World Rabbit Science

World Rabbit Sci. 2023, 31: 179-189
doi:10.4995/wrs.2023.19230
WRSA, UPV, 2003

ROLE OF HOUSING SYSTEM AND SEASON ON THE CARCASS AND MEAT QUALITY TRAITS OF GROWING RABBITS REARED IN ITALIAN COMMERCIAL FARMS

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Abstract: The aim of this study was to compare the carcass traits and meat quality of growing rabbits reared in four types of commercially available housing systems (i.e. bicellular cages, dual-purpose cages, enriched cages and elevated pens) across three production cycles covering different seasons (i.e. autumn, winter and summer) under field conditions. The rabbits originated from 12 commercial farms (three farms per housing system) located in the Northeast of Italy and were slaughtered in five commercial slaughterhouses at a slaughter age from 71 to 90 d. Twenty carcasses per farm and cycle were randomly selected at the slaughterhouse and carcass and meat quality traits were evaluated 24 h post-mortem. The heaviest carcass weights were found in rabbits reared in enriched cages, followed by those in parks, while the lightest carcasses were found in rabbits from bicellular cages. Carcass fat and *longissimus lumborum* proportions were higher and hind legs proportion lower in carcasses of rabbits kept in enriched cages compared to those from the other systems. Based on significant differences for meat quality traits (i.e. pH, L*, thawing losses and shear force) among housing systems, ante-mortem stress was likely lower in rabbits from enriched cages and parks than in those from bicellular and dual-purpose cages. Nevertheless, these differences were not translated into noticeable changes in meat quality because of the small variations among housing systems. Overall, the observed differences could not be strictly and exclusively related to the enclosure in which the animals were housed, but also to other production and ante-mortem factors. The rearing season significantly affected slaughter traits, with lower slaughter and carcass weights in summer compared to winter and autumn. Despite the limit in the sample size of investigated farms, this study highlighted that under field conditions the final product quality of rabbits is not clearly distinguishable based on the housing system *per se*.

Key Words: rabbit, carcass, meat quality, cages, parks, field conditions.

INTRODUCTION

The rabbit farming sector in the EU is facing a steady decline and the figures for 2020 pointed to a 39% fall compared to 2010, both worldwide and in the Italian scope (Trocino *et al.*, 2019; FAOSTAT, 2020), owing in large part to a decrease in rabbit meat consumption. The leading causes for this drop are a growing perception of rabbits as pets and a consumer's change in lifestyle, with the time spent cooking and eating reduced (Cullere and Dalle Zotte, 2018;

Correspondence: A. Trocino, *angela.trocino@unipd.it*. Received *February 2023* - Accepted *May 2023*.
https://doi.org/10.4995/wrs.2023.19230

Cite as: Zomeño C., Bordignon F., Xiccato G., Trocino A., Birolo M., Menegon F., Tarakdjian J., Di Martino G. 2023. Role of housing system and season on the carcass and meat quality traits of growing rabbits reared in Italian commercial farms. *World Rabbit Sci., 31: 179-189. https://doi.org/10.4995/wrs.2023.19230*

Siddiqui *et al.*, 2023). The food market is increasingly oriented towards more convenient meat products intended to minimise the time required for food preparation (Brunner *et al.*, 2010). However, very limited ready-to-cook and ready-to-eat rabbit meat products are currently marketed (Cullere and Dalle Zotte, 2018). For instance, the Italian rabbit meat distribution market mainly consisted of the whole carcass (70%), 25% cut up, and only 5% processed products in 2011 (Petracci and Cavani, 2013).

Concerns about farming practices and housing systems have grown in recent decades, being a key aspect in orienting consumer preferences (Napolitano *et al.*, 2010; Szendrő *et al.*, 2020; Leroy and Petracci, 2021; Crovato *et al.*, 2022). Indeed, based on the European Citizens' Initiative End the Cage Age, the European Parliament Resolution on minimum standards for the protection of farmed rabbits (European Parliament, 2021) asked the Commission to phase out cages in all European farms by 2027 and called for the adoption of alternative housing systems. In particular, European citizens advocate the rearing of animals in larger groups and larger spaces to allow more social contact and freedom of movement (Crovato *et al.*, 2022). Group housing systems, however, may be a source of social stress and injuries for rabbits due to negative interactions and aggression among them (Trocino *et al.*, 2022).

Recently, the European Food Safety Authority drafted a Scientific Opinion (EFSA, 2020) analysing the impact of commercially available housing systems on animal welfare, ranging from conventional cages to alternative systems (i.e. enriched cages and parks). This analysis showed that cage systems are likely associated with lower rabbit welfare, mainly because of behavioural restrictions and concerns. However, field data regarding health and welfare status in rabbits are scarce. Trocino *et al.* (2022) did not highlight major differences in the welfare and health of reproducing does and their kits or growing rabbits raised in commercial farms using different housing systems. In addition, they outlined the relevant interactions between several management and environmental factors and the housing system, and the need to integrate all of them to improve the whole rabbit production system.

Several scientific studies have compared the effect of housing systems on productive rabbit results and meat quality traits (Szendrő and Dalle Zotte, 2011). Under experimental conditions, changes in carcass and cut yields can be found according to the degree of physical activity (Matics *et al.*, 2019; Krunt *et al.*, 2021) and, especially, related to differences in growth performance and final live weight in rabbits raised under different housing systems (Dal Bosco *et al.*, 2002; Metzger *et al.*, 2003; Xiccato *et al.*, 2013a; Trocino *et al.*, 2015). Nevertheless, field data regarding slaughter results and carcass and meat quality traits both in conventional (i.e. bicellular or dual-purpose cages) and commercially available alternative systems (i.e. enriched cages or parks) are still needed to support farmers in the transition towards the required change in housing systems.

The present study was part of a project that also evaluated on-farm health and welfare status of reproducing does and growing rabbits (Trocino *et al.*, 2022) and the economic results (i.e. productivity indices and costs) (Mondin *et al.*, 2021) in the same commercial farms. It specifically tested the hypothesis of whether under field conditions the housing systems *per se* can produce clear and appreciable differences in carcass and meat quality traits, by comparing post-mortem results of meat rabbits reared in four types of commercially available housing systems (i.e. bicellular cages, dual-purpose cages, enriched cages and parks) across three production cycles which covered different seasons (i.e. autumn, winter and summer).

MATERIALS AND METHODS

Ethic statement

This study was conducted in compliance with Council Directive 98/58/EC concerning the protection of animals kept for farming purposes, enacted in Italy through Legislative Decree No. 146/2001 and approved by the Ethics Committee of the Istituto Zooprofilattico Sperimentale delle Venezie (CE_IZSVE 6/2022).

Farms and housing systems

A total of 12 commercial farms located in the Northeast of Italy were involved in the study. All farms were closed-cycle, with a number of reproducing does between 456 and 3890. Four types of housing systems were considered: bicellular cages, dual-purpose cages, enriched cages and parks. Three farms per housing system were monitored.

As detailed by Trocino *et al.* (2022), in the case of bicellular cages, at weaning, the litters were moved from the original breeding cages to the bicellular ones, while the reproducing does always remained in the same cages. The cage/park sizes differed among systems: bicellular cage surface was 1200 cm^2; dual-purpose cage surfaces were 3650 cm^2; enriched cages had a surface of around 4700 cm^2 and were equipped with a wire-mesh elevated platform (1000 cm^2); parks had an available surface of around 31000 cm^2 and were divided into four modules (each 7750 cm^2) during the reproductive phase (rabbit doe and its litter) that can be joined by removing the wire net walls between them in the growing phase of the weaned rabbits (Table 1). In dual-purpose cages, enriched cages and parks, at weaning the does were moved to new cages or to new individual modules of the parks, while the litters remained in the same cages/parks where they were born until slaughter. As stated above, in the farms using parks, four contiguous modules were joined at weaning to form parks in which animals from four/five litters were kept until slaughter in large groups (32-40 rabbits).

Besides the housing system, farms differed in other factors, such as animal genotype (Hyla, Grimaud, or Martini commercial crossbreed), reproduction rhythm (does artificially inseminated at 11 or 18 d after kindling), building characteristics (indoor or semi-open air), ventilation system (extraction with/without cooling system), the presence of plastic mats in the cages, diets and feeding programmes (*ad libitum* or restricted) (Trocino *et al.*, 2022). The weaning age of litters ranged from 32 to 38 d and the slaughter age of growing rabbits ranged from 71 to 90 d, due to market requirements and farm organisation. Within the different housing systems, it should be noted that: (1) farms using enriched cages adopted only the genotypes Hyla or Martini; (2) farms using enriched cages adopted only the reproduction rhythm with insemination 11 d after kindling; (3) farms with enriched cages and parks only used *ad libitum* feeding, while in farms with bicellular and dual-purpose cages, both restricted and *ad libitum* feeding systems were used. These issues have been considered in the discussion of results.

Production cycles and samplings

In ten farms, three production cycles were carried out in three seasons of the year (autumn, winter and summer) (Table 2). Conversely, one of the farms with parks (Farm B) was available only for one cycle (autumn), while one of the farms with dual-purpose cages (Farm G) was available for two cycles (autumn and winter). The first cycle covered the period from September to December 2018, corresponding to rabbits born from mid-August to the end of September, and was considered representative of an “intermediate” season (autumn). The second cycle took place from January to April 2019, corresponding to rabbits born from mid-December to the end of January, thus covering the winter season. The third cycle considered the summer season for a period that ranged from July to October 2019, corresponding to rabbits born from early June to mid-July.

Commercial slaughtering

The rabbits from the 12 farms were slaughtered in five different commercial slaughterhouses, based on existing agreements and contracts with the farms. Different slaughter ages and journey and lairage durations were used depending on the farm and the location of the farm and the slaughterhouse (Table 2). For each farm and cycle, 20 carcasses that did not show any evident sign of injuries or lesions were randomly selected at the slaughterhouse

Table 1: Cage size, stocking density and slaughter load (means and ranges) used at each housing system.

Housing system	Bicellular cage	Dual-purpose cage	Enriched cage	Park
Farms (n)	3	3	3	3
Available surface (cm^2)*	1200 (1008-1584)	3655 (3315-3927)	4739 (4522-5082)	30977 (30814-31304)
Available surface/rabbit (cm^2)	600	609	592	860
Growing rabbits (n/cage)	2	6	8	36 (32-40)
Growing rabbits (n/m^2)	17 (13-20)	16 (15-18)	17 (16-18)	12 (10-13)
Live weight at slaughtering (kg/m^2)	46.0 (33-56)	44.0 (40-49)	44.1 (39-47)	30.1 (29-32)

*Including the nest area and the platform surface when available.

Table 2: Slaughter age (means and individual values for each rearing season: autumn, winter and summer, respectively), journey and lairage duration (means) and number of carcasses evaluated at each farm.

Farm	Housing system	Slaughter age (d)	Journey duration (h:min)	Lairage duration (h:min)	Carcasses (n)
A	Enriched cage	76.3 [71; 74; 84]	3:30	6:30	60
B*	Park	74	1:30	6:30	20
C	Enriched cage	73.7 [73; 73; 74]	2:30	7:00	60
D	Bicellular cage	85.3 [86; 85; 85]	4:00	5:15	60
E	Bicellular cage	77.0 [77; 78; 76]	2:15	5:45	60
F	Park	77.0 [77; 78; 76]	2:15	5:45	60
G**	Dual-purpose cage	80.0 [79; 81]	4:00	5:30	40
H	Dual-purpose cage	84.3 [75; 90; 88]	3:30	5:00	60
I	Enriched cage	72.3 [72; 72; 73]	3:30	4:45	60
J	Dual-purpose cage	76.4 [73; 77; 79]	4:15	3:45	60
K	Bicellular cage	80.0 [80; 80; 80]	3:45	6:00	60
L	Park	79.3 [80; 80; 78]	4:00	3:45	60

*One rearing season (autumn) available; **Two rearing seasons (autumn and winter) available.

after exiting the refrigeration tunnel (2 h post-mortem). The refrigerated carcasses were packaged in polyethylene bags, transported in a refrigerated vehicle (4°C) to the laboratory of DAFNAE (University of Padova) and placed in a cold room at 2-3°C until the following morning.

Carcass and meat quality recordings

The day after slaughter, the pH was measured in duplicate in the *longissimus lumborum* and *biceps femoris* muscles of each carcass, using a pH meter (Basic 20; Crison Instruments Sa, Carpi, Italy) equipped with a specific electrode (cat. 5232; Crison Instruments Sa). The L*a*b* colour indexes were measured in duplicate in the same muscles using a Minolta CM–508 C spectrophotometer (Minolta Corp., Ramsey, NJ, USA).

The head, liver, thoracic organs, and kidneys were removed from the chilled carcasses to obtain the reference carcass (Blasco and Ouhayoun, 1996). Then, the reference carcass was dissected and the dissectible fat (scapular, inguinal, and perirenal) removed.

The right *longissimus lumborum* muscles were stored under vacuum in plastic bags at –20°C and used for subsequent meat quality analyses. Later, thawing and cooking losses were measured. After thawing, the samples were kept in plastic bags and cooked in a water bath for 1 h, until an internal temperature of 80°C was achieved. After a 1-h cooling period, a 7-cm length section was cut from the intermediate part of the muscle and the maximum shear force was measured with the TA.HDI dynamometer (Stabel Micro System Ltd., Godalming, UK) using the Allo–Kramer (10 blades) probe (load cell: 100 kg; distance between the blades: 5 mm; thickness: 2 mm; cutting speed: 500 mm/min) (Bianchi *et al.*, 2007).

Statistical analysis

Data were analysed using SAS (2013). Data of recordings at slaughtering and carcass and meat quality traits were analysed using the MIXED procedure and fitting the linear mixed model with the housing system (bicellular cage, dual-purpose cage, enriched cage and park), the production cycle (autumn, winter and summer) and their interaction as fixed effects, and the farm as a random effect to account for the specificity of each farm with all the different production factors. The rabbit live weight measured on the farm before slaughter, unique data per farm obtained from the animal loading documents at the slaughterhouse, was analysed with the GLM procedure and fitting a linear model with the housing system (bicellular cage, dual-purpose cage, enriched cage and park), the production cycle (autumn, winter and summer) and their interaction as fixed effects. The Bonferroni test was used to compare adjusted means between the experimental groups. Differences among means with *P*<0.05 were accepted as representing statistically significant differences.

Results are presented and discussed according to the main effects. The results of the significant interactions between housing system and rearing season are not shown because they were considered to be dependent on the limited sample size per housing system and season under the field conditions of this study as it was for rabbit welfare and health data collected on the same farms (Trocino *et al.*, 2022).

RESULTS

Effect of the housing system

The rabbit live weight measured at a batch level in the farm before loading did not differ between housing systems, averaging 2658 g in rabbits reared in standard cages, 2671 g in dual-purpose cages, 2634 g in enriched cages and 2530 g in parks (Table 3). On the other hand, rabbits from enriched cages showed the heaviest chilled (1539 g) and reference carcasses (1283 g), followed by those from parks (1496 g and 1249 g, respectively; *P*<0.001), while those from bicellular cages showed the lightest ones (1448 and 1196 g; *P*<0.001). The proportion of dissectible fat on the reference carcass was also higher (*P*<0.001) in rabbits from enriched cages (2.22%) compared to those of the other housing systems (1.86, 1.71 and 1.74% in the standard cage, dual-purpose cage and parks, respectively). Finally, the proportion of the *longissimus lumborum* muscle on the reference carcass was higher (*P*<0.001) in rabbits from enriched cages (12.1%) than in those from bicellular cages and parks (11.7%), whereas the proportion of the hind legs was lower in rabbits from enriched cages than in those from dual-purpose cages and parks, with bicellular cages in between (Table 3).

As for meat traits, rabbits reared in dual-purpose cages differed from those kept in the other systems. In detail, the final pH of *longissimus lumborum* was higher (*P*<0.001) in rabbits reared in dual-purpose cages (5.95), followed by those in bicellular cages and parks (5.87 and 5.88), with the lowest value in rabbits from enriched cages (5.79). Lightness index (L*) of *longissimus lumborum* resulted lower (*P*<0.01) in rabbits from dual-purpose cages (53.7) than in those from standard and enriched cages (54.6) (Table 4). The red (a*) and yellow (b*) indexes also showed significant differences between systems (*P*<0.001), with a lower value of a* in rabbits from bicellular cages and a

Table 3: Effects of housing system and rearing season on slaughter results and carcass characteristics of growing rabbits.

	Housing system (H)				Rearing season (S)			P-value			
	Bicellular cage	Dual-purpose cage	Enriched cage	Park	Autumn	Winter	Summer	H	S	H×S	RSD
Recordings (n)	9	8	9	7	12	11	10				
Slaughter age (d)	80.8	80.3	74.1	77.6	76.6	79.1	79.2				
Live weight* (g)	2658	2671	2634	2530	2673^{a}	2703^{a}	2493^{b}	n.s.	<0.05	n.s.	143
Rabbits (n)	180	160	180	140	240	220	200				
Chilled carcass (CC) (g)	1448^{a}	1487^{ab}	1539^{c}	1496^{b}	1483^{b}	1572^{c}	1423^{a}	<0.001	<0.001	<0.001	116
Head (% CC)	8.87^{a}	9.64^{b}	8.91^{a}	8.71^{a}	9.19^{b}	8.76^{a}	9.16^{b}	<0.001	<0.001	<0.001	0.71
Liver (% CC)	5.40^{b}	4.87^{a}	4.79^{a}	4.75^{a}	5.09^{b}	5.01^{b}	4.75^{a}	<0.001	<0.001	<0.001	0.72
Thoracic organs (% CC)	3.01^{b}	2.91^{a}	2.92^{a}	3.00^{b}	3.01^{b}	3.00^{b}	2.86^{a}	<0.01	<0.001	<0.01	0.29
Reference carcass (RC)	1196^{a}	1228^{ab}	1283^{c}	1249^{b}	1226^{b}	1309^{c}	1182^{a}	<0.001	<0.001	<0.001	103
Dissectible fat (% RC)	1.86^{a}	1.71^{a}	2.22^{b}	1.74^{a}	2.01^{b}	2.06^{b}	1.57^{a}	<0.001	<0.001	<0.05	0.77
LL (% RC)	11.7^{a}	11.9^{ab}	12.1^{b}	11.7^{a}	11.8^{b}	11.6^{a}	12.1^{c}	<0.001	<0.001	<0.10	0.94
Hind legs (% RC)	34.2^{ab}	34.3^{b}	33.9^{a}	34.3^{b}	34.1^{a}	33.9^{a}	34.4^{b}	<0.01	<0.01	n.s.	1.12

RSD: residual standard deviation; LL: *longissimus lumborum muscle*; *Average rabbit weight per farm at batch level; ^{a,b,c} Means with different letters within the same row and effect are statistically different (Bonferroni test).

Table 4: Effects of housing system and rearing season on the meat rheological and technological characteristics of growing rabbits.

	Housing system (H)				Rearing season (S)			*P*-value			
	Bicellular cage	Dual-purpose cage	Enriched cage	Park	Autumn	Winter	Summer	H	S	H×S	RSD
Rabbits (n)	180	160	180	140	240	220	200				
Longissimus lumborum											
pH	5.87[b]	5.95[c]	5.79[a]	5.88[b]	5.85	5.89	5.88	<0.001	<0.10	<0.05	0.18
L*	54.6[b]	53.7[a]	54.6[b]	54.0[ab]	54.3[a]	52.7[a]	55.7[b]	<0.01	<0.001	<0.05	2.8
a*	–0.88[a]	–0.43[b]	–0.38[b]	–0.49[b]	–0.57[ab]	–0.38[b]	–0.69[a]	<0.001	<0.01	<0.001	0.91
b*	2.99[a]	2.98[a]	2.94[a]	3.85[b]	3.52[b]	3.41[b]	2.64[a]	<0.001	<0.001	<0.001	2.13
Thawing losses (%)	5.37[b]	4.64[a]	7.13[d]	6.65[c]	7.19[c]	6.32[b]	4.33[a]	<0.001	<0.001	<0.05	2.24
Cooking losses (%)	29.2[c]	27.1[a]	28.6[b]	29.4[c]	28.2[a]	28.6[ab]	28.8[b]	<0.001	<0.001	<0.01	2.1
Shear force (kg/g)	2.81[b]	2.39[a]	2.71[b]	2.92[b]	2.78[b]	2.83[b]	2.51[a]	<0.001	<0.001	<0.001	0.74
Biceps femoris											
pH	6.14[b]	6.18[b]	6.04[a]	6.05[a]	6.09	6.13	6.09	<0.001	<0.05	<0.05	0.19
L*	51.7[b]	51.1[a]	51.8[b]	52.0[b]	51.2[b]	50.2[a]	53.6[c]	<0.001	<0.001	<0.01	2.00
a*	–0.98[a]	–0.48[b]	–0.52[b]	–0.87[a]	–0.90[a]	–0.48[b]	–0.76[a]	<0.001	<0.001	<0.001	0.83
b*	6.37	6.17	6.21	6.03	6.79[b]	6.88[b]	4.93[a]	n.s.	<0.001	<0.001	1.687

RSD: residual standard deviation; [a,b,c] Means with different letters within the same row and effect are statistically different (Bonferroni test).

higher value of b* in those reared in parks, compared to the other systems. The lowest thawing losses (4.64%) were recorded in *longissimus lumborum* of rabbits from dual-purpose cages, followed by rabbits from bicellular cages (5.37%) and parks (6.65%) and finally from enriched cages (7.13%) (P<0.001). As for cooking losses, the lowest values were observed in the meat of rabbits from dual-purpose cages (27.1%), followed by those from enriched cages (28.6%), and with the highest losses in meat of rabbits from bicellular cages and parks (29.2 and 29.4%, respectively) (P<0.001). The meat shear force was lower (P<0.001) in the meat of rabbits from dual-purpose cages (2.39 kg/g) compared to meat of rabbits from the other systems (2.71-2.92 kg/g).

In the *biceps femoris* muscle, the final pH was higher (P<0.001) in rabbits from bicellular and dual-purpose cages than in rabbits from enriched cages and parks. As for meat colour, the L* index of the *biceps femoris* was lower (P<0.001) in rabbits from dual-purpose cages than those of the other systems, whereas the a* index was lower (P<0.001) in rabbits from bicellular cages and parks compared to those from dual-purpose and enriched cages. Finally, the b* index did not vary significantly across systems (Table 4).

Effect of the rearing season

The rabbit live weight measured at a batch level in the farm before loading was higher in rabbits reared in autumn and winter compared to those reared in summer (2673 and 2703 g *vs*. 2493 g; P<0.05) (Table 3). Similarly, the weight of the chilled and reference carcass was higher (P<0.001) in winter (1572 and 1309 g) and autumn (1483 and 1226 g) compared to summer (1423 and 1182 g). The proportion of the liver, thoracic organs and dissectible fat was higher in rabbits slaughtered in autumn and winter than in those slaughtered in summer (P<0.001). On the other hand, the proportions of *longissimus lumborum* and hind legs were higher (0.001<P<0.01) in summer (12.1 and 34.4%, respectively) compared to autumn (11.8 and 34.1%) and winter (11.6 and 33.9%).

As for meat traits (Table 4), the L* index of *longissimus lumborum* and *biceps femoris* was lower (–4%; $P<0.001$) in rabbits reared in autumn and winter than those raised in summer, whereas a* and b* indexes were lower in summer and higher in winter ($0.001<P<0.01$). Furthermore, meat thawing losses were lower in rabbits reared in summer compared to those raised in autumn and winter (4.33 *vs.* 7.19% and 6.32%, respectively; $P<0.05$). Meat cooking losses were lower in rabbits reared in autumn than those in summer (28.3 *vs.* 28.8%; $P<0.01$), with intermediate values for winter (28.6%). Shear force was lower (–11%; $P<0.001$) in the meat of rabbits reared in summer compared to those reared in autumn and winter. On the other hand, on both *longissimus lumborum* and *biceps femoris* muscles, no significant differences were found for the final pH between the three rearing cycles (Table 4).

DISCUSSION

In the present study, as discussed in Trocino *et al.* (2022) about the health and welfare data collected on the same 12 commercial farms across the same production cycles, production factors were not fully balanced among the different housing systems. This was due to the sample size per housing system determined by the small number of commercial farms using alternative systems such as enriched cages and park systems. To overcome this limit, the comparison of the housing systems considered the farm with its specific combination of production factors as a random effect.

Overall, the average carcass traits and meat quality obtained in the present study were in line with the slaughtering ages and genotypes considered in the study and consistent with previous studies by the same research group (Xiccato *et al.*, 2013a,b; Trocino *et al.*, 2015, 2018). Nevertheless, the final meat pH (averages of 5.70 and 5.96 in the *longissimus lumborum* and *biceps femoris* muscles, respectively) was slightly higher than the values reported in literature, probably because of the longer journey and especially lairage times at the slaughterhouse (averages of 3:15 h:min and 5:30 h:min, respectively) undergone in the present field conditions compared to those in previous experimental studies (Lambertini *et al.*, 2006; Petracci *et al.*, 2009; Trocino *et al.*, 2018). In fact, prolonged journey and lairage times are associated with the depletion of muscle glycogen reserves, which prevents the post-mortem decrease of final muscle pH (Hulot and Ouhayoun, 1999).

Effect of the housing system

Overall, under our conditions, carcass weights were the highest in rabbits from the enriched cages, intermediate in parks and the lowest in the bicellular cages. The superior results of rabbits from enriched cages were also achieved a week earlier than in the standard ones (average slaughtering age 74.1 *vs.* 80.8 and 80.3 d, respectively), which may be a relevant economic advantage for rabbit producers. As for differences in carcass weight, these results cannot be attributed to the non-homogeneous distribution of the animal genotype, nor to that of the feeding systems across housing systems. In fact, in farms with enriched cages only the Hyla and Martini genotypes were present, which have been associated with lighter rabbits during growth compared to the Grimaud genotype (not used in farms with enriched cages) (Trocino *et al.*, 2022). Thus, in farms with the conventional cages, both *ad libitum* and restricted feeding were used, whereas in farms with enriched cages and parks only ad libitum feeding was used.

The differences in main cut proportions observed between rabbits from enriched cages and those reared in the other systems could more likely be due to differences in slaughter age, which can affect body development (Trocino *et al.* 2015; Blasco *et al.*, 2018). On the other hand, carcass fat content and proportions of *longissimus lumborum* and hind legs were similar in rabbits across bicellular, dual-purpose and park systems, which showed a similar muscle development and fat deposition despite the different possibility of movement (Gondret *et al.*, 2009; Szendrő and Dalle Zotte, 2011; Krunt *et al.*, 2021). On the other hand, Matics *et al.* (2019) found that housing in enriched pens with large groups (65 rabbits per pen) decreased the dressing out percentage and the hind leg meat to bones ratio compared to housing in enriched cages with small groups (8 rabbits/cage), whereas physical meat quality traits were not affected by the housing system.

Under our conditions, the worst results in terms of carcass weight in farms with bicellular cages could be associated with the high average final stocking density which exceeded 40 kg live weight/m^2 (Table 1), i.e. the maximum reference limit to guarantee rabbit well-being and growth (EFSA, 2005). On the other hand, although the final stocking density in farms using parks was optimal (30 kg live weight/m^2, 12 animals/m^2), the slaughter results and carcass quality traits of rabbits reared in parks were lower than those of rabbits kept in enriched cages, albeit better than those of bicellular and dual-purpose cages. The large number of rabbits per park (up to 40 animals) in some of the farms included in the study might have increased aggression and distress due to hierarchy establishment, especially during the last days of the rearing cycle when animals approach sexual maturity (Trocino *et al.*, 2015, 2022).

According to the literature, aggressions are also positively correlated with increased group size, besides stocking density and slaughtering age (Szendrő *et al.*, 2009; Trocino *et al.*, 2015), where under our conditions group size likely played a major role. In fact, at the time of a pre-slaughter visit to the farms included in the present study, the occurrence of injuries due to aggressive behaviours was numerically higher in farms using the park system (8.8 *vs.* <1%), even though the difference was not confirmed at a statistical level (Trocino *et al.*, 2022).

On the other hand, the quality of rabbit meat is rather stable and only extreme stressful conditions might produce substantial variations on the final product (Cavani *et al.*, 2009; Ebeid *et al.*, 2022). In fact, under the conditions of the present study, based on meat pH, less stress-related evidence was potentially observed in rabbits reared in enriched cages and parks compared to bicellular and dual-purpose cages. In parks, this result could be the consequence of a different stress level before slaughtering rather than during growth. In fact, park-reared animals could already be accustomed to being kept in large groups compared to rabbits in cages with smaller groups (2-6 rabbits) and, therefore, might be less affected by the handling and pre-slaughter factors.

Nevertheless, although significant, the observed differences in pH scarcely affected the related meat rheological traits (colour, thawing and cooking losses and tenderness), which may not be translated into appreciable macroscopic and sensorial differences. In fact, the degree of variation among meat of rabbits from the different housing systems was in a narrow range, in line with previous studies (Xiccato *et al.*, 2013a,b; Matics *et al.*, 2019; Krunt *et al.*, 2022). More differences can be expected when indoor cage systems are compared to free-range systems with outdoor access. Tufarelli *et al.* (2022) reported that meat from rabbits kept in the former system is more susceptible to lipid and protein oxidation compared to meat of free-range rabbits. Finally, under the field conditions of the present study, the different stocking density, group size, slaughter age and journey and lairage durations may have accounted more for the observed meat quality variations (Szendrő and Dalle Zotte, 2011; Trocino *et al.*, 2015). In fact, previous experimental studies found that only housing or feeding conditions caused large differences in animal welfare and, as a consequence, final live weights that are likely to affect slaughter results and rheological meat traits to an appreciable extent (Dal Bosco *et al.*, 2002; Trocino *et al.*, 2015). On the other hand, the results of a previous risk analysis conducted by Trocino *et al.* (2022) showed that animal genotype and feeding system, in addition to housing system and season, played a role in the health and welfare of growing rabbits reared in the same commercial farms.

Effect of the rearing season

Rabbit live weight and carcass characteristics were in line with those normally observed in the Italian market (Trocino *et al.*, 2019), with a worsening of body weight and carcass yield in the warm months. A decrease in productive performance and carcass traits was also reported by Matics *et al.* (2021) in growing rabbits kept at ambient temperatures of 28°C compared to 20°C. The negative consequences of high temperatures on body condition and productive performance are mainly associated with a reduction in animal feed intake. In fact, rabbits have a limited ability to eliminate excess body heat because they have few functional sweat glands, and their body is covered with hair. Thus, when exposed to high ambient temperatures, they reduce feed intake to diminish body heat production (Marai *et al.*, 2002).

As for meat quality, rabbits slaughtered in the summer season showed a paler (higher L*), less coloured (lower a* and b* indexes) and softer (lower shear force) meat than rabbits slaughtered in the cooler months, which is also consistent with changes reported in meat of broiler chickens in summer compared to the winter season (Petracci *et al.*, 2004). In rabbits, a similar seasonal effect was also observed by María *et al.* (2006) in colour indexes and shear force in commercial rabbits slaughtered in winter and in summer. In this latter study, meat pH values were also significantly higher in winter than in summer. Thus, based on the results of the present and previous studies, the overall picture of rabbits produced in the cooler season could be associated with a greater stress condition based on the higher meat pH of rabbits slaughtered in winter compared to the other seasons. This could be associated with the higher stocking densities on the farm, as well as the higher final slaughter weight and transport loads usually adopted in winter compared to the other periods (Caucci *et al.*, 2018). On the other hand, we could also speculate that rabbits slaughtered in winter experience higher stress due to the greater differences in temperature between the indoor farm and the outdoor transport conditions in the cooler compared to the warmer season, which could also vary with the transport and lairage time.

CONCLUSIONS

The present study aimed to test the hypothesis that different housing systems can produce appreciable differences in carcass traits and meat quality of growing rabbits, in addition to animal welfare and health. However, under the conditions of the tested farms, considering the small sample size per housing system and the field conditions of this study, changes in carcass traits were likely mostly related to rabbit slaughter age while small changes were found in meat quality traits. These latter alterations may not be translated into appreciable macroscopic changes in fresh meat of rabbits from different housing systems, while sensorial differences in cooked meat remain to be ascertained. Additionally, the observed differences could not be strictly related to the enclosure in which the animals were housed, but also to other production factors besides pre-slaughtering factors. Thus, while alternative systems provide opportunities for a wider behavioural repertoire and movement, the present study confirmed that the meat quality of growing rabbits is rather stable. On the other hand, data on carcass downgrading and slaughtering yields are required to state any weakness from an economic point of view of alternative systems.

Acknowledgements: This research was funded by the Italian Ministry of Health (Project IZSVe RC16/17; id: B23C17000190001). The authors are grateful to the farmers for their support and collaboration with the research.

Authors contribution: Zomeño C.: methodology, investigation, data curation, formal analysis, writing – original draft and writing – review & editing. Bordignon F.: investigation, writing – original draft and writing – review & editing. Xiccato G.: conceptualization, methodology, funding acquisition and writing – review & editing. Trocino A.: conceptualization, methodology, funding acquisition, supervision, writing – original draft and writing – review & editing. Birolo M.: investigation and writing – review & editing. Menegon F.: writing – original draft and writing – review & editing. Tarakdjian J.: investigation and writing – review & editing. Di Martino G.: conceptualization, funding acquisition, supervision and writing – review & editing.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

REFERENCES

Bianchi M., Petracci M., Pascual M., Cavani C. 2007. Comparison between Allo-Kramer and Warner-Bratzler devices to assess rabbit meat tenderness. *Ital. J. Anim. Sci., 6: 749-751. https://doi.org/10.4081/ijas.2007.1s.749*

Blasco A., Ouhayoun J. 1996. Harmonization of criteria and terminology in rabbit meat research. Revised proposal. *World Rabbit Sci., 4: 93-99. https://doi.org/10.4995/wrs.1996.278*

Blasco A., Nagy I., Hernández P. 2018. Genetics of growth, carcass and meat quality in rabbits. *Meat Sci., 145: 178-185. https://doi.org/10.1016/j.meatsci.2018.06.030*

Brunner T.A., van der Horst K., Siegrist M. 2010. Convenience food products. Drivers for consumption. *Appetite, 55: 498-506. https://doi.org/10.1016/j.appet.2010.08.017*

Caucci C., Di Martino G., Capello K., Mazzucato M., Trocino A., Xiccato G., Lago N., Brichese M., Bonfanti L. 2018. Risk factors for pre-slaughter mortality in fattening and breeding rabbits. *Livest. Sci., 210: 55-58. https://doi.org/10.1016/j.livsci.2018.02.005*

Cavani C., Petracci M., Trocino A., Xiccato G. 2009. Advances in research on poultry and rabbit meat quality. *Ital. J. Anim. Sci., 8: 741-750. https://doi.org/10.4081/ijas.2009.s2.741*

Crovato S., Pinto A., Di Martino G., Mascarello G., Rizzoli V., Marcolin S., Ravarotto L. 2022. Purchasing Habits, Sustainability Perceptions and Welfare Concerns of Italian Consumers Regarding Rabbit Meat. *Foods, 11: 1205. https://doi.org/10.3390/foods11091205*

Cullere M., Dalle Zotte A. 2018. Rabbit meat production and consumption: State of knowledge and future perspectives. *Meat Sci., 143: 137-146. https://doi.org/10.1016/j.meatsci.2018.04.029*

Dal Bosco A., Castellini C., Mugnai C. 2002. Rearing rabbits on a wire net floor or straw litter: behaviour, growth and meat qualitative traits. *Livest. Prod. Sci., 75: 149-156. https://doi.org/10.1016/S0301-6226(01)00307-4*

Ebeid T.A., Tůmová E., Al-Homidan I.H., Ketta M., Chodová D. 2022. The potential role of feed restriction on productivity, carcass composition, meat quality, and muscle fibre properties of growing rabbits: A review. *Meat Sci., 191, 108845. https://doi.org/10.1016/j.meatsci.2022.108845*

EFSA 2005. Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to "The Impact of the current housing and husbandry systems on the health and welfare of farmed domestic rabbits" - *EFSA-Q-2004-023 - accepted by the AWAH Panel on 11th and 12th July 2005 - Adopted on 13th and 14th September 2005. EFSA J. 267: 1-31. https://doi.org/10.2903/j.efsa.2005.267*

EFSA Panel on Animal Health and Welfare (AHAW), Saxmose Nielsen S., Alvarez J., Bicout D.J., Calistri P., Depner K., Drewe J.A., Garin-Bastuji B., Gonzales Rojas J.L., Gortazar Schmidt C., Michel V., Miranda Chueca M.A., Roberts H.C., Sihvonen L.H., Spoolder H., Stahl K., Velarde Calvo A., Viltrop A., Buijs S., Edwards S., Candiani D., Mosbach-Schulz O., Van der Stede Y., Winckler C. 2020. Scientific Opinion on the "Health and welfare of rabbits farmed in different production systems". *EFSA J., 18: e05944. https://doi.org/10.2903/j.efsa.2020.5944*

European Parliament 2021. European Parliament Resolution of 10 June 2021 on the European Citizens' Initiative 'End the Cage Age' (2021/2633(RSP)). 2021. Available online: https://www.europarl.europa.eu/doceo/document/TA-9-2021-0295_EN.html. Accessed November 2022.

FAOSTAT 2020. The Statistics Division of the FAO 2020. Available online: http://www.fao.org/faostat/en/#data. Accessed November 2022.

Gondret F., Hernandez P., Rémignon H., Combes S. 2009. Skeletal muscle adaptations and biomechanical properties of tendons in response to jump exercise in rabbits. *J. Anim. Sci., 87: 544-553. https://doi.org/10.2527/jas.2008-1286*

Hulot F., Ouhayoun J. 1999. Muscular pH and related traits in rabbits: A review. *World Rabbit Sci., 7: 15-36. https://doi.org/10.4995/wrs.1999.378*

Krunt O., Zita L., Kraus A., Bureš D., Needham T., Volek Z. 2022. The effect of housing system on rabbit growth performance, carcass traits and meat quality characteristics of different muscles. *Meat Sci., 193: 108953. https://doi.org/10.1016/j.meatsci.2022.108953*

Krunt O., Zita L., Kraus A., Volek Z. 2021. How can housing system affect growth and carcass traits, meat quality and muscle fiber characteristics in biceps femoris and mineral content of tibia and femur bones in growing rabbits? *Livest. Sci., 249: 104531. https://doi.org/10.1016/j.livsci.2021.104531*

Lambertini L., Vignola G., Badiani A., Zaghini G., Formigoni A. 2006. The effect of journey time and stocking density during transport on carcass and meat quality in rabbits. *Meat Sci., 72: 641-646. https://doi.org/10.1016/j.meatsci.2005.09.012*

Leroy F., Petracci M. 2021. Rabbit meat: a valuable source of nutrition or too-cute-to-eat? *World Rabbit Sci., 29: 239-246. https://doi:10.4995/wrs.2021.12663*

Marai I.F.M., Habeeb A.A.M., Gad A.E., 2022. Rabbits' productive, reproductive and physiological performance traits as affected by heat stress: A review. *Livest. Prod. Sci., 78: 71-90. https://doi.org/10.1016/S0301-6226(02)00091-X*

María G.A., Buil T., Liste G., Villarroel M., Sañudo M., Olleta J.L. 2006. Effects of transport time and season on aspects of rabbit meat quality. *Meat Sci., 72: 773-777. https://doi.org/10.1016/j.meatsci.2005.10.012*

Matics Z., Gerencsér Z., Kasza R., Terhes K., Nagy I., Radnai I., Zotte A.D., Cullere M., Szendrő Z. 2021. Effect of ambient temperature on the productive and carcass traits of growing rabbits divergently selected for body fat content. *Animal, 15: 100096. https://doi.org/10.1016/j.animal.2020.100096*

Matics Zs., Cullere M., Dalle Zotte A., Szendrő K., Szendrő Zs., Odermatt M., Atkári T., Radnai I., Nagy I., Gerencsér Zs. 2019. Effect of cage and pen housing on the live performance, carcass and meat quality traits of growing rabbits. *It. J. Anim. Sci., 18: 441-449. https://doi.org/10.1080/1828051X.2018.1532329*

Metzger Sz., Kustos K., Szendrő Zs., Szabó A., Eiben Cs., Nagy, I. 2003. The effect of housing system on carcass traits and meat quality of rabbit. *World Rabbit Sci., 11: 1-11. https://doi.org/10.4995/wrs.2003.492*

Mondin C., Trestini S., Trocino A., Di Martino G. 2021. The Economics of Rabbit Farming: A Pilot Study on the Impact of Different Housing Systems. *Animals, 11: 3040. https://doi.org/10.3390/ani11113040*

Napolitano F., Girolami A., Braghieri A. 2010. Consumer liking and willingness to pay for high welfare animal-based products. *Trends in Food Sci. Technol., 21: 537-543. https://doi.org/10.1016/j.tifs.2010.07.012*

Petracci M., Cavani C. 2013. Rabbit meat processing: Historical perspective to future directions. *World Rabbit Sci., 21: 217-226. https://doi.org/10.4995/wrs.2013.1329*

Petracci M., Betti M., Bianchi M., Cavani C. 2004. Color variation and characterization of broiler breast meat during processing in Italy. *Poultry Sci., 83: 12, 2086-2092. https://doi.org/10.1093/ps/83.12.2086*

Petracci M., Bianchi M., Venturi L., Cremonini M.A., Cavani C. 2009. Effect of antemortem journey and lairage at abattoir on rabbit meat quality. *J. Muscle Foods, 20: 489-500. https://doi.org/10.1111/j.1745-4573.2009.00163.x*

SAS 2013. SAS 9.4 User's Guide. *SAS Inst. Inc., Cary NC, USA.*

Siddiqui S.A., Gerini F., Ikram A., Saeed F., Feng, X., Chen, Y.P. 2023. Rabbit Meat - Production, Consumption and Consumers' Attitudes and Behavior. *Sustainability, 15: 2008. https://doi.org/10.3390/su15032008*

Szendrő Zs., Dalle Zotte A. 2011. Effect of housing conditions on production and behaviour of growing meat rabbits: A review. *Livest Sci., 137: 296-303. https://doi.org/10.1016/j.livsci.2010.11.012*

Szendrő Zs., Princz Z., Romvári R., Locsmándi L., Szabó A., Bázár G., Radnai I., Biró-Németh E., Matics Zs., Nagy I. 2009. Effect of group size and stocking density on productive, carcass, meat quality and aggression traits of growing rabbits. *World Rabbit Sci., 17: 153-162. https://doi.org/10.4995/wrs.2009.655*

Szendrő K., Szabó-Szentgróti E., Szigeti O. 2020. Consumers' Attitude to Consumption of Rabbit Meat in Eight Countries Depending on the Production Method and Its Purchase Form. *Foods, 9: 654. https://doi.org/10.3390/foods9050654*

Trocino A., Filiou E., Tazzoli M., Birolo M., Zuffellato A., Xiccato G. 2015. Effects of floor type, stocking density, slaughter age and gender on productive and qualitative traits of rabbits reared in collective pens. *Animal, 9: 855-861. https://doi.org/10.1017/S1751731114003188*

Trocino A., Zomeño C., Birolo M., Di Martino G., Stefani A., Bonfanti L., Bertotto D., Gratta F., Xiccato G. 2018. Impact of pre-slaughter transport conditions on stress response, carcass traits and meat quality in growing rabbits. *Meat Sci., 146: 68-74. https://doi.org/10.1016/j.meatsci.2018.07.035*

Trocino A., Cotozzolo E., Zomeño C., Petracci M., Xiccato G., Castellini C. 2019. Rabbit production and science: the world and Italian scenarios from 1998 to 2018. *Ital. J. Anim. Sci., 18: 1361-1371. https://doi.org/10.1080/1828051X.2019.1662739*

Trocino A., Menegon F., Zomeño C., Pasqualin D., Cunial G., Xiccato G., Pirrone F., Bertotto D., Bortoletti M., Dorigo F., Lavazza A., Di Martino G. 2022. A pilot study about on-farm assessment of health and welfare in rabbits kept in different housing systems. *Front. Vet. Sci., 9: 936643. https://doi.org/10.3389/fvets.2022.936643*

Tufarelli V., Tateo A., Schiavitto M., Mazzei D., Calzaretti G., Laudadio V. 2022. Evaluating productive performance, meat quality and oxidation products of Italian White breed rabbits under free-range and cage rearing system. *Animal bioscience, 35: 884-891. https://doi.org/10.5713/ab.21.0327*

Xiccato G., Trocino A., Filiou E., Majolini D., Tazzoli M., Zuffellato A. 2013a. Bicellular cage vs. collective pen housing for rabbits: Growth performance, carcass and meat quality. *Livest Sci., 155: 407-414. https://doi.org/10.1016/j.livsci.2013.05.013*

Xiccato G., Trocino A., Majolini D., Tazzoli M., Zuffellato A. 2013b. Housing of growing rabbits in individual, bicellular and collective cages: growth performance, carcass traits and meat quality. *Animal, 7: 627-632. https://doi.org/10.1017/S175173111200198X*