Chapter

The Genetic Improvement in Meat Rabbits

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Abstract

Rabbits are raised for many different purposes, such as breeding stock for meat, wool and fur, as an educational and experimental animal model, and as pets and show animals. However, this species is main used for meat production. France, Italy and Spain have an important role in the increase of world rabbit meat production through the development of selection programs in this species. Genetic improvement programs have based on development of maternal lines to improve prolificacy and paternal lines to improve growth rate, but the alternative development of multi-purpose lines for litter size and growth traits will be discussed. In this chapter, the variance components of these traits, the response to selection and the main commercial available lines will be reviewed. Universities and public research centers have played a leading role in the development of these lines and in the diffusion of this genetic material through a pyramid scheme from selection nuclei to farmers. Recently, others functional traits are emerging successfully as selection criteria in breeding programs such as ovulation rate, prenatal survival, longevity, feed efficiency, meat quality, uniformity in production, and resistance to digestive disorders.

Keywords: average daily gain, feed conversion rate, heritability, litter size, selection

1. Introduction

Rabbits are raised for many different purposes, such as breeding stock for meat, wool and fur, as an educational and experimental animal model, and as pets and show animals. However, this species is used mainly for meat production. China and Mediterranean countries concentrate 78% of world production meat [1]. It must note highlighting the leadership of France, Italy and Spain in development of the rabbit selection programs, which have been key to enhance the efficiency in meat production.

2. Economic important traits in meat rabbits

The selection objectives in breeding programs are established according to the economic importance of the traits. Economic weights in rabbit meat production have been estimated in different markets, such as the Spanish [2, 3], Australian [4] and French one [5], and in all these studies, the litter size and the feed conversion

Traits	Unit	Spain		Australia	France
		[2]	[3]	[4]	[5][a]
	Reproductive traits				
Litter size	Increase by 1	16.90	15.66	15.03	45.52
Lactation survival	Increase by 1%	1.96	1.71	1.70	
Replacement rate per does and year	Increase by 1%	−0.45	−0.29	−0.23	
	Growth traits				
Daily feed intake during fattening	Decrease by 1 g/d	0.41	0.50	0.49	
Daily gain during fattening	Increase by 1 g/d	1.53	1.33	1.23	11.82
Feed conversion rate during fattening	Decrease by 0.1 g/g	18.80	20.19		10.26
Healthy					
Resistance to enterocolitis					4.41

[a]*Economic weights estimated in a context of restricted feeding.*

Table 1.
Economic weights of the main traits of the profit function in €/unit of the trait.

rate have been reported as the most important traits for rabbit industry (see **Table 1**). The growth rate is easier and cheaper to record than feed conversion rate and has a favourable genetic correlation with it [6]. For this reason, rabbit commercial schemes are based on three-way cross. Two selected lines for litter size at birth or at weaning are crossed to create a commercial doe [7–13], which is mated with a terminal sire from other selected line for growth rate post-weaning or for body weight at a point close to market age [14–17]. The aim of the cross between the maternal lines is to exploit advantage of the expected positive heterosis in reproductive traits, the possible complementarity among the lines and the dispersion of the inbreeding accumulated within the lines [8].

3. Genetic parameters for litter size and growth traits

Genetic progress in the selection programs depends mainly on the heritability of the selected trait and on the selection intensity. In this section, a review of quantitative genetic components for litter size and growth traits will be carried out. For litter size at birth, the estimates of the heritability show in general low values (0.05 to 0.20 and 0.11 on average) and tended to decrease slight from birth to slaughter (0.00 to 0.13 and 0.08 on average for number born alive, 0.02 to 0.12 and 0.07 on average for litter size at weaning, and 0.06 to 0.08 and 0.07 on average for litter size at slaughter, see **Table 2**). The estimates of the ratios of permanent environmental variance to the phenotype variance are also rather low for litter size at birth. In agreement to heritability, the estimated values decrease from birth (0.11 on average) to market time (0.08 on average). These findings are an indication of high effect of environmental influence on litter size and the low repeatability. Regarding genetic correlations between litter size traits, the estimates present positive and high values, ranging from +0.96 to +0.99 for litter size at birth and number born alive, and from +0.60 to +0.98 for number born alive and litter size at weaning [11, 24, 33].

For growth traits, there are many estimates of heritability for weaning and slaughter weight (see **Table 3**). The average values of these estimates are moderate (0.18 for weaning weight and 0.22 for slaughter weight). However, these estimates

LS		NBA		NW		NS		Line/breed	References
h^2	p^2	h^2	p^2	h^2	p^2	h^2	p^2		
0.20	0.25			0.09	0.12			New Zealand White	[18]
0.10	0.07	0.07	0.09	0.07	0.07	0.07	0.06	Line selected by OR and LS	[19]
0.10	0.09							Environmental Variance of LS	[20]
0.11	0.08	0.10	0.09	0.09	0.07			Line A	[10, 21, 22]
0.08	0.12	0.05	0.09	0.02	0.07			Line H	[21, 22]
		0.09	0.10	0.08	0.08			Line LP	[21]
		0.09	0.11	0.07	0.13			Line R	[21, 22]
0.18	0.09	0.07	0.10	0.05	0.08	0.05	0.07	Line V	[23]
0.13	0.05	0.05	0.09	0.02	0.06			ITELV2006 line	[24]
		0.05	0.09					Pannon White	[25]
0.13	0.10	0.00	0.06					Pooled Poured Breed	[26]
0.05	0.09	0.03	0.09					Brazilian Synthetic Line	[27]
0.12	0.06	0.09	0.07					Pannon Ka	[28]
0.05	0.11	0.07	0.11					Pannon Large	[29]
0.07	0.10	0.07	0.09					Pannon White	[30]
0.11	0.09	0.08	0.08	0.06	0.03			Line Prat	[10]
0.09	0.21	0.12	0.20	0.09	0.16	0.07	0.12	Local line	[31]
0.19	0.19			0.08	0.19			Danish While	[32]

OR: ovulation rate.

Table 2.
Heritability (h^2) and permanent effect (p^2) of litter size at birth (LS), number of kits born alive (NBA), number of kits at weaning (NW) and number of rabbits at slaughter (NS).

present widely range of values (0.03 to 0.48 for weaning weight and 0.06 to 0.67 for slaughter weight); that can be related to different weaning age, from 28 days in semiintensive management to 42 days of age in extensive management, and different slaughter time, from 9 week in Spain to 13 weeks of age in Italy (see review by [46]). Contrarily, the estimates of heritability for growth rate show a narrow range (0.12 to 0.34) and moderate average value (0.22). A reduced number of studies has been carried out to analyse the genetic determination of feed conversion rate (see **Table 3**). The average value of heritability for feed conversion rate is similar those of growth rate (0.29), varying in a small range such as growth rate (0.22 to 0.42). The litter effect is especially important for weaning weight (0.47 on average), and in lesser extent for slaughter weight (0.28 on average), growth rate (0.19 on average) and feed conversion rate (0.12 on average). Some studies have also estimated maternal genetic effects for growth traits. Maternal heritability seems to be slightly higher for weaning weight (0.17 on average) than for slaughter weight (0.10 on average). There is only one estimation for growth rate (0.21), and no estimate has found for feed conversion rate in bibliography. In general, maternal genetic effects are much lesser important than litter effects.

Regarding genetic correlations between growth traits, weight at weaning is positive and highly correlated with weight at slaughter in agreement with [24, 33], ranging from +0.61 to +0.74. Genetic correlation between growth rate and weight at slaughter is higher than at weaning (+0.56 vs. +0.31 [33, 47]). Genetic

WW				SW				ADG				FCR		Line/Breed	Reference
h^2	c^2	p^2	h^2_m	h^2	c^2	p^2	h^2_m	h^2	c^2	p^2	h^2_m	h^2	c^2		
				0.41										New Zealand White	[34]
0.06	0.43			0.13	0.26			0.19	0.13			0.22	0.10	ConsoResidual line	[35]
0.04	0.33			0.11	0.22			0.22	0.17			0.23	0.16	ADGrestrict line	[35]
0.15		0.27		0.19		0.14		0.21		0.10				Line B	[36]
0.15		0.18		0.15		0.12		0.17		0.10				Line R	[36]
0.03	0.64	0.07		0.06	0.38	0.08								ITELV2006 line	[24]
				0.20		a		0.25		a				Pannon White	[37]
								0.27	0.14					Pannon White	[38]
0.04	0.72			0.12	0.51			0.17	0.40					Line selected by body weight at 70 d	[15]
0.48			0.25	0.39			0.11							Brazilian Synthetic Line	[27]
0.08	0.44		0.18	0.08	0.26		0.05							Brazilian Synthetic Line	[27]
0.24	0.31	0.01		0.17	0.18	0.18	0.00							Angora line	[39]
0.09	0.35	0.11		0.13	0.28	0.05		0.14	0.27	0.01				Line selected by OR and LS	[40]
0.41		a		0.37		a		0.34		a				Line Prat	[33]
								0.21	0.17			0.25	0.22	Line Prat	[6]
								0.21	0.12			0.32	0.07	Line Caldes	[41]
								0.17	0.32					Danish White	[42]
0.42		0.18	0.09	0.27			0.27	0.21			0.21			New Zealand White	[43]
0.25	0.44			0.24	0.22			0.22	0.09			0.33	0.07	AGP39	[44]
0.12	0.52			0.14	0.27			0.12	0.12			0.42	0.07	AGP59	[44]
0.09	0.52			0.67	0.26			0.41	0.21			0.27	0.17	Divergent lines for residual feed efficiency	[45]

OR: ovulation rate. LS: litter size. a: effect included in the model but not display.

Table 3.
Heritability (h^2), common litter effect (c^2), permanent effect (p^2) and genetic maternal effect (h^2_m) of weaning weight (WW), slaughter weight (SW), average daily gain (ADG) and feed conversion rate (FCR).

correlation between growth rate and feed conversion rate is negative and moderate (−0.4 to −0.5 [6, 35]). The bibliography is scarce and contradictory for genetic correlations between litter size traits and growth traits. There are high and negative estimates between litter size and weight at weaning (−0.85, −0.92 and −0.85 for litter size at birth, number born alive and litter size at weaning, respectively [24]) and estimates close to zero (−0.05, −0.07 and −0.25 for litter size at birth, number born alive and litter size at weaning, respectively [33]). Indeed, it was reported that increases in litter size resulted in a decrease of individual weight at weaning [48, 49]. The genetic correlations between litter size traits with weight at slaughter (+0.11, +0.03 and −0.16 for litter size at birth, number born alive and litter size at weaning, respectively [33]) and growth rate (+0.04, −0.06 and −0.16 for litter size at birth, number born alive and litter size at weaning, respectively [33]) show also values close to zero.

Selection is more complicated for litter size traits than for growth traits. This complexity is due to the fact that the litter size traits display a low heritability and only express in the does, and consequently selection intensity is lower than when both sexes express the trait [12, 50]. In order to increase the accuracy in estimates of genetic values, and therefore the progress into selection program, it is recommended considering as many individual and relative records as possible for genetic evaluation of the does and males, even though generational interval increases [51]. Selection for average daily gain from weaning to slaughtering has been used traditionally as selection criterion to improve of feed conversion rate thus far, since this trait has a moderate heritability and it is lesser affected to common litter effects than the individual weight at specific age (**Table 3**). Moreover, it is much easier and cheaper to measure than feed conversion rate and it has a negative favourable correlation with it [6, 35]. However, the development cheap electronic devices nowadays that enable recording of individual feed intake in this species, together moderate heritability of this trait and its moderate genetic correlation with average daily gain (−0.4 to −0.5), have challenged whether selection for average daily gain is the best way to improvement of feed efficiency, instead of direct selection (see review [46]).

4. Selected lines

Traditionally, rabbit commercial schemes have based on development of specialised lines to improve prolificacy (maternal lines) and to improve growth rate (paternal line) as it was commented in Section 2 [7–17]. However, the foundation and development of specialised lines is an activity with the high requirements, organisation, experience, and money needed, that not all countries can carry out. In countries where the rabbit industry has not yet reached a proper level of organisation, it may not be appropriate to select dam and sire lines for a subsequent cross-breeding program [52]. An alternative could be the development of multi-purpose lines, through simultaneous selection for litter size and growth traits [27].

In maternal lines, the most common direct criteria used in selection programs is litter size at birth or at weaning (see **Table 4**). Although, litter size at weaning show a lower heritability than litter size at birth (see **Table 2**); the majority of maternal lines are selected by litter size at weaning, since this trait reflects both the prolificacy as well as the maternal ability of the doe (**Table 4**). In some commercial lines, the selection criterium is weight at weaning, a trait relates to the ability of the doe for lactating and nourishing the progeny [56]. The response due to selection in these maternal lines has ranged between 0.05-0.13 kits born alive or weaned per litter and generation [8].

Name	Country	Origen	Selection criteria	Number of generations	Reference
INRA2066	France	Californian & Giant Himalayan	Litter size at birth	More than 34 generations	[53]
INRA2666	France	INRA2066 & Line V	Litter size at weaning	Since 1999	[54]
INRA9077	France	New Zealand White & Bouscat White	Litter size at birth	Since 1998	[55]
INRA1777	France	INRA1077	Litter size at birth & individual weaning weight	More than 5 generations	[56]
Line A	Spain	New Zealand White	Litter size at weaning	More than 44 generations	[57]
Line V	Spain	Four specialised maternal lines	Litter size at weaning	More than 39 generations	[57]
Line H	Spain	Hyperprolific commercial does	Litter size at weaning	More than 22 generations	[57]
Line LP	Spain	Long-lived commercial does	Litter size at weaning	More than 8 generations	[57]
Line PRAT	Spain	A closed population with crossbred animals	Litter size at weaning	Since 1992	[58]
Pannon Ka	Hungary	Crossbreds & Pannon White	Number of kits born alive	Since 1999	[59]
APRI	Egypt	Baladi Red & Line V	Litter weight at weaning	Since 2002	[60]
ITELV2006	Argelia	INRA2666 and local population	Litter size at birth and body weight at 75 days	Since 2003	[61]
Uruguay NZW	Uruguay	New Zealand White	Litter size at weaning	More than 5 generations	[62]
Uruguay V	Uruguay	Line V	Litter size at weaning	More than 5 generations	[62]

Table 4.
Maternal lines for meat rabbit production.

In paternal lines, in order to improve feed conversion rate as comment before, the most common direct criteria used in selection programs is postweaning daily gain from weaning to slaughtering. Other selection criteria used in paternal lines are those related to the weight at slaughter (see **Table 5**). Recently, residual feed intake was investigated experimentally as a direct way to improve the feed conversion rate [44, 45, 48]. The response to selection in paternal lines range between 18 and 35 g/generation for weight at slaughter and between 0.45 and 1.23 g/d generation for daily gain, with positive correlated response on adult weight and feed intake and negative correlated response on feed conversion, dressing percentage and maturity at a fixed weight [8, 48].

In multi-purpose lines, both growth and reproductive traits are selected (**Table 6**). Thus, there are lines selected simultaneously by individual weight at slaughter and litter size traits, and by thigh muscle volume (TMV) measured on computer tomography (CT) and litter weight or average daily gain. The problem of selection by TMV is the high costs and the long generation intervals [59].

The oldest program for rabbit breeding and improvement is the French program that was started in 1969 by French National Institute for Agricultural Research (INRA-SAGA, Toulouse), and followed by the Spanish programs that started in

Name	Country	Origen	Selection criteria	Number of generations	Reference
Line R	Spain	Two paternal lines	Postweaning daily gain	More than 32 generations	[57]
Line Caldes	Spain	Crossbreds	Postweaning daily gain	Since 1992	[63]
Italian Silver	Italy	Argenté de Champagne	Postweaning daily gain	Since 2000	[57]
ALEX	Egypt	Baladi Black & Line V	Postweaning daily gain	More than 7 generations	[13]
Altex	USA	¼ California & ¼ Giant Himalayan & ½ Flemish Giat	Individual weight at 70 days	Since 1994	[15]

Table 5.
Paternal lines for meat rabbit production.

Name	Country	Origen	Selection criteria	Number of generations	Reference
INRA1077	France	New Zealand White & Bouscat White	Litter size at birth & Individual weight at 63 days	More than 30 generations	[64]
Giante de España	España	Flemish Giant & Lebrel Español	Litter weight at weaning & growth rate during fattening	Since 1984	[65]
Italian New Zealand White	Italy	New Zealand White	Litter size at 21 days & Individual weight at 60 days	Since 1980	[66]
Italian California	Italy	California	Litter size at 21 days & Individual weight at 60 days	Since 1980	[66]
Pannon White	Hungary	New Zealand White & California	Litter weight at 21 days & Thigh muscle volume	Since 2010	[59]
Pannon Terminal L	Hungary	Crossbreds & Pannon White	Postweaning daily gain & Thigh muscle volume	Since 2005	[59]
Moshtohor	Egypt	Sinai Gabali & Line V	Litter weight at weaning & individual weight at 56 days	Since 2006	[13]
Saudi-3	Saudi Arabia	Saudi Gabali & Line V	Litter weight at weaning and weight at 84 days	Since 2000	[13]
Botucatu	Brazil	Norfolk line	Litter size at weaning & Postweaning daily gain	Since 1998	[27]

Table 6.
Multi-purpose line for meat rabbit production.

1976 for the Department of Animal Science at Universitat Politècnica de València (UPV, Valencia) and in 1992 for Rabbit Science Unit at Institute of Agrifood Research and Technology (IRTA). The INRA-SAGA has developed several maternal lines as INRA2066, INRA2666, INRA1777 and INRA9077, and a synthetic multi-purpose line as INRA1077. In Spain, the UPV and IRTA have created the maternal lines A, V, H, LP and PRAT and the paternal lines R and Caldes. Besides, University of Zaragoza has developed a multi-purpose line Gigante de España [57].

Other selection programs in rabbits have been carried out both inside and outside Europe. For example inside Europe, Kaposvár University in Hungary has developed the maternal line Pannon Ka and multi-purpose lines Pannon White and Pannon Terminal L, and two cooperative centres from Emilia-Romagna in Italy have created the paternal line Italian Silver and the multi-purpose lines Italian New Zealand White and California. Outside Europe, we can found the maternal lines APRI (at the Animal Production Research Institute in Egypt), ITEL2066 (at the Institut Technique de l'Elevage -ITELV- and at Tizi Ouzou University in Algeria), and Uruguay NZW and V (at Instituto Nacional de Investigaciones Agropecuarias of las Brujas in Uruguay), and the paternal lines ALEX (at Alexandria University in Egypt) and Altex (at Texas A&M University in USA) as well as the multi-purpose lines Moshtohor (at Benha University in Egypt), Saudi-3 (at King Saud University in Saudi Arabia) and Botucatu (at Faculdade de Medicina Veterinária e Zootecnia of Botucatu in Brazil). It must note that most of the lines developed outside Europe have had the collaboration of the UPV and INRA-SAGA. Furthermore, the rabbit farmer can also purchase in market animals from the maternal and paternal lines from several private companies, mainly French and Spanish as Eurolap Hyla, Grimaud Frères Sélection, Hycole, Hypharm, and Granja Jordán among others.

5. Selection experiments

New traits are emerging as criterium selection in breeding programs, both maternal lines and parental lines. Accordingly, selection experiments have been carried out in different rabbit populations. Different strategies have been adopted for estimating the genetic progress in these experiments, as the using divergently selected lines or the using a control population. Divergent selection allows us to use each line as control of the other, but estimated response can be biased when response is no symmetry in both lines. Control population provides an unbiased estimate of response to selection since working with non-selected animals from the same population. Selection for ovulation rate, prenatal survival, longevity, feed efficiency, meat quality, uniformity in production, and resistance to Pl digestive disorders has been reviewed in this section.

5.1 Selection for ovulation rate and prenatal survival

Selection for ovulation rate and prenatal survival has been proposed as an indirect approach for increasing litter size since these parameters limit it. In turn, uterine capacity limits prenatal survival, thus its selection has been postulated in order to improve litter size [67]. There has been carried out one selection experiment for ovulation rate [68], two divergent selection experiment for uterine capacity (one in UPV [69] and other in INRA-SAGA [70]), and one two-step selection experiment for ovulation rate and litter size [71]. The estimated response to selection for ovulation rate using a control population was 0.21 ova per generation without any correlated response in litter size, as consequence a reduction in fetal survival [68]. The difference between the divergent lines for uterine capacity showed that selection was effective for uterine capacity and a correlated response was found in embryo survival in the experiment of UPV [72] and in fetal survival in the experiment of INRA-SAGA [70]. An asymmetric correlated response in litter size was reported after 10 generation of selection in UPV experiment using a control population; whereas increasing uterine capacity was not accompanied by a correlated response in litter size, decreasing it reduced litter size by 0.19 kits per generation because of lower embryo and fetal survival [73]. Two-stage selection by ovulation rate and litter size has successful and showed a correlated response in litter size by 0.12 kits per generation [71].

5.2 Selection for longevity

Due partially to negative correlated response to high selection for production on voluntary culling in dam, the longevity has been proposed as new selection objective in breeding programs in rabbits. In this sense, two selection experiments have been performed to improve longevity: one in the UPV and other in the INRA-SAGA. The UPV's experiment has allowed to create the LP line. This line was founded by selecting females from commercial farms with extremely high number of parturitions (between 25 and 41 parities) and a constraint on prolificacy (from 7.5 to 11.9 young born alive) [74]. Once the LP line was constituted, the selection is being carried out by litter size at weaning and this line is currently in 17th generation. The INRA-SAGA has performed a divergent selection experiment for longevity. The selection criterium was the total number of artificial inseminations after the first parity [75]. Both experiments have showed a favourable correlated response on doe's body reserves. However, response to longevity has been limited, due to this trait has a small heritability and the time required obtaining pertinent information is long.

5.3 Selection for feed efficiency

Feed efficiency has been traditionally measured as feed conversion rate, i.e., the ratio between feed intake and body weight gain over a fixed range of days. More recently, residual feed intake has emerged as new trait for improving of feed efficiency. However, residual feed intake is no ease to measure, since to require using equations in order to estimate the difference between actual feed intake and expected feed intake according to the requirements for the maintenance and the growth of the animal. Several divergent selection experiments in rabbits for feed conversion rate [76] and residual feed intake [35, 45, 77] have been carried out. The divergent selection experiment of Moura et al. [76] reports a difference between lines, having the high line lower feed conversion rate than the low one at the end of the experiment. The estimated response to selection using mixed model technique was 0.6% per generation. The divergent selection experiment on residual feed intake of Larzul and de Rochambeau [45] only had one generation of selection, nothing can be said about whether selection was successful since the difference between the lines was not significant. The experiment of selection for residual feed intake between 30 and 65 d of age of Drouilhet et al. [35, 77] showed a decreasing in residual feed intake of 0.9% per generation (−39 g), and a correlated response of 0.8% (−0.20 g) in feed conversion rate after nine generations. No correlated response was found for growth rate, showing that selection acted upon reducing appetite [78, 79].

5.4 Selection for quality meat

Intramuscular fat is a main meat quality factor, since affecting sensory properties and the nutritional value of the meat. A divergent selection experiment on intramuscular fat in muscle *Longissimus dorsi* was carried out by Zomeño et al. [80]. After seven generations of selection, the divergence between lines was around 5% per generation (1.09 g/100 g), with a symmetrical response [81]. There were no correlated responses in pH and in colour and in any sensory attributes [82]. A positive correlated response was found on fat in *Biceps femoris*, in *Supraspinatus* and *Semimembranosus proprius* muscles, and in perirenal fat content, which was greater in the high line [83]. An increase in dissectible fat leads to deterioration in carcass. However, the amount of dissectible fat in rabbit carcasses is low still (2.5% at 9 weeks and 3.5% at 13 weeks, [84]), in order to consider that selection for intramuscular fat can deteriorate carcass in this species.

5.5 Selection for uniformity in production

Uniformity in production is an interesting trait for rabbit industry. Two divergent selection experiments for environmental variability have been carried out one in INRA-SAGA for homogeneity in weight at birth and other in University Miguel Hernández de Elche (UMH) for homogeneity in litter size at birth. The INRA-SAGA's experiment showed a lower within-litter birth weight standard deviation in the Homogeneous line than in the Heterogenous line after 10 generations (7.34 g vs. 11.26 g [85]). Moreover, the Homogeneous line exhibited higher litter size at weaning and lower mortality at birth and at weaning than the Heterogeneous line. No correlated response was reported for the individual weight at birth or the standard deviation and individual weight at weaning [86]. A higher homogeneity in weight birth within litter was related to higher length and capacity of the uterine horn, thus the divergence between the lines could be at least partly due to their characteristics of the reproductive tract [87]. In the experiment of UMH, after 10 generations of selection, the environmental litter size variance was 2.7 $kits^2$ in the Homogeneous line and 4.4 $kits^2$ in the Heterogeneous line [88]. A low variability in litter size in the Homogeneous line was related to better adaptation to environment with less response to stress and diseases, i.e. with does more resilient [89]. Therefore, decreasing litter size variability can favour the dam's survival in the farm. Moreover, selection for litter size variability shows a negative response correlated to litter size, i.e., a reduction in litter size variability was accompanied by a larger litter size at birth [88]. A higher litter size in the Homogeneous line was related to a higher number of implanted embryos [90], as consequence a higher embryonic development at early gestation in this line [91, 92].

5.6 Selection for resistance to digestive disorders

A divergent selection experiment to resistance to enteropathies disorders was performed in INRA-SAGA. A binary score based on the observed signs of enteropathy during the growing period was the selection criterion. The resistance animals showed similar mortality and growth rate to those of sensitivity animals, but cumulative mortality was lower in resistant than sensitivity animals, when animals were inoculated with an enteropathogenic *E. coli* 0103 strain [93].

6. Conclusions

Traditionally, rabbit commercial schemes have based on development of specialised lines to improve prolificacy (maternal lines) and to improve growth rate (paternal line). However, not all countries have a proper level organisation, being an alternative the development of multi-purpose lines for litter size and growth. Universities and public research centers have played a leading role in the development of these lines. Litter size and growth rate have traditionally been the selection criteria in the selection schemes for these lines. Recently, others functional traits are emerging strongly as selection criteria in breeding programs such as ovulation rate, prenatal survival, longevity, feed efficiency, meat quality, uniformity in production, and resistance to digestive disorders.

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Conflict of interest

The authors declare no conflict of interest.

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