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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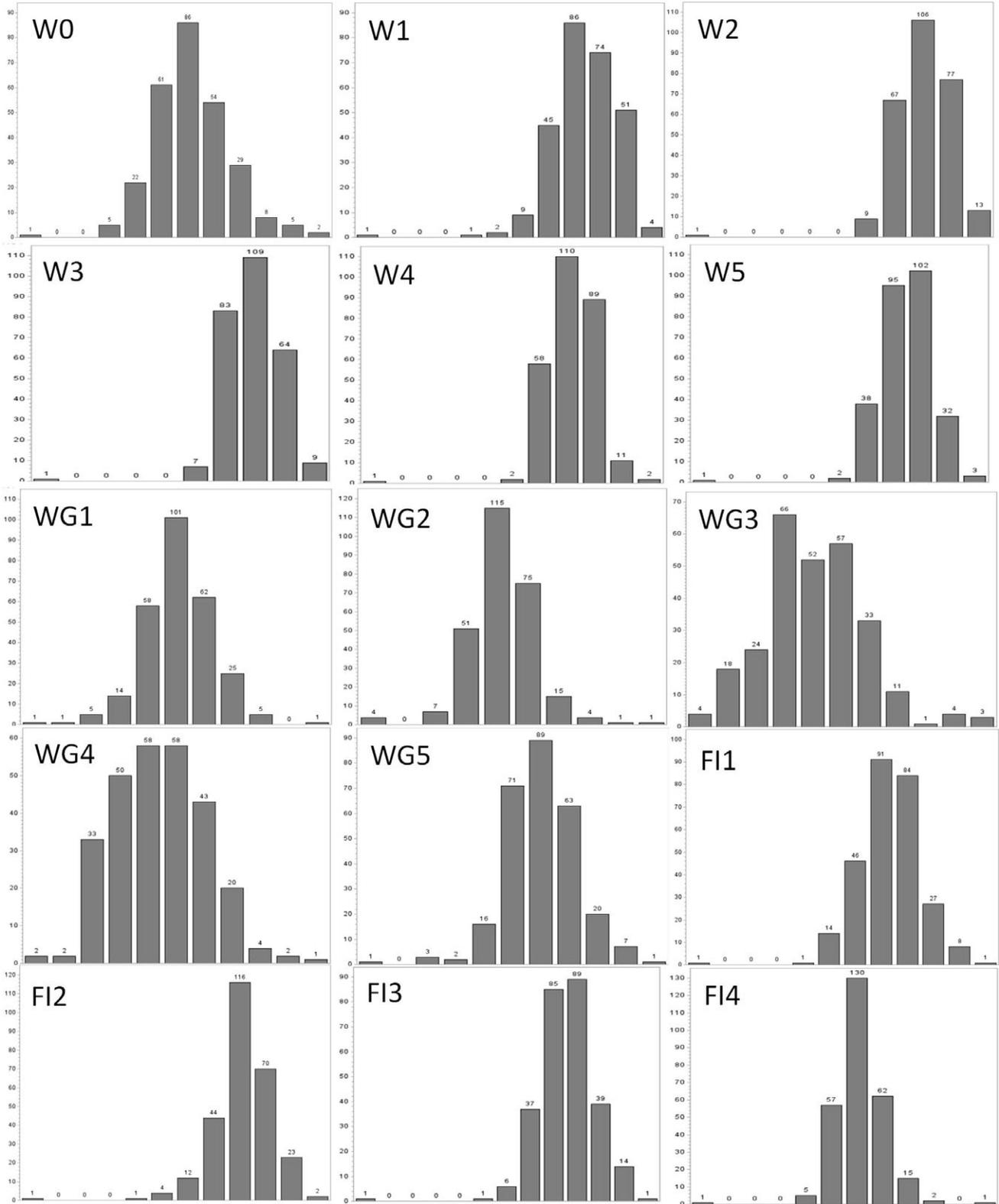
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APPENDIX 1

HISTOGRAMS FOR THE FEED EFFICIENCY ANALYSED TRAITS

W_w : live weight (g); WG_w : weight gain (g); FI_w : feed intake (g); RI_w : relative intake; TI_w : cumulated transformation index (in week w after weaning as a subindex).





APPENDIX 1 (continued)

