# UNIVERSIDAD POLITÉCNICA DE VALENCIA

# DEPARTAMENTO DE CIENCIA ANIMAL

## Effect of selection for growth rate on carcass composition and meat quality in rabbits

## Efecto de la selección por velocidad de crecimiento sobre la composición de la canal y la calidad de la carne de conejo

**TESIS DOCTORAL**

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# I. GENERAL INTRODUCTION

# 1.1. RABBIT MEAT PRODUCTION

## 1.1.1. Situation of the rabbit meat production

Rabbit meat is consumed in few countries in the world. The main producer is China, followed by Italy, Spain and France (FAOSTAT, 2004). In Spain, Cataluña is the main producer, followed by Comunidad Valenciana and Castilla la Mancha. Rabbit meat production represents the 2% of the total meat production in Spain, preceded by pig (57%), poultry (24%), beef (13%), and sheep (4%) (MAPA, 2004).

## 1.1.2. Rabbit commercial lines

Industrial rabbit meat production is usually achieved by a three-way-cross. Two lines of rabbits selected for litter size are crossed in order to obtain crossbred females. These crossbred females are subsequently mated with males from a line selected for growth rate.

The selection of commercial lines for different objectives has been originally developed in France and Spain by state-owned entities. In France, L'Institut National de la Recherche Agronomique (INRA) has selected commercial lines for litter size at weaning (Strain INRA1077) and for litter size at birth (Strain INRA2066). In Spain, L'Institut de Recerca i Tecnologia Agroalimentàries (IRTA) has selected lines for litter size at weaning (Prat Strain) and for post-weaning growth rate (Caldes Strain). In the Universidad Politécnica de Valencia, there are three lines, two of them selected for litter size at weaning (Line A and Line V) and another one selected for post-weaning growth rate (Line R), which is the line studied in the present work. There are also some private companies that have selected lines for different

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objectives, e.g. Hyla, Hyplus and Hycole in France, Zika in Germany and Hycat in Spain.

### 1.1.3. Selection of parental lines for growth rate

The objective of the rabbit breeders in the parental sires has been the reduction of the post-weaning feeding, which represents the 40% of the rabbit production costs (Baselga and Blasco, 1989). The way of reducing these costs would be selecting for reduction of the feed conversion index. The measurement of this index is difficult and expensive, since it requires recording the feed intake of the animals. Growth rate is easier to measure, and it is genetically correlated to the feed conversion index (-0.47 in the line used in the present work; Piles *et al.*, 2004). This has lead to selecting directly for growth rate, in order to select indirectly for feed conversion index. Selection for growth rate leads to a decrease of the time needed by the animals to arrive at the commercial slaughter weight and therefore, the quantity of feed that the animals need for maintenance is reduced.

### 1.1.4. Effect of selection for growth rate on growth curves in rabbits

Selection for growth rate led to an increase of the adult weight in the line of rabbits used in the present work (Line R, Figure 1a; Blasco *et al.*, 2003). The increase of adult weight when selecting for growth rate has also been observed in other species (in mice, McCarthy and Bakker, 1979; in poultry, Ricard, 1975). Higher adult weights lead to animals more difficult to handle, more maintenance costs and more problems of sore hocks. The selection for high growth rate at early stages fixing the adult weight would not be efficient, as McCarthy and Bakker (1979) observed in mice. Nevertheless, the growth curve has not been changed in shape, as can be

seen when representing the growth curves obtained by Blasco (2003) using the two genetic size-scale rules proposed by Taylor (1980; Figure 1b). These rules consist of: first, representing the maturity degree of the animal (weight/adult weight) instead of weight; second, representing metabolic age (age/adult weight$^{0.27}$) instead of age.
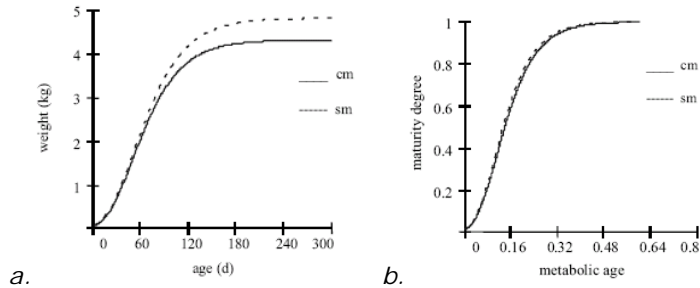


Figure 1.1. Growth curves of rabbits from Line R, a line selected for growth rate between the 4th and 9th week of age, where *sm* are males from the 10th generation of selection and *cm* males from the 3-4th generation; *a.*: representing the weight of the animal with respect to the age, where group *sm* has a higher weight than group *cm* along the whole curve; *b.*: representing the maturity degree (weight /adult weight) with respect to the metabolic age (age/adult weight$^{0.27}$), where differences between both groups disappear. From Blasco *et al.* (2003).

## 1.2. RELATIVE GROWTH

### 1.2.1. General considerations

Animal growth is due to the increment of the number of cells in the tissues (hyperplasia) and the increment of the size of the cells (hypertrophy). During the first stages, growth is due mainly to the hyperplasia, then both hyperplasia and hypertrophy and finally a stage of hypertrophy. However, the physiologic needs along growth of the animals change with time and the

animal adapt the growth of the different tissues to these needs, leading to an unequal growth of the different tissues (Brody, 1945; Richards, 1969; Robison, 1976) and changing the body composition. Nowadays, most of the rabbit breeders are paid for liveweight at slaughter, but there is a tendency to take into account the dressing out percentage. Moreover, although the 89% of the rabbit meat is sold as entire carcass (MAPA, 2003b), it is also commercialized as retail cuts. Therefore, changes in relative growth of the different parts of the carcass, organs or tissues when selecting rabbits for growth rate should be studied.

### 1.2.2. Models for relative growth

#### 1.2.2.1. Huxley's allometric equation

##### 1.2.2.1.1. History of Huxley's allometric equation

The term allometry designates the changes in relative dimensions of parts of an organism that are correlated with changes in overall size (Gayon, 2000). A detailed description of the history of the allometry can be found in Gould (1971) and Gayon (2000). According to Gould (1971), Snell (1891), Dubois (1897) and Lapicque (1898) related the weight of the brain ($y$) and body weight ($x$) from different mammals by the equation $y = bx^k$. These authors used this equation for intraspecific and interspecific comparisons. Huxley (1924, 1932) was the first author that demonstrated the relation between any component of the body ($y$) and body weight ($x$):

$$\frac{dy}{y}\frac{1}{dt} = k\,\frac{dx}{x}\frac{1}{dt}$$

This formula holds that the ratio of the relative growth rate of the component to the relative growth rate of the body remains constant, and leads to the equation $y = b x^k$ used previously by the cited authors.

This equation is based in some assumptions about growth. First, the rate of growth of an organism where all the components are growing is proportional to the size of the organism. Second, the rate of growth of the components of the organism slows down with size. Third, factors affecting to growth will affect to all the components of the body.

The parameter $k$ was called allometric coefficient (Huxley and Tessier, 1936; in Gayon, 2000). A value of $k$ higher than 1 implicates late maturing traits while $k$ lower than one early maturing traits. When $k = 1$, the component and the total body mature at similar rates and the percentage of the component with respect to the total does not change with time (Figure 1.2).

According to Huxley (1932), the parameter $b$ has not biological meaning. However, there are several works discussing the meaning of $b$ (e.g., Gould, 1971) in inter and intraspecific comparisons.


*1.2.2.1.2. Fitting Huxley's allometric equation*


For analysis, the allometric equation is transformed to logarithm scale:


$$\log y = \log b + k \log x$$


where $k$ is the slope. Fitting a strain line instead of a curve has some advantages. First, when fitting the curve, the residual variance increases with $x$ due to a scale effect, however, when transforming the equation to a logarithm scale, the errors do not increase with $x$, thus the model error variance is stabilized and the assumption of a constant variance is more closely met. Second, when representing log-linear plots, changes in $k$ would be much easier to detect. Third, standard least-squares regression

techniques can be used to fit the line. Fourth, the use of a straight line is better when comparing two groups of animals, because the laws of the straight line are similar along the line, which does not happen in a curve.

One of the disadvantages of fitting the allometric equation in logarithm scale is that it is not possible to obtain the standard errors of the parameters in the original scale, and approximate standard errors should be used. On the other hand, there is another disadvantage that is not always taken into account. In studies of carcass composition, after fitting the logarithm equation, it is usually transformed to the exponential form for prediction of $y$ values at a certain $x$:

$$y = \hat{b} x^{\hat{k}} \qquad\qquad [1]$$

However, equation [1] gives a biased estimation of the mean of $y$ (Sprugel, 1983), and $y$ values obtained are underestimated. In the logarithm form:

$$\log y = \log \hat{b} + \hat{k} \log x + \varepsilon \qquad\qquad [2]$$

the error ($\varepsilon$) is additive, with E($\varepsilon$) = 0 and variance = $\sigma^2$; when equation [2] is retransformed is obtained:

$$y = \hat{b} x^{\hat{k}} e^{\varepsilon}$$

where $E(e^{\varepsilon}) \neq 1$.

According to Sprugel (1983) this bias can be corrected by multiplying $y$ by a correction factor (CF):

$$CF = e^{(SEE^2 / 2)}$$

$$SEE = \sqrt{\sum [(\log y - \log \hat{y})^2 / (n-2)]} \qquad\qquad [3]$$

where $\log y$ is the logarithm of the data ($y$), $\log \hat{y}$ is the logarithm of the y values predicted after fitting Eq. [1], and $n$ is the number of data. Sprugel (1983) also showed that formula [3] was only valid when natural logs are used. When using base-10 standard errors, the correct procedure is converting SEE to base e by multiplying by $\log_e 10 = 2.303$.

### 1.2.2.2. Butterfield's allometric equation

*1.2.2.2.1. Butterfield's allometric equation*

Butterfield *et al.* (1983) observed that the degree of maturity of a component in an animal followed a curve that could be fitted to a quadratic equation:

$$v = p + qu + ru^2$$

considering that $v$ was the degree of maturity of the component of the animal ($v$ = weight of the component/mature weight of the component), $u$ was the degree of maturity of the animal ($u$ = liveweight/ mature liveweight) and $p$, $q$ and $r$ were the parameters of the equation.

The authors considered the conditions $p = 0$ and $r = 1\text{-}q$, because when $u$=0, then $v$=0 and when $u$=1, then $v$=1. The equation then remained:

$$v = qu + (1-q)u^2 \qquad\qquad [4]$$

where $q$ was the allometric coefficient (Figure 1.2). Values of $q$>1 represent traits that mature earlier than the liveweight and $0 \leq q < 1$ represent

traits that mature later than the liveweight. When $q = 1$ the trait matures at the same rate as the liveweight.

The advantage of the equation is that the quadratic equation of a part of the animal can be calculated from the quadratic equations of the different components of the part, which it is not possible with Huxley's allometric equation.

The model proposed by Butterfield would fit better if polynomial equations of higher order are used. However, some advantages are lost. When fitting a polynomial equation of higher order, the condition $p = 0$ is kept but it is not possible to refer the rest of the parameters to coefficient $q$. Moreover, increasing the order of the equation implies fitting better curves but these models are more *ad hoc* and the parameters obtained have not biological meaning, therefore simpler or more parsimonious models are preferred.

When relating degrees of maturity with the quadratic equation the parameter $q$ depends only on the relative growth of the component studied, whatever the scale used. The use of the model relating weights instead of degrees of maturity would be useless, because $q$ would depend not only on the relative growth of the trait but also on the scale used.

### 1.2.2.2.2. Fitting Butterfield's allometric equation

For data analysis, equation [4] is transformed to the linear form:

$$(v - u^2) = q(u - u^2) \qquad\qquad [5]$$

where Butterfield's allometric coefficient $q$ represents the slope of the curve. If model is applied to equation [4] instead of [5], $q$ can be obtained from both the $q$ value or from $(1 - q)$, which would lead to different $q$ estimations due to the model error. However, when applying equation [5] only $q$ is estimated. In addition, standard least-squares regressions

techniques can be used to fit the line and it is easier the comparison between groups.

The use of the linear form (Eq. [5]) has a disadvantage. When the degree of maturity of the animal is around 0.5, the part $(u-u^2)$ from Eq. [5] takes values close and under 0.25, leading to a high concentration of data at that point.
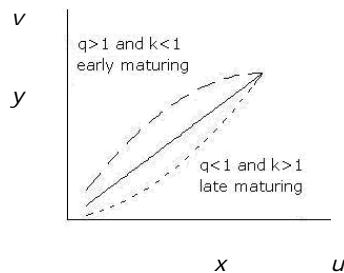


Figure 1.2. Representation of the weight of the component (*y*) with respect to the weight of the animal (*x*) or the degree of maturity of the component (*v*) with respect to the degree of maturity of the animal (*u*).

## 1.2.3. Some considerations when studying relative growth in rabbit

### 1.2.3.1. Range of age and intervals considered

In experimental design of allometry studies some considerations have to be taken into account for posterior statistical analysis. Works in rabbit of Deltoro and Lopez (1985, 1987) were developed slaughtering and measuring animals every week, in order to obtain uniform data. However, when data is transformed to logarithm scale to fit Huxley's allometric equation, the uniformity is lost, obtaining a straight line where data is bunch up at high values of liveweight. For maximum efficiency, the body weights should be placed so that in the logarithmic scale the data would be equally spaced

(Seebeck, 1968), using shorter intervals at young ages. In addition, slaughter ages can have some concordance with physiological stages or economical importance. In rabbits, appropriate slaughter ages could be 4 weeks, as the age of weaning; 9 and 13 weeks, as the ages of commercial slaughter in Europe, depending on the market; 20 weeks, as the age of beginning of reproductive life; and 40 weeks, as the moment at which animal has been considered to be close to its adult weight.

Works in relative growth in rabbits have considered ranges of age from 1 to 20 weeks of age (Deltoro and Lopez, 1985) or from 1 to 26 weeks of age (Cantier *et al.*, 1969). However, rabbits achieve adults weight at higher ages, thus data should be recorder until higher ages.

### 1.2.3.2. Cross-sectional studies

The measurement of the component for which relative growth is studied ($y$) with respect to the weight of reference ($x$) usually implies slaughtering the animals. Data will correspond in this case to different animals along time (cross-sectional studies). Data obtained at a certain time from different individuals can be considered as a set of repeated measurements in an ideal animal and then averaged.

### 1.2.3.3. Choosing the weight of reference

The weight of reference ($x$) in rabbit has been usually the empty body weight (Cantier *et al.*, 1969; Deltoro and Lopez, 1985), since it would correct variations due to the repletion of the gastrointestinal tract of the animal. However, Butterfield *et al.* (1983) defended the use of the liveweight as the weight of reference ($x$), because according to these authors the empty body weight would represent an artificial situation that is not found in real life. In addition, using the liveweight as the weight of reference permits avoiding emptying the gastrointestinal tract. According to Butterfield *et al.* (1983),

variations due to the different gastrointestinal content can be avoided by weighing and slaughtering the animals at a similar hour of the day. The use of liveweight instead of empty body weight has been applied in rabbits (Blasco *et al.*, 1990), mice (Eisen, 1986) and beef (Keane *et al.*, 2002).

### 1.2.4. Effect of selection for growth rate on relative growth in rabbit

No studies have been found about the effect of selection for growth rate in rabbit on the relative growth of the components of the carcass. Deltoro and Lopez (1985) compared the relative growth of a line of rabbits selected for growth rate with a line selected for litter size applying Huxley's allometric equation. The authors did not find any differences between the allometric coefficients of both lines. However, comparisons of both lines did not represent the effect of selection for growth rate, since the lines had a different genetic origin. In the same way, Blasco *et al.* (1990) compared Huxley's and Butterfield's allometric coefficients for fat, meat and bone of the carcass of two non contemporary groups of rabbits from a line selected for growth rate but differing in some generations of selection, using as control line a line selected for litter size. However, possible differences between groups could be due to environmental effects, because groups were not contemporary. Therefore, the effect of selection for growth rate on relative growth must be studied, because the possible changes would lead to differences in carcass composition at a determined degree of maturity with respect to unselected animals.

# 1.3. EFFECT OF SELECTION FOR GROWTH RATE ON CARCASS COMPOSITION AND MEAT QUALITY

Carcass and meat quality can be moderately affected by environmental effects, rearing techniques, preslaughter and stunning conditions and feeding level. Factors of high effect would be feeding factors regarding to dietary fat inclusion level or source, technological conditions applied to carcass and meat, age and weight at slaughter and genetic variability between populations of rabbits (Dalle-Zotte, 2002).

## 1.3.1. Effect of selection for growth rate at the slaughter age

Studies about the effect of selection for growth rate in rabbit have been usually developed comparing selected and unselected animals at a similar age, which corresponds to approximately the same degree of maturity due to the increase of the adult weight of the animals after selection (Blasco *et al.*, 2003).

### 1.3.1.1. Effect of selection for growth rate on carcass composition

Dressing out percentage was not affect by selection for growth rate when comparing selected and unselected rabbits from the same line at a similar age (Piles *et al.*, 2000; Gondret *et al.*, 2002; Hernández *et al.*, 2004; Pascual *et al.*, 2004; Larzul *et al.*, 2005). However, the effect on the percentage of the different organs, retail cuts and tissues of the carcass is not clear. In the line of rabbits used in the present thesis, the dissectible fat percentage of the carcass was lower (Piles *et al.*, 2000; Hernández *et al.*, 2004) or higher (Pascual *et al.*, 2004) in the selected group with respect to

the control group. Moreover, Gondret *et al.* (2002) and Larzul *et al.* (2005) did not find changes in perirenal fat percentage after selecting for high weight. The meat to bone ratio of the hind leg, which is highly correlated to this ratio in the whole carcass (Hernández *et al.*, 1996) was similar (Piles *et al.*, 2000; Pascual *et al.*, 2004) or higher (Hernández *et al.*, 2004) in the selected animals than in the control group.

### 1.3.1.2. Effect of selection for growth rate on meat quality

The effect of selection on meat quality is not clear either. In the hind leg, Piles *et al.* (2000) found a lower fat content in rabbits selected for growth rate with respect a control group from the same line, but when groups differed in more generations of selection this difference disappeared (Hernández *et al.*, 2004; Pascual *et al.*, 2004). The quality of the fat was influeced, finding a lower ratio of polyunsaturated/saturated fatty acids in the selected rabbits (Ramírez *et al.*, 2005). In the m. *Longissimus,* some authors found that pH and colour of the carcass and meat was not influenced by selection (Larzul *et al.*, 2005) but other authors found changes in colour (Piles *et al.*, 2000; Hernández *et al.*, 2004; Ramírez *et al.*, 2004) and pH (Hernández *et al.*, 2004). According to Ramírez *et al.*, (2004) selected rabbits seem to have higher glycolitic activity in this muscle, but the ratio aldolase: ICDH was not affected (Hernández *et al.*, 2004; Ramírez *et al.*, 2004).

Meat texture depends on the changes of the myofibrilar proteins during *post-mortem* and on the collagen content and its solubility in the connective tissue (Møller, 1980). No differences were found in the percentage of myofibrillar proteins and the activity of the proteolitic enzymes and their inhibitors when comparing rabbits selected for growth rate with a control group from the same line (Gil *et al.*, 2006). No studies have been found about the effect of selection for growth rate in the rabbit on the collagen content and solubility. Total and insoluble collagen values have been seen to be correlated to shear values in beef (Torrescano *et al.*, 2003). Texture of meat analysed instrumentally was affected by selection for growth rate,

leading to higher gumminess, hardness (Ramírez *et al.*, 2004; Gil *et al.*, 2006) and chewiness (Ramírez *et al.*, 2004) and resistance of the meat to cutting (Ramírez *et al.*, 2004) and lower tenderness of the meat (Gondret *et al.*, 2002) in selected animals than in a control group. However, Larzul *et al.* (2005) found more tenderness in meat of rabbits selected for high weight with respect to a control group. No changes in tenderness were observed when evaluating the meat with a panel test (Hernández *et al.*, 2005). The sensory analysis did not detect either relevant changes in intensity of flavour, fibrousness and juiciness although rabbits selected for growth rate had higher liver flavour and lower aniseed odour and flavour (Hernández *et al.*, 2005).

### 1.3.2. Effect of the degree of maturity

Carcass weight of rabbits required by consumers is variable in European countries, ranging from 1.0 to 1.8 kg (Colin, 1999; in Dalle-Zotte, 2002), being especially low in the Spanish market and requiring therefore slaughtering at about 2 kg of liveweight (MAPA, 2003). When selecting rabbits for growth rate, adult weight of the rabbit increased (Blasco *et al.*, 2003), being the degree of maturity of the rabbits lower at the weight fixed by the market with respect to unselected rabbits. Therefore, the effect of selection for growth rate and the consequently reduction in degree of maturity needs to be studied. To our knowledge, only Gondret *et al.* (2005) compared some carcass and meat characteristics of rabbits selected for growth rate with respect to unselected animals from the same line and at a similar weight.

#### 1.3.2.1. Effects of the degree of maturity on carcass composition

There are several authors that have reported the effect of age and, therefore, degree of maturity, on carcass composition in rabbit, by comparing

rabbits at different ages or studying the allometries of the different organs, tissues and parts of the carcass with respect to the rabbit growth. Decreasing the degree of maturity of the rabbits leads to a reduction of the dressing out percentage (Parigi-Bini *et al.*, 1992; Dalle-Zotte and Ouhayoun, 1995; Lebas *et al.*, 2001), due to the higher proportion of full digestive tract (Luzi *et al.*, 2000). Some organs of the animal like kidneys and thoracic viscera and the head, which to date are sold in the Spanish market with the carcass, have an early maturing pattern of growth with respect to the empty body weight (Cantier *et al.*, 1969), thus their percentages in the carcass could increase in less maturing animals. Liver percentage is also higher in less maturing animals (Luzi *et al.*, 2000). In the reference carcass, obtained after removing organs and head from the chilled carcass (Blasco and Ouhayoun, 1996), there could be a reduction of late maturing parts like hind legs and loin (Deltoro and Lopez, 1985), which have a higher meat to bone ratio. The meat to bone ratio in the whole carcass is also lower in low mature animals (Parigi-Bini *et al.*, 1992), due to the earlier maturing pattern of bone with respect to muscle (Cantier *et al.*, 1969; Deltoro *et al.*, 1984; Blasco *et al.*, 1990). Fat percentage may decrease because fat is a late maturing tissue (Cantier *et al.*, 1969; Deltoro *et al.*, 1984).

### 1.3.2.2. Effects of the degree of maturity on meat quality

Previous studies have shown that lightness, redness and yellowness of the carcass could be higher in low mature rabbits (Hernández *et al.*, 2004). The effect of degree of maturity on the meat colour is not clear, since some authors found lower values of lightness, redness and yellowness as age increased from 63 to 91 days old (Hernández *et al.,* 2004) whereas other authors found an decrease in lightness and an increase in redness and no changes in yellowness when varying between 93 and 105 days old (Polak *et al.*, 2006). The consequences of the possible changes in carcass and meat colour could affect to the market acceptability.

According to some authors (Xiccato *et al.*, 1994; Hernández *et al.*, 2004) pH is not affected by age. However, some authors (Dalle-Zotte *et al.,* 1996) found higher pH in younger animals, probably due to the large range of age studied (28 to 84 days). Although there is a positive correlation between pH and water holding capacity (Ristic, 1986; in Dalle-Zotte, 2002), Hernández *et al.* (2004) found a lower water holding capacity in younger animals. The enzymatic metabolism of younger rabbits leads to higher oxidative activity (Dalle-Zotte and Ouhayoun, 1995; Dalle-Zotte *et al.*, 1996; Hernández *et al.*, 2004). Some nutritional aspects could be devaluated if degree of maturity decreases, e.g. some authors have found that cholesterol and Na contents are higher in meat of rabbits with low degree of maturity (Parigi-Bini *et al.*, 1992). Low degrees of maturity are also associated to low fat content in rabbit meat, favouring moisture content (Parigi-Bini *et al.*, 1992, Cavani *et al.*, 2000; Polak *et al.*, 2006). Variations in fatty acid composition with age do not follow a clear pattern, observing no effect (Polak *et al.*, 2006) or contradictory changes (Parigi-Bini *et al.*, 1992; Xiccato *et al.*, 1994; Gašperlin *et al.*, 2006).

Although the synthesis of collagen does not increase with degree of maturity (Reiser *et al*, 1992), the number of cross-linked fraction increases and therefore the degradation of collagen is lower in more mature animals (Horgan *et al.*, 1991; Laurent, 1987; McCormick, 1994). The increase of intramuscular collagen content with degree of maturity has been observed in rabbits (Corino *et al.*, 2003). However, in rabbit degree of maturity has not influence on the hardness of the meat evaluated instrumentally (Xiccato *et al.*, 1994; Polak *et al.*, 2006) or evaluated by a panel test (Xiccato *et al.*, 1994; Jehl & Juin, 1999; Polak *et al.*, 2006; Gašperlin *et al.*, 2006). Sensory properties of the meat could be modified, finding lower values of general odour (Jehl and Juin, 1999) and flouriness (Juin *et al.*, 1998) and higher values of fibrousness (Juin *et al.*, 1998) in rabbits with a low degree of maturity, although intensity of flavour (Gašperlin *et al.*, 2006) and juiciness (Jehl and Juin, 1999; Gašperlin *et al.*, 2006) did not vary.

In conclusion, both selection for growth rate and the decrease in degree of maturity of the rabbits can affect the carcass composition and meat

quality of the rabbit, thus the comparison of selected and unselected rabbits at a similar commercial weight is needed to evaluate the practical consequences of selection.

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# II. OBJECTIVES

## 2.1. OBJECTIVES

The main objective of the present thesis is to study the effect of selection for growth rate on carcass composition and meat quality in rabbit.

The objective was achieved using line R, a line of rabbits selected for growth rate at post-weaning time in the Polytechnic University of Valencia and currently used as a terminal sire in many breeding schemes. Two contemporary groups of rabbits from line R but from different generations of selection were compared.

The specific objectives were:

1. To study the effect of selection for growth rate in line R on the relative growth of different organs, tissues, parts and linear measurements of the carcass.

2. To study the effect of selection for growth rate in line R at commercial slaughter weight on the carcass composition and meat quality.

The work was developed in the Department of Animal Science of the Polytechnic University of Valencia.

# III. EXPERIMENTS

# 3.1. EFFECT OF SELECTION FOR GROWTH RATE ON RELATIVE GROWTH IN RABBITS[1]

## 3.1.1. Abstract

The effect of selection for growth rate on relative growth of the rabbit body components was studied. Animals from the 18th generation of a line selected for growth rate were compared with a contemporary control group formed with offspring of embryos that were frozen at the 7th generation of selection of the same line. A total of 313 animals were slaughtered at 4, 9, 13, 20, and 40 weeks old. The offal, organs, tissues and retail cuts were weighed and several carcass linear measurements were recorded. Huxley's allometric equations relating the traits with respect to the liveweight by the allometric coefficient ($k$) were fitted. Butterfield's quadratic equations relating the degree of maturity of the traits and the degree of maturity of the liveweight by an allometric coefficient ($q$) were also fitted. Values of $k$ and $q$ led to similar patterns of growth in most of the traits studied. Full gastrointestinal tract and organs such as liver, kidneys, and thoracic viscera were early maturing ($k<1$ or $q>1$) whereas the chilled and reference carcass were late maturing ($k>1$ or $q<1$). The retail cuts of the reference carcass were isometric (forelegs, $k$ and $q$ not different from 1) or late maturing (breast and ribs, loin, hind legs, and abdominal walls). Dissectible fat of the carcass and meat of the hind leg were late maturing and bone of the hind leg had an early development. Lumbar circumference length was later maturing than the carcass length. No effect of selection for growth rate on $k$ and $q$ was found for any of the traits studied. Sex did not affect to most of the traits

studied. Males had *q* values showing an earlier development of full gastrointestinal tract and later growth of kidneys than females.

### 3.1.2. Introduction

Relative growth of the different body components is usually studied applying the allometric equation of Huxley (1932), but Butterfield *et al.* (1983a) proposed relating the degree of maturity of the components with respect to the degree of maturity of the animal by a quadratic equation. The quadratic equation of a part of the animal can be calculated from the quadratic equations of the different components of the part, which it is not possible with Huxley's allometric coefficient.

Rabbit meat is produced by a three-way-cross, where crossbred females from lines selected for reproductive traits are mated with males from parental lines selected for growth rate. The selection of the latter has increased the weight of the rabbits along the whole growth curve (Blasco *et al.*, 2003), but differences disappeared when representing the growth curves in the metabolic scale proposed by Taylor (1980), showing that these differences were due to a scale effect. However, selection for growth rate in rabbit may change the relative growth of the different body components.

No studies about the effect of selection for growth rate on relative growth in rabbits have been found. Deltoro and Lopez (1985) compared Huxley's allometric coefficients of two lines of rabbits selected for growth rate and litter size respectively, but the differences they found could be due to the different genetic origin of the lines. Blasco *et al.* (1990) estimated Huxley's and Butterfield's allometric coefficients in two groups of animals from the same line differing in ten generations of selection for growth rate, but the groups were not contemporary. In this work, we study the effect of selection for growth rate on relative growth by comparing two contemporary groups of rabbits with the same genetic origin and differing in 11 generations of selection for growth rate. Both Huxley's and Butterfield's models were fitted.

### 3.1.3. Material and methods

#### 3.1.3.1. Animals

The experiment was carried out with animals from a synthetic line (R) reared at the Universidad Politécnica de Valencia. Line R is selected for growth rate between the 4th and the 9th wk of age, using individual selection (Baselga, 2002), and it is currently used as a terminal sire in many breeding schemes. Animals came from two groups: Selection (S) and Control (C). At the 7th generation of selection for growth rate, embryos were recovered and kept frozen. These embryos were thawed and transferred to mature does, and offspring of the animals obtained from these embryos formed group C. Group S was formed with animals from the 18th generation of selection. Both groups were reared contemporarily under the same conditions.

Young rabbits were weaned at 4 weeks old and placed in flat-deck cages, eight rabbits per cage, and fed *ad libitum* with a commercial diet (crude protein, 16.1%; crude fibre, 16.5%; ether extract, 4.4%; ash, 8.1%). At 9 weeks old, rabbits were placed in individual flat-deck cages and fed *ad libitum* with a commercial diet (crude protein, 17.5%; crude fibre, 15.5%; ether extract, 5.4%; ash, 8.1%).

A total of 313 animals from both groups and sexes, kept without reproductive activity, were weighed and slaughtered at 4, 9, 13, 20, and 40 weeks old. Animals slaughtered at 40 weeks old were weighed weekly from 1 to 40 weeks old. After bleeding, each rabbit was weighed and the blood weight was calculated as the difference between liveweight and weight after bleeding. Skin and full gastrointestinal tract were removed and weighed. Carcasses were stored at 3 °C for 24 h.

#### 3.1.3.2. Carcass Dissection

At 24 h *post-mortem*, carcasses were weighed to obtain the chilled carcass weight (Blasco and Ouhayoun, 1996). Liver, kidneys, thoracic viscera

(the set of lungs, thymus, esophagus, and heart), and head were removed and weighed. The reference carcass obtained (Blasco and Ouhayoun, 1996) was weighed. Dorsal length was measured as the interval between the atlas vertebra and the seventh lumbar vertebra. Thigh length was measured as the interval between the seventh lumbar vertebra and the distal part of *os ischii*. Carcass length was calculated as the sum of dorsal length and thigh length. Lumbar circumference length was measured as the carcass circumference at the level of the seventh lumbar vertebra. Perirenal and scapular fat were separated and weighted. Dissectible fat weight was calculated as the sum of both fat depots. The carcass obtained was divided according to the dissection used by Deltoro and Lopez (1985), obtaining forelegs, including the muscles of insertion in the trunk; breast and ribs, by cutting at the joint between the last thoracic and the first lumbar vertebra; loin, including sacral vertebrae and excluding the abdominal walls; abdominal walls; and hind legs, including the coxal bone. One of the hind legs was dissected and meat and bone of the hind leg were weighted.

All the weights were measured in g and the carcass linear measurements in mm.


### 3.1.3.3. Statistical Analysis


As the animals were slaughtered to obtain the data, records came from different animals along time (cross-sectional studies). Data obtained from animals of the same group-sex (selected males, selected females, control males, control females) and the same slaughter age (4, 9, 13, 20, and 40 weeks old) were considered repeated measurements of an ideal animal and were averaged.

*3.1.3.3.1. Huxley's allometric equation*

Each trait was related to the liveweight by the allometric equation proposed by Huxley (1932) $y = bx^k$, where *b* is a parameter relating the scale of measure of liveweight and the trait and *k* is the allometric coefficient. According to this equation, when *k*<1 the trait is early maturing, when *k*>1 the trait is late maturing, and when *k*=1 there is isometry, maturing the trait and the animal liveweight at the same rate.

The model fitted was:

$$\log \overline{y}_{ij} = \log b_i + k_i \log \overline{x}_{ij} + e_{ij} \qquad\qquad [1]$$

where $\log \overline{y}_{ij}$ is the logarithm of the average weight of the data of all the rabbits of group-sex *i* at age *j* (logarithms in base 10), $\log b_i$ is the value of $\log b$ for group-sex *i*, $k_i$ is Huxley's allometric coefficient of group-sex *i*, $\log \overline{x}_{ij}$ is the logarithm of the average liveweight of all the rabbits of group-sex *i* at age *j*, and $e_{ij}$ is the residual. When relating carcass linear measurements to liveweight, $\overline{y}_{ij}$ was the cubic value of the average measurement of the data of all the rabbits of group-sex *i* at age *j*, in order to relate variables of first and third order (Pézard, 1918; in Gayon, 2000). The GLM procedure of SAS (SAS Inst. Inc., Cary, NC) was used.

*3.1.3.3.2. Obtaining Mature Weights*

Butterfield's equation requires estimates of the mature liveweight and mature weight or length of the traits. Mature liveweights were estimated by fitting the Gompertz's growth curve to the rabbits weighed weekly from 1 to 40 weeks old by a nonlinear regression using the NLIN procedure of SAS (SAS Inst. Inc., Cary, NC):

$$x_{ijm} = A_{im} \exp[-b_{im} \exp(-k_{im}t)] + e_{ijm}$$

where $x_{ijm}$ is the weight of animal $m$ from group-sex $i$ at age $j$, $A_{im}$, $b_{im}$, and $k_{im}$ are the Gompertz's growth curve parameters of animal $m$ from group-sex $i$, $t$ is the age (wk), and $e_{ijm}$ is the residual. The average mature liveweight of each group-sex $i$ ($\overline{x}_{Ai}$) was calculated as the average of the estimated mature weights ($A_{im}$) of all the rabbits from this group-sex.

The average mature weights of the traits (except for the full gastrointestinal tract, liver, kidneys mature weights) for each group-sex ($\overline{y}_{Ai}$) were predicted by setting $\overline{x}_i = \overline{x}_{Ai}$ in the previously fitted Huxley's equation (Eq. [1]):

$$\overline{y}_{Ai} = b_i \, \overline{x}_{Ai}{}^{k_i} \, CF_i$$

where $CF_i$ was a correction factor for group-sex $i$. The CF was proposed by Sprugel (1983) to correct the bias when the Huxley's equation is fitted in logarithm scale:

$$CF_i = \exp(2.303 \times SEE_i^2 / 2)$$

where $SEE_i$ is the SE of the estimate of the regression for group-sex $i$. The $SEE_i$ was estimated as:

$$SEE_i = \sqrt{\sum_{j=1}^{n} [(\log \overline{y}_{ij} - \log \hat{\overline{y}}_{ij})^2 / (n-2)}$$

where $\bar{y}_{ij}$ is the average value of the trait of all the rabbits of group-sex $i$ at age $j$ and $\hat{\bar{y}}_{ij}$ is the value of $\bar{y}_{ij}$ estimated after fitting equation Eq. [1].

Huxley's allometric equation did not fit properly in the cases of full gastrointestinal tract, liver and kidneys, therefore their mature weight for each group-sex $i$ ($\bar{y}_{Ai}$) was calculated as the average weight of rabbits of group-sex $i$ and 40 weeks old.

The estimated mature weights $\bar{x}_{Ai}$ and $\bar{y}_{Ai}$ are shown in Table 3.1.1.

### 3.1.3.3.3. Butterfield's allometric equation

Butterfield *et al.* (1983a) proposed studying relative growth by relating the degree of maturity of the trait ($v$) and the degree of maturity of the liveweight ($u$) by a quadratic equation. As $v=0$ when $u=0$ and $v=1$ when $u=1$, the equation remains:

$$v = qu + (1 - q)u^2$$

The interpretation of $q$ is opposite to the interpretation of $k$. When $q<1$ the trait is late maturing with respect to the liveweight, when $q>1$, the trait is early maturing with respect to the whole, and when $q=1$, the trait matures at the same rate.

The equation was transformed to a linear form and the model fitted was:

$$(\bar{v}_{ij} - \bar{u}_{ij}^2) = q_i(\bar{u}_{ij} - \bar{u}_{ij}^2) + e_{ij}$$

where $\bar{v}_{ij}$ is the average value of $v$ for all the rabbits of group-sex $i$ at age $j$ ($\bar{v}_{ij} = \bar{y}_{ij} / \bar{y}_{Ai}$), $\bar{u}_{ij}$ is the average value of $u$ for all the rabbits of group-

sex $i$ at age $j$ ($\overline{u}_{ij} = \overline{x}_{ij} / \overline{x}_{Ai}$), $q_i$ is Butterfield's allometric coefficient for group-sex $i$, and $e_{ij}$ is the residual. In the case of the carcass linear measurements is was observed that Butterfield's equation did not fit properly, due to the adjustment of a linear measurement with respect to a variable of third order. Therefore, $\overline{v}_{ij}$ was calculated as $\overline{v}_{ij} = (\overline{y}_{ij} / \overline{y}_{Ai})^3$. The GLM procedure of SAS (SAS Inst. Inc., Cary, NC) was used.

### 3.1.4. Results and discussion

Most of the $k$ and $q$ values were different from 1 (Tables 3.1.2 to 3.1.9), which indicates no isometry of the traits studied with respect to the liveweight. Although in Huxley's model the weight of the trait is related to the liveweight and Butterfield's model relates degrees of maturity of both components, in most of the traits both analyses were consistent obtaining $k<1$ when $q>1$ and $k>1$ when $q<1$.

We considered that the relative growth of the traits had a single Huxley's allometric coefficient ($k$). Some previous works in rabbit considered changes in $k$ values during growth (Cantier *et al.*, 1969; Deltoro and Lopez, 1985), and fitted more than one straight line with different $k$ values instead of a single one. However, the point of allometric change was calculated by using statistical tools and the points obtained had not always a physiological meaning. To avoid this problem, Deltoro and Lopez (1988) and Vicente *et al.* (1989) fitted a quadratic curve, considering that the change in allometry did not appear at a determined point. However, although more complex models always fit better, they are more *ad hoc*. Because of that, when possible, more parsimonious models are preferred. Moreover, the graphic representation of our data in logarithmic scale did not show changes in Huxley's allometric coefficient, and the coefficients of determination were always higher than 0.94, thus only one straight line was fitted.

Table 3.1.1. Mature liveweight (g) estimated from the Gompertz's model and mature weights (g) and carcass linear measurements (mm) of the traits predicted from the allometric equation, except for full gastrointestinal tract, liver and kidneys where mature weight (g) was obtained as the mean value of the rabbits 40 weeks old.

| Trait | Group and sex [1] | | | |
|---|---|---|---|---|
| | SM | SF | CM | CF |
| Liveweight | 4639 | 5082 | 4410 | 4953 |
| Blood weight | 151 | 173 | 140 | 161 |
| Skin weight | 767 | 722 | 725 | 735 |
| Full gastrointestinal tract weight | 564 | 706 | 559 | 680 |
| Chilled carcass weight | 2820 | 3151 | 2657 | 3072 |
| Chilled carcass | | | | |
| Liver weight | 81 | 78 | 88 | 81 |
| Kidneys weight | 20 | 19 | 20 | 18 |
| Thoracic viscera weight | 49,0 | 54,1 | 46,4 | 51,3 |
| Head weight | 206 | 204 | 195 | 195 |
| Reference carcass weight | 2422 | 2777 | 2296 | 2691 |
| Reference carcass | | | | |
| Forelegs | 255 | 262 | 238 | 252 |
| Abdominal wall | 176 | 202 | 160 | 190 |
| Breast and ribs | 616 | 712 | 592 | 699 |
| Loin | 497 | 592 | 458 | 564 |
| Hind legs | 808 | 906 | 753 | 855 |
| Carcass tissues | | | | |
| Dissectible fat | 75 | 111 | 91 | 137 |
| Meat of the hind led | 350 | 405 | 328 | 378 |
| Bone of the hind led | 52 | 49 | 47 | 50 |
| Carcass linear measurements | | | | |
| Dorsal length | 322 | 338 | 318 | 331 |
| Thigh length | 105 | 111 | 101 | 106 |
| Carcass length | 427 | 449 | 418 | 438 |
| Lumbar circumference | 227 | 243 | 223 | 240 |

[1] SM = selected males; SF = selected females; CM = control males; CF = control females.

The dissectible fat of the carcass had $r^2 < 0.01$, indicating absence of fit of the model. No references to $r^2$ were made in Butterfield *et al.* (1983a) and in the posterior works where the authors applied the model. Blasco *et al.* (1990), when studying $k$ and $q$ coefficients of muscle, bone, and fat of the carcass in rabbits also found low $r^2$ for the Butterfield's allometric coefficients of fat. According to these authors, the low $r^2$ was due to the low fat content of the rabbit carcass, which also contains head, liver, thoracic viscera, kidneys, and head, and makes the analysis of fat content inaccurate in rabbit.

The selection for growth rate did not affect to the *b* coefficient from Huxley's allometric equation in any of the traits studied (results not shown). The coefficient *b* did not differ between sexes either. A change in *b* could lead to a different percentage of the component along the whole growth of the animal even if no change in the *k* value is observed.

### 3.1.4.1. Offal and organs

The relative growth of blood, skin, and gastrointestinal tract, which are the components removed from the animal to obtain the chilled carcass, was not affected by selection for growth rate (Tables 3.1.2 and 3.1.3). Changes in the relative growth of these components would lead in changes in dressing out percentage, especially those referred to the gastrointestinal tract, which represents the higher proportion at early ages (Ouhayoun, 1989). Deltoro *et al.* (1984a) did not find differences either in *k* values of blood between two lines of rabbits selected for litter growth rate and litter size, respectively. Moreover, Butterfield *et al.* (1983b) did not find differences in *q* values of blood, skin, alimentary tract, and alimentary tract contents between two different strains of rams after selecting one of them for weight at one year-old for four generations. The relative growth of blood and skin did not differ between sexes either. No differences between sexes in relative growth of blood were found in rabbits (Deltoro *et al.*, 1984a) and sheep (Thonney *et al.*, 1987), but Walstra (1980) observed later development of skin of boars compared with sows. Although the *k* value of full gastrointestinal tract did not

differ between sexes, the $q$ value indicated an earlier development in males. Relative growth of alimentary tract and its contents did not differ between sexes in sheep (Butterfield *et al.*, 1983b).

The early maturing pattern of liver (Tables 3.1.2 and 3.1.3) was not in agreement with results found by Deltoro (1984a), where liver had isometric growth with respect to the empty body weight. It seems that the pattern of growth of this organ depends on the range of ages considered. The early maturing pattern of kidneys and thoracic viscera (Tables 3.1.2 and 3.1.3) has been observed in several species (in rabbit, Deltoro *et al.*, 1984a; in pig, Doornenbal *et al.*, 1981, Tess *et al.*, 1986, Landgraf *et al.*, 2006; in beef, Kim *et al.*, 2003; in sheep, Butterfield *et al.*, 1983b, 1984). Mice seem to be an exception, showing late maturing patterns in kidneys (Eisen, 1986; Shea *et al.*, 1987; Siddiqui *et al.*, 1992). The relative growth of liver, kidneys, and thoracic viscera was not affected by selection for growth rate. No differences were found either when comparing giant transgenic with respect to non-transgenic mice (Shea *et al.*, 1987), two different strains of rams after selecting one of them for yearling weight (Butterfield *et al.*, 1983b) or rabbits selected for growth rate with respect to rabbits selected for litter size (Deltoro *et al.*, 1984a). However, Eisen (1986), when comparing mice selected for rapid postweaning growth with the control line, found $q$ values which indicated a later maturing pattern of liver and $k$ and $q$ values indicating earlier maturing of kidneys in the selected line. Siddiqui *et al.* (1992) found, however, a later maturing of kidneys in mice selected for high insulin growth factor with respect to the low line.

The relative growth of liver and thoracic viscera did not differ between sexes, agreeing with results found by Deltoro *et al.* (1984a) in rabbit. Sex did not affected relative growth of thoracic viscera in pigs (Rook *et al.*, 1987) and liver in pigs (Rook *et al.*, 1987) and mice (Siddiqui *et al.*, 1992). Although the $k$ value of kidneys was similar for both sexes, the $q$ value indicated a later development of these organs in males than in females, in agreement with results found in pig (Rook *et al.*, 1987) and mice (Siddiqui *et al.*, 1992).

Table 3.1.2. Mean values and SE of Huxley's *log b* and allometric coefficients *k* for offal, organs and chilled carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *k* values of selected and control group (S-C) and males and females (M-F).

| Trait | *log b* | SE | *k* | SE | r$^2$ | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | S-C | SED | *P* | M-F | SED | *P* |
| Bl | -1.25 | 0.10 | 0.94 | 0.03 | 0.98 | 0.02 | 0.07 | 0.81 | -0.06 | 0.07 | 0.40 |
| Sk[1] | -0.99 | 0.08 | 1.05 | 0.02 | 0.99 | -0.02 | 0.04 | 0.63 | 0.08 | 0.04 | 0.07 |
| FGT[1] | 0.07 | 0.11 | 0.75 | 0.03 | 0.97 | 0.02 | 0.07 | 0.80 | -0.04 | 0.07 | 0.60 |
| CC[1] | -0.50 | 0.02 | 1.08 | 0.01 | 0.99 | 0.00 | 0.01 | 0.94 | -0.01 | 0.01 | 0.70 |
| Lv[1] | -0.57 | 0.23 | 0.70 | 0.07 | 0.87 | -0.03 | 0.16 | 0.85 | 0.07 | 0.16 | 0.68 |
| Ki[1] | -0.89 | 0.10 | 0.60 | 0.03 | 0.97 | -0.01 | 0.07 | 0.87 | 0.05 | 0.07 | 0.48 |
| ThV[1] | -1.46 | 0.11 | 0.86 | 0.03 | 0.98 | -0.02 | 0.07 | 0.78 | 0.00 | 0.07 | 0.93 |

Bl: Blood; Sk: Skin; FGT: Full gastrointestinal tract; CC: Chilled carcass; Lv: Liver; Ki: Kidneys; ThV: Thoracic viscera.

[1] *k* was significantly different from 1 (*P* > 0.05).

Table 3.1.3. Mean values and SE of Butterfield's allometric coefficients *q* for offal, organs and chilled carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *q* values of selected and control group (S-C) and males and females (M-F).

| Trait | *q* | SE | r$^2$ | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | S-C | SED | *P* | M-F | SED | *P* |
| Bl[1] | 1.24 | 0.09 | 0.86 | -0.10 | 0.19 | 0.61 | 0.13 | 0.19 | 0.49 |
| Sk | 0.87 | 0.07 | 0.71 | 0.04 | 0.14 | 0.79 | -0.28 | 0.14 | 0.07 |
| FGT[1] | 1.92 | 0.14 | 0.82 | -0.10 | 0.24 | 0.68 | 0.72 | 0.23 | 0.01 |
| CC[1] | 0.89 | 0.02 | 0.97 | 0.01 | 0.04 | 0.84 | 0.00 | 0.04 | 0.91 |
| Lv[1] | 3.18 | 0.13 | 0.97 | 0.31 | 0.25 | 0.23 | 0.09 | 0.25 | 0.73 |
| Ki[1] | 2.28 | 0.06 | 0.99 | -0.15 | 0.09 | 0.12 | -0.27 | 0.09 | 0.01 |
| ThV[1] | 1.33 | 0.09 | 0.84 | -0.03 | 0.20 | 0.89 | 0.02 | 0.20 | 0.93 |

Bl: Blood; Sk: Skin; FGT: Full gastrointestinal tract; CC: Chilled carcass; Lv: Liver; Ki: Kidneys; ThV: Thoracic viscera.

[1] *q* was significantly different from 1 (*P* > 0.05).

### 3.1.4.2. Retail cuts

The relative growth of head (Tables 3.1.4 and 3.1.5) did not differ between groups and sexes, agreeing with results found by Deltoro *et al.* (1984a) when comparing males and females of a line of rabbits selected for growth rate with respect to the line selected for litter size. Butterfield *et al.* (1983b) found, however, earlier development in rams selected for weight at one year old with respect to unselected animals. The early maturing of this part of the carcass has been also seen in rabbits (Deltoro *et al.*, 1984a), pigs (Evans *et al.*, 1979), and sheep (Butterfield *et al.*, 1983b, 1984). If parts such as liver, kidneys, thoracic viscera, and head, which had an early growth, are removed from the chilled carcass, the reference carcass obtained would have a later growth than the chilled carcass (Tables 3.1.4 and 3.1.5). We did not find any effect of selection for growth rate in the patterns of growth of the reference carcass. Sex did not affect either, as observed in pigs (Rook *et al.*, 1987) and sheep (Thonney *et al.*, 1987).

The patterns of growth of the retail cuts are in agreement with the waves of growth defined by Hammond (1932): first, forelegs had an earlier growth than the breast and ribs, and hind legs had an earlier growth than the loin and abdominal walls, which is in concordance with the distal to proximal limb wave of growth. Second, head was earlier than the breast and ribs, and the latest earlier than the loin, in concordance with the second wave of growth from the head to the lumbar part.

The isometric growth obtained for forelegs (Tables 3.1.4 and 3.1.5) was in agreement with results obtained by Deltoro *et al.* (1984a) in rabbits. The late maturing patterns of breast and ribs, loin, abdominal wall, and hid legs were also found in rabbits (Deltoro *et al.*, 1984a), in pigs (Evans *et al.*, 1979; Rook *et al.*, 1987; Fisher *et al.*, 2003), and sheep (Thonney *et al.*, 1987).

Table 3.1.4. Mean values and SE of Huxley's *log b* and allometric coefficients *k* for the different retail cuts of the carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *k* values of selected and control group (S-C) and males and females (M-F).

| Trait | *log b* | SE | *k* | SE | r² | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | S-C | SED | *P* | M-F | SED | *P* |
| H[1] | -0.38 | 0.06 | 0.73 | 0.02 | 0.99 | 0.02 | 0.04 | 0.63 | 0.05 | 0.04 | 0.18 |
| RC[1] | -0.85 | 0.03 | 1.16 | 0.01 | 0.99 | 0.00 | 0.02 | 0.90 | -0.01 | 0.02 | 0.67 |
| FL | -1.23 | 0.04 | 0.99 | 0.01 | 0.99 | 0.02 | 0.02 | 0.38 | 0.03 | 0.02 | 0.08 |
| BR[1] | -1.33 | 0.06 | 1.13 | 0.02 | 0.99 | -0.03 | 0.04 | 0.54 | -0.01 | 0.04 | 0.79 |
| L[1] | -1.85 | 0.05 | 1.24 | 0.02 | 0.99 | 0.02 | 0.03 | 0.43 | -0.01 | 0.03 | 0.82 |
| AW[1] | -2.53 | 0.05 | 1.30 | 0.01 | 0.99 | 0.00 | 0.03 | 0.95 | -0.03 | 0.03 | 0.30 |
| HL[1] | -1.26 | 0.02 | 1.14 | 0.01 | 0.99 | 0.01 | 0.01 | 0.44 | 0.01 | 0.01 | 0.39 |

H: Head; RC: Reference carcass; FL: Forelegs; BR: Breast and ribs; L: Loin; AW: Abdominal walls; HL: Hind legs.

[1] *k* was significantly different from 1 ($P < 0.05$).

Table 3.1.5. Mean values and SE of Butterfield's allometric coefficients *q* for the different retail cuts of the carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *q* values of selected and control group (S-C) and males and females (M-F).

| Trait | *q* | SE | r² | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | S-C | SED | *P* | M-F | SED | *P* |
| H[1] | 1.34 | 0.07 | 0.84 | 0.00 | 0.14 | 0.99 | -0.22 | 0.14 | 0.13 |
| RC[1] | 0.77 | 0.02 | 0.95 | 0.03 | 0.05 | 0.51 | 0.00 | 0.05 | 0.97 |
| FL | 0.99 | 0.03 | 0.96 | -0.04 | 0.05 | 0.48 | -0.09 | 0.05 | 0.11 |
| BR[1] | 0.74 | 0.05 | 0.58 | 0.08 | 0.11 | 0.51 | 0.05 | 0.11 | 0.66 |
| L[1] | 0.74 | 0.04 | 0.88 | -0.01 | 0.10 | 0.88 | 0.00 | 0.10 | 0.99 |
| AW[1] | 0.67 | 0.05 | 0.84 | 0.07 | 0.11 | 0.53 | 0.05 | 0.11 | 0.64 |
| HL[1] | 0.84 | 0.03 | 0.96 | -0.01 | 0.05 | 0.80 | -0.05 | 0.05 | 0.33 |

H: Head; RC: Reference carcass; FL: Forelegs; BR: Breast and ribs; L: Loin; AW: Abdominal walls; HL: Hind legs.

[1] *q* was significantly different from 1 ($P < 0.05$).

No effect of selection for growth rate on relative growth was found for the different retail cuts of the carcass (Tables 3.1.4 and 3.1.5). Deltoro *et al.* (1984a) did not find differences either in relative growth when comparing two lines selected for growth rate and litter size, respectively. No differences were found between sexes either, agreeing with results found in rabbits (Deltoro *et al.*, 1984a) and pigs (Rook *et al.*, 1987).

### 3.1.4.3. Carcass tissues

Values of *k* and *q* for dissectible fat of the carcass and meat and bone of the hind leg are shown in Tables 3.1.6 and 3.1.7. Results obtained for meat and bone of the hind leg can be generalized to the meat and bone of the carcass, because there is isometry between the muscle of the hind leg and the total muscle of the carcass (Vezinhet *et al.*, 1975) and also between the bone of the hind leg and the total bone of the carcass (Deltoro *et al.*, 1984b).

Dissectible fat of the carcass and meat of the hind leg were late maturing (Tables 3.1.6 and 3.1.7) with respect to the liveweight, whereas bone of the hind leg was early maturing. Results found for fat and bone agree with those found for fat and bone of the carcass in rabbit (Cantier *et al.*, 1969; Deltoro *et al.*, 1984a), in sheep (Butterfield *et al.*, 1983a, 1984; Thompson *et al.*, 1985; Taylor *et al.*, 1989), and pig (Evans *et al.*, 1979; Fortin *et al.*, 1987; Fisher *et al.*, 2003; Wagner *et al.*, 1999; Whittemore *et al.*, 2003). However, the muscle of carcass seems to follow a different pattern of growth in other species. Although we found that meat of the hind leg was late maturing in rabbit, muscle of the carcass was early maturing in pig (Evans *et al.*, 1979; Fortin *et al.*, 1987; Fisher *et al.*, 2003) and sheep (Butterfield *et al.*, 1983a, 1984a; Taylor *et al.*, 1989). This difference in pattern of growth of muscle is due to the little amount of dissectible fat in rabbit compared with other species, as Blasco *et al.* (1990) pointed out.

Table 3.1.6. Mean values and SE of Huxley's *log b* and allometric coefficients *k* for dissectible fat of the carcass and meat and bone of the hind leg with respect to liveweight, coefficient of determination and difference, SED and *P* between *k* values of selected and control group (S-C) and males and females (M-F).

| Trait | *log b* | SE | *k* | SE | $r^2$ | Response to selection | | | Effect of sex | | |
|-------|---------|-----|------|------|-------|------|------|------|------|------|------|
| | | | | | | S-C | SED | *P* | M-F | SED | *P* |
| DFa[1] | -3.35 | 0.25 | 1.45 | 0.07 | 0.97 | -0.06 | 0.14 | 0.69 | -0.15 | 0.14 | 0.29 |
| MHL[1] | -1.98 | 0.04 | 1.24 | 0.01 | 0.99 | -0.02 | 0.02 | 0.33 | 0.01 | 0.02 | 0.68 |
| BHL[1] | -1.04 | 0.09 | 0.74 | 0.03 | 0.99 | 0.09 | 0.05 | 0.08 | 0.05 | 0.05 | 0.33 |

DFa: Dissectible fat of the carcass; MHL: Meat of the hind leg; BHL: Bone of the hind leg.

[1] *k* was significantly different from 1 ($P < 0.05$).

Table 3.1.7. Mean values and SE of Butterfield's allometric coefficients *q* for dissectible fat of the carcass and meat and bone of the hind leg with respect to liveweight, coefficient of determination and difference, SED and *P* between *q* values of selected and control group (S-C) and males and females (M-F).

| Trait | *q* | SE | $r^2$ | Response to selection | | | Effect of sex | | |
|-------|-----|-----|-------|------|------|------|------|------|------|
| | | | | S-C | SED | *P* | M-F | SED | *P* |
| DFa[1] | 0.20 | 0.17 | <0.01 | 0.18 | 0.36 | 0.62 | 0.17 | 0.36 | 0.64 |
| MHL[1] | 0.73 | 0.03 | 0.94 | 0.02 | 0.06 | 0.73 | -0.06 | 0.06 | 0.37 |
| BHL[1] | 1.48 | 0.08 | 0.88 | -0.17 | 0.17 | 0.34 | -0.08 | 0.17 | 0.64 |

DFa: Dissectible fat of the carcass; MHL: Meat of the hind leg; BHL: Bone of the hind leg.

[1] *q* was significantly different from 1 ($P < 0.05$).

No effect of selection for growth rate on the patterns of growth of the dissectible fat, meat of hind leg, and bone of the hind leg was detected (Tables 3.1.6 and 3.1.7). These results agree with those obtained by Deltoro *et al.* (1984a) in carcass tissues of rabbits selected for growth rate compared with rabbits selected for litter size. In sheep, Butterfield *et al.* (1983a) did not find differences in these tissues in the carcass when comparing animals selected for yearling weight with an unselected strain. Thompson *et al.* (1985) did not find differences either between sheep selected for weaning

weight and a random group in relative maturing patterns of muscle of the carcass, but selected animals presented earlier development of fat and later of bone. However, studies in mice show that total fat in the carcass is later maturing in mice when selecting for post-weaning gain (Allen and McCarthy, 1980; Eisen, 1987). We did not find differences between sexes in relative growth of dissectible fat and meat and bone of the hind leg. Deltoro *et al.* (1984a) did not find differences either in muscle and bone growth in rabbit carcass between males and females, but they found a later development of dissectible fat in females. Sex seems to not affect relative growth of the three tissues in pig (Fortin *et al.*, 1987) and sheep (Butterfield *et al.*, 1984). Thompson *et al.* (1985), however, found a later development of fat depots and earlier development of muscle and bone of the carcass in sheep females than in males.


### 3.1.4.4. Carcass linear measurements


All the carcass linear measurements were late maturing with respect to the liveweight (Tables 3.1.8 and 3.1.9). Deltoro *et al.* (1984a) found also a late maturing of carcass length and lumbar circumference length in rabbits and Siddiqui *et al.* (1992) observed a late maturing pattern of nose-anus length (thus, including head) in mice. Pugliese *et al.* (2003) found, however, early growth of body length with respect to liveweight in pigs. Lumbar circumference length was later maturing than dorsal length, which would lead in a increase of conformation as age increases.

We did not find any effect of the selection for growth rate on any of the carcass linear measurements studied. Siddiqui *et al.* (1992) found an earlier growth of nose-anus measurement with respect to liveweight in mice females selected for high insulin growth factor with respect to the low line, although no differences were found between males. Deltoro *et al.* (1984a) did not find differences in the *k* values of the carcass length and lumbar circumference length with respect to empty body weight when comparing rabbits selected for growth and reproductive traits, respectively. Any of the *k* and *q* values of

carcass length measurements differed between sexes. Allometric growth of carcass length and lumbar circumference length has been seen to be similar for both sexes in rabbits (Deltoro *et al.*, 1984a).

Table 3.1.8. Mean values and SE of Huxley's *log b* and allometric coefficients *k* for the carcass linear measurements of the carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *k* values of selected and control group (S-C) and males and females (M-F).

| Trait | *log b* | SE | *k* | SE | $r^2$ | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | S-C | SED | *P* | M-F | SED | *P* |
| DL[1] | 3.80 | 0.04 | 1.02 | 0.01 | 0.99 | 0.02 | 0.02 | 0.32 | 0.00 | 0.02 | 0.92 |
| TL[1] | 1.69 | 0.07 | 1.19 | 0.02 | 0.99 | 0.02 | 0.04 | 0.69 | 0.00 | 0.04 | 0.90 |
| CL[1] | 4.01 | 0.04 | 1.06 | 0.01 | 0.99 | 0.02 | 0.02 | 0.33 | 0.00 | 0.02 | 0.90 |
| LCL[1] | 2.46 | 0.06 | 1.26 | 0.02 | 0.99 | 0.02 | 0.03 | 0.62 | -0.03 | 0.03 | 0.37 |

DL: Dorsal length; TL: Thigh length; CL: Carcass length; LCL: Lumbar circumference length.

[1] *k* was significantly different from 1 (*P* < 0.05).

Table 3.1.9. Mean values and SE of Butterfield's allometric coefficients *q* for the carcass linear measurements of the carcass with respect to liveweight, coefficient of determination and difference, SED and *P* between *q* values of selected and control group (S-C) and males and females (M-F).

| Trait | *q* | SE | $r^2$ | Response to selection | | | Effect of sex | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | S-C | SED | *P* | M-F | SED | *P* |
| DL | 0.98 | 0.03 | 0.94 | 0.02 | 0.07 | 0.82 | -0.05 | 0.07 | 0.46 |
| TL[1] | 0.70 | 0.05 | 0.75 | 0.08 | 0.10 | 0.45 | -0.08 | 0.10 | 0.43 |
| CL[1] | 0.91 | 0.03 | 0.94 | 0.03 | 0.07 | 0.64 | -0.06 | 0.07 | 0.36 |
| LCL[1] | 0.62 | 0.04 | 0.78 | -0.07 | 0.08 | 0.37 | 0.04 | 0.08 | 0.59 |

DL: Dorsal length; TL: Thigh length; CL: Carcass length; LCL: Lumbar circumference length.

[1] *q* was significantly different from 1 (*P* < 0.05).

### 3.1.5. Conclusions

Selection for growth rate has not affected the relative growth of the different parts of the carcass, carcass tissues, and carcass linear measurements. Sex did not affect to the relative growth of most of the traits, but males had Butterfield's allometric coefficients which showing an earlier development of full gastrointestinal tract and later growth of kidneys than females.

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# 3.2. CHANGES IN CARCASS COMPOSITION AND MEAT QUALITY WHEN SELECTING RABBITS FOR GROWTH RATE[1]

### 3.2.1. Abstract

Sixty rabbits from the 23rd generation (group S) of a line selected for growth rate were compared with sixty rabbits from the 7th generation of the same line (group C) to study possible relevant changes in carcass composition and meat quality due to the selection and the consequent decrease in degree of maturity at slaughter weight (2000 g). The only relevant changes in carcass composition were an increase in kidneys, liver and dissectible fat percentages and a decrease in meat to bone ratio of the hind leg. In m. *Longissimus*, group S had lower yellowness of the carcass and higher redness and yellowness of the meat. ICDH activity increased and the aldolase:ICDH ratio decreased. In the hind leg, group S had higher values of PUFA, PUFA/SFA ratio and *n*–3 fatty acids.

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### 3.2.2. Introduction

Genetic improvement of parental lines of rabbits is usually focused on selection for growth traits, which might affect the carcass composition and meat quality.

The effect of selection for growth rate on these parameters has been studied by comparing lines selected for this trait with lines selected for litter size (Blasco *et al.*, 1990; Gómez *et al.*, 1998; Ozimba and Lukefahr, 1991; Pla *et al.*, 1998), but the differences found could be attributed to the different genetic origins. In order to avoid it, other authors used coetaneous control groups of the same selected line (Piles *et al.*, 2000; Ramírez *et al.*, 2004) or used a divergent selection procedure for high and low growth (Larzul *et al.*, 2005), by comparing the selected group with the control or low growth group at a similar age, which corresponds to approximately the same degree of maturity (Blasco *et al.*, 2003; Pla *et al.*, 1997). However, slaughter weight is fixed in practice by the market and selection for growth rate leads to slaughtering at a lower age. The degree of maturity at slaughter weight is therefore lower in selected lines, which could also affect the carcass and meat quality. Thus, the consequences of selection for growth rate on carcass and meat quality should be assessed by comparing selected animals with a control group slaughtered at the same commercial weight.

The Bayesian analysis suggested by Blasco (2005) for carcass and meat quality studies has been used by some authors (Ariño *et al.*, 2006; Piles *et al.*, 2000), because it has some advantages in the interpretation of the results. Moreover, the Bayesian approach allows the use of ratios between treatments instead of differences, indicating the superiority of one treatment with respect to the other, as Hernández *et al.* (2005) and Ariño *et al.* (2006) showed.

The aim of this study was to evaluate the consequences of selection for growth rate and the associated decrease of maturity at slaughter weight on carcass composition and meat quality.

### 3.2.3. Materials and methods

#### 3.2.3.1. Animals

The experiment was carried out with 120 rabbits from a synthetic line (R), selected for growth rate between 4 and 9 weeks of age at the Universidad Politécnica de Valencia (Baselga, 2002). Animals came from two groups: Selected (S) and Control (C), with 60 animals each. In the 7th generation of selection, embryos were recovered, vitrified and conserved for several years. Meanwhile, selection for growth rate in Line R continued. Later, embryos were devitrified and transferred to mature adults, as described by Vicente *et al.* (1999). Offspring of the animals obtained from these embryos formed group C, in order to avoid the effect of vitrification–devitrification. Group S was formed with animals of the 23rd generation and both groups were bred contemporary and under the same conditions.

After weaning at 28 days of age, animals were placed in collective cages of eight kits and fed *ad libitum* with a standard diet (crude protein, 14.8%; ether extract, 3.2%; crude fibre, 16.5%; ash, 8.2%). Animals were slaughtered at a mean liveweight of 2000 g, which was achieved at 51 and 55 days of age in group S and C, respectively. One male and one female from each litter (of which almost five were born alive) weighing 2000 g ± 200 g were slaughtered without fasting. The slaughterhouse was next to the farm, thus due to transport was minimal. Animals were electrically stunned (90 V, 6 s, 50 Hz) and bled within 3 s.  After slaughtering and bleeding, the skin, the distal part of the tail, fore and hind legs, urogenital organs and digestive tract were removed, as indicated by the norms of the World Rabbit Science Association (WRSA) (Blasco and Ouhayoun, 1996). Carcasses were suspended from the tendon calcaneus for 30 min in a ventilated area and then cooled in a chamber at 3 ºC.

### 3.2.3.2. Carcass composition

At 24 h *post-mortem*, carcasses were transported to the laboratory and weighed to obtain the chilled carcass weight. Dorsal length, thigh length and lumbar circumference were measured. Carcasses were dissected according to the WRSA norms (Blasco and Ouhayoun, 1996). Head, liver, kidneys, and thoracic viscera (the set of lungs, thymus, oesophagus and heart) were removed and weighed, obtaining the reference carcass weight. Perirenal fat and scapular fat were also removed and weighed. After the Technological Division (Blasco and Ouhayoun, 1996) the forelegs, thoracic cage, loin part and hind part were weighed. One of the hind legs was accurately dissected to separate bone from dissected meat and the weight of these parts was recorded.

Dressing out percentage (chilled carcass weight × 100/ liveweight) was calculated. Length to circumference ratio was determined ((dorsal length + thigh length)/lumbar length). Head, liver, kidneys, thoracic viscera and reference carcass weights were expressed as a percentage of the chilled carcass weight. Scapular fat, perirenal fat, dissectible fat (scapular plus perirenal fat), forelegs, thoracic cage, loin part and hind part weights were expressed as a percentage of the reference carcass weight. Meat to bone ratio of the hind leg was calculated as the relationship between dissected meat weight and bone weight of the hind leg.

### 3.2.3.3. Meat quality

#### 3.2.3.3.1. Colour measurements

Colour measurements in the CIELAB space (Lightness, L*; redness, a* and yellowness, b*) (CIE, 1976) were measured at 24 h *post-mortem* using a Minolta CR-300 Minolta Chromameter (Minolta Camera, Osaka, Japan), which gives L*, a* and b* values at each point. Carcass colour was determined on the surface of the right m. *Longissimus*, at the level of the fourth lumbar

vertebra (Pla *et al.,* 1995). Meat colour was measured in the transversal section of the m. *Longissimus* at the level of the sixth lumbar vertebra.

### 3.2.3.3.2. pH measurement

pH was measured at 24 h *post-mortem* (pH24h) in the right m. *Longissimus* at the level of the fourth lumbar vertebra at 20 ºC and penetrating 3 mm, with a Mettler Toledo MP220 pH Meter provided with a InLab® pH combination puncture electrode.

### 3.2.3.3.3. Cooking losses

The left m. *Longissimus* of each animal were weighed (F), vacuum packed in plastic bags and frozen at -20 ºC. When required, m. *Longissimus* were thawed at 4 ºC for 24 h and cooked vacuum packed in the plastic bags at 80 ºC for 1 h by immersion in a water bath. Cooked samples were cooled by immersion in water for 10 min. After cooling, samples were removed from the bags and weighed (C). Cooking losses were calculated as $(F - C) \times 100/F$.

### 3.2.3.3.4. Water holding capacity

A sample of 300 ± 5 mg of meat from the left m. *Longissimus*, corresponding to the sixth lumbar vertebra, was weighed (G) (0.1 mg accuracy) and deposited on a previously desiccated and weighed (P) 7-cm disk of Whatman No. 1 filter paper. Then the sample on the paper was placed between two Plexiglass plates and a load of 2.25 kg was applied. After 5 min, the load was removed and areas of meat spot (M) and released juice (T) were drawn on clear plastic and the damp paper filter was weighed (D) after removing the compressed meat. The mean of two replicates was used in the

analysis. Water-holding capacity (WHC) was calculated as M × 100/T of the areas (Pla and Apolinar, 2000). The percentage of released water (PRW) was calculated as (D − P) × 100/G.

### 3.2.3.3.5. Enzymatic activity

A sample of meat between the fifth and sixth lumbar vertebra from both m. *Longissimus* was cut and frozen at -20 ºC until required for the estimation of metabolic enzymes activity. The enzymatic activity of Aldolase (fructose-1,6-diP aldolase) (EC 4.1.2.13) and ICDH (NADP-isocitrate dehydrogenase) (EC 1.1.4.41) was quantified according to Ansay's method (1974). Enzyme activities are expressed as µmol of substrate hydrolyzed at 37 ºC in 1 min per gram of muscle.

### 3.2.3.3.6. Chemical composition

For each animal, at 24 h *post-mortem*,meat dissected from one hind leg was ground in a domestic mincer and scanned with a monochromator (model 5000, NIR Systems Inc., Silver Spring,MD, USA). Two sample round cups with quartz windows of 3.8 cm diameter were filled from each animal and two spectra, rotating each cup 90º, were recorded. The four reflectance spectra of each animal were averaged. Crude protein, crude fat and moisture percentages were calculated by applying equations previously calculated by Pla *et al.* (2004). Saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), *n*-3, and *n*-6 fatty acids were estimated by applying equations previously calculated by Pla *et al.* (2007). The ratio between PUFA and SFA fatty acids (PUFA/ SFA) and the ratio between *n*-6 and *n*-3 fatty acids (*n*-6:*n*-3) were calculated.

### 3.2.3.4. Statistical analysis

The model used included the effects group (S and C) and sex (males and females). A Bayesian analysis was performed, using bounded flat priors for all unknowns. The marginal posterior distributions were obtained by Gibbs Sampling. Chains of 100,000 samples were obtained, with a lag of 10 and a burning period of 2000, i.e. marginal posterior distributions were estimated with a chain of 8000 samples. Convergence of the chains was tested using the Z criterion of Geweke (Geweke, 1992). Details of the procedure can be found in Blasco (2001).

Means of the marginal posterior distributions of mean value and standard deviation of each trait were obtained. Marginal posterior distributions of the ratio between groups S and C (S/C) were estimated, in order to compare the groups as the superiority of one group with respect to the other. From the marginal posterior distribution of S/C of each trait, the following parameters were obtained: S/Cmean; high posterior density interval at 95% probability (HPD(95%)); probability of S/C being higher than 1 (P(S/C) > 1); probability of relevance (Pr), which in this study was considered as the probability that one group was at least 5% higher than the other group; probability of relevance of group S being at least 5% higher than the group C (Pr(S > C)); k1 of the interval (-∞, k1] containing a probability of 95% and k2 of the interval [k2, + ∞) containing a probability of 95%.

### 3.2.4. Results and discussion

#### 3.2.4.1. Carcass composition

Mean values of the traits of carcass composition are shown in Table 3.2.1. Pla *et al.* (1998) studied the same line of rabbits at a similar weight to those used in the present work, obtaining similar mean values of chilled and

reference carcass weight and dressing out percentage. Forelegs and thoracic cage percentages were lower than those observed in the present study (17.5% and 12.4% versus 16.7% and 12.0%; in Pla *et al.*, 1998), but loin part and hind part percentages and meat to bone ratio of the hind leg were similar. We found higher percentages of head (9.4%), thoracic viscera (2.8%) and liver (8.1%) in respect of the chilled carcass weight than Piles *et al.* (2000) (8.5%, 2.5% and 7.1%, respectively) and Pascual *et al.* (2004) (8.5%, 2.7% and 7.0%, respectively) obtained in the same line of rabbits. In the cases of head and thoracic viscera, the higher percentage in our study might be due to the lower degree of maturity of the animals (51 or 55 days old) compared with those used by Piles *et al.* (2000) and Pascual *et al.* (2004) (63 days old), since these variables were defined by Cantier *et al.* (1969) and Deltoro and López (1985) as parts or organs with early growth. However, the growth of the liver is isometric (Cantier *et al.*, 1969; Deltoro *et al.* 1984), thus similar percentages should have been found regardless of the degree of maturity of the animals studied.

Mean values of dorsal length (237 mm) and lumbar circumference (157 mm) are lower than obtained by Pla, *et al.* (1996) (249 and 163 mm, respectively) in the same line and at a similar weight to those studied here (Table 3.2.1), while thigh length (73 mm) was similar. Length to circumference ratio (2.04), which is usually considered a measure of carcass conformation, was similar to that obtained by Pla and Cervera (1997) with animals from a three-way-cross and weighing about 2 kg.

Inferences of the marginal posterior distribution of the ratio between groups S and C are shown in Table 3.2.1. For all the traits, Montecarlo standard errors were very low (under 0.001) and the Geweke test did not detect any lack of convergence, thus values are not shown.

Chilled carcass weight, reference carcass weight and dressing out percentage were different between groups, although the differences were not relevant (Table 3.2.1). Gondret *et al.* (2005) did not find differences either in dressing out percentage when comparing rabbits selected for growth rate with a control group at a similar weight. It seems that differences in degree of maturity between groups were not large enough to cause relevant changes

in dressing out percentage, which usually increases with degree of maturity (Ouhayoun, 1989).

Table 3.2.1. Features of the marginal posterior distributions of the means, standard deviations (sd) and ratio of the group effects, Selected/Control, for the main traits of the carcass composition in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] | k1[f] | k2[g] |
|---|---|---|---|---|---|---|---|---|---|
| CCW (g) | 1029 | 82 | 0.97 | 0.94, 1.00 | 0.02 | 0.07 | 0.00 | 1.00 | 0.95 |
| DoP (%) | 51.7 | 2.0 | 0.99 | 0.97, 1.00 | 0.03 | 0.00 | 0.00 | 1.00 | 0.98 |
| DL (mm) | 237 | 9 | 0.98 | 0.96, 0.99 | 0.00 | 0.00 | 0.00 | 0.99 | 0.96 |
| TL (mm) | 73 | 5 | 0.99 | 0.97, 1.02 | 0.25 | 0.00 | 0.00 | 1.01 | 0.97 |
| LCL (mm) | 157 | 7 | 0.99 | 0.97, 1.00 | 0.06 | 0.00 | 0.00 | 1.00 | 0.97 |
| LTCR | 2.04 | 0.09 | 1.00 | 0.98, 1.01 | 0.35 | 0.00 | 0.00 | 1.01 | 0.98 |
| HP (%) | 9.4 | 0.5 | 1.00 | 0.98, 1.02 | 0.50 | 0.00 | 0.00 | 1.02 | 0.98 |
| KiP (%) | 1.3 | 0.1 | 1.08 | 1.05, 1.11 | 1.00 | 0.98 | 0.98 | 1.11 | 1.06 |
| LvP (%) | 8.1 | 0.5 | 1.13 | 1.06, 1.21 | 1.00 | 0.98 | 0.98 | 1.20 | 1.07 |
| LHP (%) | 2.8 | 0.3 | 0.99 | 0.96, 1.02 | 0.27 | 0.01 | 0.00 | 1.02 | 0.96 |
| RCW (g) | 801 | 72 | 0.96 | 0.93, 0.99 | 0.01 | 0.31 | 0.00 | 0.98 | 0.93 |
| RCP (%) | 77.8 | 1.6 | 0.99 | 0.98, 0.99 | 0.00 | 0.00 | 0.00 | 0.99 | 0.98 |
| DFP (%) | 2.1 | 0.4 | 1.07 | 1.00, 1.14 | 0.98 | 0.74 | 0.74 | 1.14 | 1.02 |
| FLP (%) | 17.5 | 0.7 | 1.04 | 1.02, 1.05 | 1.00 | 0.07 | 0.07 | 1.05 | 1.03 |
| TCP (%) | 12.4 | 0.8 | 1.01 | 0.99, 1.04 | 0.89 | 0.00 | 0.00 | 1.03 | 1.00 |
| LPP (%) | 30.1 | 1.0 | 1.00 | 0.98, 1.01 | 0.22 | 0.00 | 0.00 | 1.01 | 0.99 |
| HPP (%) | 37.8 | 0.8 | 0.98 | 0.97, 0.98 | 0.00 | 0.00 | 0.00 | 0.98 | 0.97 |
| MTBR | 4.4 | 0.5 | 0.95 | 0.91, 0.98 | 0.00 | 0.60 | 0.00 | 0.98 | 0.92 |

CCW: chilled carcass weight; DoP: dressing out percentage; DL dorsal length; TL: thigh length; LCL: lumbar circumference; LTCR: length to circumference ratio; HP: head percentage; KiP: kidneys percentage; LvP: liver percentage; LHP: thoracic viscera percentage; RCW: reference carcass weight; RCP: reference carcass percentage; DFP: dissectible fat percentage; FLP: forelegs percentage; TCP: thoracic cage percentage; LPP: loin part percentage; HPP: hind part percentage; MTBR: meat to bone ratio in the hind leg. [a] S/Cmean: mean of the ratio selected/control; [b] HPD(95%): high posterior density interval at 95% probability; [c] P(S/C>1): probability of (S/C>1); [d] Pr: probability of relevance, the probability of one group being at least 5% higher than the other one; [e] Pr(S>C): probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C; [f] k1: limit of the interval $(-\infty, k1]$ containing a probability of 95%; [g] k2: limit of the interval $[k2, +\infty)$ containing a probability of 95%.

The carcasses from group S had a lower dorsal length, thigh length and lumbar circumference than those from group C (Table 3.2.1) but differences were not relevant. Moreover, length to circumference ratio was similar for both groups.

Kidney percentage was 8% higher in group S than in group C and the difference was relevant with 98% probability (Table 3.2.1). Moreover, parameter k2 = 1.06 indicated that, with 95% probability, kidney percentage is, at least, 6% higher in group S. The higher percentage of this organ in group S might be due to the effect of selection for growth rate (Pascual *et al.*, 2004; Piles *et al.*, 2000) and also to the lower degree of maturity, since it was defined as an early growth organ (Cantier *et al.*, 1969; Deltoro *et al.*, 1984; Deltoro and López, 1985).

Liver percentage was 13% higher in group S (Table 3.2.1) and the difference was relevant with 98% probability. The parameter k2 = 1.07 indicates that the percentage was at least 7% higher in group S than in group C, with 95% probability. This does not seem to be due to the different degree of maturity of the groups, since this organ was defined by Cantier *et al.* (1969) and Deltoro *et al.* (1984) as an organ with almost isometric growth. The higher liver percentage in group S might be a consequence of the higher food ingestion in group S with respect to group C, observed by Sánchez *et al.* (2004), since the fat deposition in the organ could be higher. Piles *et al.* (2000) also found higher liver percentages when comparing both groups at a similar stage of maturity.

No relevant differences between groups were found in thoracic viscera percentage (Table 3.2.1), although these viscera have been reported as early growth organs (Cantier *et al.*, 1969; Deltoro *et al.*, 1984; Deltoro and López, 1985).

Reference carcass percentage was 1% lower in group S (Table 3.2.1), but the difference was not relevant.

Dissectible fat percentage had 98% probability of being higher in group S than in group C. The mean value was 7% higher in group S (Table 3.2.1) and the difference was relevant, with 74% probability. Fat is considered as a late growth tissue (Cantier *et al.*, 1969), and from this, group S, with a lower

degree of maturity, would have had a lower fat percentage. The higher percentage in group S could be a consequence of the higher food ingestion of the group compared with group C, as Sánchez *et al.* (2004) observed. In pigs, it has been shown that as feed intake increases, fat and protein deposition increase but, over a particular feed intake level, deposition of protein stops and the extra-feed consumption goes into the production of fat (Whittemore, 1993). Increase in fat tissue as a consequence of selection for growth rate has been also seen in poultry (Crawford, 1990).

Inferences about retail cuts are shown in Table 3.2.1. Group S had higher forelegs and thoracic cage percentages and a lower hind part percentage than group C, but differences could not be considered relevant. The loin part was similar for both groups. The different retail cuts of the carcass have been seen to have different allometric coefficients, i.e. their percentages on the carcass change as the degree of maturity of the animal increases (Deltoro *et al.*, 1984; Deltoro and López, 1985). In this case, it seems that differences in degree of maturity between groups were too small to affect these percentages.

Meat to bone ratio in the hind leg was 5% lower in group S (Table 3.2.1), the difference being relevant with 60% probability, as a consequence of the lower degree of maturity of this group at slaughter weight, since this ratio has been seen to increase as rabbits grow (Hernández *et al.*, 2004). However, Gondret *et al.* (2005) did not find differences in meat to bone ratio of the hind leg when comparing rabbits selected for growth rate with a control group at a similar weight. Meat to bone ratio in the hind leg has been reported to be a good predictor of the meat to bone ratio of the whole carcass (Hernández *et al.*, 1996), thus a negative effect could have been caused, decreasing the meat in the carcass in favour of a higher bone percentage.

### 3.2.4.2. Meat quality

Meat quality mean values and inferences of the marginal posterior distribution of the ratio between groups S and C are shown in Tables 3.2.2 and 3.2.3. For all the traits, Montecarlo standard errors were very low (under 0.001) and the Geweke test did not detect any lack of convergence.

Mean values of carcass and meat colour obtained (Table 3.2.2) differed to those obtained by Pla *et al.* (1996, 1998) in animals of the same line, age and weight, giving lower values of lightness (53.96) and yellowness (0.92) in the carcass than Pla *et al.* (1996) (57.1 and 2.8, respectively) and higher meat lightness (52.53) than Pla *et al.* (1998) (50.01).

Lightness of the carcass (Table 3.2.2) was lower in group S with 77% probability (since P(S/C > 1) = 0.23), but the difference was not relevant (S/Cmean = 0.99 and Pr = 0.00). Similarly, redness of the carcass was lower in group S with 72% probability, but the difference was not relevant. Yellowness of the carcass in group S was at least 30% lower than in group C (k1 = 0.70), with 95% probability, and the difference was relevant (Pr = 1.00). As the S/C mean = 0.48, the mean value of group S was less than one half the mean value of group C. This result agrees with Ramírez *et al.* (2004), who observed lower yellowness values in rabbits selected for growth rate compared with a control group of similar maturity. No differences between groups in carcass colour due to the different degree of maturity were found, since low degrees of maturity (group S) imply higher values of lightness, redness and yellowness of the carcass (Hernández *et al.*, 2004), probably due to a higher content of subcutaneous fat in older animals.

Lightness of meat (Table 3.2.2) was lower in group S with 80% probability, but the difference was not relevant. This parameter is not influenced by selection when comparing animals at a similar stage of maturity (Piles *et al.*, 2000) but the influence of the degree of maturity on this is not clear. Dalle-Zotte *et al.* (1996) found no differences when comparing rabbits slaughtered at 55 and 87 days of age. However, Hernández *et al.* (2004) and Polak *et al.* (2006) observed a decrease in lightness with age, in the ranges 63–91 days and 93–105 days, respectively.

Rabbits from group S had 7% and 13% more redness and yellowness of the meat, respectively, and the differences were relevant, with a high probability (Pr(S > C) = 0.67 and 0.89, respectively). The yellowness of the meat was at least 2% higher in group S, with 95% probability (k2 = 1.02). This difference between groups is a consequence of the differences in maturity, since Hernández *et al.* (2004) observed higher values in 63 days old rabbits compared with 91 days old ones, but at the same stage of maturity no differences in yellowness were found.

Mean values of pH24h, cooking losses and water holding capacity (Table 3.2.2) were similar to those obtained by Pla *et al.* (1998) in animals from the same line at a similar weight.

Although pH24h had 84% probability of being higher in group S, the narrow high posterior density interval (HPD(95%)) led to no differences between groups (S/Cmean = 1.00, Table 3.2.2), agreeing with results found by Gondret *et al.* (2005) when comparing rabbits selected for growth rate with a control group at a similar weight. Other authors observed that pH is not influenced by selection for growth rate when comparing animals at similar stages of maturity (Larzul *et al.*, 2005; Piles *et al.*, 2000; Ramírez *et al.*, 2004) or by age (Hernández *et al.*, 2004). However Dalle-Zotte and Ouhayoun (1995) and Dalle-Zotte *et al.* (1996), found that pH decreased with age, in rabbits ranging from 56 to 84 or 55 to 87 days old, respectively.

Cooking losses and percentages of released water did not differ between groups (Table 3.2.2). According to some authors, the selected group should have had a higher percentage of released water, since this parameter increases when selecting for growth rate and is higher in young animals (Hernández *et al.*, 2004). Also cooking losses have been seen to increase with selection for growth rate (Piles *et al.*, 2000) although differences in degree of maturity did not seem to affect it (Xiccato *et al.*, 1994). The water holding capacity was 2% lower in group S (S/Cmean = 0.98) but the difference was not relevant (Table 3.2.2). This property has been seen to decrease when selecting for growth rate (Hernández *et al.*, 2004; Piles *et al.*, 2000) and is lower in young animals (Hernández *et al.*, 2004).

Mean values of enzymatic activity (Table 3.2.2) were similar to those obtained by Hernández *et al.* (2004) in m. *Longissimus* lumborum of rabbits 63 and 91 days old from the same line of rabbits.

Table 3.2.2. Features of the marginal posterior distributions of the means, standard deviations (sd) and ratio of the group effects, Selected/Control, for the carcass and meat colour, pH, cooking looses (%), percentage of released water (%), water holding capacity (%) and enzymatic activity (µmol min$^{-1}$ g$^{-1}$) of m. *Longissimus* in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] | k1[f] | k2[g] |
|---|---|---|---|---|---|---|---|---|---|
| Carcass colour | | | | | | | | | |
| L* | 53.96 | 2.22 | 0.99 | 0.98, 1.01 | 0.23 | 0.00 | 0.00 | 1.01 | 0.98 |
| a* | 3.22 | 0.78 | 0.98 | 0.90, 1.04 | 0.28 | 0.32 | 0.04 | 1.04 | 0.90 |
| b* | 0.92 | 1.14 | 0.48 | 0.21, 0.72 | 0.00 | 1.00 | 0.00 | 0.70 | 0.26 |
| Meat colour | | | | | | | | | |
| L* | 52.53 | 2.82 | 0.99 | 0.97, 1.01 | 0.20 | 0.00 | 0.00 | 1.01 | 0.98 |
| a* | 5.60 | 1.21 | 1.07 | 0.99, 1.15 | 0.95 | 0.67 | 0.67 | 1.14 | 1.00 |
| b* | 3.44 | 1.10 | 1.13 | 1.00, 1.26 | 0.98 | 0.89 | 0.89 | 1.24 | 1.02 |
| pH24h | 5.64 | 0.16 | 1.00 | 0.99, 1.02 | 0.84 | 0.00 | 0.00 | 1.01 | 1.00 |
| CL | 38.9 | 4.1 | 1.00 | 0.96, 1.04 | 0.60 | 0.02 | 0.01 | 1.04 | 0.97 |
| PRW | 32.5 | 2.6 | 1.00 | 0.97, 1.03 | 0.62 | 0.00 | 0.00 | 1.03 | 0.98 |
| WHC | 33.6 | 5.2 | 0.98 | 0.93, 1.03 | 0.21 | 0.16 | 0.00 | 1.02 | 0.93 |
| Enzymatic activity | | | | | | | | | |
| ICDH | 4.41 | 0.93 | 1.10 | 0.99, 1.21 | 0.97 | 0.83 | 0.83 | 1.20 | 1.01 |
| Ald | 768 | 275 | 1.04 | 0.87, 1.23 | 0.63 | 0.59 | 0.42 | 1.19 | 0.89 |
| Ald:ICDH | 184 | 72 | 0.92 | 0.73, 1.12 | 0.20 | 0.73 | 0.09 | 1.09 | 0.76 |

L*: lightness; a*: redness; b*: yellowness; ph24h: ph measurement at 24 hours *post-mortem*; CL: cooking losses; PRW: percentage of released water; WHC: water holding capacity; ICDH: isocitrate dehydrogenase; Ald: aldolase; Ald:ICDH: ratio aldolase/isocitrate dehydrogenase. [a] S/Cmean: mean of the ratio selected/control; [b] HPD(95%): high posterior density interval at 95% probability; [c] P(S/C>1): probability of (S/C>1); [d] Pr: probability of relevance, the probability of one group being at least 5% higher than the other one; [e] Pr(S>C): probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C; [f] k1: limit of the interval (-∞,k1] containing a probability of 95%; [g] k2: limit of the interval [k2,+ ∞) containing a probability of 95%.

The oxidative metabolic enzyme isocitrate dehydrogenase (ICDH) had 97% probability of being higher in group S than in group C (Table 3.2.2). Moreover, the mean value was 10% higher in group S (S/Cmean = 1.10), and this difference was relevant, with 83% probability. Aldolase activity was 4% higher in group S but the difference was not relevant. The aldolase/ICDH ratio was 8% lower in group S. This difference was relevant, with 64% probability (estimated as the difference between Pr and Pr(S > C)). No differences in ICDH, aldolase or aldolase:ICDH in m. *Longissimus* lumborum were found when comparing these groups at approximately the same degree of maturity (Hernández *et al.*, 2004). Differences between groups seem to be due to the lower degree of maturity of group S, associated with higher ICDH activity and lower aldolase/ICDH ratio (Dalle- Zotte and Ouhayoun, 1995; Dalle-Zotte *et al.*, 1996).

Chemical composition of the hind leg is shown in Table 3.2.3. The protein (20.7%) and moisture (74.6%) contents were similar to those observed by Pla et al. (1998) in the same line at a similar age and weight, but fat content was higher (3.7% versus 2.9% in Pla *et al.*, 1998).

Protein and fat percentages were 2% lower and moisture 1% higher in group S, but differences were not relevant (Table 3.2.3). No changes in protein and moisture percentages were observed by Piles *et al.* (2000) when comparing the same groups at a similar stage of maturity, while the effect on fat percentage is contradictory, some finding higher values in group S (Pascual *et al.*, 2004) and some in group C (Hernández *et al.*, 2004; Piles *et al.*, 2000). Reducing the degree of maturity of the animals, as in group S, is characterized by increased moisture and decreased fat, while the protein content is the same (Parigi-Bini *et al.*, 1992) or decreases (Dalle-Zotte *et al.*, 1996). It seems that differences in degree of maturity between our groups were too small to cause any relevant change.

The Department of Health and Social Security (1994) recommended a ratio of 0.45 or higher for PUFA/SFA and a maximum of 4.0 for the *n*-6:*n*-3 ratio. The PUFA/SFA ratio in the hind leg of rabbit is over 0.45, (mean = 1.09, Table 3.2.3), as found by other authors (Pla *et al.*, 2007; Ramírez *et al.*, 2005). However, the *n*-6:*n*-3 ratio is higher than 4.00 (mean = 13.4), as

also found by Pla *et al.* (2007) and Ramírez *et al.* (2005). The high value has been attributed to the high linoleic acid content in rabbit meat. In the perirenal fat of rabbit, the ratio is less, but still above 4.00 (about 8.5, Ramírez *et al.*, 2005).

The rabbits from group S had lower percentages of SFA and MUFA, but differences were not relevant (Table 3.2.3). PUFA fatty acids were 5% higher in this group, the difference being relevant with 41% probability. The PUFA/SFA ratio was relevantly increased when selecting for growth rate. Also the *n*-6 and *n*-3 percentages increased, but this change was only relevant for the *n*-3 fatty acid. The *n*-6:*n*-3 ratio was 4% lower in group S but the difference was not relevant. If these differences increase as selection for growth rate continues, a desired decrease in the ratio might be occur. According to Polak *et al.* (2006), the fatty acid indices did not changed with age in rabbits 93–105 days old. Ramírez *et al.* (2005) observed an increase in saturated and decrease in PUFA/SFA and *n*-6 when comparing groups at a similar stage of maturity.

The increase in PUFA/SFA ratio can be considered as a positive effect for human health. However, the negative aspects of having a high PUFA/SFA ratio need to be considered. High contents of polyunsaturated acids, especially those with more than two double bounds, leads to oxidation and the shelf-life of the meat is reduced due rancidity and colour deterioration; the texture of the meat could also be affected (Wood *et al.*, 2003). Thus, changes in meat colour observed in group S could be due to the higher PUFA/SFA ratio of the meat. However, no changes in texture (instrumental analysis) and flavour (sensory analysis) were found (Pascual and Pla, unpublished data). Possible changes in flavour and texture and the effect on lipid oxidation should be considered in further selection for growth rate.

Table 3.2.3. Features of the marginal posterior distributions of the means, standard deviations (sd) and ratio of the group effects, Selected/Control, for the chemical and fatty acid composition in the hind leg in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] | k1[f] | k2[g] |
|---|---|---|---|---|---|---|---|---|---|
| Chemical composition | | | | | | | | | |
| Protein (%) | 20.7 | 0.4 | 0.98 | 0.98, 0.99 | 0.00 | 0.00 | 0.00 | 0.99 | 0.98 |
| Fat (%) | 3.7 | 0.7 | 0.98 | 0.92, 1.05 | 0.28 | 0.19 | 0.02 | 1.04 | 0.93 |
| Moisture (%) | 74.6 | 0.8 | 1.01 | 1.00, 1.01 | 1.00 | 0.00 | 0.00 | 1.01 | 1.00 |
| Fatty acids composition | | | | | | | | | |
| SFA (%) | 34.6 | 2.3 | 0.98 | 0.96, 1.01 | 0.08 | 0.00 | 0.00 | 1.00 | 0.96 |
| MUFA (%) | 28.3 | 2.4 | 0.96 | 0.94, 0.99 | 0.02 | 0.09 | 0.00 | 0.99 | 0.94 |
| PUFA (%) | 37.2 | 4.1 | 1.05 | 1.00, 1.09 | 0.99 | 0.41 | 0.41 | 1.08 | 1.01 |
| PUFA/SFA | 1.09 | 0.19 | 1.06 | 1.00, 1.13 | 0.97 | 0.62 | 0.62 | 1.12 | 1.01 |
| *n*-6 (%) | 39.6 | 5.1 | 1.04 | 0.99, 1.09 | 0.95 | 0.32 | 0.32 | 1.08 | 1.00 |
| *n*-3 (%) | 3.0 | 0.4 | 1.08 | 1.03, 1.13 | 1.00 | 0.86 | 0.86 | 1.12 | 1.03 |
| *n*-6:*n*-3 | 13.4 | 2.6 | 0.96 | 0.90, 1.03 | 0.13 | 0.36 | 0.00 | 1.02 | 0.91 |

SFA: saturated fatty acids = C14:0 (myristic) + C16:0 (palmitic) + C18:0 (stearic).;

MUFA: monounsaturated fatty acids = C16:1 *n-7* (palmitoleic) + C18:1 *n-9* (oleic) + C18:1 *n-7* (vaccenic) + C20:1 (eicosenoic).;

PUFA: polyunsaturated fatty acids = C18:2 *n-6* (linoleic) + C18:3 *n-3* (α -linolenic) + C20:2 *n-6* (eicosadienoic) + C20:3 *n-6* (eicosatrienoic) + C20:4 *n-6* (arachidonic).

PUFA/SFA: ratio polyunsaturated/saturated fatty acids;

*n-6* = C18:2 *n-6* (linoleic) + C20:2 *n-6* (eicosadienoic) + C20:3 *n-6* (eicosatrienoic) + C20:4 *n-6* (arachidonic).

*n-3* = C18:3 *n-3* (α-linolenic).

[a] S/Cmean: mean of the ratio selected/control; [b] HPD(95%): high posterior density interval at 95% probability; [c] P(S/C>1): probability of (S/C>1); [d] Pr: probability of relevance, the probability of one group being at least 5% higher than the other one; [e] Pr(S>C): probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C; [f] k1: limit of the interval $(-\infty, k1]$ containing a probability of 95%; [g] k2: limit of the interval $[k2, +\infty)$ containing a probability of 95%.

### 3.2.5. Conclusions

Selection for growth rate in rabbit and the consequent decrease in degree of maturity of the animals at slaughter weight caused some relevant changes in some carcass composition variables. Carcasses had higher percentages of viscera (kidneys and liver) and higher percentages of dissectible fat. Meat to bone ratio in the hind leg decreased, which might lead to a decrease in this ratio in the carcass. In m. *Longissimus*, carcass and meat colour changed, which could affect acceptability. The oxidative metabolism route was increased. Other characteristics of the meat such as pH and water holding capacity were not affected. The positive effect on rabbit meat quality when selecting for growth rate was the effect on PUFA/SFA ratio in the hind leg, which increased.

Further selection for growth rate might cause a relevant decrease of the *n*-6:*n*-3 ratio, which would be positive. The negative effects of a possible increase in lipid oxidation on colour, texture and flavour of the meat due to the increased PUFA/SFA ratio should be considered.

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# 3.3. CHANGES IN COLLAGEN, TEXTURE AND SENSORY PROPERTIES OF MEAT WHEN SELECTING RABBITS FOR GROWTH RATE[1]

### 3.3.1. Abstract

The consequences of selection for growth rate and the associated decrease of maturity at slaughter in rabbits on collagen content, collagen solubility, meat texture (Warner-Bratzler shear device) and the sensory properties of the m. *Longissimus* were studied. Sixty rabbits from the 7th generation of a line selected for growth rate (group C) were compared with 60 rabbits from the 23rd generation of the same line (group S). Both groups were contemporarily reared and slaughtered at 2000 g. No changes on collagen content were found, but group S had a higher (5%) collagen solubility. Shear force, shear firmness and area or total work needed to cut the sample were not different between groups, and hardness evaluated in the panel test was not relevantly changed. Most of the sensory properties studied did not differ relevantly between groups. Group S had 8% less aniseed odour and 10% more juiciness.

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### 3.3.2. Introduction

Rabbit meat is usually produced by a three-way cross, where females from a cross of two lines selected for reproductive traits are mated with males from a line selected for growth rate. There are few studies on how this selection affects meat tenderness, which is usually determined by mechanical procedures or sensory analysis, and results are not clear. Ramírez *et al.* (2004) and Gil *et al.* (2006), comparing rabbits selected for growth rate with a control population, observed an increase in the shear firmness in the selected rabbits, which indicates more resistance of the meat to cutting. Gumminess, chewiness and hardness also increased. Gondret *et al.* (2002), in an experiment involving divergent selection for weight at slaughter age, observed higher values of the maximum shear force and total energy needed to cut the meat in the rabbits selected for high body weight compared with those selected for low body weight. Conversely, Larzul *et al.* (2005) found a lower value of the maximum shear force in animals selected for high body weight at slaughter compared with those from a control group from the same line. Only Hernández *et al.* (2005) studied the effects of selection for growth rate on the sensory properties of the rabbit meat. No differences were found in texture, juiciness and fibrousness. Liver flavour was relevantly higher in rabbits selected, to the detriment of the aniseed odour and flavour.

Taylor (1985) suggested comparing animals from different species or breeds at the same stage of maturity, in order to avoid differences due to the different physiological age. For this reason, the articles cited above on the effects of selection for growth rate compared selected and control groups at a similar age, which corresponds to approximately the same degree of maturity (Blasco *et al.*, 2003; Pla *et al.*, 1997). However, the selection for growth rate in rabbits increases the adult weight (Blasco *et al.*, 2003). Thus, at the weight fixed by the market, the animals selected for growth rate have a lower degree of maturity. Several authors have studied the influence of the degree of maturity on the texture (Polak *et al.*, 2006; Xiccato *et al.*, 1994) and sensory properties (Jehl and Juin, 1999; Juin *et al.*, 1998; Polak *et al.,* 2006) of rabbit meat, slaughtering animals at different ages. A study of the

consequences of selection for growth rate when slaughtering the animals at the fixed market weight is, therefore, needed.

Meat tenderness depends on the changes of the myofibrilar proteins during *post-mortem* and on the connective tissue (Møller, 1980). Collagen is the principal constituent of the connective tissue. Meat tenderness does not only depend on the quantity of collagen but also on its solubility (Bailey and Light, 1989). According to Bailey (1985), age (and, therefore, degree of maturity) affects the structure of collagen. The effect of selection for growth rate on collagen content and its solubility has not previously been studied in rabbit meat.

Blasco (2005) suggested the use of the Bayesian approach for the study of carcass and meat quality, due to some advantages when interpreting the results. Some authors (Hernández *et al.*, 2005; Piles *et al.*, 2000) applied the Bayesian analysis to study the effect of selection for growth rate on carcass composition and meat quality in rabbit. The Bayesian approach permits the estimation of the ratio of the treatments, which indicates the superiority of one treatment opposed to another. The use of this ratio is especially useful when studying the sensory properties, where it is difficult to determine what is an important difference. This ratio has been previously used before for the study of the sensory properties of rabbit meat (Ariño *et al.*, 2007; Hernández *et al.*, 2005).

The objective of this work was to study the consequences of selection for growth rate and the associated decrease of maturity at slaughter weight on collagen content and collagen solubility, texture and sensory properties of rabbit meat.

### 3.3.3. Material and methods

#### 3.3.3.1. Animals

A total of 120 rabbits were used. The rabbits came from line R, a synthetic line selected for growth rate between 4 and 9 weeks of age at the

Universidad Politécnica de Valencia (Baselga, 2002). The animals came from two groups: Selected (S) and Control (C), with 60 animals in each group. Embryos belonging to the 7th generation of selection were recovered, vitrified and conserved for several years. Meanwhile, selection for growth rate in line R continued. Later, embryos were de-vitrified and transferred to mature adults, following the procedure described by Vicente *et al.* (1999). The offspring of the animals derived from these embryos formed group C, in order to avoid the effects of vitrification and de-vitrification. Group S was formed with animals from the 23rd generation and both groups were contemporarily bred under the same conditions.

After weaning at 28 days of age, animals were placed mixed in collective cages of 8 kits and fed *ad libitum* with a standard diet (crude protein, 14.8%; ether extract, 3.2%; crude fibre, 16.5%; ash, 8.2%). Animals of groups S and C were weighed at 51 and 55 days of age, respectively, ages at which both groups achieved a mean value of liveweight of 2000 g. One male and one female from each litter (of which almost five were born alive) weighing 2000 g ± 200 g were slaughtered without fasting. The slaughterhouse was next to the farm, thus stress caused by transport was minimal. Animals were electrically stunned (90 V, 6 s, 50 Hz) and bled within 3 s. Following slaughter and bleeding, the skin, the distal part of the tail, the fore and hind legs, the urogenital organs and the digestive tract were removed, as indicated by the World Rabbit Science Association (WRSA) (Blasco and Ouhayoun, 1996). Carcasses were suspended from the tendon calcaneus for 30 minutes in a ventilated area and then cooled in a refrigerated chamber at 3 ºC.

At 24 hours *post-mortem*, carcasses were cut between the seventh and eighth thoracic vertebrae and between the sixth and seventh lumbar vertebrae, and both m. *Longissimus* were recovered.

### 3.3.3.2. Collagen content and collagen solubility

Samples between the sixth and seventh lumbar vertebrae from both m. *Longissimus* of each animal were removed and stored at -20 ºC to estimate

the collagen content and its solubility. Total and soluble hydroxyproline contents were estimated in 17 rabbits per group, following the method described by Bonnet and Kopp (1984). The total and soluble collagen were estimated multiplying total and soluble hydroxyproline by the factor 7.14 (Etherington and Sims, 1981). The collagen solubility was calculated as the percentage of soluble collagen in the total collagen.


### 3.3.3.3. Texture analysis

The left m. *Longissimus* from each animal was vacuum packed and stored at -20 ºC for texture analysis. Samples were thawed at 4 ºC for 24 hours and cooked at 80 ºC for 1 hour by inmersion in a water bath (Combes *et al.*, 2004). They were then cooled down by immersion in water at 20 ºC for 10 minutes and then unpacked. The samples for the Warner-Bratzler shear test were obtained by cutting 1 to 5 rectangles of 2 x 1 cm of cross section. Samples were completely cut using a Warner-Bratzler shear blade with a triangular slot cutting edge, using a Texture Analyser Mod. TA XT Plus (Stable Micro Systems, UK). Three parameters were measured: the maximum shear force ($N/cm^2$); the shear firmness, obtained as the slope of the line drawn between the origin of the curve and the maximum shear force ($N/s\ cm^2$), and the area ($N\ s/cm^2$) under the curve or total work performed to cut the sample.


### 3.3.3.4. Sensory analysis

The right m. *Longissimus* from each animal was vacuum packed and stored at -20 ºC for the sensory analysis. A quantitative descriptive analysis (Stone *et al.*, 1974) of the m. *Longissimus* from 42 rabbits per group was performed with 6 trained tasters of rabbit meat over 14 sessions, following a complete block design (Steel and Torrie, 1980). Vacuum packed samples were thawed at 4 ºC for 24 hours and then cooked at 80 ºC for 1 hour by

immersion in a water bath. Cooked samples were unpacked and cut into four pieces and distributed to the tasters. The samples were evaluated on a scale of 0 to 10 for aniseed odour, liver odour, aniseed flavour, liver flavour, intensity of flavour, hardness, juiciness, fibrousness and flouriness.

### 3.3.3.5. Statistical analysis

The model used for the texture analysis, collagen content and collagen solubility was:

$$y_{ijk} = \mu + G_i + S_j + e_{ijk}$$

where $\mu$ was the general mean, $G_i$ was the group (S and C), $S_j$ was the sex (males and females) and $e_{ijk}$ was the residual.

For the sensory analysis, the model was:

$$y_{ijklmno} = \mu + G_i + S_j + D_k + O_l + L_m + T_n + e_{ijklmno}$$

where $\mu$ was the general mean, $G_i$ was the group (S and C), $S_j$ was the sex (males and females), $D_k$ was the session (14 sessions), $O_l$ was the order of sample presentation to the taster (4 orders), $L_m$ was the muscle location (4 locations), $T_n$ was the taster (6 tasters) and $e_{ijklmno}$ was the residual. A Bayesian analysis was performed, using bounded flat priors for all unknowns. The marginal posterior distributions were obtained using Gibbs Sampling. One chain of 100000 samples was obtained, with a lag of 10 and a burning period of 2000, thus marginal posterior distributions were estimated using a chain of 8000 samples. Convergence of the chains was tested using the Z criterion of Geweke (Geweke, 1992). More details of this procedure can be found in Blasco (2001).

From the marginal posterior distributions of each trait, the mean value and the standard deviation of the trait were obtained. The marginal posterior distributions of the ratio between the Selected and Control groups (S/C) were estimated, in order to compare the superiority of one group with respect to the other. From the marginal posterior distribution of the S/C of each trait, the following parameters were obtained: S/Cmean; high posterior density interval at 95% of probability (HPD(95%)); probability of S/C being higher

than 1 (P(S/C>1)); probability of relevance (Pr), which in this study was considered as the probability that one group was at least 5% higher than the other group; probability of relevance of group S being at least 5% higher than group C (Pr(S>C)).

### 3.3.4. Results and discussion

MonteCarlo standard errors were very small for all the traits (under 0.001 in all the cases) and Geweke test did not detect lack of convergence in any case. Therefore, these values have not been presented in the tables.

#### 3.3.4.1. Collagen content and solubility

Mean values for collagen content and its solubility are given in Table 3.3.1. Ariño *et al*. (2006) observed similar values for collagen content when comparing 63 days old rabbits selected for different objectives (6.8 mg/g fresh meat). Corino *et al.* (2003) compared intramuscular collagen content in animals of different ages and fed with different diets and Combes *et al.* (2004) studied collagen content in 70 days old rabbits, but the results cannot be compared due to the different methods used to determine collagen content. The collagen content in m. *Longissimus* in rabbit is higher than the values observed in m. *Longissimus* of pork 160 days old (5.0 mg/g fresh meat, Čandet-Potocar *et al.*, 1998), m*. Longissimus thoracis* in 14 months old bovines (3.4 to 5.8 mg/g fresh meat, Monsón *et al.*, 2004) or m. *Pectoralis* in 210 days old chicken (3 to 4 mg/g fresh meat, Liu *et al.*, 1996). High collagen content is associated with increased meat toughness. However, the role of collagen on meat tenderness not only depends on the collagen content but also on its solubility or cross-linking. This solubility is high in rabbit meat compared with m. *Longissimus thoracis* from pigs of 115 kg liveweight (12-113%, Correa *et al.*, 2006), m. *Longissimus thoracis* in 14

months old bovines (34-44%, Monsón *et al.*, 2004) and m. *Pectoralis* in 210 days old chicken (30-40%, Liu *et al.*, 1996).

Table 3.3.1. Means and standard deviations (sd) and features of the marginal posterior distribution of the ratio of the group effects, Selected/Control, for the collagen content (CC, mg/g fresh meat) and collagen solubility (CS, %) in m. *Longissimus* in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] |
|-------|------|------|-------|------------|-----------|------|---------|
| CC | 6.80 | 1.07 | 1.02 | 0.90, 1.13 | 0.64 | 0.41 | 0.30 |
| CS | 47.6 | 9.0 | 1.05 | 0.91, 1.20 | 0.77 | 0.58 | 0.52 |

[a] S/Cmean: mean of ratio selected/control.

[b] HPD(95%): high posterior density interval at a 95% of probability.

[c] P(S/C>1): Probability of (S/C > 1).

[d] Pr: Probability of relevance, the probability of one group being at least 5% higher than the other.

[e] Pr(S>C): Probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C.

There were no differences between the groups with regards to collagen content, but collagen solubility was a 5% higher in group S (S/Cmean = 1.05), and the difference in favour of group S was relevant with 52% probability (Pr(S>C) = 0.52, Table 3.3.1). Corino *et al.* (2003) observed an increase of intramuscular collagen content as the degree of maturity increased, when comparing rabbits ranging from 76 to 104 days of age. It may be that we did not find any differences in collagen content between groups because the difference in degree of maturity was too low to cause an effect, although it affected collagen solubility. As age increases, collagen synthesis is not modified (Reiser *et al.*, 1992) but the cross-linked fraction, more resistant to collagenase action, increases and, consequently, the degradation of collagen is lower (Horgan *et al.*, 1991; Laurent, 1987; McCormick, 1994). No studies concerning the effect of selection for growth rate on these parameters when comparing groups at a similar stage of maturity have been found. Ariño *et al.* (2006) observed a lower collagen

content and solubility in the line used in the present study than in other lines selected for different objectives, but differences could be due to the different genetic origins.

### 3.3.4.2. Texture analysis

Mean values for the texture parameters analysed with the Warner-Bratzler test are given in Table 3.3.2. Mean values for shear force and area were similar to those observed by Gil *et al*. (2006) and Ramírez *et al*. (2004) in the same line of rabbits. However, mean value for shear firmness was higher in the present work.

Table 3.3.2. Means and standard deviations (sd) and features of the marginal posterior distribution of the ratio of the group effects, Selected/Control, for the shear force (N/cm$^2$), shear firmness (N/s cm$^2$) and area (N s/cm$^2$) of the texture analysis by Warner-Bratzler in m. *Longissimus* in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] |
|---|---|---|---|---|---|---|---|
| Shear Force | 36.0 | 11.1 | 0.99 | 0.86, 1.11 | 0.40 | 0.45 | 0.17 |
| Shear Firmness | 17.3 | 5.9 | 1.00 | 0.86, 1.14 | 0.48 | 0.49 | 0.24 |
| Area | 58.5 | 19.6 | 0.98 | 0.85, 1.12 | 0.39 | 0.49 | 0.17 |

[a] S/Cmean: mean of the ratio selected/control.

[b] HPD(95%): high posterior density interval at a 95% of probability.

[c] P(S/C>1): Probability of (S/C > 1).

[d] Pr: Probability of relevance, the probability of one group being at least 5% higher than the other.

[e] Pr(S>C): Probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C.

The texture parameters analysed did not differ between groups (Table 3.3.2), agreeing with Xiccato *et al*. (1994) and Polak *et al*. (2006), who reported no changes in these variables in rabbits of different degrees of

maturity, when studying animals from 77 to 91 and from 93 to 105 days of age, respectively. However, studies on the effect of selection for growth rate, when compared at a similar stage of maturity, show changes in texture parameters. The shear firmness from the Warner-Bratzler test and chewiness, gumminess and hardness from the Texture Profile Analysis of rabbit meat were increased (Gil *et al.*, 2006; Ramírez *et al.*, 2004). In an experiment involving divergent selection for slaughter weight, Gondret *et al.* (2002) also found higher values of the shear force and total energy needed to cut the sample in animals of high weight. However, Larzul *et al.* (2005) reported a decrease of the maximum shear force when comparing rabbits selected for high weight with a control group. Our results suggest that the increase of collagen solubility was not enough to change meat texture.

### 3.3.4.3. Sensory analysis

Aniseed odour was 8% lower in group S (S/Cmean = 0.92), the difference in favour of group C being relevant with 69% probability (obtained as the difference between Pr and Pr(S>C), Table 3.3.3). This is in agreement with results of Hernández *et al.* (2005), who observed a lower value for this trait in group S when comparing both groups of animals at the same stage of maturity. No differences were found in aniseed flavour. The effects of changes in degree of maturity on aniseed odour and aniseed flavour in rabbit have not been previously studied.

Liver flavour was 3% stronger in group S (Table 3.3.3), although the difference was not relevant. Hernández *et al.* (2005) found a higher value of this trait in group S than in group C when comparing both groups at a similar stage of maturity. Liver odour, which according to Ariño *et al.* (2007) has a correlation of 0.49 with liver flavour, did not differ between groups. To our knowledge, the possible changes in liver odour and liver flavour when varying the degree of maturity in rabbits have not been studied before.

The lower aniseed odour of meat from group S (Table 3.3.3) would suggest a lower general odour in animals from this group. Jehl and Juin

(1999) have reported an increase of the general odour of the rabbit meat, as degree of maturity increases, when studying animals from 70 to 98 days old. However, Polak *et al*. (2006) did not find differences between 93 and 105 days old rabbits.

Table 3.3.3. Means and standard deviations (sd) and features of the marginal posterior distribution of the ratio of the group effects, Selected/Control, for the sensory panel test in m. *Longissimus* in rabbits.

| Trait | mean | sd | S/Cmean[a] | HPD(95%)[b] | P(S/C>1)[c] | Pr[d] | Pr(S>C)[e] |
|---|---|---|---|---|---|---|---|
| Aniseed odour | 0.14 | 0.10 | 0.92 | 0.78, 1.04 | 0.10 | 0.72 | 0.03 |
| Liver odour | 1.86 | 0.67 | 0.99 | 0.92, 1.09 | 0.38 | 0.22 | 0.07 |
| Aniseed flavour | 0.28 | 0.30 | 1.00 | 0.76, 1.27 | 0.47 | 0.65 | 0.31 |
| Liver flavour | 1.59 | 0.50 | 1.03 | 0.96, 1.12 | 0.77 | 0.26 | 0.24 |
| Intensity of flavour | 2.47 | 0.40 | 1.00 | 0.97, 1.04 | 0.54 | 0.00 | 0.00 |
| Hardness | 2.89 | 0.88 | 0.97 | 0.91, 1.05 | 0.20 | 0.25 | 0.00 |
| Juiciness | 1.09 | 0.46 | 1.10 | 0.99, 1.21 | 0.97 | 0.83 | 0.83 |
| Fibrouness | 1.68 | 0.66 | 0.97 | 0.90, 1.08 | 0.25 | 0.34 | 0.05 |
| Flouriness | 1.87 | 0.92 | 0.96 | 0.86, 1.09 | 0.20 | 0.52 | 0.05 |

[a] S/Cmean: mean of the ratio selected/control.

[b] HPD(95%): high posterior density interval at a 95% of probability.

[c] P(S/C>1): Probability of (S/C > 1).

[d] Pr: Probability of relevance, the probability of one group being at least 5% higher than the other.

[e] Pr(S>C): Probability of relevance in favour of group S or the probability of group S being at least 5% higher than group C.

The intensity of the flavour of the meat was similar for both groups (Table 3.3.3). This sensory property does not change with maturity (Juin *et al*., 1998; Polak *et al*., 2006) and Hernández *et al*. (2005) did not find relevant differences between groups when comparing them at a similar stage of maturity.

Hardness was 3% lower in meat from group S (Table 3.3.3), but the difference was not relevant. Therefore, the increase in collagen solubility

(Table 3.3.1) was not sufficient to cause changes in meat texture (Table 3.3.2) or to relevantly decrease hardness evaluated by the panel test. According to some previous studies, meat tenderness assessed by a panel test is not influenced by selection for growth rate (Hernández *et al.*, 2005) or changes in the degree of maturity (Jehl and Juin, 1999; Polak *et al.*, 2006).

Juiciness was 10% higher in meat from group S (Table 3.3.3), which can be considered as a positive change, and the difference was relevant, with an 83% probability (Pr = 0.83). This was an unexpected result, since in previous studies, Hernández *et al.* (2005) did not find any differences due to the selection for growth rate when comparing both groups at approximately the same degree of maturity and other authors (Jehl and Juin, 1999; Juin *et al.*, 1998; Polak *et al.*, 2006) did not observed changes in the juiciness of rabbit meat when varying the degree of maturity. Initial juiciness is affected by water freed by mastication and by the pH level, while sustained juiciness depends on the meat lipids (Cross *et al.*, 1978). However, no differences between groups were found in cooking losses, the percentage of released water, the water holding capacity and the ultimate pH of m. *Longissimus* or in the fat and moisture content of the hind leg (Pascual and Pla, In Press).

Fibrousness was 3% lower in meat from group S (Table 3.3.3). However, this difference cannot be considered as relevant. Hernández *et al.* (2005) did not find any differences when comparing both groups at approximately the same degree of maturity. Juin *et al.* (1998) observed a decrease of fibrousness as the degree of maturity increased, but due probably to the ample range of ages studied.

Finally, flouriness was 4% lower in meat from group S, but the difference was not relevant (Table 3.3.3). Jehl and Juin (1999) did not find any changes when increasing the degree of maturity of the animals. Juin *et al.* (1998) observed an increase with age probably because of the large difference of age between groups. Effect of selection for growth rate when comparing at similar degrees of maturity has not been reported.

### 3.3.5. Conclusions

Selection for growth rate and the consequently decrease of maturity of the animals at the commercial weight did not change collagen content. Collagen solubility increased, but it did not affect meat texture and the hardness evaluated by the panel test was not relevantly modified. The only relevant changes on sensory properties were a decrease of aniseed odour and an increase of juiciness. Therefore, we can conclude that selection for growth rate does not affect the meat tenderness, nor does it affect most of the sensory properties of meat from rabbits slaughtered at the commercial weight, since no changes have been observed after sixteen generations of selection. Moreover, the relevant changes in juiciness would be positive, and any consequences regarding changes in aniseed odour would depend upon the intended consumer market.

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# IV. GENERAL DISCUSSION

## 4.1. GENERAL DISCUSSION

The selection for growth rate of line R led to an increase of the weight along the whole growth curve (Blasco *et al.*, 2003). However, we did not know if the relative growth of the carcass components had also changed. Carcass composition has an increasing importance nowadays, because both liveweight and dressing out percentage are considered in meat merchandising. Moreover, the percentage of rabbit meat sold as retail cuts has recently augmented (Hassan and Monier-Dilhan, 1999; in Dalle-Zotte, 2002). Some previous studies reported changes in relative growth when modifying growth rate in other species (Allen and McCarthy, 1980; Eisen, 1987; Thompson *et al.*, 1985). In rabbit, effect of selection has been indirectly studied by comparing with other lines (Deltoro and López, 1985) or non contemporary control groups (Blasco *et al.,* 1990). To our knowledge, this is the first study about the effect of selection for growth rate on the relative growth of the carcass components in rabbits where selected and unselected groups have the same genetic origin and are contemporary. We did not find any effect of selection for growth rate on the relative growth of the different organs, tissues, retail cuts and carcass linear measurements. Therefore, rabbits selected for growth rate would have similar carcass composition than unselected rabbits at a similar degree of maturity.

The effect of selection for growth rate on carcass composition and meat quality at slaughter age has been previously studied by comparing selected animals with a control group of similar age (63 days old), which corresponds to approximately the same degree of maturity (Blasco *et al.*, 2003; Pla *et al.*, 1997). However, selected animals have a lower degree of maturity than unselected animals at the slaughter weight, which is fixed by the market, because the selected animals have a higher adult weight. Several authors have reported that carcass composition and some meat characteristics change with degree of maturity, therefore the effect of selection for growth

rate was studied by comparing selected and unselected rabbits at a similar slaughter weight.

Selection for growth rate and the consequently decrease of degree of maturity practically did not affect the dressing out percentage of the carcass. In the Spanish market, the carcass is still sold including liver, kidneys, thoracic viscera and head. Although kidneys and liver percentage in the carcass increased, it did not lead to a relevant change in the percentage of reference carcass, which is the part involving the meat. The different retail cuts were not relevantly affected either. Dissectible fat of the carcass increased. According to the late maturing pattern of this tissue, the lower degree of maturity of the selected animals at the fixed slaughter weight should have decreased their fat percentage. We think that the increase that we found is due to the higher food ingestion of selected animals with respect to the control group (Sanchez *et al.*, 2004). In pigs, the deposition of protein deceases over a level of food ingestion and the extra food ingested is used for fat deposition (Whittemore, 1993). An increase of fat tissue when selecting for growth rate was also observed in poultry (Crawford, 1990). Nevertheless, rabbit carcass is still a low fat carcass compared with other species (Ouhayoun, 1989). Meat to bone ratio was lower in the selected animals than in the control group, because meat of the hind leg is late maturing and bone early maturing. Our results can be extrapolate to the meat to bone ratio of the carcass, because it is highly correlated to this ratio in the hind leg (Hernández *et al.*, 1996).

Some changes in meat quality were also observed when comparing both groups at a similar weight. The relevant decrease in yellowness of the carcass and increase of redness and yellowness in the meat in the m. *Longissimus* could affect to the market acceptability. Although the oxidative metabolism in this muscle increased, it did not affect to other characteristics like pH or water holding capacity. The fat percentage of the meat of the hind leg was not affected, but some positive changes in its composition from the human health point of view were observed. First, the ratio polyunsaturated/saturated fatty acids (PUFA/SFA) was higher in the selected group. Second, although the *n*-6: *n*-3 ratio was not relevantly lower, in the

future a relevant decrease could be found if selection continues, improving meat quality. Both high PUFA/SFA and low *n*-6*: n*-3 ratio are recommended by the Department of Health and Social Security UK (1994). However, the negative consequences of the increase of PUFA/SFA should be also considered, because a high content of PUFA in meat could lead to oxidize, producing rancidity and changes in odour and flavour. In the m. *Longissimus*, the panel test found only a decrease in aniseed odour, but any of the flavour characteristics were different between groups. The juiciness was higher after selecting for growth rate, in spite of no changes in pH, water holding capacity and fat percentage in the meat, which are related to meat juiciness (Cross *et al.*, 1978). The meat texture, measured instrumentally and evaluated by a panel test, was not relevantly changed, in spite of the higher collagen solubility found in the selected animals.

In summary, we can say that selection for growth rate did not change the relative growth of the different components of the carcass. Moreover, most of the carcass and meat characteristics were not relevantly affected by selection for growth rate and the consequent decrease of degree of maturity at slaughter weight. The negative consequences of reducing the degree of maturity may be overcome by slaughtering the rabbits at higher ages, which will be possible if carcasses are destined to be sold as retail cuts.

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