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Rabbit growth performance, carcass traits and hind leg bone characteristics as affected by the sire breed, season, parity order and sex in an organic production system*

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Live performance, carcass traits and hind leg bone characteristics of crossbred rabbits of both sexes (Sx) of two sire breeds (SB): Vienna Blue – (VB) and Burgundy Fawn – (BF) born with different parity orders (P: 1, 2, ≥3), reared organically and slaughtered in the spring and summer, when they reached 2.8 kg, were evaluated. The slaughter age of VB crossbreds increased between P1 and P2 (P<0.05). During the summer, the rabbits exhibited a higher slaughter age (P<0.01), reference carcass yield (P<0.01), and hind leg meat-to-bone ratio (P<0.05). The P2 crossbreeds exhibited the lowest incidence of scapular fat (P<0.05). The weights of the full gastrointestinal tract and skin were 2.4% higher and 1.5% lower in females, respectively (P<0.01), and head proportion was higher in males (P<0.05). Females exhibited a longer femur and thicker tibia than did the males (P<0.05). The results confirmed the slow growth rate of the crossbreds evaluated, which may represent an interesting genetic resource for organic production of rabbits.

KEY WORDS: carcass traits / growth performance / organic production system / rabbit / sire breed / slaughter season

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According to the European Council [December 2009]: “Sustainable development remains a fundamental objective of the European Union”. The need for the conservation and the management of biodiversity and natural resources has also been stated [Fortun-Lamothe *et al.* 2009]. Sustainable agriculture and alternative rearing systems thus became an objective, but they require genetic resources that are characterised by high adaptability, such as local breeds or populations that are suitable for intense conditions.

In addition, in Italy, organic rabbit production must follow the guidelines for organic livestock systems (Council Regulation – EC No. 1804/1999), as well as those of two official certification organizations [ICEA 2007; AIAB 2001], which state that only pure breeds, their first generation crosses, and local populations are admitted, and red-eyed breeds are banned [Dalle Zotte and Paci 2013].

In Italy, the demand for rabbit breeds, whether pure or their crosses, that are characterized by slow growth and good resistance to diseases is rising. However, at the time of this study, there were not enough farms with a sufficient number of purebred coloured rabbits to adequately supply the emerging rabbit organic farms. A strategy to overcome this difficulty was the use of crossbred rabbits derived from sires of coloured breeds crossed with females of medium-to-large sized breeds, excluding the Californian and New Zealand White breeds.

Among the coloured breeds, the Vienna Blue and Burgundy Fawn are the most suitable breeds for this purpose. Information concerning the characteristics of coloured breeds is limited or out of date, compared to the many scientific reports on commercial hybrids, where the effects of season, sex and parity order on growth performance and carcass quality have been extensively studied [Auxilia 1968, Castellini *et al.* 2003, Chiericato *et al.* 1993, Dalle Zotte 2005, Lazzaroni *et al.* 2009, Marai *et al.* 2002, Masoero 1992, Metzger *et al.* 2011, Nardone *et al.* 2010, Ortiz Hernandez and Rubio Lozano 2001, Paci *et al.* 1995a, Parigi Bini *et al.* 1989, Parigi Bini *et al.* 1992, Pascual *et al.* 1998, Raimondi and Auxilia 1973, Szendrő 2000, Zeferino *et al.* 2011, 2013].

The aim of this study was to compare the live performance and carcass traits of rabbits derived from two sire breeds – Vienna Blue and Burgundy Fawn – born with a different parity order and reared in organic systems during two seasons.

Material and methods

Animals, housing system and diets

The study was conducted during the spring and summer on a rabbit farm certified for organic production, located in the Lombardy region of Italy (Azienda Agricola “Noi e la Natura”, www.noielanatura.it; 45° 5’20.20”N; 10° 9’40.81”E).

Vienna Blue (VB) and Burgundy Fawn (BF) sire breeds were chosen for evaluation of the productivity of crossbreds obtained from mating them with females derived from a mix of crossbreds of several medium-to-large sized breeds, excluding the white breeds, e.g., California and New Zealand White, in accordance with an official Italian certification organization regarding organic agriculture [AIAB 2001].

A total of fifty-eight weaned rabbits (at day 46±6 of age) of both sexes and derived from rabbit does with different parity orders (P: 1= nulliparous; 2= primiparous; ≥3= multiparous), were used. Thirty of the weaned rabbits were derived from the VB sire breed (SB), and 28 from the BF (SB). The live performances of the litters prior to weaning are presented by Dalle Zotte and Paci [2013].

At weaning, five animals were housed together (≤8 rabbits/m^2) in collective wire cages with plastic slat floors; the cages were located in a fattening building supplied with a natural ventilation system and natural lighting, according to the directives of EC Regulation 1804/1999 and the AIAB [2001] regulations. Throughout the experiment, the environmental conditions followed the seasonality, with temperatures ranging from 10°C to 30°C and relative humidity ranging from 60 to 75%.

The rabbits were fed an organic pelleted diet (Tab. 1) and drinking water *ad libitum*.

Table 1. Analysed chemical composition (g kg^{-1}) of the organic diet

Item	Organic diet
Dry matter	923.3
Crude protein	133
Ether Extract	40
Crude fibre	145
Ash	88
Neutral detergent fibre (NDF)	280
Acid detergent fibre (ADF)	175
Acid detergent lignin (ADL)	32
Gross Energy (GE), MJ/kg	16.51

Live performance data collection

Throughout the study, an individual rabbit's body weight was determined at weaning and every week after week 14 of age, stated by AIAB as the minimum age of slaughter, to find when it reached the prefixed slaughter weight of 2.8 kg. The daily weight gain (DWG) was then calculated. The mortality rate was monitored.

Slaughter and carcass measurements

The rabbits were slaughtered during two seasons (22 in the spring and 36 in the summer) when they reached an average slaughter weight (SW) of 2.8±0.13 kg. The rabbits were slaughtered in the farm abattoir by electrical stunning followed by cutting of the carotid arteries and jugular veins. The carcass dissection procedures followed the World Rabbit Science Association (WRSA) recommendations, as described by Blasco and Ouhayoun [1993].

The slaughtered rabbits were bled, and the skin and paws, genital organs, urinary bladder, and full gastrointestinal tract were removed and individually weighed. The carcasses, with the head, thoracic cage organs (heart, lungs, thymus, trachea, and oesophagus – HLTTO), liver, kidneys, the perirenal and scapular fat, were weighed 30 minutes after slaughter (hot carcasses – HC), and were then chilled at +4 °C for 24 h in a ventilated room. After 24 h of chilling, the carcasses (CC) were weighed. The head, HLTTO, liver and kidneys were removed from each carcass to obtain the reference carcasses (RC), which included the meat, bones and fat deposits.

The carcass yield (carcass weight as % of SW) was expressed as either the hot carcass (HC) or the chilled carcass (CC) weights, and the ratio of the carcass traits and the organs to both the SWs and the CC weights were calculated as required.

The perirenal fat, scapular fat and other dissectible fat, and the hind legs and loin joint (between the 1st and the 7th lumbar vertebra) were dissected from the RCs and weighed, and the ratio to the RC weights was calculated. The right hind legs were deboned, and the meat-to-bone ratio was calculated according to Blasco and Ouhayoun [1993]. The left hind legs were deboned after boiling (water bath cooking; core temperature 80°C; Ouhayoun and Dalle Zotte [1996]) and were subjected to rheological measurements.

Rheological measurements

The weights and Warner Bratzler fracture toughness (WBFT) of the boiled tibiae and the raw femurs of the 28 rabbits slaughtered in the summer (15 VB and 13 BF) were determined. The WBFT values of the boiled femur bones were determined for each of the 58 rabbits of the two SS under consideration. The lengths and diameters of the tibial and femoral bones were measured using a dial caliper (±0.02 mm). All of these dimensions were obtained following the methods described earlier by Dalle Zotte *et al.* [2009]. The bone length was determined by measuring the distance between the proximal and distal epiphyses. The bone diameter was measured in terms of the minor thickness at the mid-diaphysis, which corresponds to the breaking point. The bones were subjected to a three-point flexure test conducted with a universal testing machine (INSTRON 1000). The distance between the two fulcrum points supporting the bones was 45 and 38 mm, for the femoral and tibial bones, respectively; the load rate was 5 mm/min. The bones were consistently positioned for testing with their natural convex shape downward. The flexure fixture used was specific for testing the bone fracture toughness (INSTRON).

Analytical measurements

The organic diet provided throughout the trial was sampled. Table 1 presents the chemical composition and gross energy content of diet. AOAC procedures [2000] were used to determine, in duplicate, the dry matter content (DM – 934.01) and the contents of ash (942.05), crude protein (CP – 976.05), crude fibre (CF – 978.10), neutral detergent fibre (NDF – 2,000.04), acid detergent fibre (ADF), and acid detergent lignin (ADL – 973.18) using an ANCOM TECHNOLOGY system (Macedon, NY, USA) and filter bags (F57). The ether extracts (EE – 920.39) were determined after acid-hydrolysis. The gross energy (GE) was determined using an adiabatic bomb calorimeter [ISO 1998].

Statistical analysis

The data were evaluated with an ANOVA by the GLM procedure in the SAS [2007] programme, including the sire breed (SB: VB, BF), season (SS: spring, summer), parity order (P: P1, P2, P≥3), sex (Sx: male, female), and their interactions. The weaning age was used as a covariate. The least squares means (LSM) were calculated for all of the effects involved in the model, and the statistical significance of the differences was assessed using the Tukey test [SAS 2007].

Results and discussion

Growth performance

During the experimental period no rabbit mortality was observed. The effects of SB, SS, P, Sx, SB x P and SB x Sx interactions on the growth performance are shown in Table 2.

The genetic origin and sex had no effect on the growth performance. SS had a significant (P<0.001) effect on the daily weight gain (DWG) and the slaughter age (Tab. 2): the rabbits slaughtered in the summer exhibited a slower DWG than those reared in the spring, and they reached the fixed slaughter weight later.

As expected, this study did not reveal differences in growth performance attributable to the SB (VB or BF) tested or to the sex when the slaughter weight was fixed at 2.8 kg. These findings support those reported by Jensen and Tuxen [1982] for purebred VB and BF rabbits. As early as 1973, in a study conducted to compare the growth performance of purebred BFs and its crosses with the New Zealand White and Californian breeds, Raimondi and Auxilia [1973] highlighted their slow growth, observing that they reached the commercial live weight (2.5 kg) at week 15 of age. In other studies [Auxilia 1968, Masoero 1992], the VB breed was considered a good sire for crosses, although the growth efficiency was not always improved, whereas the BF breed was characterized by a high variation of the DWG. However, the BF breed has been demonstrated to have an encouraging growth potential when used as an SB, with the offspring exhibiting a higher growth rate when reared under intense conditions [Paci *et al.* 1995a] compared to those reared in organic production systems, such as the offspring in this study.

The slow growth rate exhibited by the rabbits in this study, apart from being related to the features of the sire breeds used, may also depend on their feeding regimen because the organic diet was low in crude protein content (133 g kg^{-1}) and was not supplemented with synthetic amino acids, vitamins and minerals, in accordance with the certification institute (AIAB). It is thus likely that the amino acids requirement was not fulfilled.

The growth performance might also have been affected by the organic rearing system, in which the rabbits were reared in collective cages with a low stocking density (5 rabbits/cage, ≤8 rabbits/m^2). As observed by other authors, the slower growth rate and the consequently longer time required to reach the commercial slaughter weight under low stocking-density conditions may be attributable to the larger space, which promoted increased locomotive activity relative to the ingested energy [Paci *et al.* 2013].

As regards the effect of the season (SS) on the growth performance, high temperatures (e.g., above thermal-neutrality) are known to reduce feed intake, which impairs the growth rate and alters many physiological functions, thus affecting the growth efficiency [Dalle Zotte 2002]. The decrease in the DWG and the increase in the fattening period during the summer have been demonstrated in many different genotypes of rabbits [Chiericato *et al.* 1993, Chiericato *et al.* 1996, Marai *et al.* 2002, Pla *et al.* 1994, Villalobos *et al.* 2010, Zeferino *et al.* 2011]. In the present study, the summer temperature also decreased the rabbits' growth rate; these rabbits showed a significantly longer fattening period (+12 days) to reach the fixed slaughter weight. This result suggests that the crossbred rabbits derived from

Table 2. Growth performance of growing rabbits

Item	Sire breed (SB)		Season (SS)		Parity (P)			Sex (Sx)		P-value						RMSE[1]
	VB	BF	spring	summer	1	2	≥3	female	male	SB	SS	P	Sx	SBxP	SBxSx	
No. of rabbits	30	28	22	36	31	16	11	24	34							
Weaning age[2]	45	47	43	48	45	47	48	46	46							
Individual weaning weight (g)	1142	1150	1154	1139	1142	1132	1165	1142	1151	ns	ns	ns	ns	ns	ns	129.5
Days of fattening	65.7	66.6	63.1	69.2	62.8	69.3	66.3	68.6	63.7	ns	ns	ns	ns	ns	ns	9.6
Daily weight gain (g/d)	26.4	24.9	27.9	23.4	27.1	24.9	25.0	25.2	26.1	ns	***	ns	ns	ns	ns	2.8
Live weight at slaughter (g)	2808	2805	2833	2780	2789	2814	2817	2826	2787	ns	ns	ns	ns	ns	ns	99.7
Slaughter age (days)	112	112	106	118	108^a	115^b	112^{ab}	114	110	ns	***	*	ns	*	ns	7.2

[1]Residual means standard error. [2]Covariate; ns: not significant. *P<0.05; ***P<0.001.
[ab]Within rows means bearing different superscripts differ significantly at P<0.05.

VB and BF were highly sensitive to the thermal conditions, thus confirming their difficulty in acclimatising to being reared under an indoor organic system. It is likely that group-rearing, although with a low stocking density, does not allow sufficient heat dissipation. Indeed, Paci *et al.* [1995b] studied the effects of a hot season on crossbred rabbits derived from BFs reared in outdoor and indoor systems and found better performance in the rabbits reared outdoors.

A significant (P<0.05) SB x P interaction was observed for the slaughter age (Fig. 1); in the crossbred rabbits derived from the VB (SB), the slaughter age significantly increased between P1 and P2, whereas in those derived from the BF (SB) no difference in the slaughter age due to the P value was observed. As regards these results, a younger slaughter age of the rabbits from the VB crossbreeds and the nulliparous does might be related to their individual weight at birth. As reported in our earlier paper, the nulliparous does mated to VB males delivered litters with significantly lower individual weights at birth [Dalle Zotte and Paci 2013]. Notably, the SB x P interaction pattern observed for the slaughter age was very similar to that observed for the individual weights of the rabbits born alive, particularly for VB offspring [Dalle Zotte and Paci 2013].

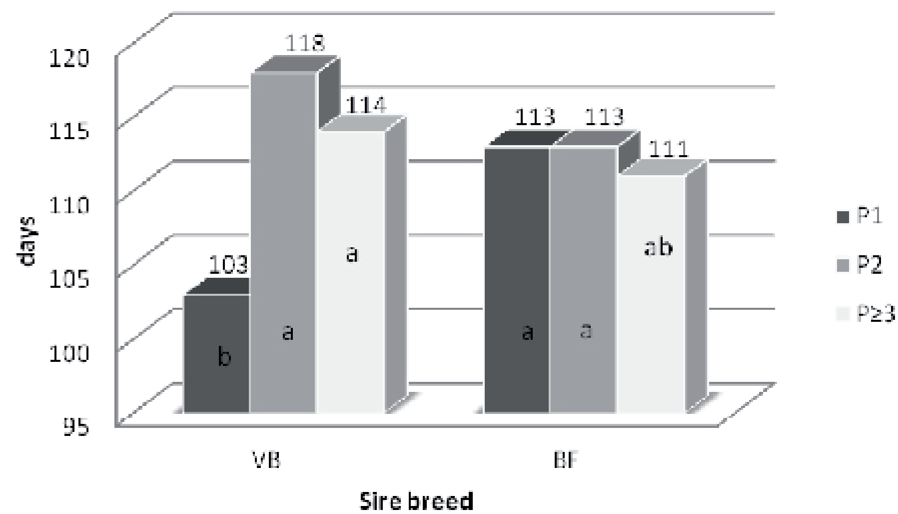

Fig. 1. Interaction effect SB x P (sire breed x parity order) on slaughter age (a, b: P<0.05).

These results suggest that when the individual weight at birth is low (e.g., for the VB P1 and the BF P3), the rabbits often exhibit compensative growth, reaching the same slaughter weight earlier than rabbits with a higher birth weight. However, it is well known that rabbit growth is affected not only by the birth weight but also by the feeding regimen, litter size, milk intake and parity order. The available literature relates a greater litter size and weight at birth with an increasing parity order and a lower growth rate in rabbits derived from and reared in a large litter [Castellini *et al.*

2003, Metzger *et al.* 2011, Parigi Bini *et al.* 1989, Pascual *et al.* 1998, Scapinello *et al.* 1999, Szendrő 2000]. With regard solely to the VB offspring, our findings partly confirm those reported in the literature [Castellini *et al.* 2010, Rebollar *et al.* 2009] indicating that P2 offspring presents lower post-weaning growth attributable to the negative energy balance of the does, thus leading to the increased time required to reach the same slaughter weight.

Carcass traits

Table 3 presents the effects of SB, SS, P and Sx on the carcass traits of growing rabbits. No significant interaction among the main factors was observed.

The SB did not affect the carcass traits, whereas the SS affected almost all of the studied parameters. In the rabbits slaughtered in the summer, the slaughter yields (expressed as HC and CC) were significantly higher ($P<0.05$), the proportion of a full gastrointestinal tract was 2.4% lower and that of the skin and paws 1.4% higher ($P<0.001$) than that of rabbits slaughtered in the spring.

Comparing the rabbits slaughtered in different seasons demonstrated that those slaughtered in the summer had a lower feed intake and thus a slower growth rate, resulting in a lower slaughter weight at the same slaughter age and often, a better slaughter yield, which was due to the smaller proportions of the skin, empty gut and offal [Chiericato *et al.* 1993, 1996, Lebas and Ouhayoun 1987]. Because our rabbits were compared at the same weight but at different stages of maturity, the lower proportion of full gastrointestinal tracts might be explained by both allometry and the decreased feed intake due to the higher ambient temperature [Dalle Zotte 2002].

Age and live weight are important factors in the variation of the dressing percentage because the latter changes markedly due to the different allometry of organs and tissue; when the slaughter age is postponed, higher slaughter yields are generally achieved [Cantier *et al.* 1969, Dalle Zotte 2002].

Despite the more advanced age of the rabbits slaughtered in the summer, they showed a higher incidence of the skin with the paws. This trend contrasts with the results reported by Chiericato *et al.* [1993, 1996] and Dalle Zotte [2002], who observed that hybrids reared under intense conditions exhibited a decrease in the proportion of the skin with the subcutaneous fat with increasing environmental temperatures. However, a recent study [Zeferino *et al.* 2013] reported a linear increase in the paws incidence with an environmental temperature, although the authors did not explain the relationship.

The RC yield (as % of CC) occurred also significantly higher in rabbits reared in the summer (83.3 *vs.* 81.6%, $P<0.01$) as the liver and kidneys contents were by 1.54% ($P<0.001$) and by 0.12% ($P<0.01$) lower, respectively. Chiericato *et al.* [1993] and, more recently, Zeferino *et al.* [2013] also reported a positive relationship between the RC yield and the ambient temperature and the reduction in the relative proportion of the metabolic organs was attributed to the increased heat stress. However, the differences in the RC yields between the two SS might also be ascribed to the different ages of the rabbits at slaughter because the allometric coefficients of the liver and kidneys

Table 3. Carcass traits of growing rabbits

Item	Sire breed (SB)		Season (SS)		Parity (P)			Sex (Sx)		P-value				RMSE[1]
	VB	BF	spring	summer	1	2	≥3	female	male	SB	SS	P	Sx	
No. of rabbits	30	28	22	36	31	16	11	24	34					
							weight (g)							
Slaughter weight (SW)	2808	2805	2833	2780	2789	2814	2817	2825	2787	ns	ns	ns	ns	99.3
Hot carcass (HC)	1680	1690	1683	1687	1672	1683	1700	1687	1682	ns	ns	ns	ns	63.5
Chilled carcass (CC)	1618	1633	1624	1628	1614	1624	1639	1628	1623	ns	ns	ns	ns	62.1
Reference carcass (RC)	1339	1343	1326	1356	1324	1351	1347	1348	1334	ns	ns	ns	ns	50.5
							%SW							
Full gastrointestinal tract	18.8	18.4	19.8	17.4	18.7	19.2	17.8	19.8	17.4	ns	***	ns	***	1.65
Skin and paws	16.9	16.6	16.1	17.5	16.7	16.3	17.3	16.0	17.5	ns	***	ns	***	1.0
Hot carcass yield (HC)	59.8	60.3	59.4	60.7	60.0	59.9	60.3	59.7	60.4	ns	*	ns	ns	1.53
Chilled carcass yield (CC)	57.7	58.3	57.3	58.6	57.9	57.8	58.2	57.6	58.3	ns	*	ns	ns	1.56
Drip loss percentage	2.18	2.02	2.09	2.11	2.07	2.09	2.13	2.10	2.10	ns	ns	ns	ns	0.54
							%CC							
Head	8.8	8.7	8.9	8.6	8.7	8.7	8.9	8.5	9.0	ns	ns	ns	*	0.66
HLTTO[2]	1.87	1.85	1.89	1.82	1.90	1.79	1.88	1.84	1.88	ns	ns	ns	ns	0.25
Liver	6.04	6.16	6.87	5.33	6.59^{b}	5.54^{a}	6.18^{ab}	6.06	6.14	ns	***	*	ns	0.95
Kidneys	0.99	1.04	1.07	0.95	0.98	0.99	1.06	1.02	1.00	ns	**	ns	ns	0.11
RC yield	82.7	82.2	81.6	83.3	82.1	83.2	82.2	82.8	82.2	ns	**	ns	ns	1.49

[1]Residual means standard error. [2] HLTTO: heart, lung, thymus, trachea and oesophagus; ns: not significant. *P<0.05; **P<0.01; ***P<0.001.
[ab]Within rows means bearing different superscripts differ significantly at P<0.05.

generally decrease with age [Cantier *et al.* 1969, Hernández *et al.* 2004, Pla 2008].

As regards the composition of the reference carcasses (Tab. 4) also the hind leg meat-to-bone ratio was affected by the SS: the rabbits slaughtered in the summer exhibited a better meat-to-bone ratio (P<0.05). This result most likely depended on their older slaughter age, thus confirming the data in the literature [Gondret *et al.* 2005].

The P values significantly affected the liver incidence (P<0.05), which was lower in the P2 than in P1 group (Tab. 3) and the scapular fat weight (P<0.05), which was lower in the P2 rabbits than in the P1 or P≥3 rabbits (Tab. 4). The lower incidence of liver in P2 crossbred rabbits than in the P1 rabbits, once again, was explained by their older age. The trend observed for the incidence of scapular fat is similar to that reported in pigs [Gondret *et al.* 2006]. Indeed, in an experiment conducted to determine the effects of birth weight on the adipose tissue content, the group with low birth weights showed higher fat content at slaughter age than the group with a high birth weight. In our study, the crossbred rabbits born by nulliparous and multiparous does had lower birth weights [Dalle Zotte and Paci 2013] and higher scapular fat contents than did those born by primiparous does, and these results may be attributed to compensatory growth.

Sex differences were observed for some of the carcass traits (Tab. 3). The full gastrointestinal tract and skin were 2.4% higher and 1.5% lower in females than in males, respectively (P<0.001); however, no significant differences were found in their dressing percentage. Males exhibited a higher head incidence than did females (9.0 *vs.* 8.5%; P<0.05), but this ratio did not affect the RC weights.

Table 4. Composition of the reference carcass (RC)

Item	Sire breed (SB)		Season (SS)		Parity (P)			Sex (Sx)		P-value				RMSE[1]
	VB	BF	spring	summer	1	2	≥3	female	male	SB	SS	P	Sx	
No. of rabbits	30	28	22	36	31	16	11	24	34					
Hind leg meat to bones ratio (raw)	5.1	4.8	4.7	5.2	5.0	4.9	5.0	4.9	4.9	ns	*	ns	ns	0.49
							%RC							
Perirenal fat	1.82	1.88	1.97	1.74	1.93	1.76	1.87	1.93	1.78	ns	ns	ns	ns	0.64
Scapular fat	0.51	0.57	0.49	0.58	0.61^b	0.42^a	0.59^b	0.58	0.49	ns	ns	*	ns	0.19
Other dissectible fat	0.42	0.27	0.46	0.23	0.44	0.28	0.31	0.37	0.32	ns	ns	ns	ns	0.42
Total dissectible fat	2.76	2.72	2.92	2.55	2.98	2.46	2.77	2.88	2.60	ns	ns	ns	ns	0.96
Hind legs	34.5	34.0	34.1	34.3	34.2	34.0	34.4	34.3	34.2	ns	ns	ns	ns	1.10
Loin (1^{st} – 7^{th} lumbar vertebra)	24.9	25.0	24.6	25.3	25.2	25.3	24.4	24.9	25.0	ns	ns	ns	ns	1.66

[1]Residual means standard error. ns: not significant. *P<0.05; **P<0.01; ***P<0.001.
[ab]Within rows means bearing different superscripts differ significantly at P<0.05.

Table 5. Hind leg bones characteristics of rabbits slaughtered in summer

Item	Sire breed (SB)		Parity (P)			Sex (Sx)		P-value						RMSE[1]
	VB	BF	1	2	≥3	female	male	SB	P	Sx	SBxP	SBxSx	PxSx	
No. of rabbits	15	13	8	11	9	10	18							
Age at slaughter (d)	115	120	113	122	117	120	115	ns	ns	ns	ns	ns	ns	8.72
Femur bone:														
length (cm)	9.44	9.42	9.33	9.40	9.57	9.60	9.27	ns	ns	*	ns	ns	ns	0.25
diameter (cm)	0.77	0.84	0.78	0.85	0.79	0.82	0.79	ns	ns	ns	ns	ns	ns	0.07
raw weight (g)	14.5	15.5	13.6[a]	16.3[b]	15.1[ab]	15.2	14.8	ns	*	ns	ns	ns	ns	1.57
boiled weight (g)	11.9	12.3	11.4[a]	12.8[b]	12.2[ab]	12.2	12.0	ns	**	ns	ns	ns	ns	0.66
raw WBFT (kg)[2]	42.0	40.8	40.3	46.9	36.9	39.8	43.0	ns	ns	ns	ns	ns	ns	11.3
boiled WBFT (kg)[3]	32.8	34.0	32.8	34.0	33.4	33.7	33.2	ns	ns	ns	ns	ns	ns	4.69
Tibia bone:														
length (cm)	10.2	10.0	9.9	10.2	10.2	10.1	10.1	ns	ns	ns	ns	ns	ns	0.44
diameter (cm)	0.65	0.74	0.73[b]	0.73[b]	0.63[a]	0.73	0.67	*	**	*	*	*	*	0.05
boiled weight (g)	9.7	10.3	9.7	10.4	10.1	10.3	9.8	ns	ns	ns	ns	ns	ns	0.98
boiled WBFT (kg)	26.1	27.0	23.8	26.6	29.4	26.8	26.3	ns	ns	ns	ns	ns	ns	3.29

[1]Residual means standard error; [2]WBFT: Warner–Bratzler fracture toughness; [3]measured on all rabbits (spring + summer slaughtering); ns: not significant; *: *P*<0.05; **: P<0.01; Different letters indicate significant different means within row: a, b: P<0.05

The sex effect found in the present study for the full gastrointestinal tract, skin and head values confirms the reports from the literature [Bernardini Battaglini *et al.* 1995, Dalle Zotte 2005, Lazzaroni *et al.* 2009, Paci *et al.* 1995a, Parigi Bini *et al.* 1992, Pascual *et al.* 2008, Pla 2008]. Pascual *et al.* [2008] used the allometric equation of Butterfield *et al.* [1983] to study the relative growth of different body components and found that the full gastrointestinal tract developed earlier in males. This could explain the lower proportion of the full gastrointestinal tract observed in the males in this study. It is also likely that this sexual dimorphic trait depends on the lack of selection of this trait in the two SBs used.

It should be emphasized that in growing rabbits, the sex differences emerge gradually as the rabbits approach puberty. In rabbits, sexual dimorphism appears after they reach puberty at approximately 13-14 weeks of age [Ouhayoun 1984]; because our crossbreds were slaughtered after week 15 of age, the differences observed are justified.

Bone characteristics

The characteristics of the hind leg bones of the rabbits slaughtered in the summer are shown in Table 5. The P status significantly affected the weight of the raw and boiled femur bones, which were heavier in P2 than in P1 rabbits ($P<0.05$ and $P<0.01$, respectively). The femur bone length was significantly affected by sex, with females presenting longer bones than did males ($P<0.05$). The SB, P and Sx values had significant effects on the tibial diameter.

The heavier weights of raw and cooked femoral bones from the rabbits born by primiparous does compared to those from rabbits born by nulliparous does were age-dependent, because the P2 offspring were significantly older than the P1 offspring because they reached the fixed slaughter weight later. It is generally assumed that when rabbits are slaughtered at a given weight, the development of their tissues depends on how quickly they reach the fixed weight, and because the slower growth rate increases the relative growth of the early maturing tissues, the bones are more developed [Ouhayoun 1998].

The sex differences observed in the length of the femurs also depended on the animal's slaughter age, which demonstrates a sex precocity for rabbits slaughtered after week 15 of age. The femur length is an indicator of an animal's age and/or physiological maturity; thus, when slaughtering rabbits with the same live weight, a significant increase in the length of the femur and tibia with age is often observed [Combes *et al.* 2004].

Significant SB x P, SB x Sx and P x Sx interactions ($P<0.05$) were observed for the tibial bone diameters.

The effect of the SB x P interaction (Fig. 2) on the diameter of the tibial bone revealed differences attributable to parity order only in the BF crossbreds, where 125-day-old P2 rabbits had thicker tibia than did 116-day-old P3 rabbits. However, the VB crossbreds did not show the same trend, although the VB P1 rabbits evaluated

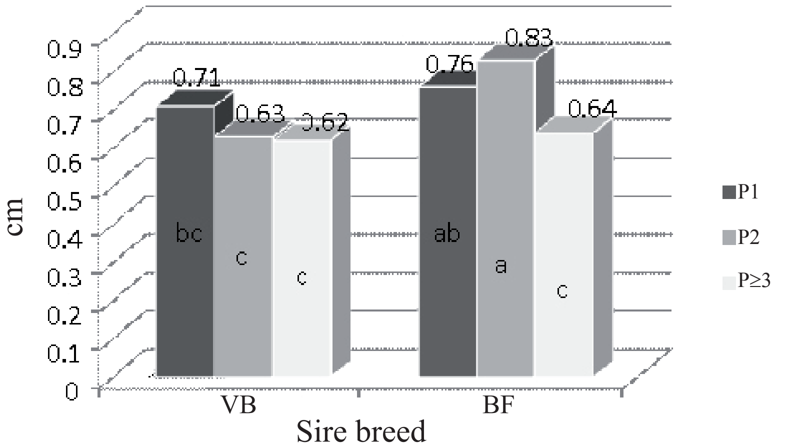

Fig 2. Interaction effect SB x P (sire breed x parity) on tibia bone diameter (a, b, c: P<0.05.)

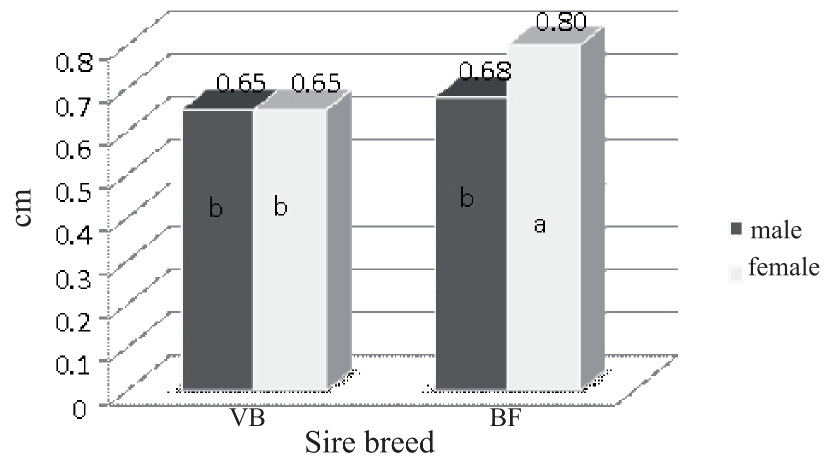

Fig. 3. Interaction effect SB x Sx (sire breed x sex) on tibia bone diameter (a, b – P<0.05).

were much younger than were the VB P2 and P≥3 rabbits (107 *vs*. 119 or 118 days of age). The differences observed are difficult to explain and the small number of rabbits tested suggests that further research is required.

As regards the SB x Sx interaction, in the BF crossbreds, the females showed a larger tibial bone diameter than did the males, whereas in the VB crossbreds, this dimension did not differ between males and females (Fig. 3). The P x Sx interaction indicated that nulliparous does (P1) produced females with a thicker tibia than in males, whereas in the P2 and P≥3 groups, no Sx difference was observed (Fig. 4). These results suggested that all of the experimental factors were responsible for its modification, depending on the animal's age at slaughter.

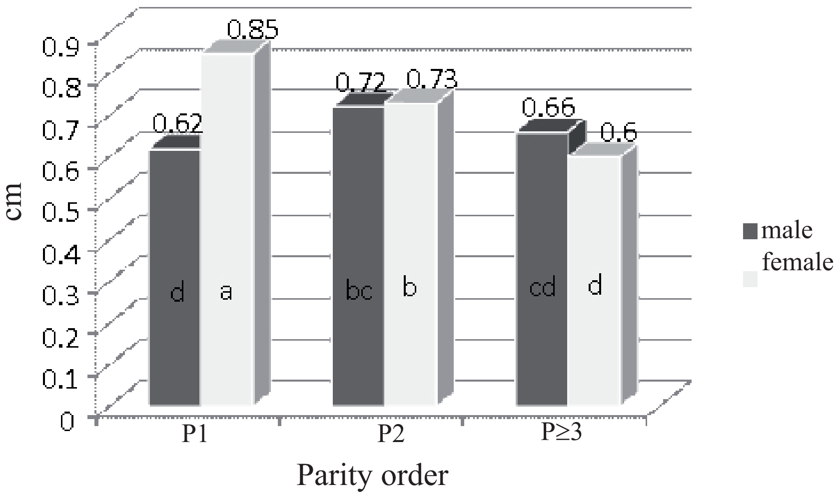

Fig. 4. Interaction effect P x Sx (parity order x sex) on tibia bone diameter (a, b, c, d – P<0.05).

Different levels of development of the hind leg bones could also depend on the housing conditions. As observed by several authors, the femoral and tibial bones tend to be heavier and wider in rabbits reared in pens and those reared at a low stocking density [Buijs *et al.* 2012, Combes *et al.* 2010, Dalle Zotte *et al.* 2009] due to their increased physical exercise.

In this study, none of the considered factors modified the bone strength, and in no case was the bone weight or shape likely to modify the breaking strength. Buijs *et al.* [2012] reported the lack of changes in bone strength when the cage size was changed. Based on these results, it appears that significant differences in the incidence of hind leg bone fractures would emerge only under extreme housing conditions or with an unbalanced feeding regimen.

In conclusion, the results obtained in this study confirmed the slow growth rates of the genotypes evaluated. The sire breeds used represent an interesting genetic resource for an organic production system, where the intense conditions and the slow growth of the rabbits are priorities. The offspring of sires of both breeds experienced difficulties overcoming the negative effects of high temperatures. The hot season further increased the productive period, which negatively affected the *in vivo* performance but favoured the carcass quality. In addition, both sire breeds were characterized by a pronounced sexual dimorphism, which was more evident in the Burgundy Fawn sire breed.

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