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A review of the effects of housing system on production and welfare in growing rabbits*

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The aim of this review was to evaluate the effect of different housing systems on productive traits, carcass, meat quality and muscle fibre properties in growing rabbits. Rabbit breeding for meat production is nowadays under the pressure of decreasing rabbit meat consumption and unsatisfactory animal welfare conditions. It is necessary to review which housing systems are the most suitable from the production point of view with respect to animal welfare. It is crucial to implement environmental enrichment of these systems in order to eliminate aggressive or stereotypical behaviour. There are several studies in scientific literature, which examined effects of group size, stocking density and floor types on productive traits, carcass traits, meat quality or welfare, but very few studies considered the potential impact of these factors on muscle fibre properties, which are the determining factor of carcass quality. Nowadays, more possibilities to enrich the housing system environment are available. Generally, gnawing sticks are used to eliminate the negative behaviour, while platforms have no effect on productive traits, although the exercise function is well received by rabbits. Additionally, mirrors may be used to decrease the effect of feeling isolated and thus improve welfare conditions.

KEYWORDS: carcass / housing systems / meat quality / productive traits / welfare

Housing of rabbits was confirmed as a factor, which influences productive performance [Dal Bosco *et al*. 2002, Dalle Zotte *et al*. 2009] and meat quality [Xiccato *et al*. 2013, Mattioli *et al*. 2016]. The effect of housing systems on muscle

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fibre characteristics is still in the research phase. Group size, stocking density and floor type were examined by several authors across the scientific spectre [Lambertini *et al*. 2001, Matics *et al*. 2014, Trocino *et al*. 2015]. Rabbits used for meat production conventionally are specifically hybridised strains and their meat is generally exported to most European markets [Cullere *et al*. 2018]. A commercial supply chain of this final product includes input suppliers, meat rabbit producers, abattoirs, logistic platforms, supermarkets and final consumers [Baviera-Puig *et al*. 2017]. Thus the best options need to be implemented for housing, stocking density, group size and other effects. EFSA [2020] provides a division of housing systems to meet the requirements of conventional farms and niche systems. The former group includes conventional cages, enriched cages and elevated pens. The latter group comprises floor pens, outdoor and organic systems. Individual housing systems have been used for a long time with the benefit of the best productive performance [Maertens and De Groote 1984] and superior meat quality [Xiccato *et al*. 2013]. Nevertheless, group housing systems with environmental enrichment have become increasingly popular because of the better welfare status of animals, which could have more social interactions with their mates [Buijs *et al*. 2011]. On the other hand, group housing of rabbits in groups bigger than 10 rabbits leads to a deterioration in productive performance, as well as lower carcass and meat quality [Dal Bosco *et al*. 2002, Xiccato *et al*. 2013]. The productive performance, carcass traits, meat quality and muscle fibres of growing rabbits in commercially used housing systems with their effects were compared in this study. The review is focused specifically on housing technologies, which according to scientific studies significantly influence previously mentioned parameters. These parameters (such as productive traits) are connected with animal welfare by affecting both animal well-being and performance thanks to environmental enrichment (e.g. gnawing sticks), with environmental enrichment being also a part of alternative housing systems.

Productive performance, carcass and meat quality characteristics

Productive traits

Growth, body weight gain or feed intake are these important characteristics, which have a serious impact on rabbit meat production. Several studies examined the effect of housing systems on productive performance with the proven greater growth and live weight in rabbits reared in cages compared to those of rabbits housed in pens of either small groups [Lambertini *et al.* 2001, Princz *et al*. 2009] or bigger groups [Dal Bosco *et al*. 2002, Combes *et al*. 2010]. The effect of group size, stocking density and floor type on productive performance will be discussed.

When comparing different group sizes [6, 12, 18, 30, 42, 54 individuals] no effect on growth and feed intake was recorded [Rommers and Meijerhof, 1998]. On the other hand, Xiccato *et al.* [1999] found that daily feed intake significantly decreased in animals kept in groups compared to individual cages. More free space was observed

in larger cages because animals tended to rest in one part of the cage. Locomotion activity increased with the greater available space and it negatively influenced feed intake [Rommers and Meijerhof 1998]. Also, rabbits housed in large groups showed lower feed intake due to a higher level of stress and aggressiveness [Maertens and Van Herck 2000]. In contrast, Matics *et al*. [2018] found no effect of housing system [size of group] on feed intake. The related greater activity in bigger groups affected growth rate and made it slower [Lambertini *et al.* 2001, Dal Bosco *et al.* 2002]. Nevertheless, the greatest body weight and weight gain were observed in the individual housing system [Xiccato *et al*. 1999]. The higher body weight gain was recorded in cage-housed rabbits in contrast with pen-housed rabbits resulting in a better feed conversion ratio in rabbits aged from 7 to 9 weeks [Matics *et al.* 2018]. However, no effect of group size on weight gain or final weight was found [Princz *et al.* 2009, Szendrő *et al*. 2009]. Some authors [Princz *et al.* 2009, Szendrő *et al*. 2009, Combes *et al*. 2010] showed a decline in daily weight gain ranging between 1.0 and 9.3 g/day]. Matics *et al.* [2014] observed no changes in rabbits reared in small groups. On the other hand, Matics *et al*. [2019] found significantly better results of final body weight in rabbits housed in smaller groups.

When stocking density was reduced from 20-23 to 15-16 rabbits/m^2 growth performance would improve [Morisse and Maurice, 1997]. This is consistent with the findings reported by Mousa-Balabel [2009] and El-Bayoumi *et al*. [2018], who observed the lowest body weight gain and body weight in rabbits kept at a stocking density of 28 rabbits/m^2 compared to those reared at a stocking density of 20 or 12 animals/m^2. Princz *et al.* [2008], Szendrő *et al*. [2009], Szendrő and Dalle Zotte [2011] and Paci *et al*. [2013] found either no or only random effect of reducing stocking density to a lower level than 15-17 rabbits/m^2. Nevertheless, higher stocking densities caused lower feed intake in the fattening period [Morisse and Maurice 1997, Trocino *et al*. 2004].

Different types of floor were examined over the years. When comparing three different floor types [wire-mesh vs. plastic-mesh vs. deep litter] a greater body weight was reported in rabbits [aged from 7 to 10 weeks] reared on the plastic-mesh floor than on wire-mesh floor or deep litter. The difference was also found between plastic-mesh and deep litter in 11-week old rabbits. Better results of body weight gain were found in favour of plastic-mesh floor against deep litter [Gerencsér *et al.* 2014]. Trocino *et al.* [2015] observed a higher daily weight gain, feed intake and live weight in the case of plastic floor when compared to wooden slatted floor. When comparing wire-mesh and steel slats floors, greater feed efficiency was found in the case of wire-mesh flooring [Trocino *et al*. 2004]. Indeed, Dalle Zotte *et al*. [2009] compared wire-mesh and plastic-mesh floors with no significant differences in growth performance, which is in accordance with the observations by Dal Bosco *et al.* [2015]. From the productive point of view, deep litter caused a decrease of weight gain and body weight because of its consumption, which has a negative effect on the intake of pellets [Lambertini *et al*. 2001, Matics *et al.* 2014]. Moreover, the effect of using deep litter on a reduction of productive performance was found by Dal Bosco *et al*. [2015].

Carcass traits

The effect of group size on carcass traits was confirmed by several authors [Dal Bosco *et al.* 2002, Dalle Zotte *et al.* 2009, Combes *et al.* 2010, Matics *et al*. 2014]. Lower slaughter and carcass weight, carcass adiposity and greater development of hind parts were reported in rabbits housed in larger groups. This may be caused by increased locomotor activity of rabbits in a bigger space, where the opportunity to move and run is greater [Combes *et al*. 2010]. Also, the dressing out percentage is lower [Dal Bosco *et al.* 2002, Dalle Zotte *et al.* 2009]. Similarly, it also caused a lower fat deposition and a decrease in the meat-to-bone ratio [Combes *et al*. 2010]. A low percentage of dissectible fat in the carcasses was observed in rabbits reared in the outdoor system than in cage-housed rabbits. It is substantiated by a greater energy disbursement involved in moving, jumping and running [Loponte *et al.* 2018]. Some controversial results were published by Machado *et al*. [2019], who observed no effect of housing system [cage vs. pen] and group size [3 vs. 6 rabbits per housing system] for carcass yield, dissectible fat and hind leg yield. They reported the effect of adaptation to the floor system over time. On the other hand, Metzger *et al*. [2003] found significantly better results for carcass yield and slaughter weight in favour of rabbits reared in pens, while Matics *et al*. [2018] reported greater hind parts in pen-raised rabbits.

The stocking density exceeding 15-17 rabbits/m^2 caused an increase in the dressing out percentage [Trocino *et al*. 2004]. At a reduction of the stocking density from 16 to 12 rabbits per cage their carcass weight significantly increased [Trocino *et al*. 2015]. The best parameters of carcass traits were found at a stocking density of 5 rabbits/m^2. The highest skin percentage was found in the housing system of 16 rabbits/m^2 [Paci *et al.* 2013]. There are reports in scientific literature made by Dal Bosco *et al*. [2000] and Pla [2008] showing a trend towards a decreased hind leg proportion when the stocking density increases. That is consistent with statements of Matics *et al*. [2018] on greater higher hind part development, which is favoured by consumers [Dal Bosco et al. 2002].

The effect of floor type on carcass traits was not observed as significant by Princz *et al.* [2009]. On the other hand, Trocino *et al.* [2015] found greater live and carcass weights and dressing out percentage in rabbits reared on the plastic floor compared to those kept on the wooden floor, with these rabbits also having higher muscle-to-bone ratios in hind legs. Dressing out percentage was significantly higher in the case of the wire net floor in comparison with steel slat, plastic slat, wire net and straw litter on wire net floors [Trocino *et al*. 2008]. However, a statement of Dal Bosco *et al.* [2002] also needs to be reported here: "Only when growth is greatly lowered due to unsuitable floors, carcass and meat quality traits are also impaired."

Meat quality – physical and chemical properties

Rabbit meat is a rich source of proteins and essential amino acids and has a high nutritional value. Saturated fatty acids [SFAs] and polyunsaturated fatty acids

[PUFAs] are the most common acids in rabbit meat. The health-promoting value of meat depends on SFAs and fat. The effects of housing systems will be summarised in this section to elucidate the problems. The effect of group size on meat traits such as final pH [24 h *postmortem*] or meat colour was found by several authors [Dal Bosco *et al.* 2002, Dalle Zotte *et al.* 2009, Combes *et al.* 2010, Xiccato *et al.* 2013, Matics *et al.* 2018], who observed the effect of different stress levels on meat colour. Aggressive behaviour and related stress in pen-housed rabbits resulted in the response affecting their muscles, which changed colour due to the lower pH values [Matics *et al.* 2018]. In contrast, Lambertini *et al*. [2001] found no effect of group size on meat colour. The pH values were higher in the *longissimus thoracis et lumborum* muscle in cage-housed rabbits [Dal Bosco *et al*. 2002, Dalle Zotte *et al.* 2009]. However, no changes of pH were found by Combes *et al*. [2010], Xiccato *et al*. [2013] and Palka *et al.* [2018], whereas Lazzaroni *et al.* [2009] observed higher pH in *biceps femoris* and *longissimus lumborum* in pen-housed rabbits due to the capture of rabbits, when they were caught for slaughter. Szendrő and Dalle Zotte [2011] reported the effect of group size on redness [a*] and yellowness [b*] values as unclear. To be exact, Dal Bosco *et al.* [2002] and Dalle Zotte *et al.* [2009] found that *L*a*b** colour values were higher in cage-housed rabbits. In contrast, Combes *et al.* [2010] and Mattioli *et al*. [2016] found these values to be lower in rabbits reared in cages. Szendrő and Dalle Zotte [2011] offered the explanation that the lightness [*L**] value will not change if the pH is not affected by housing system [group size]. Dal Bosco et al. [2002] stated that when the amount of SFAs and monounsaturated fatty acids [MUFAs] in body fat increases, the levels of PUFAs will also increase. Szendrő and Dalle Zotte [2011] explained this trend as the effect of housing of larger groups of rabbits with a decreasing meat lipid content, resulting in an increase in the relative amount of PUFAs.

According to Szendrő and Dalle Zotte [2011], the effect of stocking density on meat composition is not entirely clear, because of examining only stocking densities lower than 17 rabbits/m^2. Following this statement, Preziuso et al. [2009] found higher values for *a** and lower for *L** in rabbits reared at a stocking density of < 5 rabbits per m^2. Matics *et al.* [2014] compared 10.5 rabbits/m^2 and 16.3 rabbits/m^2 finding no differences in colour values of the *longissimus dorsi* muscle. These results are in conflict with those of Dalle Zotte *et al*. [2009] and Paci *et al*. [2013], who found higher *L** values in rabbits housed in higher stocking densities. More researches should be done to examine exact values within a wider range. The effect of stocking density [10 vs. 4 rabbits/m^2] on total PUFA and MUFA contents was reported by Volek *et al*. [2014] in favour of higher stocking density. The floor type could also affect the fatty acid profile in muscles. According to Dal Bosco *et al*. [2015], differences may be observed when comparing wire mesh, plastic mesh and deep litter flooring. Lower amounts of MUFAs in *m. longissimus thoracis* et *lumborum* were detected in the case of the wire mesh floor. Lower PUFA levels were recorded in rabbits kept on the deep litter floor. These values can be discussed only when comparing similar studies. For example Dalle Zotte *et al.* [2009] found that PUFAs did not change in two different

types of housing [cage vs. pen] with no significant effect of floor type [wire mesh vs. plastic net]. In contrast, Dal Bosco *et al.* [2002] recorded a significantly higher level of PUFAs in *longissimus lumborum* and Chodová *et al*. [2014] reported higher PUFA contents in straw bedded rabbits than in caged ones.

Muscle fibres properties

In terms of meat composition, Lefaucher [2010] reported that muscles consist of muscle fibres, type I [βR] and type II [αR, αW]. In rabbits two most dominant muscles are mostly examined [*biceps femoris* and *longissimus thoracis et lumborum*]. Muscle fibres affect the development of postmortem changes, while meat quality is also influenced [Hernández *et al.* 2006]. Two basic characteristics which define muscle fibres are their diameter and perimeter. The size of muscle is also affected by these two characteristics, with cross-sectional area being the third determining factor [Chodová *et al.* 2014]. The effect of stocking density on muscle fibre characteristics in the *biceps femoris* muscle was evaluated by Volek *et al*. [2014]. In rabbits kept at the stocking density of 10 rabbits/m^2 vs. 4 rabbits/m^2 the proportion of αW fibres was 79.3 vs. 59.2%. Comparing the same densities, the proportion of αR fibres was 24.5 vs. 14.2%. Likewise, the distribution of βR fibres was higher at a lower stocking density and amounted to 16.3%, while at a higher stocking density it was only 6.5%. These results were explained by the higher physical activity of the rabbits. The area of βR type muscle fibers was significantly lower in rabbits kept at a lower stocking density [1882 vs. 2744 μm^2], whereas the area of αR and αW fibers was almost unchanged due to stocking density. Very few studies were published on the subject. Chodová *et al.* [2014] discussed two housing systems [collective wire net cages vs. straw-bedded pens] and the resulting development of *biceps femoris* muscle fibres. A different nomenclature of muscle fibre types was used in that study, with type I comprising βR muscle fibres and type II including αR and αW muscle fibres. The trend towards a larger cross-sectional area of muscle type II in comparison with muscle type I was observed in caged rabbits [Gondret *et al*. 2002, Dalle Zotte *et al*. 2005, Chodová *et al.* 2014]. The cross-sectional area of βR fibres [type I] was significantly bigger in rabbits reared in cages at higher stocking densities, with the muscle fibre diameter also being bigger when compared to the cross-sectional area and the diameter of muscle fibres [*biceps femoris*] in rabbits reared at lower stocking densities.

Environmental enrichment of housing systems

Several types of environmental enrichment and their effect on productive or carcass traits were examined in scientific studies, e.g. gnawing sticks [Rizzi *et al*. 2008, Buijs *et al.* 2011, Zucca *et al.* 2012], mirrors [Reddi *et al*. 2011, Musco *et al.* 2019] or platforms [Farkas *et al*. 2016, Matics *et al.* 2018]. The effect of gnawing sticks on productive performance and carcass traits was observed by Hesham and Nasr [2016] indicating better body weight at slaughter, total weight gain, daily feed intake and higher carcass weight. Rizzi *et al*. [2008] found an improvement only in

Table 1. Evaluation of used housing systems with different environmental enrichment types along with their effect on production and welfare of growing rabbits

Authors	Enrichment	Housing system	Effect on production	Effect on welfare
Rizzi *et al*. [2008]	gnawing sticks	individual cages	higher feed intake and growth rate	no data
Buijs *et al*. [2011]	gnawing sticks	open-top wire cages	no data	less social contact, cage manipulation and lateral lying
Zucca *et al*. [2012]	gnawing sticks	enriched cages	low effect on productive performance and meat quality	increased allogrooming
Trocino *et al*. [2013]	gnawing sticks	individual cages x bicellular cages x open-top collective cages	no data	eliminated biting, licking barns or aggressive behavior
Hesham and Nasr [2016]	gnawing sticks	individual cages	better body weight at slaughter, total weight gain, daily feed intake and greater carcass weight	no data
Reddi *et al*. [2011]	mirrors	individual cages	higher body weight gains	higher activity
Mastellone *et al*. [2019]	mirrors	free range	affected energy balancing and consequent productive performance	higher allogrooming, changed behavioral repertoire of isolated rabbits
Musco *et al*. [2019]	mirrors	free range	better growth performance and carcass traits	lower activity, changed behavioral repertoire of isolated rabbits
Farkas *et al*. [2016]	platforms	pens with (plastic or wire-mesh) or without platforms	no significant effect on productive performance due to greater movement in pens in general	no significant effect on welfare
Matics *et al*. [2018]	platforms	pens with (plastic or wire-mesh) or without platforms	no significant effect on productive performance due to greater movement in pens in general	lower frequency of being under platform than in front of them due to urinating by rabbits being on platforms
Trocino *et al*. [2019]	platforms	collective pens	no significant effect on productive performance due to greater movement in pens in general	longer time of resting, being in stretched position and biting or licking objects

feed intake and weight gain. In contrast, Princz *et al*. [2008], Buijs *et al.* [2011] and Zucca *et al*. [2012] found no effect of gnawing sticks on productive and carcass traits. Nevertheless, gnawing sticks should be installed for their benefit of eliminating biting, licking the cage or aggressive behaviour [Trocino *et al*. 2013]. Musco *et al.* [2019] recommended using mirrors in free range rearing rabbits. Placing mirrors in the raising area led to improvement of carcass traits, increased growth performance and dressing out percentage. Rabbits could focus their energy on exploring mirrors, which decreases locomotion activity and increases parameters of live performance traits. In an individual housing system, mirrors had the effect on productive performance, particularly higher growth rate [Reddi *et al*. 2011]. Specifically, mirrors could have an

effect on unwanted behaviour and could eliminate the feeling of isolation [Mastellone *et al.* 2019]. Platforms are generally the most common type of environmental enrichment. While their effect on productive performance is still being investigated, platforms are used to provide environmental enrichment to eliminate agonistic or stereotypical behaviour [Matics *et al*. 2018]. Until recently several studies indicated no significant effects of using multilevel platforms on growth performance [Princz *et al*. 2009, Farkas *et al.* 2016, Matics *et al*. 2018]. When introducing platforms to the cage their correct position inside the cage or pen must be selected to eliminate unhygienic conditions [Trocino *et al*. 2019].

Conclusion

Considering the productive and carcass performance traits, better values of daily weight gain, feed intake, live weight, carcass weight, dressing out percentage and muscle-to-bone ratios were observed in the case of the plastic floor than the wooden slats floor and deep litter. Generally, deep litter caused a reduction of weight gain and body weight, because rabbits consumed the deep litter material. A greater dressing out percentage was found in the case of the wire net floor in comparison with the other floor types. Housing growing rabbits at high stocking densities caused the occurrence of aggressive behaviour, pale meat and lower muscle fibre characteristics. Nevertheless, the best parameters of carcass traits were found at a stocking density of 5 rabbits/m2. Meat quality, such as pH values and lightness, are correlated. If the pH values do not change as a result of the adopted housing system, lightness will be comparable. After the years, scientific literature sources are not consistent in terms of the effect of different housing systems on meat quality in growing rabbits. Very few research studies have evaluated how different rearing systems influence muscle fibre properties. The cross-sectional area, which determines muscle size, is mostly developed in rabbits reared in cages. βR muscle fibres are more developed in housing systems with lower stocking densities, because of greater locomotion activity in these rabbits. The environmental enrichment is very important to reduce stereotypical behaviour. Its effect on productive or carcass traits has not been completely elucidated. Some studies reported no influence of environmental enrichment, whereas different studies informed on greater body weight or better daily feed intake in the case of gnawing sticks and better growth performance in the case of mirrors used for free ranged rabbits. Gnawing sticks should be installed to avoid aggressive behaviour in growing rabbits after sexual maturity. Also mirrors could reduce abnormal behaviour, such as feeling isolated, especially in single-housed rabbits. According to literature research, housing smaller groups of rabbits at stocking densities of 5 rabbits/m2 on the plastic floor with multilevel platforms placed in the middle of the housing system could be recommended.

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