UNIVERSITÀ DEGLI STUDI DI SASSARI

SCUOLA DI DOTTORATO DI RICERCA
Scienze e Biotecnologie
dei Sistemi Agrari e Forestali
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Growth performances of suckling Sarda breed piglets

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Chapter 1

SUCKLING PIGLETS DEVELOPMENT AND GROWTH

1. *Introduction*

Postnatal growth performance has an important economic relevance in pigs breeding. There are a lot of different factors which affect piglets growth rate like prenatal condition, maternal nutritional and hormonal status, breed, litter size. It's also well known the importance of the weight at birth, which has a direct effect on weaning weight and the consequent post weaning growth performance. Heavier piglets at weaning will have more appetite, will react better when turned away from their mother, will grow more and better. Additionally will have less health problems, as intestinal diseases, and will have a better feed conversion index (Bertacchini et al., 2013). In several studies it has been evidenced the direct link between lower birth weights and lower weight gains, less carcass quality and an increase of pre-weaning mortality (Quiniou N., 2002; Václavková E., 2012). Indeed lighter newborn piglets are less vital, have greater difficulty in thermoregulation and harder to reach quickly the breasts to feed. This makes the survival of these piglets even more complicated. Not taking the adequate amount of colostrum in a short time, in fact, makes the animals immunodeficient and therefore more exposed to pathologies (Quiniou N., 2002). Furthermore low birth weight is not recovered neither in later life, significantly affecting yield (Wu G., 2006; Václavková E., 2012).

2. Birth weight

Birth weight is affected by a lot of different factors which are closely interrelated.

To simplified each of following aspect will be separately analyzed:

- congenital condition (intrauterine fetuses development and increase)
- maternal nutrition (under- or over-nutrition) and hormonal status
- breed
- litter size
- sex

2.1 Congenital condition

Fetuses development and increase

Many factors have a considerable influence on swine fetal growth rate such as genetic, nutritional status and gestational stages of sows. A fetus can reach birth weight following different growth trajectories. Figure 1 shows what can happen during gestation changing nutritional sow condition.

In particular:

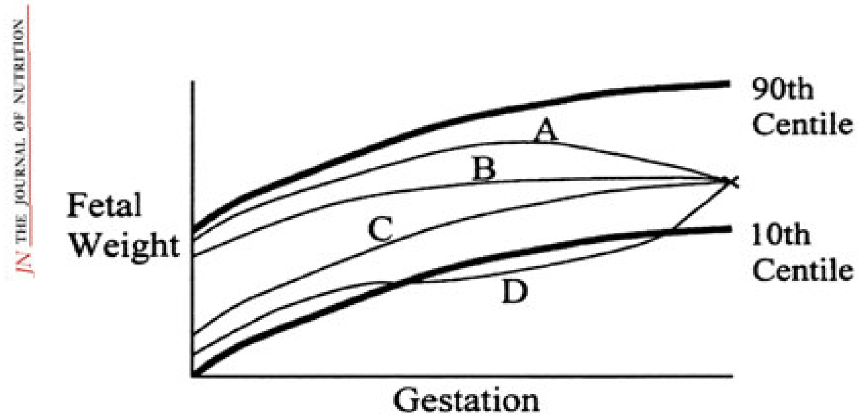
A: late growth restriction and fetal wasting;

B: early growth restriction;

C: normal growth;

D: late growth restriction followed by catch-up growth.

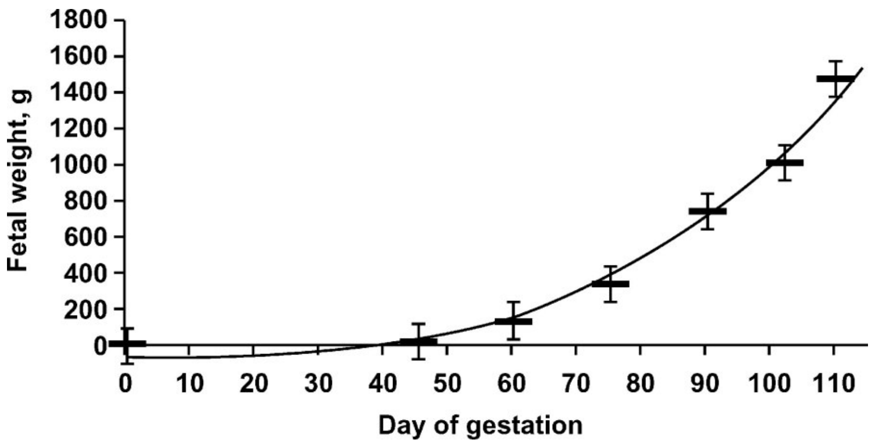
Figure 1: Fetal growth trajectories



Fall et al., 2003

A study carried out by McPherson et al. (2004) demonstrates that fetuses bodyweight increases cubically with the pregnancy progresses. In means that fetal growth undergoes a notable rise during second half of gestation. In figure 2 is shown the fetal weight increasing during the progression of gestation.

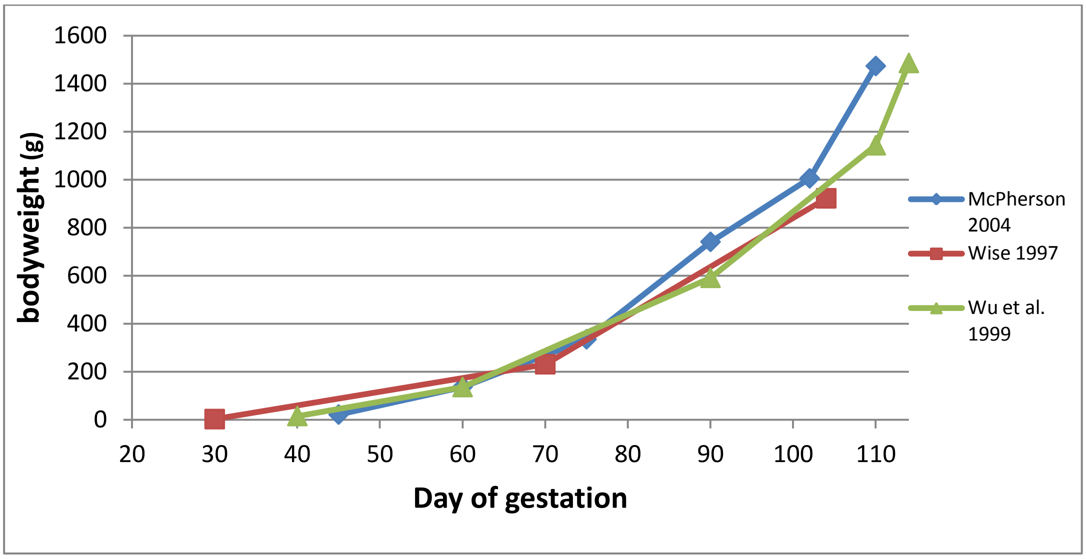
Figure 2: fetal weight growth



McPherson et al., 2004

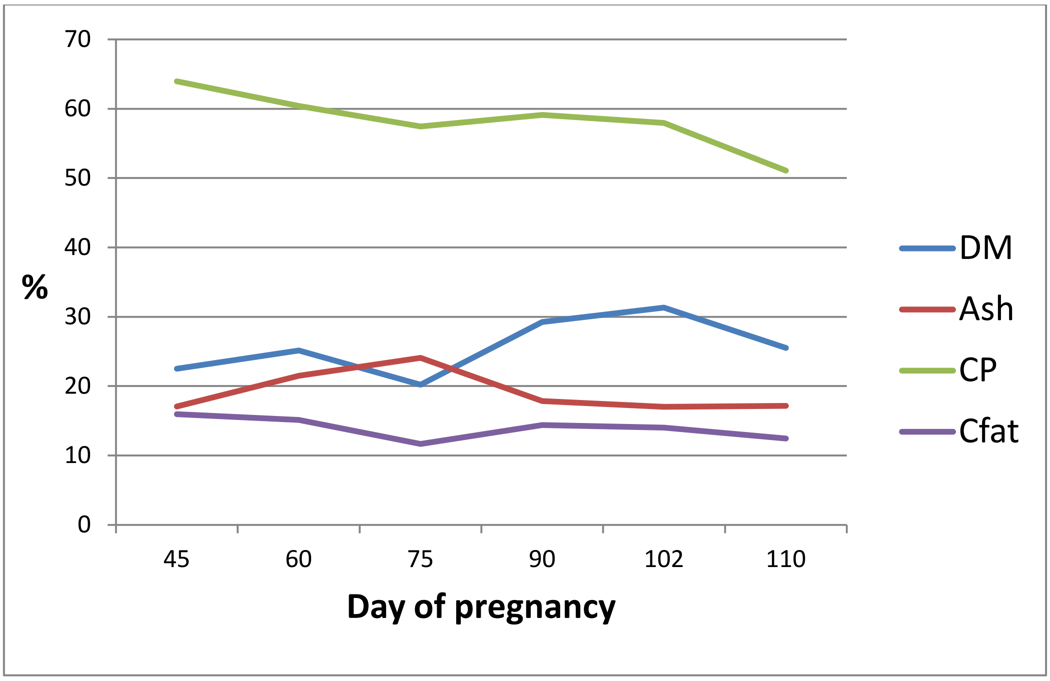
Graph 1 reports data from different studies on fetal growth. Data coming from McPherson study (2004) show fetal weights heavier than those reported by Wu (1999) and Wise (1997). Even a research carried out by Leenhouwers in 2002, which reported an average fetal bodyweight of 1155g at 111d of gestation, confirms the increasing trend. This is probably due to selection done on sows aimed to have high lean gain and high prolific performance (McPherson et al., 2004).

Graph 1: fetal bodyweight growth during gestation, from different studies



The composition of fetal tissues is subjected to dynamic changes linked to pregnancy progress. Graph 2 reports the fetal carcass chemical composition on different stage of gestation. After 69th day of pregnancy the fatty and the protein components increase notably (McPherson RL., 2004). It means that the composition of maternal diet must be varied in relation to the new requirement of the piglets. If it does not occur newborn piglets will have problems in term of weight at birth and in term of carcass quality.

Graph 2: chemical composition of fetal carcass on different days of pregnancy



Data from Mc Pherson et al., 2004

As it is shown in the graph the protein part of fetal body is predominant compared to the other, contrariwise the fat mass is the less significant one. It means that piglets will born with a low reserve of energy utilizable just after birth, and will have problem of thermoregulation. They have less of 2% body fat, the majority of it is not disposable for oxidative processes, because it is a structural constituent of cell membranes (Theil et al., 2014).

A study carried out by Rehfeld and Kuhn (2006) shows the differences in body composition of piglets according to weight at birth. It is important to highlight that to a low weight at birth corresponds an inferior yield at slaughter as well as lower meat quality. In particular low-weight piglets (birth weight <1.2kg) have a higher percentage of internal organs and bones and an inferior percentage of muscle tissue than middle- (1.2-1.62kg) and high-weight (> 1.62kg). Additionally chemical analysis reported a significant higher content of water (80%) and fat (1%) in smaller piglets at birth than in both others weight group (MW and HW), and a decreasing in protein content from heavier to lighter piglets. In means that heavier piglets will have a major protein part but also a bigger fat reserve component. Furthermore Rehfeldt et al. report, in a successive study (2008) on postnatal growth performance of pigs in relation to weight at birth, that light newborn piglets show a lower lean mass than medium and heavy pigs, but a similar increase in back fat thickness and pery-renal fat, which is indicative of lower carcass quality.

2.2 Maternal nutrition

Maternal diet has a direct effect on fetal growth, being the source of all essential nutrient as proteins and glucose. In particular, the nutrients in mother's diet are mainly directed towards supporting growth fetal tissue at the expense even of the sow itself. Fetal growth restriction, due to non adequate maternal feeding, reduces neonatal survival, has a bad effect on postnatal growth and affects negatively feed efficiency utilization in offspring. Maternal over-nutrition, as under-feeding, retards intrauterine fetuses growth. Furthermore it has negatively consequences on piglets meat quality.

Over-nutrition can be a consequence of increasing intake of protein and/or energy. Several studies have shown that maternal over-nutrition is the cause of retards placental and fetal growth, and increases fetal and neonatal mortality in different species such as in pigs (Wu et al., 2004).

At the same time reducing maternal protein intake during all pregnancy decreases offspring birth weight as well as reducing feed energy during and before gestation (Wu et al., 2004). In fact in pigs, an inadequate supply of nutrients through the placenta, resulting in piglets 15-20% low birth weight (<1.1kg), whose survival and postnatal growth performance severely reduced. Therefore, the poor performance of some animals during the postnatal growth and finishing phases can be a consequence of growth restriction *in utero* (Wu et al., 2004). Other studies report contrasting results on the ability of underweight piglets to achieve an adequate weight at weaning in a right laps of time. In a study carried out on Iberian newborn piglets characteristics, in relation to maternal nutrition during pregnancy, is reported a significant influence of the under- or over-feeding of sows on offspring. Until the 90th day of pregnancy the embryos belonging to under-nourished sows were smaller than the embryos from overfed females. In this case the difference between fetuses disappeared at the end of gestation. It means that fetal growth conditioned by malnutrition from first stage of pregnancy is mainly synchronized at the end of the gestation, ensuring a adequate body weight at birth (Gonzales-Bulnes et al., 2013). However it seems that transitional feed restriction has no permanent effect, whereas severely restricted feed intake throughout gestation results in a lasting damaging effects on postnatal growth of muscles in newborn animals (Rehfeldt et al., 2006) and consequent weight increase. Contrariwise an *ad libitum* maternal diet in pregnancy (25th -50thd; 25th-70thd) did not have any positive effect on muscle fiber number and area in the offspring but seems (*ad libitum* diet from 25th to 50th day on gestation) to have a negative effect on postnatal muscle growth in piglets, even more in lighter ones (Nissen et al., 2003).

2.3 Breed

Conventional crossbreed are the results of a selection done to improve sows prolificacy and offspring growth performance. Improving sow productivity is the main objective for selection in maternal lines. Several studies carried out on commercial hybrids detect a weight at birth ranged from a minimum value of 1.0kg to 2.0kg (table 1). A trial carried out on native Polish swine breeds reports weight at birth ranged from about 1.5 kg to 1.7 kg (Szulc et al., 2011). Contrariwise Iberian pigs, an autochthonous Spanish breed, has an average birth weight of about 1.3-1.4 kg (Castellano et al., 2014). Analyzing data in literature is can be deduced that usually conventional breeds are generally heavier than native breeds at birth.

However, many breeding programs do not consider piglet body weight and uniformity in body weight within litters. Heterogeneity in birth weight within the litter may cause management problems, increased mortality during the suckling period and decreased growth rate (Quiniou et al., 2012). Also, intense selection for faster growth and leanness may affect post-weaning piglets growth (Holm, 2003).

2.4 Litter size and parity

Litter size and birth weight are negatively correlated (Gipp W.F., 1969; Škorjenc D., 2007; Akdag F., 2009; Beaulieu A.D., 2010). Selection done in order to increase the size of litter has resulted in a decrease of weight of piglets at birth and a notably non-homogeneity of weight at birth of piglets belonging to the same litter. Within litter birth weight variation reduces piglets survival, due to a general lower weight at birth and to competitive disadvantages of smaller newborns compared to heavier piglets (Milligan et al., 2002). Contrariwise litters with homogeneous birth weights tend to reduce pre-weaning mortality and enhance homogeneity of weight in next rearing stages (Zindove TJ., 2013). That's a really important aspect for animals management in all phases of breeding. Furthermore animals with birth weight mean at birth give higher quality of carcasses compared to lights (≤1.22 kg) or too heavy piglets (≥ 1.54 kg) (Rehfeldt C., 2008). The decrease of weight at birth caused by the accretion of litter size is directly due to the reduction of individual space and an higher competition of the fetuses in utero for nutriments (Milligan et al., 2002; Quiniou et al, 2002; Rehfeldt et al., 2006). Quiniou (2002) demonstrate that Increasing litter size from less or equal to 11 to equal or more than 16 piglets results in a reduced average weight at birth from 1.59kg to 1.26 kg, which a mean decrease of 35g per each additional piglet born.

Furthermore some studies reported that sows at first or second parity had smaller litter than those of higher one (Milligan B.N. 2002; Škorjenc D., 2007;

Akdag F. 2009). The effect of parity on birth weight has been studied by several authors. In Milligan study piglets mean birth weight was significant higher in second parity sows than in primiparous sows and in older one (Milligan et al., 2002). Contrariwise in the study carried out by Akdag et al. (2009) the effect of parity on piglets birth weight was not significant. Another study done by Čechová et al. (2006) indicated a positive trend in birth weight of piglets with the increasing rank of parity. Birth weights culminated on the 5th parity (1337 g) and then gradually decreased to 1111 g on the 10th parity. In table 1 are reported the weights at birth recorded in different trials on commercial cross breeds and the correspondent litter size. Observing data on table 1 it is noted how to an increase of litter size it corresponds a reduction in weight at birth.

Table 1: birth weight and litter size of commercial cross breeds by different authors

Reference	Birht Weight (kg)	Litter size (n°pig/litter)
De quelen et al., 2010	1,65 1,61	14,8 13,6
Beaulieu et al., 2010	1,57 1,37 1,27	6,5 12 16,5
Pardo-mariño et al., 2010	1,74 1,23	13,3 14,8
Akda F. et al., 2009	1,12 1,06	≤8 >8
Akdag F. et al., 2009	1,67 1,57	≤8 >8

2.5 Sex

The effect of piglets sex on weight at birth and growth performance has been analyzed by several authors, in different native or conventional cross breeds. Generally studies reported that males at birth are on average heavier than females (Quiniou et al, 2002; Bee, 2004) but sex does not significantly affect birth body weight (Gipp et al., 1969; Škorjenc et al., 2007). Contrariwise in a study carried out by Čechová in 2006, on factors which affect weight at birth, revealed a statistically significant difference between males and females (P <0.01). Likewise in a trial carried out on Iberian newborn piglets characteristics in relation to maternal nutrition during pregnancy, is reported a significant difference according to sex, males were heavier than females (Gonzales-Bulnes et al, 2013).

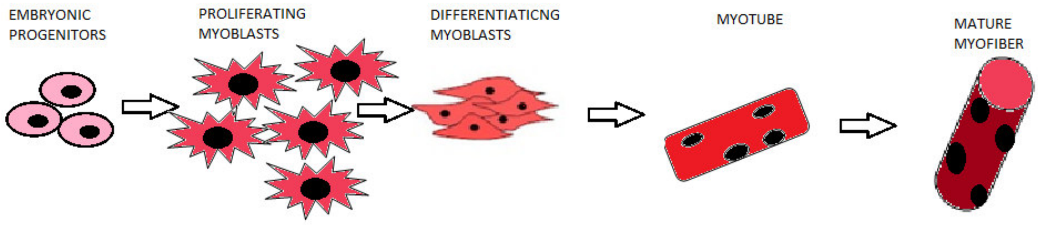
3. Postnatal growth

Piglets increase after birth is due to a lot of variables. The principle factor in the determination before of birth weight and then of postnatal weight is the muscle tissue development and growth. During intrauterine life fetus muscle fibers develop in a particular process called myogenesis. The number of muscle fiber is essential in determining birth weight (Rehfeldt C. et al., 2006). After birth muscles grow in weight increasing their dimensions (hypertrophy) but not their number which is fixed before birth.

3.1 Myogenesis and postnatal muscle development

Muscle tissue is mainly constituted by a peculiar cell named myocyte or muscle fiber. Muscle fibers are elongated tubular cells that develop from undifferentiated embryonic progenitors, that specialize becoming myoblasts, through a process called myogenesis (fig.1). Each muscular cell derived from the fusion, during embryonic development, of numerous myoblasts so myocites are multinucleated cells (syncytium). These events determine the number of muscle fibers that are formed prenatally.

Figure 1: myogenesis steps



Another population of myoblasts, called satellite cells, does not form fibers but is placed close to the myofibers. These cells are able to divide and serve as a source of new myonuclei during postnatal growth. They supply fiber size growth and also contribute to regeneration processes, whereas myonuclei themselves remain mitotically quiescent (Rehfeldt el al., 2006).

In skeletal muscle each myofiber contains myofibrils, long chains of sarcomeres, the contractile functional unit of cells. Sarcomeres are constituted of thin and thick filaments. The thin filaments are made of a protein called actin, the thick one is composed by another fundamental protein, the myosin.

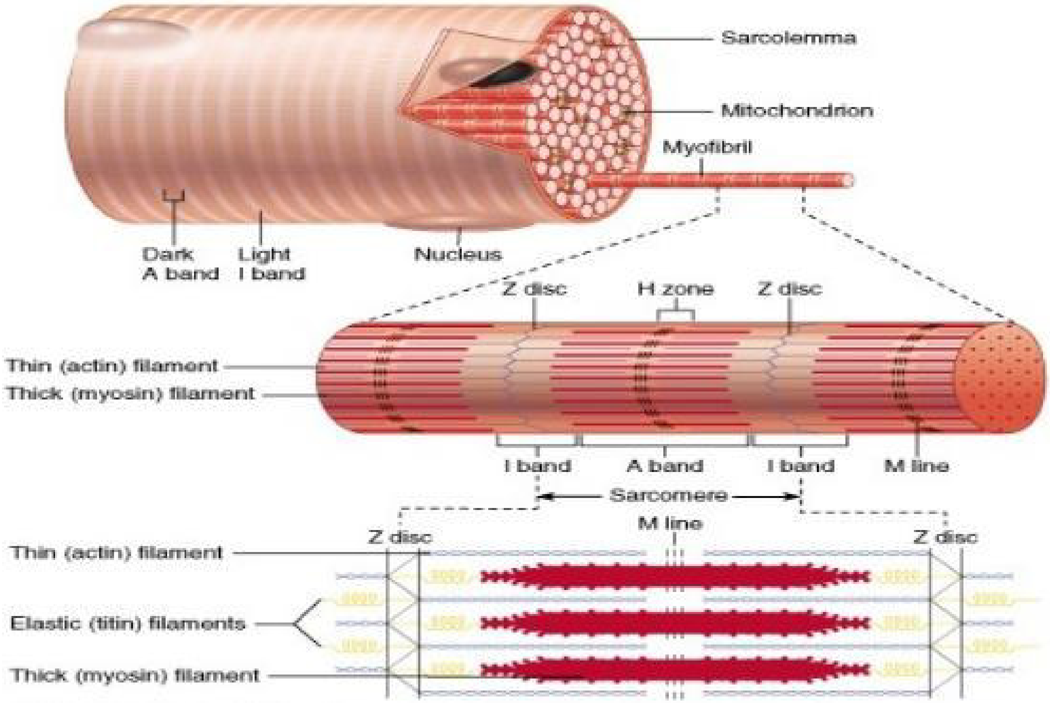
Along the major axis of the myofibril is marked a line, due to the alternation of regular light and dark bands.

In particular :

- the dark bands are called bands A;
- the light bands are called I bands;
- each band I was divided in two by a disc Z;
- each band A is divided in two by a trail, called H, placed in its central part;

as shown in figure 2:

Figure 2: myofiber structure



Individual muscle fibers and their different combination characterized the various skeletal kind of muscle. Fiber type composition can vary noticeably in different species and muscle types, depending on function, and other factors that contribute to fiber type variation: sex , age, breed, hormones and physical activity (Choi et al., 2009).

The fibers number that compose muscles is defined during intrauterine life. During postnatal growth muscles increase weight is due to muscle fiber hypertrophy, namely individual myofibers size and length increase. The capacity of the muscle to growth, in term of volume and consequent weight, depends by the number of myofibers which compose them (Rehfeldt C. et al., 2006; Foxcroft GR., 2008). In fact myofiber size is inversely related to their number, that is that growth rate of each myofiber is lower when there are numerous myofibers, and higher when there are low numbers of myofibers (Rehfeldt et al., 2000). On the other hand, both number and size of myofibers are positively correlated with the cross-sectional area of the muscle (Foxcroft, 2008; Rehfeldt et al., 2006). Both fiber number and size are influenced by pigs selection, indeed they are positively correlated with percentage of lean meat (Rehfeldt et al., 2000). Myofiber number and hypertrophy is limited by genetic and physiological factors. Therefore, an inferior post-natal growth can be expected in low birth weight piglets, which have a low numbers of muscular fibers (Rehfeldt, 2000).

The size and number of muscle fibers are factors that influence muscle mass and meat quality (Rehfeldt et al., 2006). During postnatal development, when the number of muscle fibers is high, fibers generally grow more slowly. Thus, fiber number is negatively correlated with fiber area, whereas both fiber number and area are positively correlated with muscle mass in pigs. Pigs with a higher total number of fibers tend to exhibit smaller fiber sizes, and exhibit higher muscle pH45 (meat pH measured 45 min. after slaughter) and lower drip loss than pigs with a lower total fiber number and large fiber size. Even the kind of fibers which constitute muscle is important for determine meat quality. The most frequently accepted classification method is based on differences in the acid and alkaline stability of the myosin ATP-ase reaction. This method can distinguish three different fiber kind: I, IIA and IIB. Type I fibers is negatively correlated with drip loss contrariwise higher amounts of IIB fiber is linked with increasing drip loss, and also with differing measurements for water-holding capacity. Furthermore fiber size is important to determine meat tenderness. Muscles with a larger fibers size, especially IIB fibers, exhibit tougher meat than muscles of smaller size ones. Moreover muscles with greater hardness are related to a larger fiber area.

In conclusion muscles with higher numbers of low or medium size fibers tend to exhibit good meat quality, without significant differences in muscle mass. Conversely, selecting for leaner pigs can result in large muscle fibers, especially IIB fiber, which seems to be connected with poorer meat quality (Choi et al., 2009).

3.2 Colostrum and milk

During the first two weeks of life piglets can efficiently use only lactose, proteins and fats from maternal milk (Bertacchini F., 2013). It makes both the quantity and the quality of colostrum and milk determinant factors in animals development. The colostrum intake is a factor which affects before the survival and then piglets growth performance. Inadequate colostrum intake decreases the body temperature of newborn piglets (Theil et al., 2014) getting worse a already difficult thermoregulation. Additionally colostrum have a fundamental importance being the first source of immunity for newborn piglets. Furthermore it has been shown that colostrum intake has also a long-term effects on piglet growth. In table 3 (are reported the average value of protein, fat and lactose in colostrum and milk in sows. The protein content is maximum at farrowing with a value of 18g/100ml, due to its high component in immunoglobulin, then it decreases throughout lactation. During all suckling period milk represent the principal font of energy, so fat content is higher in milk than in colostrum (Aumaitre et al., 1978).

Table 2: composition of colostrum and milk in sows

	colostrum	**milk**
DM (%)	24,5	18,3
Fat (%)	6,0	6,6
CP (%)	13,8	5,3
Lact (%)	3,2	5,5

DM=Dry Matter; CP=Crude Protein; Lact=Lactose.

Piglets that consumed 290 g of colostrum grow about 2 kg more at 6 weeks of age. To guarantee that piglets survive, receive an adequate immunity and achieve acceptable growth, the minimum recommended colostrum intake is about 200g (Devillers et al., 2011). Considering that the colostrum production of sows can range from 1.9 to 5.3 kg is clear that it can be difficult for many sows to adequately care for more than 10 piglets. On the other hand colostrum yield has a big variability, due to several maternal factors such breed, ranging from 1.91 kg to 5.31 kg, during the first 24 hours after parturition (Devillers et al., 2007).

The reduced ingestion capacity is another factor limiting the growth of piglets, even more in the transition to solid diet. For this reason, the diet must necessarily be as digestible as possible, maximizing the consumption of feed and minimizing the nutrients eliminated with feces (Bertacchini et al., 2013). The characteristics of the singular components of the diet in terms of quality (protein content and kind, energy content, mineral integration) and palatability are equally important in a delicate phase as the transition to weaning, an example is fat diet that generally is not very digestible. Those which appear to have a higher digestibility have high content of unsaturated fatty acids (soybean oil, sunflower oil) or short-chain fatty acid (coconut oil) (Bertacchini et al., 2013). Several authors have studied the importance of the contribution of fatty acids in sows milk before that in the solid diet, verifying the possibility of modulating the fatty acid profile of the tissues of piglets by changing the ration of sows during pregnancy and lactation (Farmer et al., 2009; Rossi et al., 2010; Smiths et al., 2011;). Furthermore it has been shown that specific fatty acids have a potential beneficial power for intestinal mucosa, being anti-microbial and anti-inflammatory, and having immune-modulator activity. Particular fatty acids, as short chain FA and medium chain FA, could increase preventive effect on gastrointestinal disease, which characterized post-weaning phase in piglets. These effect on intestinal mucosa appears to be even more important in weaning piglets. Indeed piglets in this phase are stressed due to changing processes of intestine structure to adapt gastrointestinal system to solid feed (Rossi et al., 2010). Furthermore has been demonstrated that sow diet supplemental fat during lactation improved suckling pig growth rates and weaning weights (Gatlin et al., 2002).

3.3 The Average Daily Gain (ADG)

The growth rate in suckling piglets depends on the quality but also on the quantity of milk consumed (Quiniou et al., 2002). In this phase of piglets life the growth in term of ADG and in term of rapidity depends first of all by maternal factors and then by the vitality of the piglet. Even environmental condition as ambient temperature and photoperiod can affect growth rate. Factors related to the mother are: milk production and functional teats available to the offspring. Factors which are mainly linked to piglet are birth weight, newborns vitality and the consequential access to the udder (Skok et al., 2007).

A decrease of milk production related to maternal factor such health, results in a reduction of ADG. This effect is either be directly because of lower milk available for piglets and indirectly due to higher disease incidences among piglets, being the sow a source of infection. Being treated for disease, having abrasions or injuries (as in just castrated males) is negatively associated with ADG. On average piglets treated during suckling period grow lower than healthy ones, with a reduction that ranges from 8g to 38g/d, according to kind of disease (Johansen et al., 2004). Litter size and birth weight, that are closely interlinked, have a direct effect on piglets gain rate. Johansen et al. (2004) report that the effect of 100g increased birth weight per piglet results in an increase of 340g of weight at weaning, additionally increasing piglets birth weight of 100g results in an augmentation of body weight of 8g/d. The influence of weight at birth on ADG has been studied by several authors. Beaulieu et al. recorded ADG value ranging from 210g/d in lighter newborn piglets to 270g/d in heavier ones. In agreement with these values DeQuelen et al. (2010; 2013) report ADG of suckling piglets belonging to conventional breeds of 250g/d. Studies on native swine breed highlight smaller piglets ADG during nursing phase. Castellano et al. (2013) record mean values of 170-180g/d in Iberian breed. Porcu et al. (2007) report in Sarda breed piglets a longer time to reach the right weight at weaning than commercial breeds. It means that these piglets growth slower than conventional breeds. This is probably due to a lighter weight at birth and/or to an inferior ADG during suckling period.

Johansen et al. have found that even ambient temperature affect ADG. In higher environmental temperature piglets had an higher growth rate than during colder period. Other variables could affect piglets ADG and consequent weight at weaning. To extend daily light in piglets breeding from birth to weaning has positive effects on growth performance and weaning weight, probably due to a higher feed intake (Simitzis et al., 2013). Contrariwise a study carried out in 2012 by Lessard et al. demonstrated that exposure of piglets to long photoperiod (16h daily light) during lactation seems to reduce the capacity animals to develop a strong immune response to novel antigens, this may have important consequences on the capability of piglets to resist toward future infections. Another study on the performance of pregnant sows and their litters on light exposure, during gestation and lactation, highlights the influence of photoperiod on litter size and on immunological status of newborn piglets. Even in this trial long photoperiod has a negative effect on the ability of offspring to be resistant to diseases in post-weaning period (Niekamp et al., 2006).

3.4 Weaning weight

Weaning weight appears to be due to the cumulative effect of a combination of different factors. In fact it is the results of pre-natal factors such intrauterine development and increase, and postnatal performance, directly affected by milk intake and quality, piglets and sows management.

The average daily weight gain of piglets is associated with several factors including birth weight and litter size (Quinon et al., 2002 Milligan et al., 2002; Akdag et al., 2009; Beaulieu et al., 2010), level of sow nutrition (Nobelt et al., 1986; Akdag et al., 2009), sow feed intake and composition (Nissen et al., 2003; Wu et al., 2004; Rehfeldt et al., 2006), breed (Aguinaga et al., 2011) environmental temperature (Chiston, 1987; Le Dividich, 1981; Black et al., 1993), piglets access to udder (Skok et al., 2007), cross-fostering (Heim et al., 2012; Gomes Camargo et al., 2013), season (Johansen et al., 2004). All these factors contribute to milk production and milk intake, having therefore a direct effect on weaning weight. In fact increasing piglets milk intake even the ADG increase and the consequent weight at weaning.

Another factor which can affect the weight at birth is piglets health. Even this aspect is strictly linked to piglets nutrition, intended as colostrum, importance as a fundamental source of immunization for newborn piglets, and milk, basic to provide energy to keep under control thermoregulation.

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Chapter 2

SWINE SARDA PUREBREED

Officially recognized only in June 2006 (DM 21664 8/06/2006) the swine Sarda breed has been inserted among the Italian local pig breeds of which were already part Cinta Senese, Mora Romagnola, Nero Siciliano, Casertana and Calabrese.

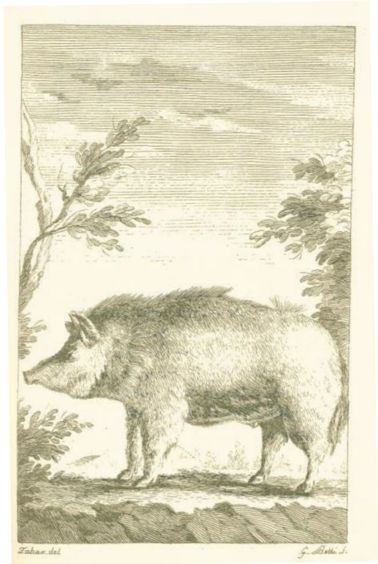
1. Origin and characteristics

It is a hardy breed in Sardinia since prehistory well adapted to the wild and semi-wild breeding in mountainous terrain, rough and difficult to access, where this type of farming is more widespread.

Some authors highlight considerable morphological similarities between the pig population in Sardinia and the wild boar (Sus scrofa) already in the late Neolithic (Cherchi Paba F, vol.I, 1974). Even in later periods pig farming played an important role. Due to rich heritage of acorn trees, Sardinia had a great swine patrimony throughout Roman Age.

Fig. 1 shows the morphological description and imagine of ancient Sardinian pig, designed by Cetti in 1774, a Jesuit zoologist and mathematical who observed and described for the first time Sarda swine breed.

Figure 3: Sarda breed pig (Cetti F., 1774)



In reality from bone remains found during archaeological excavations that breeding pig in Sardinia has very ancient origins, dating back to the VI already millennium BC (early Neolithic). Belonging to the nuragic period, 1800-238 BC, in addition to bone remains have been found some bronzetti (statuettes made in bronze which belong to the VIII and the lV century BC) representing both domestic pigs and wild boar. Bronzetti were inside the “nuraghi”, stone construction with truncated cone shape, located on the whole territory of Sardinia, representative of Nuragica civilization, place of devotion in which the most used as votive animal offering was pig (Porcu et al., 2007). During archeological research have been found in Sirai mountain (sud Sardinia) bone remains belonging to swine of Phoenician period (between the end of VII and the beginning of the VI BC). This proves that pigs represented the majority of reared and consumed animals, with a percentage of bones found bigger than other species (36%). Furthermore the bones fragments indicated an age of pigs at slaughter of maximum 4 years, probably reproducers. However the majority of pigs were killed having less than 1 year of life (Campanella et al., 2008).

Furthermore under the government of the Roman Empire, Sardinia paid pork meat as in-kind contributions, furthermore Romans were owned of specialized farms in pig breeding (Cetti, 1774; Cherchi Paba, 1974; Meloni 1990). In the Middle Age the importance of pig farming is evidenced by many writings laws that regulated the production and sale of sausage ("Codice del Libero Comune di Sassari") and prohibited to graze pigs on land reserved grazing other species: cattle, horses, pack animals (Porcu et al., 2007).

1.1 Actual Sarda purebreed pig

Table 1 shows both the morphological characteristics of the breed and the characters which determine exclusion from the herd-book .

Figure 2: Sarda purebreed lactating sow

Figure 3: lactating Sarda purebreed sow and its piglets

Figure 3: Sarda breed piglets

Table 3: Sarda breed morphological traits

TYPE	Small with solid skeleton
COAT AND PIGMENTATION	Pigmented skin at least partially. Coat of various colors: black, white, red, gray, fawn, uniform or pied. Thick bristles, sometimes wavy or curly which cover abundantly the whole body. Present a dorsal mane with long bristles. It could be present a lumbar tuft.
HEAD	Middle development, straight fronto-nasal profile, hanging ears ahead or sideway.
NECK	Short and strong
TRUNCK	Not much developed, dorso-lumbar line straight and slightly convex, sloping back; light shoulders, thorax not well developed, gaunt thigs. Long tail with bristles which, sometimes forms a peculiar tuft.
LIMBS	Short and strong
SEXSUAL CHARACTHERISTICS	Male: well pronounced testicles; number of nipples not inferior to 8. Female: number of udders not inferior to 8, with normal, well pronounced and pervious nipples.
MORPHOLOGICAL TRAITS WHICH DETERMINE EXCLUSION BY HERD-BOOK	Failing of bristles; straight ears; concave fronto-nasal profile completely not pigmented skin; streaked coat or agouti; presence of white thoracic band, even if partial.

In figures 3, 4 and 5 are shown different kind of coat colors, uniform or pied. Thick bristles (wavy or curly) on the whole body.

Figure 4: Sarda breed piglets

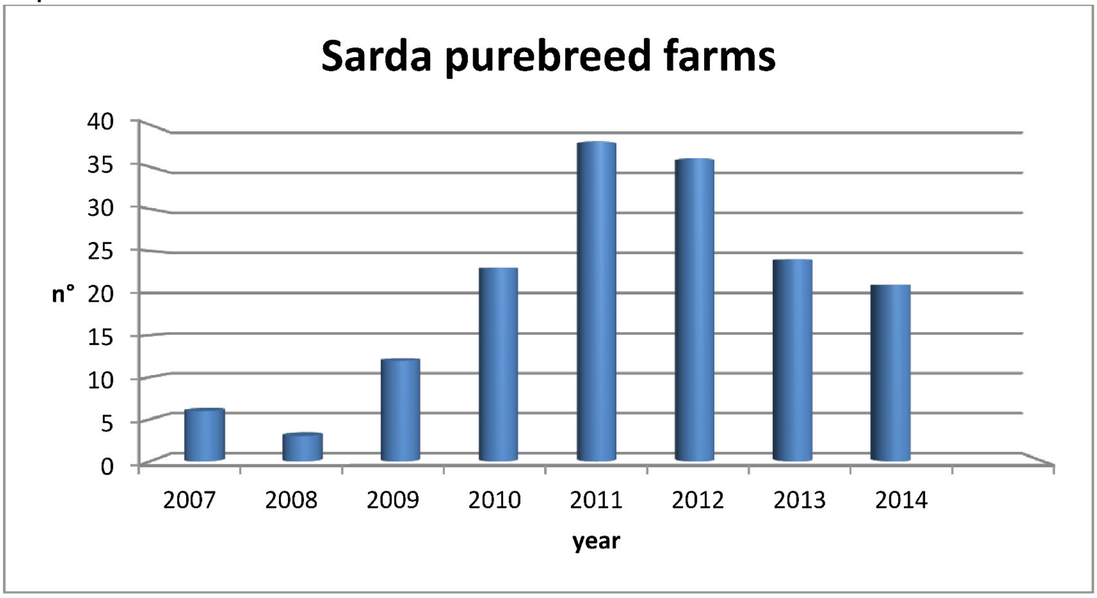
Figure 5: Sarda breed lactating sow

2. Population amount and distribution

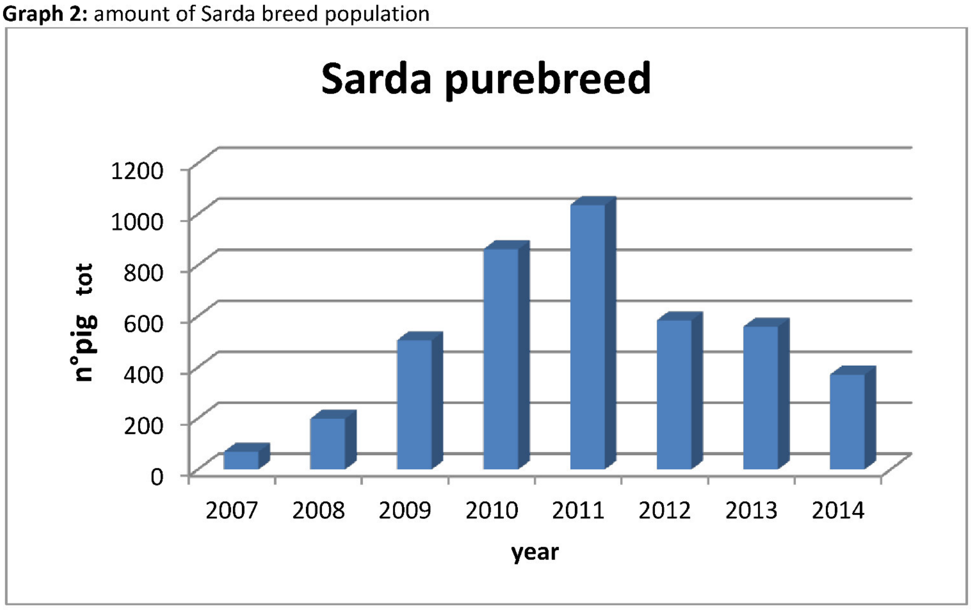
Following graphs shown how the official size of Sarda pigs population is changed throughout the last years, starting from breed official recognition (2006) as an Italian local breed.

Graph 1 shows the evolution of the quantity of farms. Graph 2 reports the Sarda swine population in the same lapse of time (2007-2014).

Graph 1: amount of farms of Srda breed

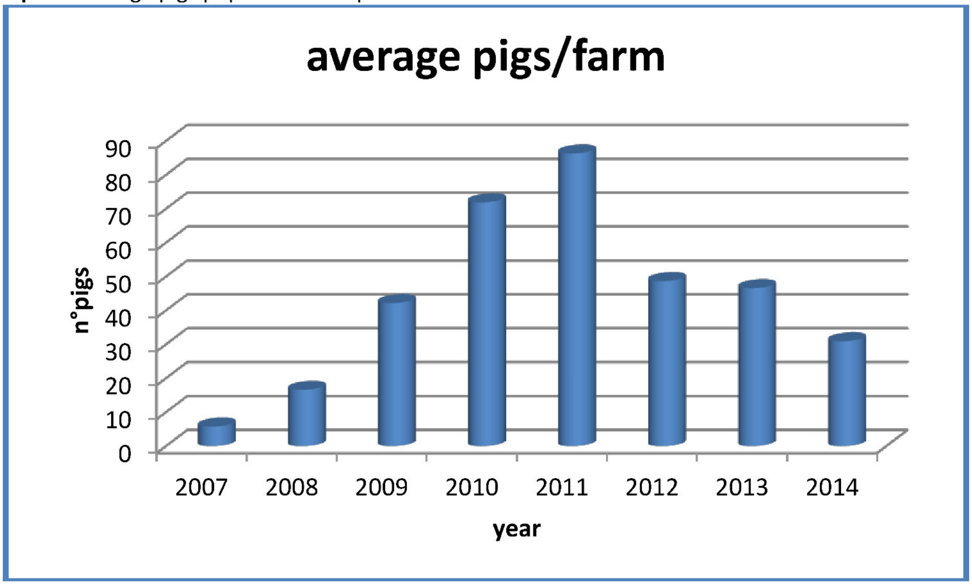


Graph 2: amount of Sarda breed population



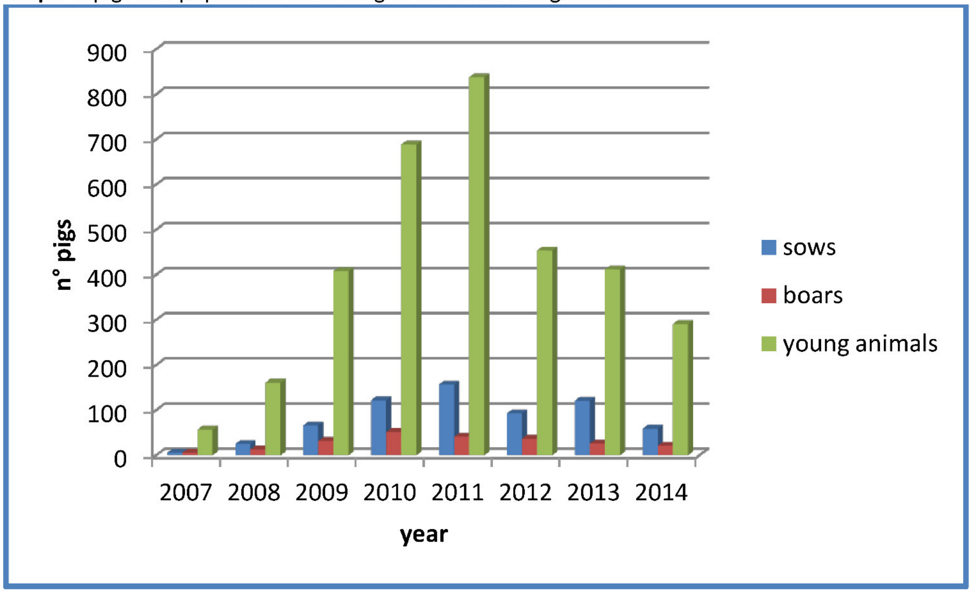
Is interesting to notice that from 2007 until 2011 the number of farms rises in a constant way. In 2012 the trend has an inversion. There is a reduction of farmers and a symmetrical decrease of registered animals. Furthermore the average numbers of animals per farm follows the same trend, increasing from 2007 to 2012 and reducing again in successive years (graph3). This is doubtless due not to a real decrease of animal, but to an inferior inscription of newborn pigs in the Sarda herd-register. Probably the not adequate development and promotion of the breed, which have followed the breed recognition.

Graph 3: average pigs population size per farm



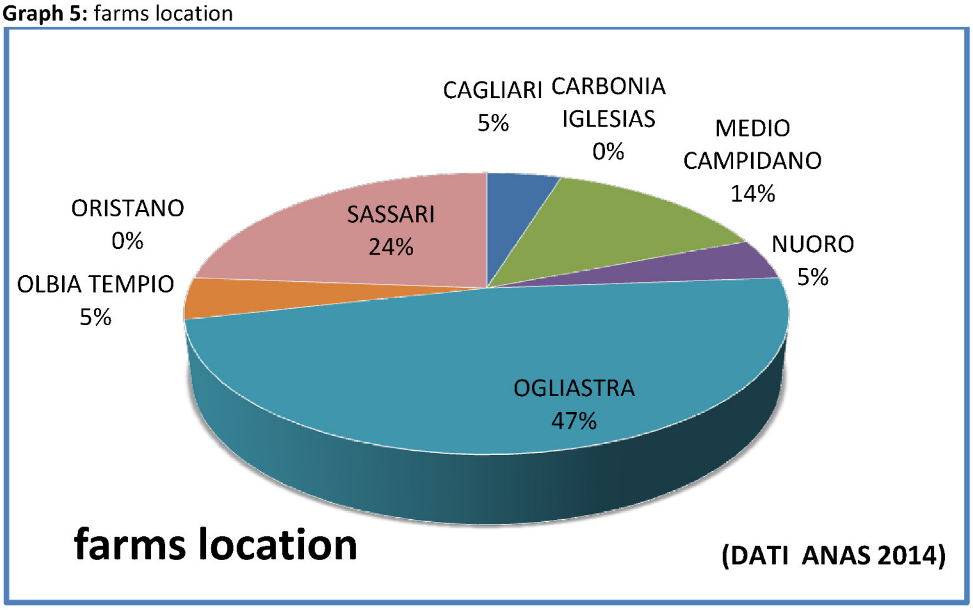
This reality is confirmed observing the distribution of pigs population in categories: sows, boars and young animals throughout the years (graph 4).

Graph 4: pigs size population according to different categories

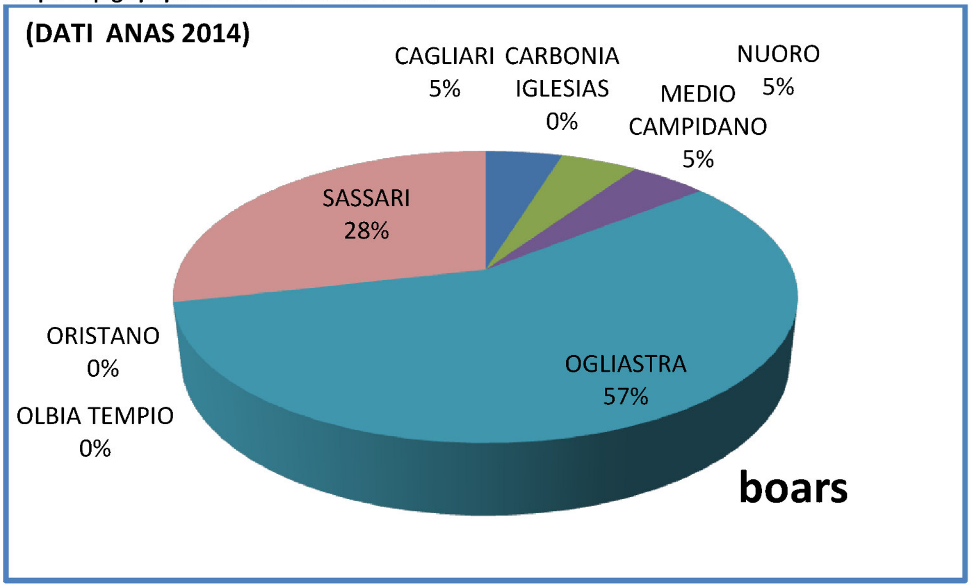


Graph 5, 6, 7 and 8 concern to 2014. It is interesting observe that the majority of farms rearing Sarda pigs are located in Ogliastra, the more mountainous region of the island. This area is characterized by forests and very rugged territory where pigs rearing outdoor is a custom.

Graph 5: farms location

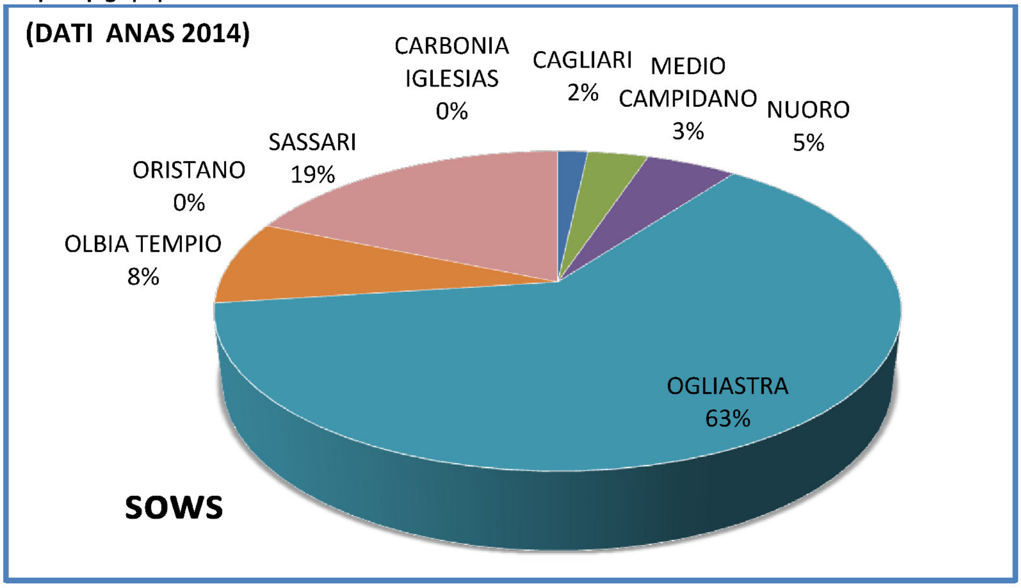


Graph 6: pigs population distribution: boars

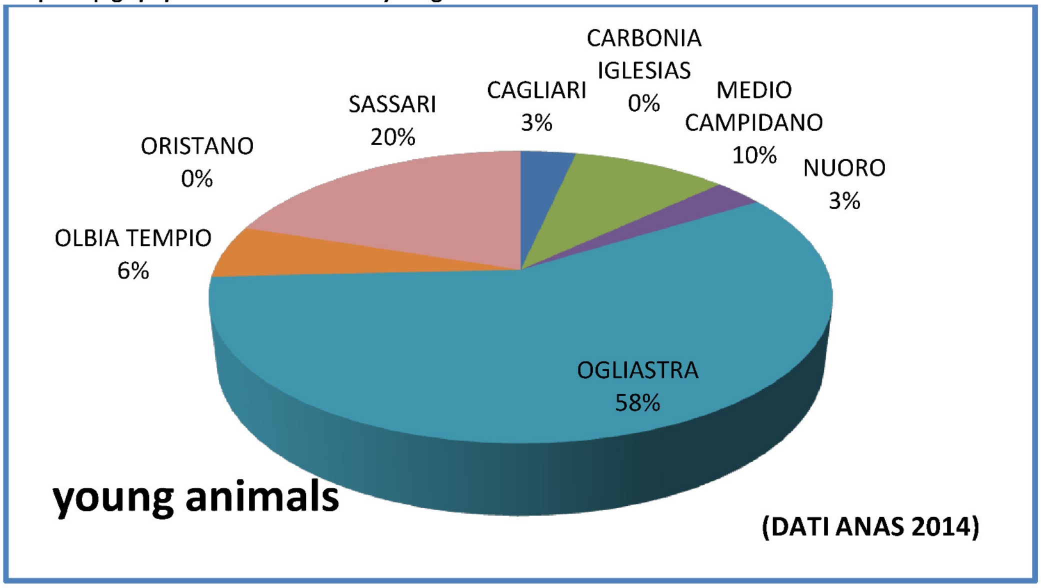


The pigs location for each pigs category is similar to farm position.

Graph 7 pigs population distribution: sows



Graph 8: pigs population distribution: young animals



3. Rearing system

Preliminary studies on pigs rearing system in Sardinia had revealed 3 principal kind of pig breeding:

Intensive: this group consists of specialized companies, present mainly in the plains or lower hills of the island. There is bred only selected animals and their hybrids, farming system of which is controlled in each phase,, Breeding system provide specific feeds according to the physiological needs of the animal;

Semi-intensive: small size farm, pigs often born of crossing, have access to controlled grazing and kept in stalls only during certain times of the year. In general, pig breeding, of secondary importance, is often associated with a significant farm of dairy sheep. To integrate pigs feeding are used traditional or specific feed: flour, maize grains and beans and by-products of the cheese industry.

Extensive: this rearing system is characterized by an extensive use of pasture, often in oak and chestnut trees, using hardy animals with morphological features that recall the neighboring genotype (Carta A., 2007)

These two last rearing system are typical of Sarda purebreed pigs, overall in mountain region of island. This fact is more evident observing the distribution of Sarda pigs, considering that the majority of farms are located in Ogliastra, the most mountainous province in Sardinia (Graph 5).

4. Reproductive performance

Due to the recent recognition as a native breed few data are available. Preliminary studies show that the Sarda is less prolific than commercial breeds, with an average number of births/farrowing of 7.3± 1.0 and resulting in fewer piglets produced on average per sow/year 14.3 ± 2.2 (Porcu et al., 2007). This low prolificacy is a feature common to other 5 local breeds nationally recognized (Table 2) (Franci O. and Pugliese C., 2007). Furthermore sows have a greater and more variable age at first mating (months 8.5 ± 2.4 vs 7.8 ± 0.9), an higher percentage of primiparous on the amount of pluriparous sows (Porcu et al., 2007).

Table 4: Italian local swine breed prolificacy

Breed	Mean litter size (piglets/litter)
Mora Romagnola	7.13 ± 2.58
Cinta Senese	7.00 ± 2.13
Casertana	7.26 ± 3.22
Calabrese	6.12 ± 2.64
Nero Siciliano	6.78 ± 1.22
Sarda	7.3± 1.0

5. Production performances

As muscle fibers number even precursor cells of adipocytes are determined during fetal stage. Pigs belonging to fat breeds have a bigger number of precursor cells of adipocytes than lean breeds. This could be one of the reason of a larger development of the fat mass in fat breeds (Mourot et al., 1999). Sarda breed pigs are incline to deposit subcutaneous fat when have greater food supply, as demonstrated in other autochthonous breeds (Porcu S., 2012). This is a characteristic in common with other local breeds as Iberian pig, which body composition has a double fat content of commercial breed (Aguinaga M.A. et al., 2011). Not only feed intake and quality affect the activity of lipidic synthesis but even management factors as castration and environmental temperature (Mourot J. et al., 1999). Considering the peculiarity of Sarda rearing system (semi extensive), and the farms location (mountain regions) the environmental characteristics appear to be important affecting factors of lipogenesis. Furthermore, speaking of intramuscular fat, animals with naturally high adiposity, posses a higher ability to synthesize intramuscular fat than lean genotypes: not just the age difference observed between these animals at certain weight, which justifies the differences in levels of intramuscular fat, but a different lipogenic potential. The potential of the lipogenesis and glucose uptake in isolated adipocytes are higher in fat compared to animals breeds leaner (as Large White or Pietrain) such differences are mainly due to the activities of enzymes involving in lipogenesis, which, in the same position, are three times higher in fat pigs (Mourot J. et al., 1999). In a review on meat quality the content of intramuscular fat has been used to distinguished improved pigs breed from native breeds, as the best trait of meat quality (Pugliese et al., 2012).

Table 2: Intramuscolar Fat Content (IMF) in different pigs breeds as reviewed by Pugliese C. and Sirtori F. 2012)

Author	Breeds	IMF (%[a])
Mayoral et al. (1999)		
on Longissimus lumborum (LL)		
and Biceps femoris (BF)	Ibérico	~ 10
Labroue et al. (2000) (on LL)	Basque	3.9
	Gascon	3.2
	Limousine	3.4
	Blanc de l'Ouest	2.9
Karolyi et al. (2007)	Black Slavonian	~ 6
Zullo et al. (2003) (means of several muscles)	Casertana	~ 4
Salvatori et al. (2008) on LL	Casertana	~ 2
Fortina et al. (2005) on Longissimus Thoracis (LT)	Casertana	~ 5
Poto et al. (2007) on LL	Chato Murciano	~ 10
Franci et al. (2005) on LL	Cinta Senese	> 3
Coutron-Gambotti et al. (1998)	Corsican (on BF)	8.2
Fernández et al. (2007) on LL	Ibérico	~ 10 (3.27–29.21)
Fortina et al. (2005) on LT	Mora Romagnola	~ 6
Pugliese et al. (2004) on LT	Nero Siciliano	> 3

[a] = % on weight basis

in table 2 are shown the differences in fat intramuscular content between several native pigs breed. Compared with values recorded for conventional breeds (Large White, less 1%), native breeds as Iberian (~ 10) and Corsican breed (8.2) have of content of intramuscular fat notably bigger.

Other characteristics of muscles of Sarda pigs have been studied by Decandia et al. (2012). They compared the effect of different rearing system on meat quality. In particular analyzing colorimetric parameters meat results to be darker and redder than other breeds (commercial intensive reared breeds and autochthonous one). The composition of carcass (fat, lean yield and connective) is affected by diet regimen. Fat in particular is positively affect by *ad libitum* feeding system. The major fat component results in a main springiness and a less hardness of meat. The yield at slaughter varies from 78% to 82% (Decandia et al., 2012) results comparable with values recorded on other native swine breeds as Nero Siciliano (Madonia et al., 2007). A report of LAORE (Sardinia regional agency for development in agriculture) (2013) on swine Sarda breed rearing shows value of ADG, in post-weaning fattening phases, ranging from 330g/d to 530g/d, results similar to other native swine breed as Iberian (Daza, 2000)

6. Why Sarda breed?

Last decades data on regional productions show that the types are mainly represented in Sardinia are piglets (6-10kg) and pigs with a weight of 90-110kg (LAORE, 2013). Especially the piglet, representing a typical production, consumed throughout the island both locals and tourists, has considerable importance, even more so when we speak of the autochthonous "Sarda purebreed". Belonging to a recognized local breed gives this product a value not only culinary but purely cultural and link with the territory. The constant growth of farmers who chooses to raise Sarda pigs that has characterized years from 2006 is certain due to the desire of preserve native breed biodiversity and give , in this way, an additional value to local products. This trend changes in 2011 may be due to a disillusion and a non economic sustainability breeding, except in cases where it is a secondary production. In fact the Sarda rearing is usually practiced in farms with other primary zootechnic productions, which justifies and amortizes costs.

From a zootechnic point of view to have native pigs well adapted to the harsh conditions of farming in our island is certainly an advantage. Is necessary to increase the knowledge about Sarda purebreed and in particular on piglets rearing in order to optimize animals management, keeping costs under control, valorizing the membership of the breed to Sardinia island.

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Chapter 3

EFFECT OF FARM AND LITTER SIZE ON SUCKLING PIGLETS GROWTH IN SARDA PUREBREED

1. Introduction

Sarda swine breed is an Italian local breed officially recognized in 2006. It is included in the Italian register of swine native breeds to preserve its genetic diversity and typical productions. Data on production performance are few, due to its recent recognition and its exiguous number of members which belong to the breed. This is emphasized speaking about suckling piglets, that represents a typical Sardinian production, used for traditional local dishes. The variables that influence piglets performance have been object of several studies, from gestation to weaning, in different breeds. In particular:

- maternal factors: genetics, parity (Milligan et al., 2002; Škorjenc et al., 2007; Akdag et al., 2009), nutritional and hormonal status (Rehfeld et al., 2004; McPherson et al., 2004; Wu et al., 2004), colostrums and milk production (quality and quantity) (Bertacchini et al., 2013).

- piglets factors: litter size, weight at birth (Gipp et al., 1969; Škorjenc et al., 2007; Akdag et al., 2009; Beaulieu et al., 2010), immunological status (colostrums), nutritional status (colostrum and milk intake) (Bertacchini et al., 2013).

Litter size is commonly recognized to affect piglets weight at birth. To an increasing size of litter corresponds a reduction of weight at birth. In addition birth weight is a determinant factor for the subsequent growth performance. This is well known about commercial breeds pig. Speaking of Sarda purebreed is necessary to investigate and analyze breed peculiarities, in order to enlarge the knowledge on piglets during suckling period.

The aim of this study is to investigate how litter size and farm can affect the weight at birth of Sarda piglets and how suckling piglets growth is affected by litter dimension and farm.

2. Materials and methods

First of all two smallholders farms have been identified (farm A and Farm B). The choice was made considering the peculiarities of Sarda breed rearing system, small farms located in mountainous areas of Sardinia, where Sarda pigs breeding is not the principal source of income. Both farms are agritourism. The swine breeding is a secondary source of income. Pigs are reared overall to produce meat and derivates (as ham) for the own consumption and the farm restaurant. Likewise piglets are reared as a typical dish for restaurant customers, for own consumption, to replace reproducers. The surplus share is sold as a source of secondary income. Generally all phases or rearing are made outdoor, in groups according to animals category (young animals, pregnant sows, boars). Only last weeks of pregnancy and lactation are in singular boxes. Animals are feeding with commercial feeds and or by-product of milk and bread industry in relation to growth or physiological status of animals (pregnancy and lactation, weaning). Usually the reproduction is manages using external genetic material or own boars in relation to progeny destination: to produce new reproducers, suckling piglets or fattening pig.

It table 1 is reported the amount of pigs in each of the two farms at the moment of the trial.

Table 5: pigs per farm

farm	N° pig (tot)	boars	sows	young animals
A	116	44	11	61
B	23	2	3	18

2.1 Animals

Have been identified 11 pluriparous pregnant Sarda purebreed sows. Two weeks prior to farrowing sows were housed in individual pens. Sows were fed with a commercial gestation feed. Within two days of life every piglets has been weighted (Fig. 2) and identified. To an ear of each piglets has been applied a plastic tag reporting an univocal chronological numeration (fig. 1). Sex has been annotated. Stillbirths and born alive, deaths of animals were recorded during all the trial. Born alive piglets were weighed every week until an average body weight from 8 to 10kg, at weaning weight. In table 1 sows number per farm and piglets divided according to farm and sex.

During the experiment all sows fed, ad libitum, a complete diet formulated, by using ingredient of local market, in order to meet, or exceed, the requirements of lactating sows for energy, protein and lysine. The ingredients and chemical composition of the diet are reported in table 2.

Table 6: ingredients and chemical composition of the experimental diet.

Ingredients, as feed	
Peas, *%*	35
Barley, *%*	30
Corn; *%*	35
Nutrients, dry matter basis	
Protein, *%*	13.3
Lysine, *%*	0.99
Energy, *DE kcal/kg*	4200

In table 3 are shown animals included in trial: sows number per farm and piglets divided according to farm and sex.

Table 3: sows and piglets per farm

Item	farm		tot
	A	B	
Sows (n)	6	5	11
Piglets (n)			
Male (n)	24	16	40
Female (n)	22	24	46
Tot (n)	46	40	86

Figure 1: plastic tags and tags applicator

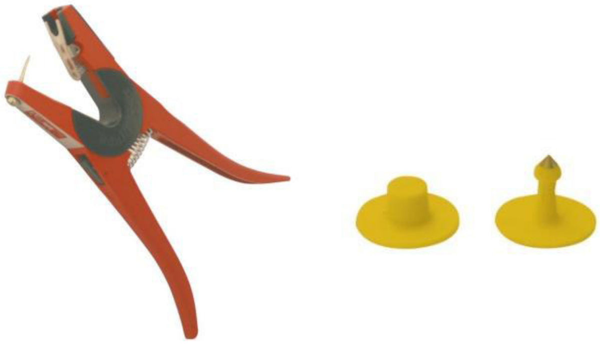


Figure 2: individual weighing of piglets.

2.2 Statistical analysis

Piglets were grouped according to litter size: medium-small (4 to 7 piglets) and medium-large (8 to 12 piglets).

Effect of farm, birth weight, litter size group and sex on individual average daily gain (ADG) were tested with ANOVA model.

A Linear Regression analysis has been done between body weight and age at slaughter of both litter size group medium-small (4-7 piglets) and medium-large (8-12 piglets).

3. Results and discussion

3.1 Birth weight

The ANOVA results showed a significant difference ($P<0.05$) between the birth weight of piglets in the two farms. Piglets belonging to farm B are significantly heavier than piglets of farm A at birth.

In table 4 the results of ANOVA analysis between weight at birth and farms.

Table 4: ANOVA analysis: of birth weight

		Birth weight	p-value
Farm	A	1263.7 ± 206.3	0.042
	B	1377.5 ± 296.7	

The weight at birth can be affected a lot of different factors which include genetics, maternal factors, management. Considering that the farming system of both A and B farm is similar, the difference in term of weight of piglets at birth could be linked to animal genetics. The breed and the parental genetic line have a rule in the determination of birth weight. Even if in both farms pigs are regularly register as Sarda purebred, some morphometric characters of adult sows were clearly different between the two farms. This large phenotypic variability between animals within breed can be explained by the novelty of the Register institution for this swine breed. A large range of phenotypic traits has been adopted for the initial implementation of pigs into the register, although the breed traits of the Sarda were strongly preserved.

In table 5 are reported different average weight at birth recorded during trials done on different commercial crossbreeds.

Table 5: piglets weight at birth by different trials on various swine crossbreeds

References	**Swine breed**	**Birth weight (Kg)**
Akdag F. et al., 2009	Bulgarian LW x LB x Turopolje	1.09-1.6
DeQuelen F. et al., 2010	(LWxL)xPietrain	>1.6
Beaulieu A.D. et al., 2010	commercial cross	1.37
Smiths R.J. et al., 2011	LWxL	1.9-2.0
Pardo-mariño C. el al., 2010	Swiss LW	1.2-1.7
Farmer C. and Petit H., 2009	(YxL)xL	1.07-1.18
Kuo-Bin Jean and Shu-Hsing Chiang	LxD	1.4-1.5

L=Landrance; LW=Large White; LB=Large Black; Y=Yorkshire; D=Duroc;

In our study the weight at birth had an high variability, ranging from 770 to 2000g with a average value of 1317±275 g. The mean birth weight of our Sarda breed piglets is lower of the majority of crossbreeds reported in table 5. A trial carried out on native Polish swine breeds reports weight at birth ranged from about 1,5 kg to 1,7 kg (Szulc et al., 2011). Even in this last case the average value is bigger than our mean birth weight. Contrariwise analysis of data from other native pigs breed shows that our results are coherent with it. Iberian pigs, an autochthonous Spanish breed, has a average birth weight of about 1,3-1,4 kg (Castellano et al., 2014).

An important variable that could have a relevance in the determination of piglets birth weight is the maternal nutrition during all gestation. The content of energy and protein of sow feeding during pregnancy have a fundamental rule in offspring weight at birth and subsequent performance (Rehfeldt et al, 2004; Wu et al., 2004; Wu et al., 2006).

Table 7: ANOVA analysis: birth weight *versus* litter size group

		Birth weight (g)	p-value
Litter size	Medium-small	1394.3± 292.8	0.029
	Medium-large	1268.7 ±222.2	

Litter size influences negatively weight at birth. Piglets belonging to large litter size are significantly lighter than belonging to small litter size group ($P<0.05$).

Several studies done on piglets growth demonstrated the influence of litters dimension on offspring weight. A lot of trials carried out on different breeds of pigs have found a negative correlation between the size of litters and the birth weight of piglets (Gipp et al., 1969; Škorjenc et al., 2007; Akdag et al., 2009; Beaulieu et al., 2010). Our results seems to be in accord with outcomes of these studies.

It is important to highlight that the size of litters belonging to Sarda breed are very inferior in comparison to commercial breeds one. Table 7 shows the size of litters of commercial swine crosses in different trials.

Table 7: pigs litter size in different crossbreeds by various authors

<table>
<tr><th>References</th><th>Swine breed</th><th colspan="3">Litter size</th></tr>
<tr><td>Akdag et al., 2009</td><td>Bulgarian LW x LB x Turopolje</td><td colspan="2">≤8
medium-small</td><td>>8
medium-large</td></tr>
<tr><td>DeQuelen et al., 2010</td><td>(LWxL)xPietrain</td><td colspan="3">13.6-14.8</td></tr>
<tr><td>Beaulieu et al., 2010</td><td>Commercial cross</td><td>3-10
small</td><td>11-13
medium</td><td>14-19
large</td></tr>
<tr><td>Smiths et al., 2011</td><td>LWxL</td><td colspan="3">10.1-10.4</td></tr>
<tr><td>Pardo-Mariño el al., 2010</td><td>Swiss LW</td><td colspan="3">13.3-14.8</td></tr>
</table>

L = Landrance; LW = Large White; LB = Large Black.

Observing the dimension of litters, according to their breed, and comparing it with Sarda litter size is clear the difference. Having to employ the parameters used in table 6 to categorize our Sarda breed litter, they must be all classified as "small". Contrariwise doing a comparison with other local Italian swine breeds the numbers are similar each other. Table 8 (Franci et al., 2007) shows the average litter dimension of all 6 Italian local breeds officially recognized.

Table 8: Average litter size in different local Italian breeds

Breed	Mean litter size (piglets/litter)
Mora Romagnola	7.13 ± 2.58
Cinta Senese	7.00 ± 2.13
Casertana	7.26 ± 3.22
Calabrese	6.12 ± 2.64
Nero Siciliano	6.78 ± 1.22
Sarda	7.3± 1.0

Data referred to each of the other local Italian swine pigs are comparable with our results. The birth weight ranged from about 6 piglets per litter to about 7,3 newborn per litter, comparable with our results of 8,6 ± 2,5 alive piglets per litter. The same trend has been found in studies on crosses of different genetic lines of Iberian pigs breed showed litter size ranging from a minimum of 6,5 piglets up to a maximum of 8,5 piglets per litter (Dabao et al., 1988). A Sardinia Region report on productive performance of Sarda purebreed pigs shows an average litter size of 9,4 alive piglets (LAORE, 2013), a value coherent with our mean litter dimension.

Table 9: ANOVA analysis of birth weight for sex

		Birth weight	p-value
Sex	Male	1354,6 ±233,9	0,197
	Female	1281,9± 274,7	

As shown in table 9 male are heavier than female at birth with mean weight respectively of 1354.6±233.9 and 1281.9±233.9. But in our study birth weight does not appear to be significantly influenced by sex (P=0.197).

As well as detected in our trials, other studies reported that males at birth are generally on average heavier than females (Quiniou et al, 2002; Bee, 2004) but sex does not significantly affect birth body weight (Gipp et al., 1969; Škorjenc et al., 2007). Contrariwise in a study carried out by Čechová in 2006, on factors which affect weight at birth, revealed a statistically significant difference between males and females (P <0.01). Likewise in a trial carried out on Iberian newborn piglets characteristics in relation to maternal nutrition during pregnancy, is reported a significant difference according to sex, males were heavier than females (Gonzales-Bulnes et al, 2013).

3.2 Average Daily Gain

In table 10 is reported the ANOVA analysis of ADG in relation to farm.

Table 10: ANOVA analysis of Average Daily Gain for farms

		ADG	p-value
Farm	A	104.47 ± 32.07	0.971
	B	104.22 ± 30.54	

The ADG of the piglets during the suckling time do not differ in relation to farm (P>0.05). The results could be explained considering the similar farm system and the sows diets, equal for all sows involved in the trial.

Table 11: ANOVA analysis: Average Daily Gain *for* litter size

		ADG	p-value
Litter size	Medium-small	122,28 ± 29,16	0.001
	Medium-large	92,62 ± 26,76	

Effect of litter size on average daily gain is highly significant (P<0.01), as reported in table 11. Piglets belonging to small litter size grew faster, with an average daily gain of 122 g, than piglets of large litters, with an increase in weight per day of about 93 g. Considering the significantly different birth at weight in relation to litter size, this could be an expected results. The weight at birth is, in fact, one of the most important factors which affect postnatal growth, it is positively correlated to growth rate in pre-weaning phase (Quiniou et al. 2002; Škorjenc et al., 2007; Beaulieu et al., 2010). Increasing of weight of newborn piglets during suckling phase is strictly linked to milk intake. The growth rate in suckling piglets depends on the quality but also the quantity of milk consumed (Quiniou et al., 2002). In this phase of piglets life weight increasing depends first of all by maternal factors and then by the vitality of the piglet. Principal factors related to the mother are: milk production and functional teats available to the offspring. The elements are mainly related to piglet are again birth weight, newborns vitality and the consequential access to the udder (Skok et al., 2007). The competition to reach access to udder is bigger when litter size is more numerous, furthermore piglets are lighter and suffer still more the hierarchy.

Table 12: ANOVA analysis: Average Daily Gain *fors* sex

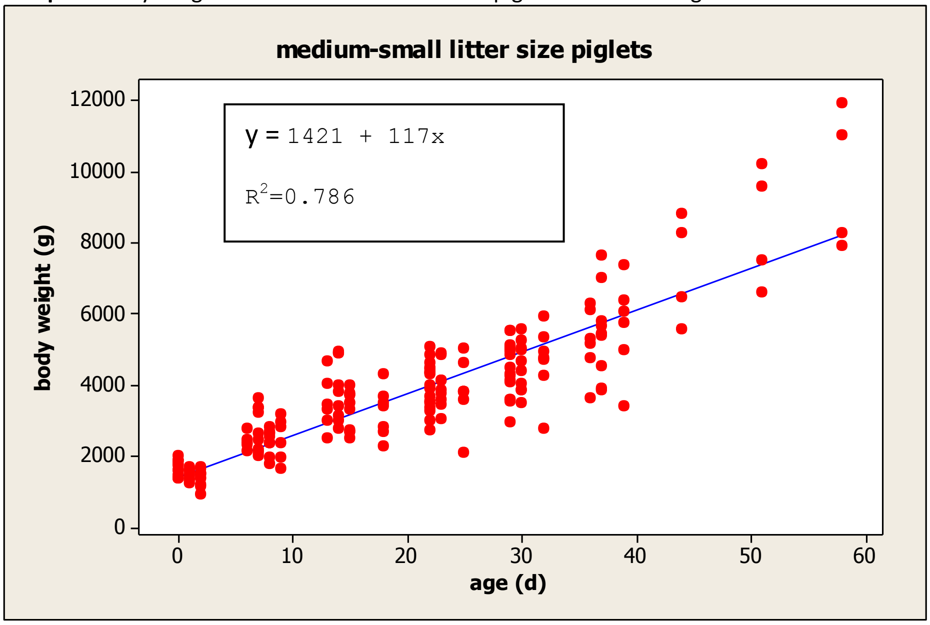
		ADG	p-value
Sex	Male	102.42± 30.78	0.595
	Female	106.04 ±31.77	

The ADG of the piglets during the suckling time does not differ for sex (P>0.05). The effect of piglets sex on weight at birth and growth performance has been analyzed by several authors, for both conventional and native swine breeds. In some studies male compared to female had a lower ADG in the suckling period (Johansen et al., 2004). Contrariwise several trials report that piglets gender does not affect birth weight and ADG (Bee, 2004; Škorjenc et al., 2007).

3.3 Linear Regression analysis

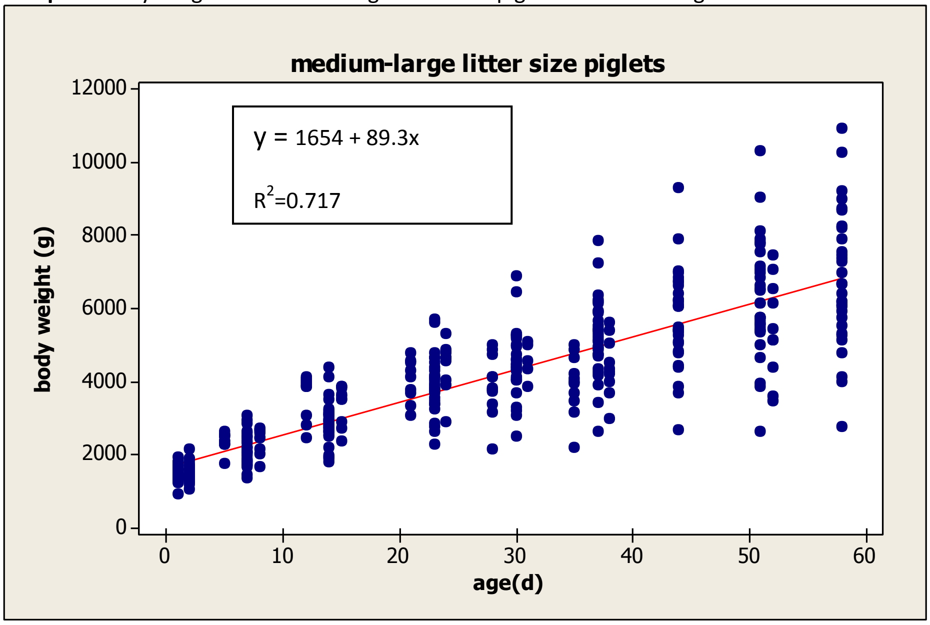
In graph 1 and graph 2 are reported the linear regression between body weight and age of each piglets of both litter size group medium-small (4-7 piglets) (graph 1) and medium-large (8-12 piglets) (graph 2).

Graph 1: body weight of medium-small litter size piglets at different ages



Results of regression analysis on small-medium litter size group (R-Sq = 0.78) indicate a significant influence of age and litter size (P<0.01) on body weight.

Graph 2: body weight of medium-large litter size piglets at different ages



Even for large-medium litter size group results of regression analysis (R-Sq = 0.71) indicate a significant influence of age on body weight. The piglets weight at birth (intercept) is bigger in larger litters (1654g) compared to smaller one (1421g). In contrast with our results, in several studies on litter size effect on piglets growth development and performance, reported a negatively correlation between litter size and weight of piglets at birth (Gipp et al., 1969; Škorjenc et al., 2007; Akdag et al., 2009; Beaulieu et al., 2010). Contrariwise the ADG is higher in piglets belonging to medium-small litters (117g/d) than piglets belonging to larger litters (89g/d). This is probably due to an easier access to the udders, due to a reducer hierarchic competition.

It is interesting highlight the increasing of the variability of piglets body weight in relation to age. This aspect is emphasized in animals with a poorly growth of both litter size classes, medium-large and medium-small litters. Additionally the weight variability is higher in piglets belonging to bigger litters, probably due to an augmentation of hierarchic competition to reach milk, linked to a major number of piglets per sow.

4. Conclusion

Data analyzed give a more clear description of suckling time of Sarda purebreed piglets. As in other swine breeds birth weight and consequent ADG are affected by several different variables, in relation to sows, piglets and management factors. In agreement with several other studies on native and commercial cross breeds, even suckling piglets growth in Sarda breed is affected significantly by litter size. The effect of management is not a determinant factor in our trial. This is probably due to a common rearing system which characterized the breeding of Sarda swine breed. The study on the effect of sex on ADG has given a lot of contrasting results in several trials. Generally males are heavier than females, but not ever the difference between sexes is significant, as in our results. Anyway the growth rate of Sarda suckling piglets is not constant and uniform. The piglets growth is characterized by an high variability in ADG even within litters.

It is necessary to investigate other aspects of piglets growth and carcass quality in order to identify limiting factors and strength of the breed. It remains of fundamental importance the development of an adequate rearing system, to optimize animals management, keeping costs under control and promote Sarda piglet as a typical island product.

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Chapter 4

EFFECT OF DIETARY ENERGY LEVEL IN DIET OF LACTATING PRIMIPAROUS SOWS OF SARDA BREED AND THE GROWTH PERFORMANCE OF THEIR PIGLETS

*1.**Introductio**n*

Daily energy intake is a major determinant of lactation performance of sows for its clear effect on milk production and the litter growth rate. During last decades litter size of sows of conventional breeds has considerably increased. The milk production increased so also the nutritional and energy requirements of lactating sows rose (Noblet et al., 1990) even if the voluntary feed intake by lactating sows did not have a proportional trend (Noblet et al., 1998). Actually, the feed intake in lactating sows is often not adequate to meet their nutritional requirements with a resulting mobilization of the body reserves. Moreover, the improvements of swine selection for conventional breeds are mainly focused on prolificacy and mothering ability of sows, growth performances and leanness of carcasses. Standards of dietary requirement for lactating sows are adapted to meet the nutritional needs of conventional swine breeds (Schinckel et al. 2010). The nutritional status of the sow has a direct effect on piglets birth weight and on offspring growth performance, first in gestation and then during lactation (Wu et al., 2004). Inadequate feed intake during lactation in primiparous sows is particularly relevant, in comparison with pluriparous females, since their body reserves are lower (Eissen et al., 2003).

In Europe the energetic concentration recommended for pregnant sows diet is about 3000kcal/kg feed of Digestible Energy (DE) equal to 2880 kcal/kg feed of Metabolizable Energy (ME) (Bertacchini et al., 2013; Galassi, 2014). During pregnancy a diet with a protein content of 13-14% and 0.55% of digestible lysine could be considered adequate (Bertacchini et al., 2013). The 70-80% of total energy intake is used for sow maintenance, fetuses growth and reserve fat store. The diet in lactation must consider that milk production needs the 75-80% of total energy, the 80% of the protein and the 95% of total lysine. A content of protein of about 15% (0.5% lysine) and feed with about 3100 kcal/kg of ME appear to be adequate to lactating sow needs (Bertacchini, 2013; Galassi, 2014). The requirement of sows during pregnancy and lactation is satisfied modulating the quantity of feed, with the characteristics mentioned above, according to litter size and age of piglets.

The measurement of back-fat thickness of sows is a key parameters useful to evaluate the nutritional status of animals during lactation since its strong dependence by feed intake and milk yield.

Almost all of studies focused in order to recognize the dietary requirements of lactating sows, and evaluation of the nutritional status of animals, were carried out considering conventional pig breeds as reference. Very few data are available for the dietary requirements of lactating sows of no-conventional breeds, such as Sarda pigs, that are characterized for the genetic large capacity for fat tissue deposition.

In small farms where pigs of Sarda are reared, the lactating sows are hand-fed with complete feeds purchased in markets of the conventional swine industry. For farmers involved in rearing of Sarda pigs the main income is usually represented by the retail of piglets at the end of suckling time. Carcasses form suckling piglets are largely appreciated in Sardinian meat markets where are used to prepare traditional dishes. The profitability of farms rearing Sarda pigs is strongly affected by the growth performance of suckling piglets and, therefore, the proper feeding of lactating sows.

The aim of this study is to evaluate how the variation in sows diet energy content can affect piglets growth performance, evaluating the evolution of fatness of sow during lactation.

2. Materials and methods

2.1 Animals and diets

Were identified 8 primiparous and multiparous Sarda purebred pregnant sows. Sows were maintained into individual boxes from two last weeks of pregnancy until the end of lactation.

The day of parturion sows were randomly assigned to one of two different diet treatment group. The assignation to one or the other one diet was made in alternate way. From the day of farrowing it was administered one of the two commercial lactation feed as shown in tab.1, Feed were isoproteic with different energy content. In particular:

- High Energy (HE) feed (TM431) contains 3.830,57 kcal/kg Metabolizable Energy on dry matter;
- Low Energy (LE) feed (TM430) contains 3.503,59 kcal/kg Metabolizable Energy on dry matter.

The daily amount of feed given to each sow, during the lactation, increases along time and litter size, as reported in table 1

Table 1: schedule followed for the administration of feed ration to sows

Days from farrowing (n)	Maintaining feed (kg)	Feed in addition for each suckling piglet (kg)
1	2	0
2	2	0.1
3	2.5	0.1
4	2.5	0.15
5	3	0.15
6	3	0.2
7+	3	0.2
14+	3	0.2
21+	3	0.25
28+	3	0.25
35+	3	0.25
42+	3	0.25
49+	3	0.25
56+	3	0.25

Tab. 2 and 3 show chemical composition of both High Energy (Tab. 2) and Low Energy (Tab. 3) feed.

Table 2: chemical composition of HE feed (TM431)

	AF	DM
DM (%)	87.73	86.88
CP (%)	16.09	18.34
CFat and Crude oil (%)	4.92	5.61
Ash (%)	5.36	6.11
NDF (%)	14.51	16.54
ADF (%)	5.87	6.69
ADL (%)	1.4	1.6
ME (Metabolizable Energy) (kcal/kg)	3.360,63	3.830,57
Lys (%)	0.75	0.86
Ca (%)	0.13	0.15
P (%)	0.40	0.46

(AF=as feed; DM=dry Matter)

Table 3: chemical composition of LE feed (TM430)

	AF	DM
DM (%)	87.91	88.35
CP (%)	16.21	18.44
CFat and Crude oil (%)	4.49	5.10
Ash (%)	4.01	4.57
NDF (%)	15.7	17.86
ADF (%)	6.22	7.08
ADL (%)	1.54	1.75
ME (Metabolizable Energy) (kcal/kg)	3.079,85	3.503,59
Lys (%)	0.76	0.87
Ca (%)	0.47	0.54
P (%)	0.43	0.49

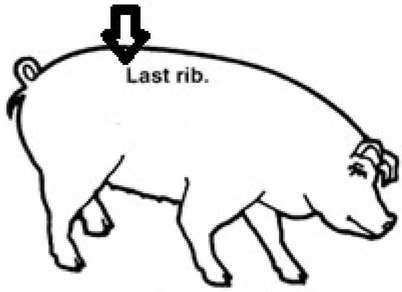
(AF=as feed; DM=dry Matter)

2.2 Traits

Sows: From day of farrowing until the end of lactation back fat thickness was weekly measured with an ultrasound lean meter (fig.1). To relief the thickness of fat the probe of the instrument had to be perpendicular to animal back ever in the same position: on side of the last rib, 6cm lateral to the spine as shown in figure 2.

Figure 1: Ultrasound lean meter used to the measurement of dorsal fat thickness

Figure 2: site where probe must be applied (P2: last rib, 6.5cm lateral to spine)



In figure 3 the measurement during trial.

Figure 3: measurement of back fat thickness in lactating sows

Piglets: Within two days of life every piglets has been weighted and identified. To each piglets has been applied a plastic tag reporting an univocal chronological numeration. Sex has been annotated. Stillbirths and born alive, deaths of animals were recorded during all the trial. Born alive piglets were weighed every week until an average body weight from 8 to 10kg , at slaughtered or weaning weight.

Sixteen piglets weighing about 8-10 kg, the age ranged between 35 to 76 days, were slaughtered by electronarcosis immediately followed by exsanguination.

For each piglet was recorded the weight of:

- body
- carcass
- organs (liver, lungs, heart, kidneys; intestine and stomach);

were also measured:

- length of small intestine
- back fat thickness at:
  - 9th cervical vertebra
  - last thoracic vertebra
  - last lumbar vertebra.

2.3 Statistical analysis

In order to evaluate the change of back fat thickness of sows, during lactation, a regression analysis has been done between back fat thickness and time (in week of lactation). To evaluate maternal diet effect on sows and suckling piglets growth performance, has been done an ANOVA analysis on:

- sows back fat thickness
- piglets ADG

- piglets yield at slaughter
- piglets weight of:
    - body
    - carcass
    - organs (liver, lungs, heart, kidneys; intestine and stomach);
    - length of small intestine
- piglets back fat thickness at:
    - 9th cervical vertebra
    - last thoracic vertebra
    - last lumbar vertebra.

3. Results and discussion

3.1 Piglets

The recorded average weight at birth of piglets was 1559 ± 516. The medium litter size was 6.6 ± 1.5 newborn piglets. It has been calculated the main daily gain of suckling piglets in relation to maternal diet. Graph 1 shows the ADG (in grams) of piglets during lactating period in relation to maternal diet. In table 4 is reported the ANOVA analysis of sows diet on piglets ADG.

Graph 1: Average Daily Gain (ADG) of piglets in relation to maternal diet

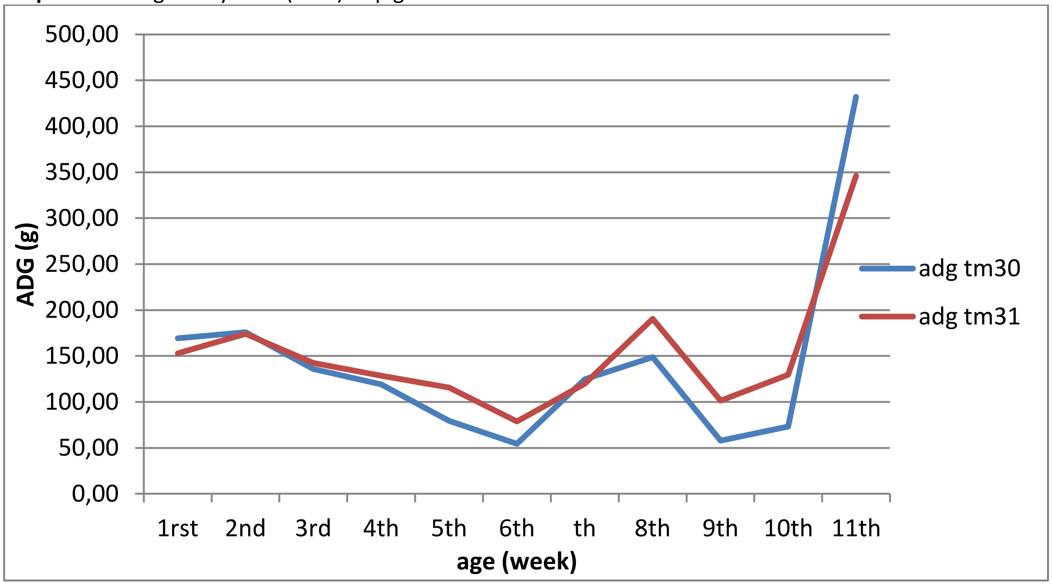


Table 4: ANOVA analysis: Average Daily Gain *vs* diet

		ADG	p-value
Sows diet	LE	114.16 ± 70.37	0.022
	HE	161.82 ± 71.23	

The ANOVA on diet effect on ADG is significant ($p<0.05$). Mean weight increase per day is significantly higher in piglets born by sows fed with HE feed (160g/d) than piglets belonging to sows fed with LE feed (114g/d). The ADG in suckling piglets depend by a lot of variables linked to ability of piglets to reach milk and to sows milk production (Quiniou et al., 2002; Skok et al., 2007). Lower weight at birth results in a competitive disadvantages of smaller newborns compared to heavier piglets (Milligan et al., 2002). The maternal factors are overall health and welfare status which can affect the capability of the organism to produce milk. The effect on the ADG of the piglets might be directly because of lower milk production and/or indirectly due to risk that sows become a source of disease for the offspring (Johansen et al., 2004). Even maternal nutritional status and feeding during pregnancy and lactation has a relevant role (Quiniou.et al., 2002). Reducing energy level of sows diet during lactation has a negative effect on the capability to regenerate the body fat reserve of sow for successive pregnancies and lactations (Bertacchini et al., 2013) but some authors reports that less energy in sows diet has not effect on litter growth performance (Noblet et al., 1986). Nevertheless has been demonstrated that increasing ME intake, adding supplemental fat in sows diet during lactation, improves suckling piglets growth rates (Tilton et al., 1999; Gatlin et al., 2002). Another study carried out by Rosero et al, (2012) confirmed an higher body weight increase in piglets nursed by sows fed with fat supplemented diet, in high ambient temperature, but only in 3rd -7th parity. Our results are consistent with these trials, with an ADG of piglets belonging to sows fed with HE diet higher of 42% respect to others piglets.

Lactation period has been divided in 3 phases in relation to piglets age:

- phase 1: 1st -2nd week of lactation
- phase 2: 3rd – 4th week of lactation
- phase 3: >4th week of lactation

In table 5 are reported the ADG in relation to lactation phase and maternal diet.

Table 5: piglets ADG (g) according to lactation phase and maternal diet

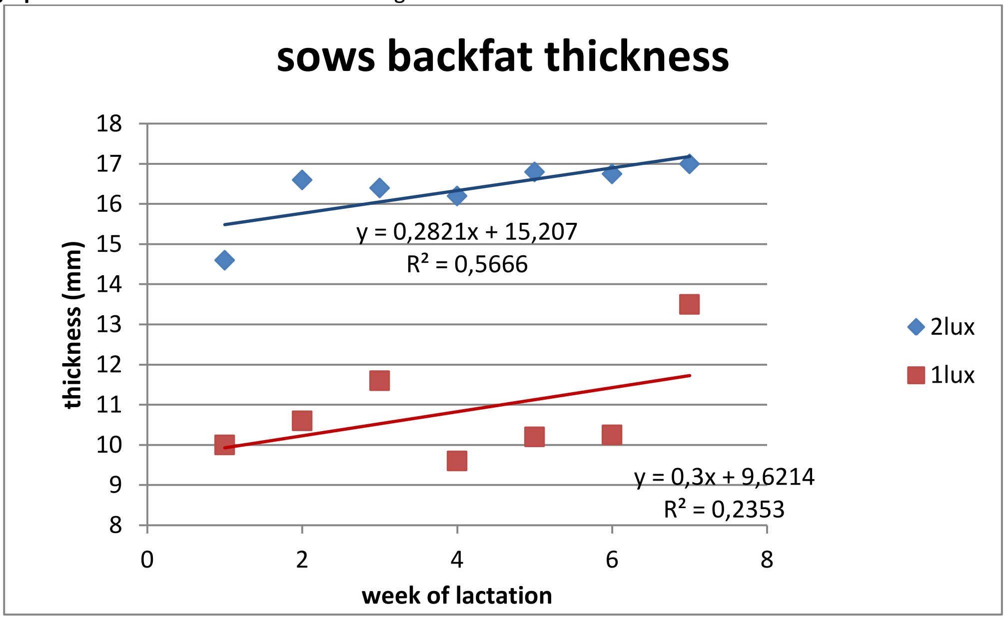
	Sows diet		**p-value**
ADG	**LE**	**HE**	
1st phase	161 ± 38	178 ± 72	0.32
2nd phase	116 ± 81	155 ± 88	0.12
3rd phase	105 ± 101	122 ± 73	0.56

The ADG variation in relation to lactation week is not significantly different in according to diet (p>0.05). The medium weight increase of piglets of HE maternal fed is higher than the other piglets and more uniform. In our study the ADG decreases from early lactation to the end of suckling period. This is in contrast with studies which demonstrated an increase of ADG in relation with lactation advancement in different breeds (DeQuelen et al., 2010; Castellano et al., 2014). Skok et al. (2007) reported that during the first 2 weeks of lactation there is an increase in ADG of piglets followed by a constant diminution of ADG during suckling period, as in our results.

3.2 Sows

The ultrasound lean meter, used to measure thickness of dorsal fat in lactating sow, is provide with a light indicators. Each indicator shows a layer. The instrument is able to detect until 3 different levels. Generally first layer (lux 1) includes the skin thickness, generally <3mm. in our trial have been measured the first and the second layers (lux 1 and lux 2). In graph 2 is reported the evolution of back fat thickness of sows during lactating period.

graph 2: thickness of dorsal fat in lactating sows

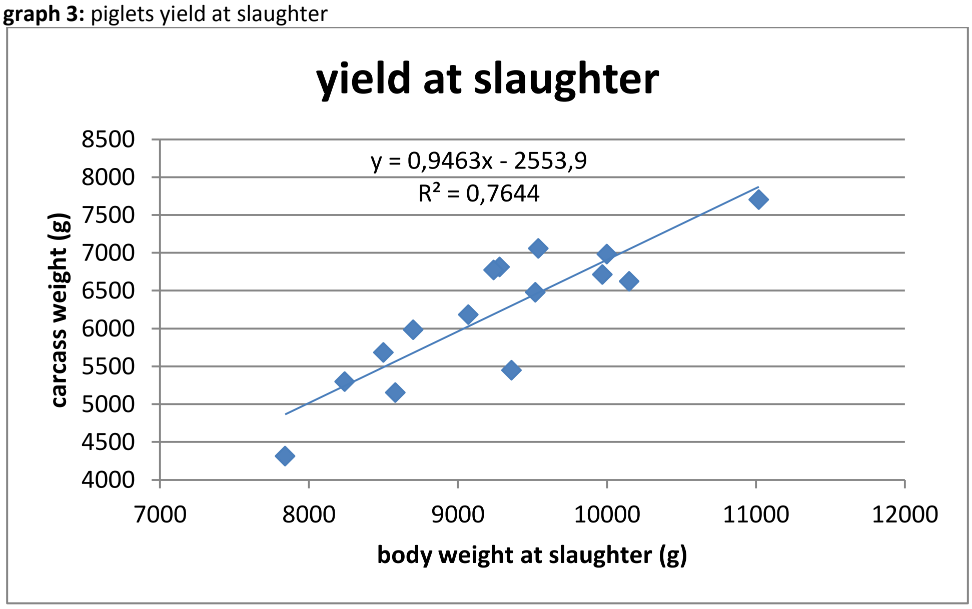


Studies on the variation of the physical condition of sows during pregnancy and lactation have shown a significant decrease in the thickness of the back fat with the progress of lactation. This trend varies in the opposite direction with the end of nursing period and the beginning of a new pregnancy (Bee, 2004; Farmer et al., 2009). In our study the thickness of dorsal fat has not had a specific inclination. The low R2 value (0.23) not underlines a direct influence of lactation advancing on subcutaneous dorsal fat of sows. Furthermore the different diet does not have effect on back fat thickness variation (p>0.10). Considering that the expected trend was a progressive and constant decrease, result on our data are probably due to suckling piglets health status. Piglets in a precarious health have a reduced feed intake due to a lower capability to reach milk (Skok et al., 2007). The back fat thickness, usually used as a parameter to evaluate the welfare status of sows, has to decrease due to the use of body fat. In fact lactating sows mobilize energy body reserves, as dorsal subcutaneous fat, to overcome to the higher nutritional needs of piglets, in a physiological way (Bertacchini et al., 2013).

3.3 Piglets yield at slaughter

The graph 3 shows the yield of piglets at slaughter.

graph 3: piglets yield at slaughter



The regression shows a direct dependence of yield at slaughter (carcass weight/body weight at slaughter) by piglets body weight with an R^2 of about 0.77. In table 2 is shown the analysis of effect of maternal diet on piglets yield at slaughter.

Table 6: ANOVA: piglets yield at slaughter *vs* maternal diet

		Yield at slaughter (%)	p-value
Sows diet	LE	66.9	0.92
	HE	66.7	

The piglets yield at slaughter is not affected by maternal diets.

Table 7: ANOVA analysis on sows diet effect

	sows diet		**p-**
item	**LE**	**HE**	**value**
bowel weight (g)	1623 ± 158	1615 ± 148	0.97
liver. Kidneys. heart. lungs. weight (g)	529 ± 23	517 ± 21	0.70
small intestine length (cm)	1179 ± 44	1141 ± 42	0.54
fat thickness last lumbar vertebra	6. 1± 1.2	6.6 ± 1.0	0.76
fat thickness last thoracic vertebra	4.4 ± 0.8	5.2 ± 0.7	0.50
fat thickness 9th cervical vertebra	13 ± 1.2	14 ± 1.1	0.56

ANOVA analysis on piglets internal organs is not significant ($p>0.5$), likewise the length of small intestine is not influenced by maternal diets with a p value of 0.54. Neither the level of fatness of piglets carcasses is influenced by energy content of sows diet.

Analyzing our results on piglets growth performance we can assert that the difference in ADG is probably due to a real increase of muscle mass. In a comparable study carried out on energy content in lactating sows feed, was find a similar result, highly energy content in sows diet gave as results superior piglets ADG. However, contrarily to our conclusions, sows diet with fat supplementation improves piglets weight gains during lactation, caused by a weight increase due to body fat (Tilton et al., 1999; Gatlin et al., 2002).

Table 8: ANOVA: piglets carcass fatness *vs* maternal diet

Point of measurement	**p-value**
fat thickness last lumbar vertebra	0.76
fat thickness last thoracic vertebra	0.50
fat thickness 9^{th} cervical vertebra	0.56

In our trial the subcutaneous fat of piglets carcasses is not influenced by maternal feed (p value for all three fat thickness detected is >0.5).

4. Conclusion

In our trial supplemental energy during lactation improved suckling piglets growth rates and consequently reduced the time to reach the slaughter or weaning weight. Considering that Sarda breed piglets achieve the right weight in a time twice greater than commercial cross breeds, this result has considerable importance, especially for piglet farming, representing a typical production, consumed throughout the island. It is necessary to increase the knowledge on Sarda breed pigs, especially on this aspect of rearing, enlarging the number of animals per trial and expanding the information on sows and previous animal management, to better understand the results.

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Chapter 5

EVALUATION OF LINEAR AND NON-LINEAR MATHEMATICAL MODELS TO DESCRIBE THE BODY WEIGHT GROWTH OF SARDA SUCKLING PIGLETS

1. Introduction

Models are mathematical representations of natural phenomena. They are abstraction and representation of reality.

Models are used in order to study, understand and control mechanisms that govern the nature. They are also useful to predict which could be the behavior of a given phenomenon in a laps of time, under the influence of the different variables that can affect it.

A model can be built following two different ways:

A: develop conceptual ideas and interactions, parameterize model variables with adapted data (theoretical model);

B: study background of a biological phenomenon and combine its experimental data in a methodological way (empirical model).

During development and testing of a model it is of fundamental importance to do adequate statistical analysis. Models created must be tested in order to evaluate the applicability to the biological system that we want to study and their predictive capability. In other words, a model should be adequate to respect the natural process it represents. The adequacy of a model, useful also to select one of alternative models, can be assessed by using two concepts: the precision and the accuracy (Tedeschi, 2006).

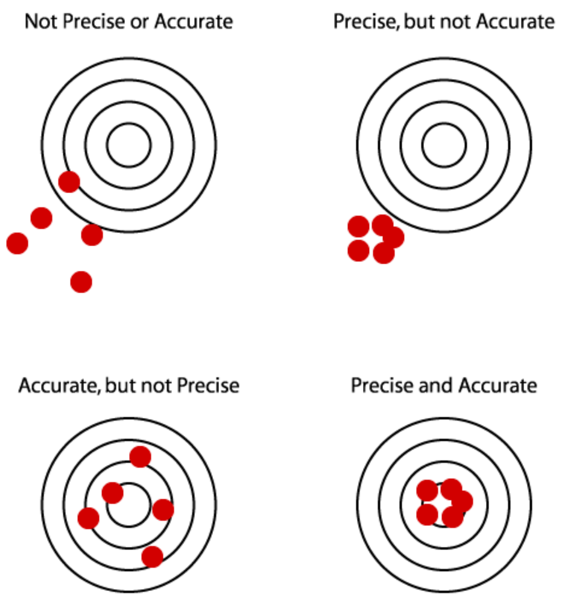
In particular:

- Precision: measures how values predicted by model are closely each other. Namely, it represents the model ability to predict similar values in a consistent way;
- Accuracy: measures how values estimated by the model are close to real one. In other words, it depicts the predictive capability of the model.

Contrariwise inaccuracy, or bias, is the systematic deviation from the truth (Tedeschi, 2006).

Figure 1 explain better the difference between accuracy and precision of a model.

Figure 1: precision *vs* accuracy



To measure the precision of a model the better indicator is the coefficient of determination, R^2. It has been calculated doing a regression between observed values, on Y-axis, and predicted values, on X-axis. Higher R^2 means bigger model precision. Intercept and line slope are good indicators of accuracy. They have to be currently closer to 0 (intercept) and to 1 (line slope), respectively. To assess the adequacy of a model, both indicators are important. However, accuracy is fundamental to evaluate the model ability to predict real values. Often, when the adequacy of two or more mathematical models have to be assessed, is used the mean square error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-2}}$$

The method consists in calculate the RMSE of each model and choose the smaller one, that indicates the more accurate model between all models compared (Tedeschi, 2006).

Growth curves are a common method to illustrate the animal growth during a certain lapse of time. Several linear e non-linear models have been used in numerous species (Lopez et al., 2000), included livestock one, like quails (Narincet al., 2010), llamas (Cnaza-Cayoet al., 2015), eagles (Borlotti et al., 1986) bats (Kunstet al., 1995) sea lions (Childerhouseet al., 2010) cattles (Kaps et al., 2000; Johnson et al., 2012) sheeps (Johnsonet al., 2012; Lupi et al., 2015;) hourses (Santos et al., 1999) chickens (Mignon-Grastauet al., 2000; Tompić et al., 2011) to describe and study the develop in terms of quality and weight, genetics, and all variables which affect growth performance. Even to design piglets growth have been used mathematical non-linear models (Schinckel et al., 2003; Pârvu et al., 2011).

Several studies have been done to develop growth model starting from non-linear functions as Logistic, Gompertz, Von Bertalanffy and Michaelis-Menten model.

The purpose of this study was to investigate different growth models in order to identify which of those was best suited to describe the trend of the growth Sarda breed suckling piglets.

2. Materials and methods

2.1 Data

Two separate datasets (tab.1) related to Sarda breed piglets growth, which included individual body weight (BW) weekly recorded from birth to weaning, were created. All data was from piglets, males and females, belonging to 11 litters, in total 74 piglets, of Sarda breed sows reared in two smallholder farms. Two weeks prior to farrowing, sows were housed in individual pens. Within two days of life every piglets were identified, ear tagged and weighted. Born alive piglets were weekly weighed until weaning (average body weight from 8 to 10kg). According to piglets weight at 50d of life, the two datasets were created. The first dataset referred to animals weighing more than 6kg at 50d of age, “normal growth piglets” (NGP), the other one included data from animals with body weight equal or less than 6kg at 50d of age, “underweight piglets” (UWP). Table 1 shows the average body weight (in grams) at different age (in days) of both piglets groups. The weighing were effectuated every week from day 0 (day of birth) to weaning day (58th day of life) in 2 different farms. Due to different day of birth and consequent different age at the day of weighing, table shows different number of animals to calculate each mean weight.

Table 4: animal age in days (d), number of animals, mean body weight (BW) ± standard deviation (Sd)

normal growth piglets				underweight piglets			
age (d)	**animals (n)**	**Mean BW(g)**	**sd**	**age (d)**	**animals (n.)**	**Mean BW(g)**	**sd**
0	9	1650	±235	0	3	1633	±263
1	5	1520	±255	1	16	1484	±225
2	29	1488	±246	2	12	1380	±232
5	1	2540	0	5	10	2336	±236
6	5	2388	±237	6	1	2340	0
7	29	2325	±576	7	11	2085	±410
8	4	2493	±323	8	6	2317	±369
9	4	2568	±529	9	1	1640	0
12	1	4040	0	12	10	3592	±600
13	5	3680	±670	13	1	2480	0
14	29	3242	±766	14	11	2632	±621
15	4	3475	±424	15	6	3275	±610
18	4	3490	670	18	2	2550	±382
21	1	4520	0	21	8	3938	±595
22	5	3904	±484	22	1	2710	0
23	28	4118	±650	23	12	3383	±613
24	4	4758	±528	24	6	4217	±732
25	4	4243	±664	25	2	2925	±1209
28	1	4980	0	28	10	3767	±784
29	5	4404	±541	29	1	2950	0
30	29	4764	±755	30	11	3774	±634
31	3	4883	±282	31	2	4090	±353
32	4	5160	±575	32	2	3845	±1520
35	1	4840	0	35	10	3828	±787
37	5	5504	±644	36	1	3610	0
38	29	5690	±911	37	11	4236	±776
39	4	4960	±629	38	6	4010	±684
42	4	6385	±701	39	1	3990	0
42	1	5750	0	42	10	4092	±735
43	5	6504	±542	43	1	4730	0
44	29	6537	±1096	44	12	4564	±835
45	4	5640	±569	45	6	4450	±1086
51	25	7207	±1395	51	10	4745	±998
52	4	6795	±589	52	6	4508	±850
58	25	8044	±1640	58	10	4843	±967

2.2 Statistical analysis

Using mean body weights at different ages, 5 non-linear growth models and a linear regression model were testedin the two datasets.in order to identify which equation better designs each of the two kinds of growth. The choice of mathematical models is linked to study aim.All these non-linear models have been largely used to design different kind of developments: body growth, population dynamics (Human, livestock species, other animals species) and enzymatic dynamics.

In tab. 2 are shown all different equation tested in this study. In each model y is the piglets mean body weight (in grams) recorded at time t (in days). Animals growth parameters in Non-linear models are: A, the asymptotic weight, intended as animal mature weight; B, the proportion between average weight increase from birth to weaning, and asymptotic weight; k, maturation rate of animals, interpreted as weight change in relation to mature weight to indicate how fast the piglets reach mature weight.

In particular, the parameters were calculated as follows:

A is the asymptotic weight, the average maximum weight achievable by piglets in this phase of growth.

B = (A -Average Birth Weight)/A

K= Average Daily Gain/(A-Birth Weight)

Referring to Linear Model:

b_0 = (intercept) Birth Weight

b_1 = curve slope (growth rate)

t = age in days

Table 5: Equation of models used to design piglets growth

Model	Equation
Linear Regression	$y = b_0 + b_1 x + \varepsilon$
Gompertz (Laird, 1965)	$y = ae^{-be^{-kt}} + \varepsilon$
Brody (Brody, 1945)	$y = a(1 - be^{-kt}) + \varepsilon$
Von Bertalanffy (Von Bertalanffy, 1957)	$y = a(1 - be^{-kt})^3 + \varepsilon$
Logistic (Nelder, 1961)	$y = a(1 + be^{-kt})^{-1} + \varepsilon$
Michaelis-Menten	$y = \frac{at}{b + t} + \varepsilon$

Each equation was applied to both groups of data, in order to estimate parameters and expected weights predicted by the model. The goodness of fit was tested following the Tedeschi's suggestions (Tedeschi, 2006). Accuracy and precision of linear and non-linear models were emphasized by using linear regression method. Observed data was arranged in ordinate axis whereas estimated data in abscissa axis. The ideal growth model should predict results identical to the observed ones. In consequence, the RMSE (Root Mean Square Error) should have a value equal to 0, which means that there is no prediction mistakes. In this condition, the R^2 (determination coefficient) should be equal to 1, the intercept (b_0)equal to 0 and the curve slope (b_1) equal to 1. Obviously In reality this is not possible. However, the more a model has those indicator values near to 1, 0 and 1, respectively, the more it is adequate. All these indicators were calculated for each model and used, also considering the biological meaning of the estimated parameters, to chose the model that better represents the growth of piglets.

The selected model was applied to data belonging to each piglet to fit the individual curve. To test if the model fitted data, of the two groups in different manner, estimated parameters were submitted to an ANOVA analysis with the following linear model:

$y=\mu+G+F+G*F+\varepsilon$

where :

y were estimated parameters (A, B, and k); μ was overall mean; G was a categorical variable indicating the two groups, NGP and UWP; F represented the farms involved in the study; G*F was the interaction effect and, finally, Ɛ were the random residuals.

3. Results and discussion

3.1 Models testing and choice

In table 3 are reported the starting values for A, B and kparameters, used in non linear fitting proceeding.

The value of A wasfixed taking into account the average weight of piglets belonging to both groups at the end of the suckling period, whereas B and K were calculated as follows:

B= (A-mean birth weight)/A

K= Average Daily Gain/A

Table 6: growth parameters used to test all different models

Parameters	NGP	UWP
A	9000	6000
B	0.84	0.78
K	0.017	0.017

Tab. 4 and 5 show the estimated parameters by the different models for both NGP and UWP group. In particular, for non-linear models, the values of asymptotic weight (A), the growth rate (B) and the maturation rate (k) of animals predicted by each model are shown. For Regression model, values reported refer to birth weight (b_0, intercept) and to average daily gain (b_1, curve slope).

Table 4: NGP dataset: predicted parameters by different models

Model	Parameters		
	A	**B**	**k**
Brody	34674	0.95	0.00
Gompertz	11711	1.82	0.02
Logistic	9609	3.78	0.04
Von Bertalanffy	34674	0.05	0.00
Michaelis-Menten	9705	25.99	
	b_0	**b_1**	
Linear Regression	1815	101	

Table 5: UWP dataset: predicted parameters by different models

Model	Parameters		
	A	B	k
Brody	6005	0.74	0.02
Gompertz	5306	1.19	0.04
Logistic	5023	1.98	0.06
Von Bertalanffy	6005	0.04	0.02
Michaelis-Menten	5203	10.44	
	b0	b1	
Linear Regression	1855	58.1	

At first observation, Brody and Von Bertalanffy models overestimate the asymptotic weight of NGP during suckling period with values of about 34.7kg, considering the average weight of 8.04kg recorded at the end of the period taking into account. The same observation can be done on UWP predicted parameters with an A value of 6.0kg and an observed mean body weight at weaning of 4.8kg. Even the others evaluated models, Gompertz, Logistic and Michaelis-Menten estimate mature body weight bigger than real data, but closer to observed weights than Brody and Von Bertalannfy, both for NGP and UWP.

The birth weight predicted by Regression model is over estimated in both piglets groups. Furthermore animals classified as "underweight piglets", due to their not adequate growth, are estimated to have heavier weight at birth.

This is probably due to the fact that both NGP and UWP must achieve a different asymptotic weight (NWP = 9000g; UWP= 6000g) with initially B value very closed each other, respectively 0.84 and 0.78, in the same range of time. These starting conditions allow to the model the possibility to vary only the weight at birth. The results of the linear regression, for observed data vs. predicted data, used to test goodness of fits of all models are shown in tab. 6 and 7.

Table 6: NGP data. Goodness of fits evaluated by different models: intercept (a), line slope (b), determination coefficient (R^2), root mean square error (RMSE)

Model	**Parameters**		R^2	**RMSE**
	a[1]	**b**[2]		
Linear regression	0.07152 ±191,23237	1.00000 ±0.04071	0.95	386.74
Michaelis- Menten	**811.51276 ±237.66329**	**0.84048 ±0.05090**	0.89	557.93
Gompertz	-29.58498 ±201.19272	1.00592 ±0.04285	0.94	403.60
Brody	0.10947 ±190.18702	0.99998 ±0.04049	0.95	384.72
Von Bertalannfy	0.10947 ±190.18702	0.99998 ±0.04049	0.95	384.72
Logistic	-55.54432 ±210.84943	1.01116 ±0.04492	0.94	419.88

1:values in bold indicate that a is significantly different from 0 (P<0.05);

2:values in bold indicate that a is significantly different from 0 (P<0.05);

The determination coefficient (R^2), had in all 6 models quite high values, ranging from 0.89 to 0.95. That indicates that data estimated by each model are close to real data, all models have an high precision. Therefore to verify the goodness of prediction capability the determinant factor is the accuracy. Michaelis-Menten model must be excluded because of intercept (a) and slope line (b) values are significantly different from 0 (P=0.0017) and from 1 (P=0.0036),respectively. It means that the Michaelis-Menten model has not a reliable predictive power. Excepted for the Michaelis-

Menten function, both intercept and slope were not significant for all other models. The lowest RMSE values are in Brody and Von Bertalannfy models, both equal to 384.72. However analyzing values of the estimated parameters (tab. 6) the asymptotic weight (A) and the maturation rate (B),

it seems to be more appropriate the Logistic model. In fact the real average asymptotic weight is very near to predicted one by the Logistic equation.

Table 7: UWP data. Goodness of fits evaluated by different models: intercept (a), line slope (b), determination coefficient (R^2), root mean square error (RMSE)

Model	**Parameters**		R^2	**RMSE**
	a[1]	**b**[2]		
Linear regression	-0.20268 ±275.45995	1.00005 ± 0.07950	0.83	430.87
Michaelis- Menten	**800.27642 ±255.46676**	**0.78070 ± 0.07413**	0.77	496.66
Gompertz	-11.92961 ±257.11632	1.00333 ± 0.07415	0.85	405.32
Brody	0.09055 ±253.35894	1.00002 ± 0.07306	0.85	401.38
Von Bertalannfy	0.09055 ±253.35894	1.00002 ± 0.07306	0.85	401.38
Logistic	-26.69859 ±261.56490	1.00742 ± 0.07544	0.84	373.74

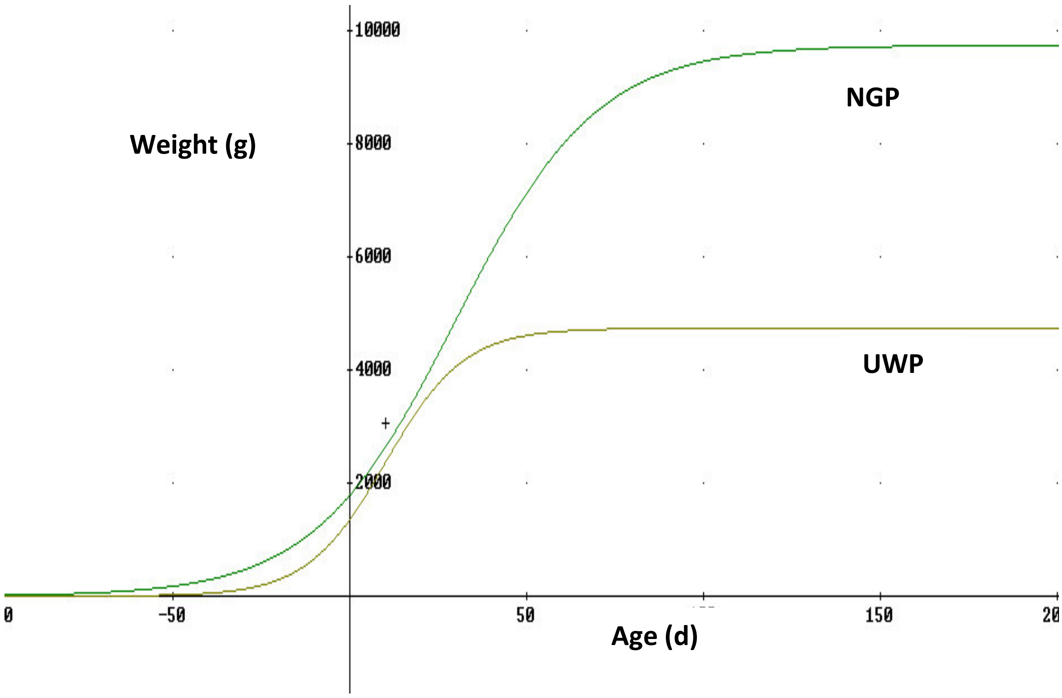
1: values in bold indicate that a is significantly different from 0 (P<0.05);

2: values in bold indicate that b is significantly different from 1 (P<0.05)

The same models applied to the underweight dataset gave following results. The R^2 ranged from 0.77 (Michaelis-Menten) to 0.85 (Gompertz, Brody, Von Bertalannfy). Michaelis-Menten model must be excluded because, as in the NGP, the test for the intercept and the slope were significant, P=0.0036 and P=0.0057, respectively. Except Linear regression model, all others have very close RMSE values. It means that all other models have bigger predictive power than linear one. The lower RMSE belongs to Logistic model (373.74) and even for underweight piglets data, the real average asymptotic weight is very near to those predicted by the Logistic equation.

Analyzing the obtained results, the most adequate model for fitting individual growth curves, both for “normal growth piglets” and “underweight piglets”, seems to be Logistic model.

Graph 1: Mean growth curve curves (grey line=underweight piglets; green line=normal growth piglets)



The Logistic model estimates that the average birth weight of piglets belonging to NGP group is 2010g. Since the confidence interval (95%) for the group NGP is 1197-1382 g with an average value of 1290 ± 244, it seems obvious that the Logistic model overestimates, albeit slightly, the real average birth weight. The same happens with the average birth weight of piglets belonging to UWP group. The confidence interval (95%) 1235.6-1413.7g with average value of 1324.7 ± 289, does not include, in fact, the group mean value of about 1650g, the one predicted by the model.Contrariwise the model calculates average predicted value for parameter A (asymptotic weight) which are included in the confidence interval (95%) for both NGP and UWP groups. In particular the attended mean value of A for NGP was 9609g, comprise in the interval of confidence of 8414-10171g, with an average value of 9292 ± 2784. Likewise the mean value of parameter A estimated for UWP equal to 5023g, is contained in the range of 4261-5042g. This data confirms the goodness of model choice. In

fact all tested models estimated the values of asymptotic weight (A) which are not included in range of confidence interval, for both piglets groups (NGP and UWP) (table 4 and 5 respectively).

To explain better how can vary the curve of growth designed by the Logistic model, in relation to the changing of the parameters (A, B or k), are reported following graphs(2, 3, 4 and 5).

In the application of Logistic equation for each dataset, the parameter A waskept fixed (6000g for UWP and 9000g for NWP group)while the value of B or k changed, as shown in tables below each graph.

Graph 29: NGP: variation of growth curve designed by Logistic model according to the variation of the parameter B

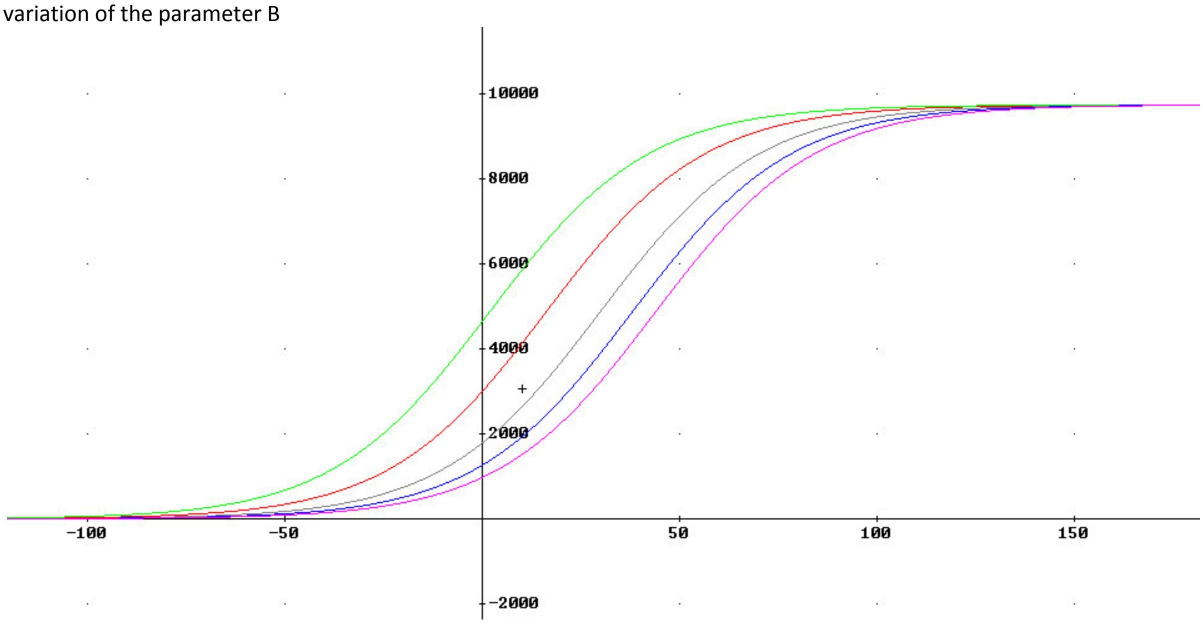


Table 8: NormalGrowthPiglets

Parameters value graph 2			Line color
A=9609	B=3.78	K=0.04	Grey
A=9609	B1=1.89 (50%B)	K=0.04	Red
A=9609	B2=0.945 (25%B)	K=0.04	Green
A=9609	B3=5.67(150%B)	K=0.04	Blue
A=9609	B4=7.56(200%B)	K=0.04	Fuchsia

The graph 2 shows how growth curves vary in relation to the change of B value. In table 8 the values assumed by the three parameters (A, B, k) for each of the 5curves are listed. The grey curve is designed from the equation with the growth parameters predicted by the Logistic model. Curves of different color indicate values of B greater (200% B; 400% B) or lower (50% B; 25%B).

Graph 3: NGP: variation of growth curve designed by Logistic model according to the variation of the parameter k

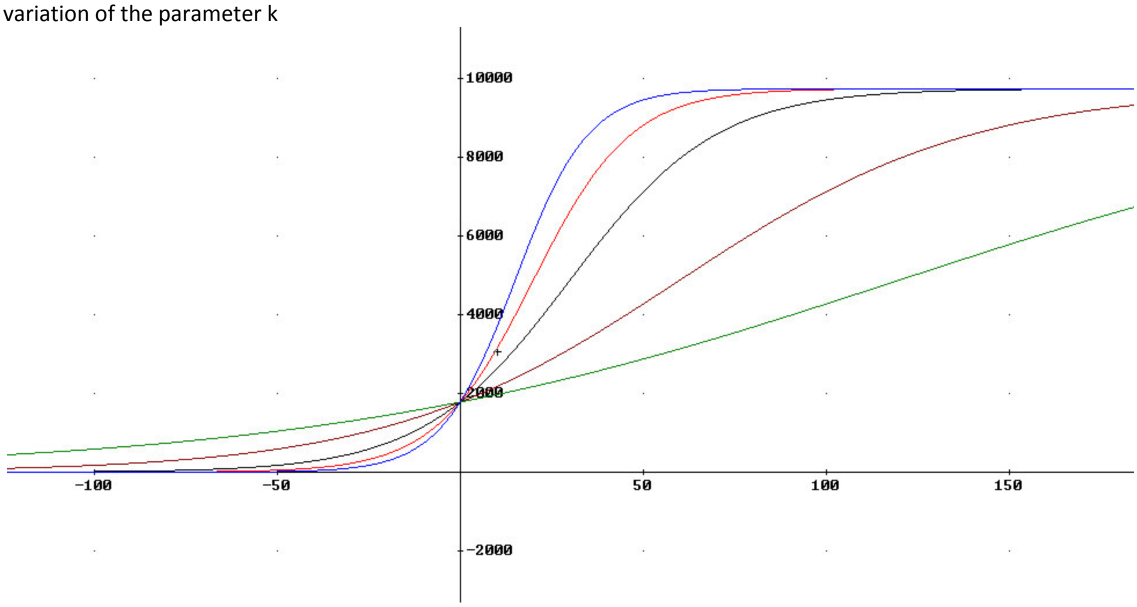


Table 9: Normal Growth Piglets

Parameters value graph 3			**Line color**
A=9609	B=3.78	K=0.04	Grey
A=9609	B=3.78	K1=0.02 (50%k)	Violet
A=9609	B=3.78	K2=0.01 (25%)	Green
A=9609	B=3.78	K3=0.06 (150%k)	Red
A=9609	B=3.78	K4=0.08 (200%k)	Blue

The graph 3 shows the different growth curves of the group NGP designed by Logistic model in relation to parameter B variation. In table 9 the values assumed by each of the three parameters (A, B, k) for each curve are displayed. Grey curve is drawn from the equation with the growth parameters predicted by the Logistic model for NGP group. The curves of different color indicate values of k greater (200% k; 400% k) or lower (50% k; k 25%).

Graph 4: UWP: variation of growth curve designed by Logistic model according to the variation of the parameter B

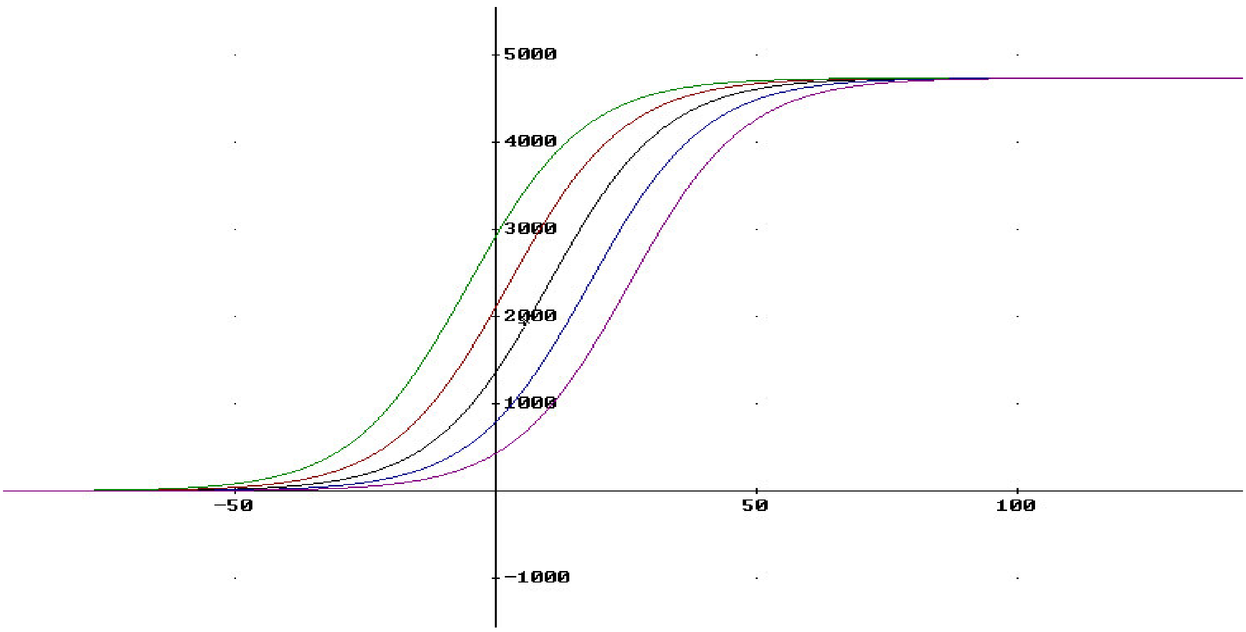


Table 10: Underweightpiglets

	Parameters value graph 4		Line color
A=5023	B=1.98	K=0.06	Black
A=5023	B1=0.99 (50%B)	K=0.06	Red
A=5023	B2=0.495 (25%B)	K=0.06	Green
A=5023	B3= 2.97(150%B)	K=0.06	Blue
A=5023	B4=3.96 (200%B)	K=0.06	Fuchsia

Graph 4 shows how growth curves of UWP group vary in relation to the change of B value. In table 10 the values assumed by the three parameters (A, B, k) for each of the5curves. The black curve is designed from the equation with the growth parameters predicted by the Logistic model. Curves of different color indicate values of B greater (200% B; 400% B) or lower (50% B; 25%B).

Graph 5: UWP: variation of growth curve designed by Logistic model according to the variation of the parameter k

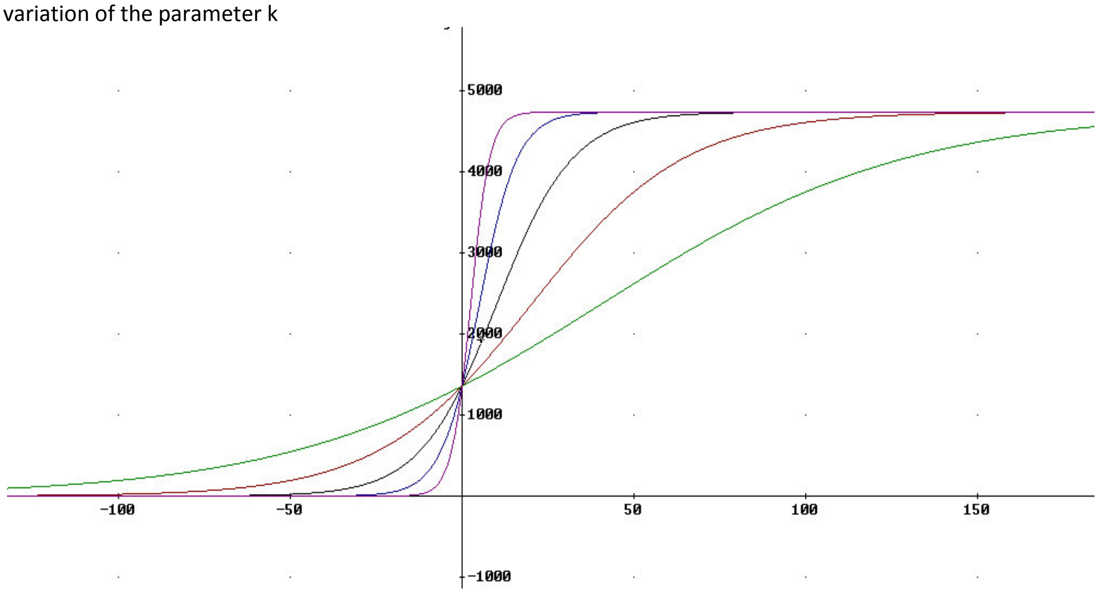


Table 11: Underweight piglets

	Parameters value graph 5		Line color
A=5023	**B=1.98**	**K=0.06**	**Black**
A=5023	B=1.98	K1=0.03 (50%k)	Red
A=5023	**B=1.98**	**K2=0.015 (25%)**	**Green**
A=5023	B=1.98	K3=0.09(150%k)	Blue
A=5023	**B=1.98**	**K4=0.12 (200%k)**	**Fuchsia**

Graph 5 shows the different growth curves of the group NGP designed by Logistic model in relation to parameter k variation. In table 11 the values assumed by each of the three parameters (A, B, k) for each curve. Black curve is drawn from the equation with the growth parameters predicted by the Logistic model for UWP group. The curves of different color indicate values of k greater (200% k; 400% k) or lower (50% k; 25%k).

3.2 Application of Logistic Equation on datasets

The Logistic model was then applied to data belonging to each piglet. In tab. 12 and 13 are shown the new growth parameters predicted by Logistic model for every piglet of both animals group NGP (tab. 12) and UWP (tab. 13).

To respect to beginning dataset, 11 piglets were eliminated because the model did not converge.

Table 12: NGP dataset: new growth parameters estimated by Logistic model

Growth parameters		
A	**B**	**k**
7545	2.0	0.06
9918	3.2	0.04
7317	1.8	0.06
15036	4.9	0.03
10786	4.7	0.04
12206	4.4	0.04
6717	2.8	0.08
10213	5.0	0.05
5623	3.4	0.14
5016	3.3	0.10
4980	2.5	0.13
6328	3.2	0.09
5345	1.9	0.13
5731	3.6	0.10
11618	6.6	0.05
13365	8.9	0.05
13645	6.5	0.05
8866	4.5	0.05
6656	3.0	0.08
11362	4.8	0.05
6591	2.9	0.06
9756	3.7	0.05
6629	3.3	0.06
7061	5.1	0.09
10032	7.3	0.06
11843	6.1	0.05
12255	4.1	0.05
12255	4.1	0.05
7618	4.0	0.06
12531	5.4	0.06
11566	6.6	0.05
14088	8.9	0.06
7865	4.5	0.07
7942	5.8	0.07
6454	3.5	0.07
11497	6.3	0.05
8571	5.1	0.06
9641	7.5	0.05
7445	4.9	0.05
9533	5.8	0.06
11547	6.2	0.05

Table 13: UWP dataset: new growth parameters estimated by Logistic model

growthparameters		
A	**B**	**k**
3921	1.9	0.15
5577	2.9	0.09
6392	3.1	0.06
2771	1.1	0.07
5744	4.6	0.08
4737	2.4	0.05
4848	2.8	0.08
5522	3.4	0.10
5409	3.9	0.09
4146	1.6	0.15
4684	2.7	0.14
4688	2.7	0.16
5542	3.2	0.13
4397	2.7	0.16
3254	2.7	0.12
4288	2.3	0.23
3968	2.2	0.30
5080	2.3	0.17
3847	1.7	0.27
3627	1.5	0.15
4080	1.9	0.25
4150	2.1	0.24
4570	3.0	0.25
6395	4.9	0.04

3.3 ANOVA analysis

Table 84: general linear model parameter A*vs* farm; piglets group.

source	DF	Seq SS	Adj SS	Adj MS	F	P
farm	1	36703092	5216525	5216525	0.98	**0.325**
pigletsgroup	1	2.95E+08	2.93E+08	2.93E+08	55.28	**0.000**
farm*group	1	50150	50150	50150	0.01	**0.923**
Error	61	3.24E+08	323591378	5304777		
Total	64	6.56E+08				

ANOVA analysis on the asymptotic weight (A) (table 14), indicates that it is not affected by the farm (p=0.325). in consequence, the mean values of A predicted by Logistic model, both for NGP and UWP, are not significantly different (graph 6). It means that the management of animals does not have a relevant influence on piglets asymptotic weight. Contrariwise, group effect is highly significant. The average asymptotic weight discriminates significantly the two different piglets groups (NGP and UWP). NGP have an asymptotic weight predicted by model significantly heavier than the asymptotic weight of UWP, with a value of 9236g and 4719g respectively (graph 6).

There is no significant interaction between the farm and group effect (p=0.923).

Graph 610: Least Squares Means for parameter A for farm (A *vs* B) and for piglets group (NGP *vs* UWP)

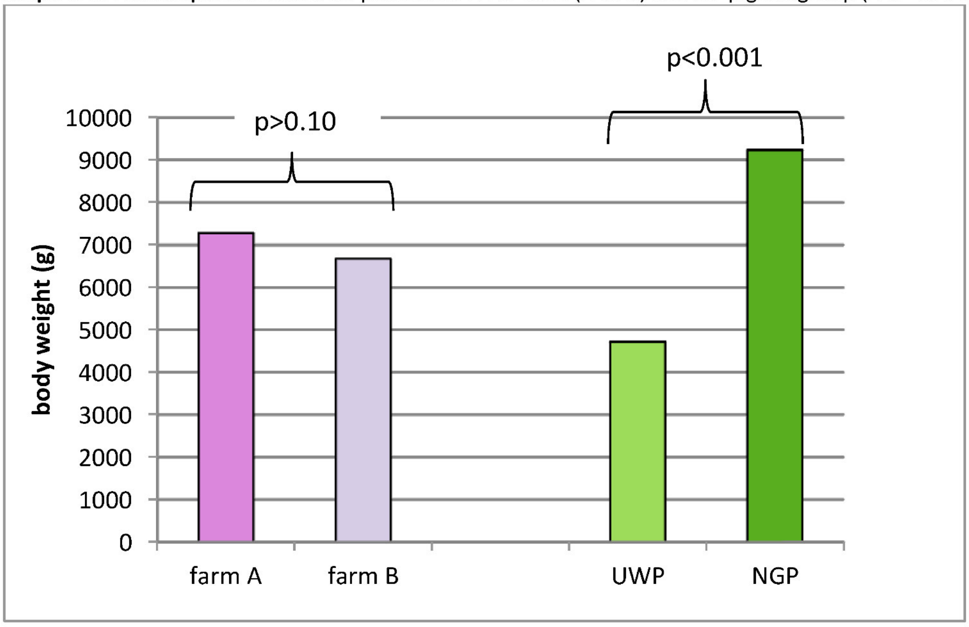


Table 15:general linear model parameter B*vs* farm; piglets group

source	DF	Seq SS	Adj SS	Adj MS	F	P
farm	1	23.739	8.072	8.072	**3.79**	**0.056**
pigletsgroup	1	50.102	51.433	51.433	**24.17**	**0.000**
farm*group	1	1.691	1.691	1.691	**0.79**	**0.376**
Error	61	129.793	129.793	2.128		
Total	64	205.325				

The B parameter (table 15) tended to be affected by farm. In fact, the mean B values predicted by the model for each piglets group, NGP and UWP, are close to be significantly different (p=0.056), with a value of 4.02 and 2.28 respectively. Probably the rearing system linked to feeding, animal welfare, sow pregnant and lactating management, has an effect on piglets grow rate. Because of very similar farming system the difference detected by analysis between the two farms, in relation to grow rate, is probably due to animal genetics. The ANOVA analysis on parameter B is highly significant in relation to the two groups (p<0.001). Considering that piglets have been divided in two groups according to their body weight (>6kg or <6kg) at a definite age, it is clear that the rate of growth is the principal factor which affect their belonging to the group of normal growth piglets or to underweight ones (graph 7). There not interaction between farm and piglets group (p=0.38) (graph 7).

Graph 7: Least Squares Means for parameter B for farm (A *vs* B) and for piglets group (NGP *vs* UWP)

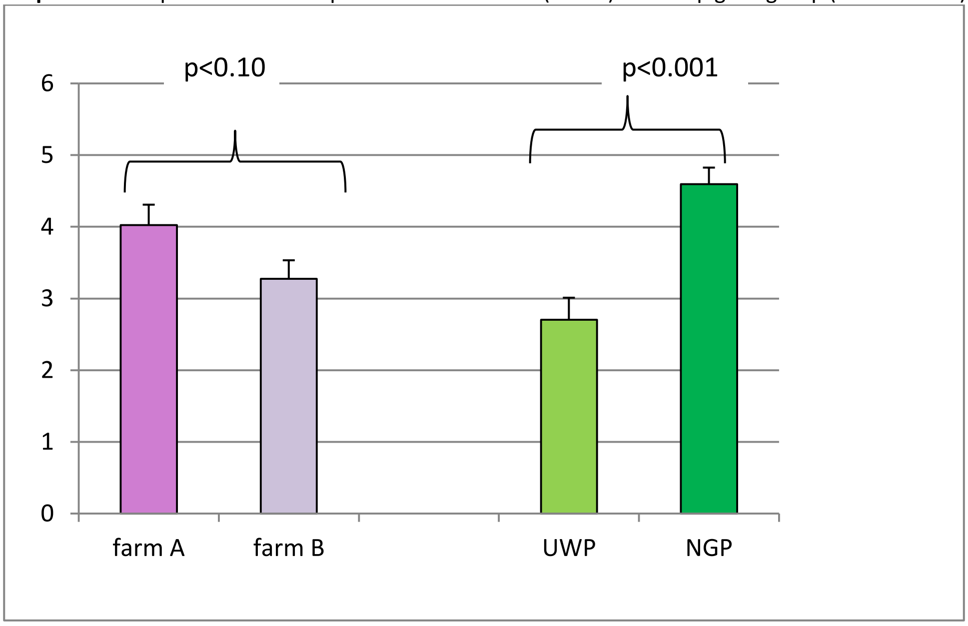
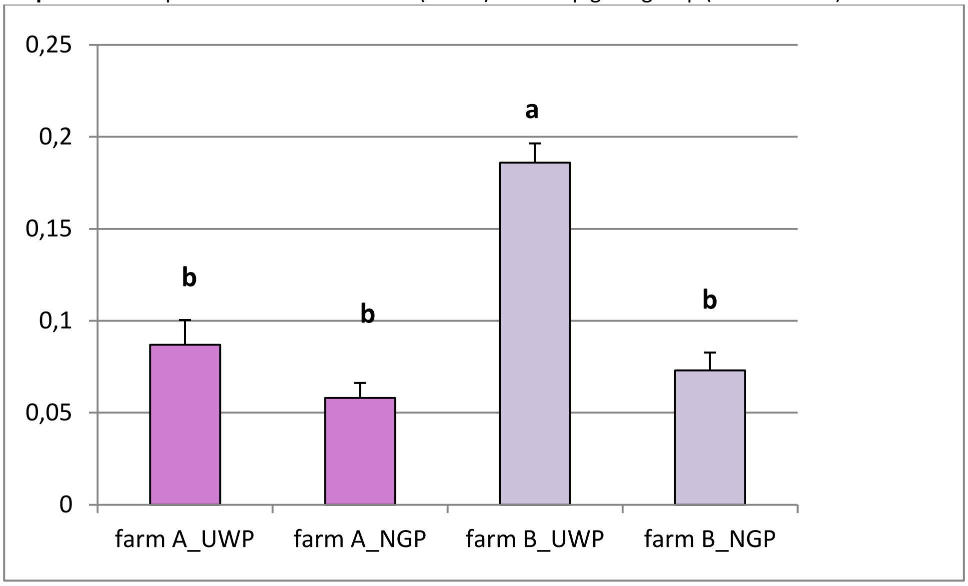


Table 15:general linear model parameter k*vs* farm; piglets group.

source	DF	Seq SS	Adj SS	Adj MS	F	**P**
farm	1	0,058565	0,046631	0,046631	28,89	**0,000**
pigletsgroup	1	0,081347	0,071998	0,071998	44,6	**0,000**
farm*group	1	0,025034	0,025035	0,025036	15,51	**0,000**
Error	61	0,098474	0,098474	0,001614		
Total	64	0,26342				

The k parameter is highly significant affected by farm, group and interaction between farm and group (table 15). In graph 8 are reported the least square means according to farm (A or B) and to piglets group (UWP or NWP).

Graph 8: Least Square Mean for k for farm (A *vs* B) and for piglets group (NGP *vs* UWP)



All factors which affect the growth rate of young animals have an effect even on the k parameters, the rapidity of piglets to reach a determinate weight.

This is clearer by observing the variations of the curves (in function of the change in the value of the parameters B or k). The results are very similar for both groups, the NGP and the UWP.

The parameter K indicates the rapidity of growth. Increasing the value of this parameter has as a result a sudden rise of growth curve, showing a change in the type of growth. The asymptotic weight is reached in a shorter time if k increases. In the case of UWP group seems that the growth is more rapid. But, in reality, underweight piglets must achieve a much lower asymptotic weight of NGP, 6000g and 9000g, respectively. That's why the curve shows a more rapid attainment of mature weight. In trials done on other species like llamas the k parameters appear to be affected by factors as mouth and year of birth, or rearing management (Canaza-Cayo et al., 2015). These are factors difficult to evaluate in our study, because it comes from animals born the same year, in the same season in comparable farming systems.

The rapidity of growth in suckling piglets depends on the quality but also the quantity of milk consumed (Quiniou et al., 2002).In this phase of piglets life the growth in term of ADG and in term of rapidity depends first of all by maternal factors and then by the vitality of the piglet. Factors related to the mother are: milk production and functional teats available to the offspring. The elements are mainly related to piglet are birth weight, newborns vitality and the consequential access to the udder (Skok et al., 2007).

Sarda purebreed piglets have a bigger age at weaning than other swine breeds. Sarda piglets begin to make up to higher nutritional requirement taking even solid feed. In this phase the speed of growth is linked, in addition to the availability of food, to the animal welfare. The general condition of piglets is a direct consequence of a possible non adequate neonatal life. Animals that until this moment have not taken the right amount of colostrum and milk, are immunosuppressed animals, underweight and hierarchically disadvantaged (Skok et al., 2007; Devillers et al., 2007; Devillers et al., 2011). The rapidity to reach weaning weight will be adversely affected by these factors (Akdag et al., 2009; Bealieu et al., 2010).

B indicates the growth rate. By increasing or decreasing the value of this parameter does not change the curve shape but simply move through time indicating a harmonious growth. With increasing days of life increases proportionally and constantly the weight of the animals, until reaching the asymptotic weight, regardless of the values of the parameter B.

Because B is a function of asymptotic weight (A) and birth weight (B = (weight gain from birth to the achievement of A) / A,) if the value of B increases, by holding the A constant, it highlights an inferior weight at birth. Contrariwise to the increase in weight at birth (leaving the mature weight constant) the growth rate decreases.

This is due not to the fact that heavier animals grow less, but to the fact that the weight gain from birth to the achievement of the asymptotic weight is lower in piglets with birth weight greater. In fact, the weight at birth, which is shown graphically by the intersection of the curves with the ordinate axis, moves along the axis varying the value of B.

Growth rate (B), in fact is significantly greater in group NGP (3.78) than in group UWP (1.98) while the rapid achievement of mature weight (k) is significantly higher for piglets belonging to UWP group (0.06) than those of the group NGP (0.04) (Table 4 and 5).

Factors which affect value of B are ones that influence piglets weight at birth. Are variables like genetics, sow nutritional and hormonal status (Rehfeld et al., 2004; Wu et al., 2004) and litter size (Škorjenc et al., 2007; Akdag et al., 2009; Beaulieu et al., 2010), parity (Milligan et al., 2002; Škorjencet al., 2007; Akdag et al. 2009) and sex (Quiniou et al, 2002; Bee, 2004). Additionally the quality and the milk intake have an important role in this phase of animal growth.

4. Conclusion

The development and the use of mathematical models are essential to study the growth of suckling piglets. The Logistic model appears to be a good device to design Sarda purebreed. Due to the dimension of the sample more research must be carried out to evaluate the effect of genetics and environmental conditions on piglets growth. Particular attention must be used to breeding and feeding considering peculiarity of the breed, with its advantages and disadvantages, in order to make the farming of swine Sarda purebreed economically sustainable.

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GENERAL CONCLUSION

Data analyzed give a more clear description of suckling time of Sarda purebreed piglets. In agreement with results on other breeds (conventional and native one) birth weight and consequent ADG are affected several variables, in relation to sows, piglets and management factors. Litter size significantly affect birth weight. Contrariwise piglets gender does not have any influence on weight of newborn piglets and their subsequent growth. The effect of management is not a determinant factor in our trial. This is probably due to a common rearing system which characterized the breeding of Sarda swine breed. Anyway the growth rate of Sarda suckling piglets is not constant and uniform. The piglets growth is characterized by an high variability in ADG even within litters. the research demonstrates that increasing energy content of maternal diet during lactation increases suckling pig growth rates and consequently reduced the time to achieve the slaughter or the weaning weight. Considering that Sarda breed piglets reach the right weight in a time twice greater than commercial cross breeds, this result has considerable importance. Even more for piglet farming, representing a typical production, consumed throughout the island. The mathematical models are indispensable instrument to study the growth of suckling piglets. The Logistic model appears to be a good device to design Sarda purebreed growth, in consideration of non uniform growth of piglets, because of its goodness of fitting real weight values.

It is necessary to study other aspects of piglets growth and carcass quality in order to recognize limiting factors and strength of the breed. More research must be carried out to evaluate the effect of genetics and environmental conditions on piglets growth. It remains of fundamental importance the development of an adequate breeding system, to optimize animals management, keeping costs under control and promote Sarda piglet as a typical island product. For this purpose is necessary to enlarge the number of animals per trial and expanding the information on sows and previous animal management, to better interpret the results.

Particular attention must be used to breeding and feeding considering peculiarity of the breed, with its advantages and disadvantages, in order to make the farming of swine Sarda purebreed economically sustainable.