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Par

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Analyse d'une expérience de sélection divergente pour le poids total de la toison chez le lapin angora

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Résumé

Dans cette thèse nous présentons une analyse d'une expérience de sélection divergente chez le lapin Angora français. Les objectifs de l'expérience étaient d'évaluer la réponse à la sélection pour le poids total de toison et pour les caractères corrélés et d'analyser une expérience de sélection sur une population conduite en générations chevauchantes. Nous présentons une vue d'ensemble des facteurs génétiques et non génétiques des caractères quantitatifs et qualitatifs influençant la production de fibre. Parmi des effets fixes, le numéro de récolte est le plus important. Les paramètres génétiques et les tendances génétiques ont été analysés en utilisant un BLUP appliqué à un modèle animal. Pour l'estimation des paramètres génétiques on a employé un modèle avec mesures répétées des mesures dans lequel les récoltes successives ont été considérées comme un caractère répété. Les résultats ont prouvé que la sélection pour le poids total de toison a été efficace et une divergence de trois écarts types génétiques a été observée entre les souches haute et basse après huit années de sélection. La sélection pour le poids total de toison a augmenté de manière significative la longueur de jarres et le rapport entre les nombre de follicules secondaires et primaires (rapport S/P). Dans le même temps, la compression, la résilience, le diamètre de duvets, et le diamètre moyen de fibre ont diminué. Ces changements s'expliquent par des corrélations génétiques moyennes à élevées entre le poids de toison et la longueur des jarres, et entre les dimensions de fibre et le rapport S/P, la compression et la résilience. Ainsi, la sélection pour augmenter le poids total de toison a induit une augmentation des composantes quantitatives et qualitatives de la production de laine du lapin Angora français. La mesure du poids total de toison est simple et facile au niveau de l’élevage.

Cette thèse fournit également de nouveaux paramètres génétiques résultant des mesures par l'analyseur de diamètre de fibre optique (OFDA). Il s'agit d'une méthode rapide pour mesurer les caractéristiques de la fibre Angora. Certaines de ces mesures sont intéressantes en raison d'une corrélation génétique élevée avec les caractéristiques du follicule pileux. La méthodologie OFDA est une alternative intéressante pour évaluer des caractéristiques importantes telles que le diamètre de fibre et le coefficient de variation du diamètre des fibres.

Nous décrivons les paramètres démographiques et généalogiques de la population étudiée. En outre, nous étudions la différentielle de sélection pour le poids total de toison et le poids corporel. La caractéristique principale de notre approche est la description de la différentielle de sélection en comparant les candidats à la sélection, les parents potentiels et les parents théoriques. La description démographique et génétique a prouvé que dans les deux souches sélectionnées on a appliqué pendant 8 ans une conduite proche. Notre travail apporte des résultats originaux sur les effets de la sélection chez le lapin angora et sur la conduite d'une sélection en générations chevauchantes.

Cette thèse a aussi un intérêt pratique pour les sélectionneurs de lapin Angora. Cette thèse est également le dernier projet de recherche de l'INRA après presque 30 ans de recherche sur cet animal.

Mots clés : lapin Angora, sélection divergente, générations chevauchantes, héritabilité, laine.

Abstract

In this thesis, we present our research to analyze the efficiency of an experiment of divergent selection in French Angora rabbit. Objectives of the experiment were a) to assess genetic parameter estimates for total fleece weight and correlated trait and b) to get an experience on management of a population of angora rabbits under selection with overlapping generations. This thesis is also the last research project of INRA after nearly 30 years of research on this animal. We present an overview of the genetic and non-genetic factors of quantitative and qualitative traits influencing fibre production. Among fixed effects, number of harvest was the most important. The genetic parameters and genetic trends were analysed using a BLUP animal model. For estimation of genetics parameters the repeatability model was used in which wool harvests from third until 12th have been considered as a repeated trait. Results showed that selection for high and low total fleece weight was successfully performed and a divergence of three genetic standard deviations was observed between the high and low lines after eight years of selection. Selection for total fleece weight significantly increased bristle length, secondary to primary follicle ratio and comfort factor and decreased compression, resilience, bristle diameter, and average fibre diameter. These changes resulted from moderate to high genetic correlations between total fleece weight and bristle length, and between fibre dimensions and secondary to primary follicle ratio, comfort factor, compression and resilience. Thus, selection for increasing total fleece weight results in an increase of both quantitative and qualitative traits of wool production in the French Angora rabbit. Measurement of total fleece weight is simple and easy at the farm level. Selection for this trait has positive effects on fleece characteristics such as bristle length, follicle population and fibre diameter.

This thesis also contains new genetic parameters Angora fibres resulting from measurements by Optical Fibre Diameter Analyser that we provide a rapid method for measuring the characteristics of Angora fibre. Some of these measurements are interesting because of having a high genetic correlation with follicle traits of skin. The OFDA methodology is an interesting alternative to evaluate important characteristics such as fibre diameter, CV of fibre diameter and bristle content through measuring of comfort factor.

We describe the demography and genealogy of the studied population. In addition, we study differential of selection for total fleece weight and body weight. The main characteristic of our approach is the use of new method for description of differential of selection in candidates of selection, parent and theoretical parents. Description of demography and the genetic structure in this study showed that in the two divergent lines, the similar management of reproducers has been done successfully during 8 years of selection. Our work contributes to the research in two areas that are estimation of genetic parameters with multivariate models of best linear unbiased prediction of breeding value and theoretical investigation of selection in populations with overlapping generations.

This thesis is also of practical interest for Angora rabbit breeders for knowledge of effects of selection for total fleece weight and correlated traits.

Keywords: Angora, divergent, heritability, overlapping generations, rabbit, selection, wool.

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Contents

Abbreviations

TFW	Total fleece weight
9LW	Live weight 9 weeks before wool harvest
WAJ1	weight of bristly (Jarreux) wool
WAW1	weight of woolly wool
HOM	Homogeneity
LW4	Live body weight at age of 4 weeks
LW8	Live body weight at age of 8 weeks
LW12	Live body weight at age of 12 weeks
LW16	Live body weight at age of 16 weeks
LW20	Live body weight at age of 20 weeks
BL	Bristle length
DL	Down length
BD	Bristle diameter
AFD	Average fibre diameter
CF	Comfort factor
S/P	Secondary to primary follicle ratio

Introduction

Before the beginning of recorded history, the complete fleece of sheep was spun and made into clothe by man and there seems little doubt that one of the earliest textile fibres available for spinning into yarn and then weaving into cloth was wool from sheep. The art of spinning wool into yarn developed about 4000 B.C. and encouraged trade among the nations in the region of the Mediterranean Sea. In other world areas, other natural fibres such as cottons or silk were used to make desirable clothing. The ancient Egyptians, Babylonians, Greek and Hebrews did hand spinning and hand weaving in the home even women of high rank made their own clothing. The wool industry developed all over the world along the lines of a household craft rather than as a primitive factory system and the Romans probably established the first wool factory.

The beginning of the textile industry is traced to the end of the 17th century. Then in the 1700s, English textile manufacturers developed machines that made it possible to spin thread and weave cloth in large amounts quantities. The establishment of more and larger cloth factory influences the development of sheep breeding and the improvements in the wool supply from the 19th century. In parallel, cashmere produced by goats and other rare or luxurious fibres such as mohair from angora goats, angora from Angora rabbit, alpaca from South American camelids were progressively used and processed by the textile industry to make superb apparel fabrics and luxurious products. From the end of the Second World War, due to a large increase in demand of textile products, synthetic fibres such as nylon and polyester were developed to complete and substitute natural fibres. Thus, the part of animal fibres in total textile fibres use by manufacturers declined progressively to about 3% today. World demand for textile fibres was 44 million tons in 2005. Wool is the largest animal fibre industry with 1.3 million tons/year while luxurious fibres such as mohair, cashmere angora and alpaca represent only 3% of the total animal fibre production.

Angora fibre production is the third largest fibre industry in the world after wool and mohair (sheep fine wool 100,000, Angora goat 25,000, rabbit angora 8,500, Cashmere goat 5,200 and Alpaca 4,000 tons in 1998). France dominated the world market for Angora fibre prior to the 1950s. Until 1970, world production was stable at around 1,000 tons per year. There were regular fluctuations in demand, and prices reflected this demand fluctuation. As prices rose and Angora fibre in storage was sold, there was a rise in price followed by a collapse in trade due to a lack of supply. Farmers were unable to increase production during this period due to financial constraints for investment and uncertainty about future prices. However, from 1976 to 1988, there was a sharp increase in demand and the increase in demand was at a higher level than the previous increases in demand. However, supply only increased slowly at first as production could not be increase rapidly. From 1988 to the end of 1991, the number of Angora rabbits in France fell from 280 000 to 60 000. The main cause of the sharp decline in number was low demand for top-quality angora wool and increased production of cheaper angora wool in China (Thébault et al., 1992). China dominates the world Angora fibre trade, producing more than 90% of the world angora fibre. China has taken over the position in the world market traditionally held by France as the main source of angora up to the 90's. Today the Angora rabbit production in France was estimated to be approximately 5000-8000 rabbits with an annual production of 2 tonnes of fibre in 2005 (personal communication with Union of French Angora Rabbit Breeders). Most of the farms contain 10-200 rabbits. These farms are located mainly in the Pays de Loire region. The current raw Angora fibre price for classed wool is approximately 40 €/Kg in the domestic markets while price on the world market is 15 €/kg. Farmers' association now integrate and organise the marketing of French Angora and producers control all the steps from farm to final consumer. In recent years, there has been no supply of raw Angora wool originating from European breeders on to the world markets. Competition with Chinese suppliers is economically difficult for European procedures. German-bred Angora rabbits are of high international repute, and every year German breeders export sires for breeding. The Angora wool production in India has been estimated to be 25 to 30 tonnes per annum (Risam et al., 2005).

Genetic improvement of fibre-producing animals

Genetic improvement programmes for fibre production are different due to difference in coat composition, fibre growth, fleece and fibre characteristics between fibre-producing animals.

Wool is not a homogenous product but varies enormously among breeds in its characteristics and therefore, its end use. Merino wools are relatively fine, soft and white and are primarily processed through the worsted manufacturing process to produce light- and medium-weight apparel fabric. The wool from the majority of British breeds and crosses with finer types are coarser, mainly white and processed through both the worsted and the woollen manufacturing systems to produce heavyweight apparel fabric and fabric for upholstery and their interior textiles. The carpet-type wools from speciality carpet-wool breeds, as well as hairy sheep breeds, are generally coarse, medullated and sometimes pigmented. This wool is most frequently used in floor covering and other furnishing fabrics and fillers. Merinos and crossbred Merino types dominate world wool production and form the vast majority of the total value of the traded wool in the world. Genetic improvement of raw wool is aimed at increasing the production of fibre from a fixed resource to give a greater economic return per hectare; and/or improving the quality of the fibre so that it can be processed into superior end-product s, than attracting a higher unit value for the wool produced.

The development of efficient breeding programmes relies on the following steps:

- Identifying the appropriate traits that should be improved and attaching a relative economic value that will dictate the emphasis to be applied to each within the breeding programme.

- A precise knowledge of the genetic parameters (heritability and correlations), so that an effective prediction of response to selection can be made and so that animals may be appropriately evaluated for their potential contribution to the breeding programme.

- Evaluating selection strategies that will lead to the most cost-effective means for achieving progress in the breeding objective.

Defining the objectives of improvement is an important initial requirement in establishing breeding programmes in sheep, goat and rabbit improvement.
In “fine apparel wool” of sheep, clean fleece weight, fibre diameter and freedom from coloured fibres should be the objectives of fleece improvement in Merino sheep.

In “general purpose wools” there is little advantage in selecting for finer fibre diameter since, in international trade, there is only a very small price differential for fineness.
In “speciality carpet wools”, increasing fleece weight again is the highest importance in controlling financial return from carpet wool production.

In Angora goat the weight of mohair produced per animal is a major factor in the profitability. Fineness, softness, lustre, freedom from kemps and continuously growing medullated fibres and from pigmentation is also important in mohair breeding programmes. In French Angora goats, an ideal 18-month-old animal with a high clean fleece weight, an average fibre diameter lower than 30 µm, free of kemp and medullated fibres are breeding objectives.

In cashmere goats, down weight, length and diameter of cashmere as well as number of kids weaned per doe and body weight are the traits that have been considered in Cashmere goat improvement programs in China.

In Angora rabbit, improvement programs tend to increase fleece weight but fleece quality criteria depend on the strain. The French breed is selected for producing a bristly wool in which long guard hair within a well structured staple are desirable fibres for making garments and fashion knitwear having a brush appearance. The German breed is selected for a woolly and finer fibre to make soft and very fine yarns for fashion knitwear and thermal underwears. Heritability for fleece traits has been established for both German and French Angora rabbit types.

China has also established a system of State rabbit breeding farms to improve rabbit productivity. The breeding farms with more than 10,000 does are Tianyu Rabbit Co. Ltd., Zhenghai Rabbit Co. and Jingling Rabbit Breeding Farm located in Zhejiang and Jiangsu Provinces of south east China. There are also a number of medium size rabbit breeding farms of about 1,000 does in the South Eeastern and Eastern regions of China. Chinese Angora rabbit breeding programs with double-coated rabbits showed that it was possible to achieve a single coated rabbit with a low level of bristle in the fleece. However, there were serious problems with wool felting on the rabbits and the handling of the fibre in the processing systems. This led the Chinese industry to breed for a double-coated Angora over the past two decades to reduce the incidence of wool felting on the rabbit.

In Australia, Schlink and Liu (2003) proposed that breeding of Angora rabbits with low bristle content or bristle removal during processing may provide an alternative to high value fabric based on as Shahtoosh which has a fibre diameter of approximately 11.5 microns, a minimum fibre diameter of six and maximum of 17 microns. This fibre diameter range is well within the fibre diameter distribution of Angora rabbit down. Australia may have an opportunity to specialize in the production of Angora fabrics based on breeds with low bristle content and/or develop processing systems to remove any bristles that are present in Angora fleeces.

The Chinese and French industries currently produces fibre that are not suitable for the production of next to skin fabrics wear due to the high micron bristle fibres in the yarns. Chinese textile training institutions were of the opinion that Angora was not suitable for next to skin wear due to the bristle content of the yarns produced. However, Germany until the late 1980s produced extensive lines of next to skin wear as sport underwear and lightweight suiting fabric. There are small quantities of these products still on the market as health wear products. German processors also produced wash and wear fabric for the men's suiting market. France still maintains a presence in the Angora industry by retaining ownership of the fibre until at least the yarn stage of processing.

Questions to be answered

In sheep wool breeding, many estimated genetic parameters are available given us a relatively precise prediction for expected responses to selection. Strictly, though, such estimates are population-specific and are relevant to one generation of selection, despite their frequent use across a wide range of populations and many rounds of selection. Selection flocks, where selection has been based on a single trait or a restricted range of traits, have been used widely in the Merino. The major aim of such flocks was to check the prediction that selection response would be effective, but important secondary aims were to improve the understanding of wool and skin biology and to investigate the physiological consequences of selection on production traits.

In contrast to sheep, few genetic studies have been conducted with the Angora rabbit, and these studies estimated genetic parameters generally with regression method in non-selected populations. The objectives of thesis were to study direct and correlated responses to two-way (divergent) selection, to throw further light on the relative importance of the components of wool weight, and to provide animals differing widely in single character for use in future studies. Our work in this thesis consists in the analysis of an experiment of divergent selection in French Angora rabbit that was realised from 1994 to 2001.

This manuscript is structured as follows: In Chapter 1 we present literature review on genetic and non-genetic factors of quantitative and qualitative traits influencing fibre production in rabbits and others fibre-producing animals. In chapter 2, we study non-genetic effects and direct response to selection. Finally, we give in this chapter the effect of selection on total fleece weight at adult age on this trait at young age.

In chapter 3, new characteristics of Angora fibre using the Optical Fibre Distribution Analyser are described. This work was motivated by the fact that there is no study about fibre curvature in Angora fibres. In chapter 4, we study correlated responses in wool characteristics. New genetic parameters of fibre diameter and hair follicle density in Angora rabbit will be described in this chapter.

In Chapter 5, we describe the demography and genealogy of the studied population including methods that we developed to compute the generation intervals in French Angora rabbits. Also in the same chapter, we study differential of selection for total fleece weight and body weight.

In the appendix, I present *the new chapter in the thesis* that I did with CABINET PROGRESS (www.progress-rh.com). It helped me to be aware of all the assets I held from my doctoral education and I thought about using them to convince employers. In addition, it leads me to regard my thesis, no longer as a scientific subject only, but as a personal and professional experience, a genuine project I have managed in every aspect and which allowed me to develop many different skills.

Finally, we give some conclusions and possible tracks that deserve further research.

1 Literature review: Genetic and non genetic factors of quantitative and qualitative traits influencing fibre production in Angora rabbit and other fibre-producing animals

RESUME

Ce chapitre propose une revue bibliographique sur la biologie des pelages, la croissance des poils et l'amélioration de la production de toison chez différentes espèces animales produisant des fibres à usage textile. L'objectif est de déterminer les relations entre la quantité de poils et les caractéristiques de la toison et des fibre produites en vue de définir les critères de sélection chez le lapin angora à partir d'une analyse bibliographique des facteurs de variations génétiques et non génétiques de la production de poils chez le lapin angora.

Les fibres kératiniques animales représentent 3% de l'ensemble des fibres utilisées par l'industrie textile. La laine produite par le mouton représente l'essentiel (97%) de ces fibres animales, mais les fibres spéciales telles que le mohair, l'angora et le cachemire sont très recherchées pour la fabrication de fils particuliers et la confection de vêtements hauts de gamme.

La laine et le mohair sont produits respectivement par le mouton et la chèvre angora. Ce sont des espèces dont le pelage est composé d'un seul type de fibres à croissance permanente. Le poids total de toison et la finesse des fibres sont les principaux critères déterminant le revenu des éleveurs. La présence de fibres grossières et médullées n'est pas souhaitée. La toison est récoltée par tonte une fois par an chez le mouton et tous les 6 mois chez la chèvre angora pour une production annuelle de laine propre qui est de 1 à 3 kg chez le mouton et de 2 à 3 kg chez la chèvre angora.

Le cashemire correspond au duvet de la toison d'un type de chèvre dont la toison est composée de 2 types de fibres: des jarres grossiers indésirables et des duvets fins qui doivent être séparés lors de la récolte par peignage puis par éjarrage mécanique. La croissance des poils est saisonnière et la récolte doit avoir lieu 1 fois par an avant la mue de printemps. La chèvre produit entre 100 et 500g de cashemire propre par an.

L'angora est une fibre médullée produite par le lapin Angora dont la toison composée de 2 types de poils désirables est récoltée tous les 3 mois. Le lapin angora produit 1 kg de laine propre par an.

Il existe 2 types de lapin angora.

Le type « français » est porteur d'une toison parfaitement structurée avec des jarres de 8-10 cm et des duvets fins de 6-8cm de longueur. Sa toison est récoltée par dépilation, ce qui permet d'induire et de synchroniser la croissance d'un nouveau pelage avec une mèche bien structurée. Ce type de toison dit « jarreux » est recherché pour la fabrication de fil « fleuffé » et la confection de tricots haut de gamme.

Le type « allemand » est porteur d'une toison « laineuse » récoltée par tonte avec une proportion de poils grossiers moins importante et une mèche non structurée où les 2 types de poils ont des longueurs similaires.

Par rapport aux autres espèces produisant des fibres textiles, le lapin angora présente les caractéristiques suivantes.

- Il produit 1 kg de poils par an soit le quart de son poids adulte. Ce ratio est très faible (de l'ordre de 1 à 7%) chez les autres espèces.
- Le développement du pelage et la multiplication des follicules pileux se poursuit après la naissance jusqu'à l'age de 8-10 semaines lorsque l'animal atteint 50% de son poids adulte. Chez le mouton et la chèvre, la très grande majorité des follicules pileux sont présents dès la naissance.
- La toison du lapin angora est composée de 2 types de poils où les poils longs et grossiers sont des fibres désirables pour la fabrication de fils « fleuffés » et la confection de tricots haut de gamme ayant un aspect volumineux.
- Le mâle a une production de poils plus faible que la femelle. Cet effet est contraire chez le mouton et la chèvre.
- La production maximale de poils est observée en hiver chez le lapin et en été chez le mouton et la chèvre.

Chez le lapin Angora, les principaux facteurs non génétiques influençant le poids de toison et les caractéristiques de la toison et des fibres sont l'age, le sexe, la méthode et la saison de récolte, le statut physiologique de reproduction et les conditions d'élevage. La production de fibres augmente de façon très importante avec l'age jusqu'à la 4ème ou 5ème récolte. La femelle angora produit 5 à 30% plus de poils que le mâle mais la mise à la reproduction de la femelle entraîne une diminution de sa production de poils.

Chez le lapin angora, les valeurs d'héritabilité pour le poids total de toison, les caractéristiques de la toison et des fibres rapportées dans la littérature sont très variables mais les valeurs les plus probables sont de l'ordre de 0.20 à 0.50. Les corrélations génétiques entre les différents caractères de la toison sont peu nombreuses et variables. La méthode utilisée pour estimer les paramètres génétiques constitue la principale cause de variation observée dans la littérature, l'essentiel des études ayant été réalisées à l'aide de la méthode des moindres carrés sur de faibles effectifs.

1.1 Introduction

1.1.1 Animal fibre characteristics

Wool is a protein fibre principally composed of keratin produced by sheep. The fibre is made up of overlapping cuticle scales and an inner cortex. Both the cortex and the cuticle influence the fibre properties of the wool and the fibre is slightly elliptical, unlike other animal fibres. With the wide range of sheep breeds, the fibre properties of the produced wool are equally wide ranging. The particular fibre characteristics of specific breeds can be exploited by processing the fibre into appropriate end products. In a general sense, wool varies from the super fine Merino producing a fibre similar to cashmere, very high lustre English breeds producing mohair-like fibre, and coarse hairy wools similar to the guard coat of some goats.

The range of fleece weights produced annually by sheep is from 2-5 kg clean depending on the breed and the farming environment of sheep. The fleece is usually shorn annually. In the countries where sheep owners’ income from wool is less important, the annual fleece weights are lower, i.e. from 1-3 kg clean. The range of fibre diameters between the different sheep breeds varies from 15 microns grown by superfine Merinos through to 45 microns produced by the carpet wool sheep. The length of wool produced is influenced by breed and fibre diameter. Merinos range from 60-110 mm if shorn annually through to the coarse carpet wools ranging from 100-200 mm annually.

Angora goats produce mohair. It is a white, smooth and lustrous fibre with a silky, luxurious appearance and has a high tensile strength but it is also very hard wearing. The flat, overlapping scales covering the fibre cause the smooth lustrous appearance. Although mohair - like wool - consists of the protein keratin, it nevertheless differs from wool in certain respects. The cross-section of wool is slightly elliptical, whereas the very fine mohair fibre is round. The scales are larger than wool and lie flatter, making a smoother fibre surface. The resultant greater reflection of light gives mohair its characteristic lustre.

The fleece value determined by fibre diameter, lustre, softness, freedom or near freedom from kemps, and clean yield. Kemps are short, heavily medullated and coarse fibres. Kemp fibres contain air spaces (medulla) which reduce the effectiveness of dye and in a finished cloth show up as being much lighter in colour than the other fibres. Although in certain end uses kemp can be used to create a special effect, in mohair kemp is undesirable - too much kemp will cause serious problems in spinning and dyeing. The presence of any foreign material in the fleece will affect the quality of the final product and will have to be removed prior to processing, adding to the cost of manufacture. Kemp can be controlled or reduced by genetic selection. Angora goat provides approximately 2-3 kg of mohair per shearing. This is typically done two times a year. The fibre length averages 12 to 15 cm long. Range of fibre diameter varies from 25 to 40 microns depending mainly on the age of animal.

Cashmere is a type of goat, not a breed. Cashmere fibre can be clipped from almost any goat other than Angora. Cashmere is from the undercoat and is usually combed off the goat. White, brown or grey solid coloured goats are preferred over mixed coloured goats. The average yield is between 150 to 500g of down per goat per year. The coarse and down hairs are separated by a mechanical process called dehairing. The long fibres are used in knitted garments. Shorter cashmere fibres go into woven fabrics. The fibre diameter must be less than 19 microns to be classified as cashmere. The typical range is 16 to 19 microns. China leads the world in cashmere production.

South American Camelids produce alpaca. There are two types of alpaca; the huacaya, which accounts for 80 per cent of the total, and the suri, which makes up the remaining 20 per cent. The fibre obtained from the suri is the longest and most highly prized. The fibre of the alpaca is medullated, fine and silky, between 20 and 34 microns in diameter and 8-12 cm in length. The fleece comes in a wide variety of shades, which is a special characteristic of the alpaca. Colours range from pure white and various shades of white - which represent about 80-85 per cent of the clip and have the highest value - to warm fawns, reddish browns and a variety of greys and black. Animals are shorn once a year. The range of fleece weights is 1-2 kg depending on the breed and farming conditions. The quality of the fleece is graded according the presence or not of double coat, the presence of naturally curled or crimped staple and the presence of crimped or straight fibres combined with differences in external shapes (Frank et al., 2006).

Angora is a medullated fibre that is produced by the Angora rabbit. There are two types of angora. The first, known as the "French type", is a typical double coat with a well structured staple made of two main kinds of hair, long coarse bristles of 10-12 cm long which is hollow and does not take dye and shorter and finer undercoat of 6-8 cm long. Used in garments, this type of hair shows up as contrasting pale fibre and is often used to create a fine, brushed appearance. The second type of hair is finer and is produced by an angora rabbit with German origins. It is less spiky in character, and can be used to make a softer yarn that is sometimes viewed as an alternative to cashmere. It is used in very fine yarns for high fashion knitwear and thermal underwear. In the German type, the distinction between bristle and undercoat is not so well defined as the length of bristle is shorter and more variable than in the French type. This difference is mainly due to the harvest method. The German type is shorn every 70-80 days while the French type is plucked every 3 months. Fleece weight range at harvest is 200-350 g for an annual production of about 1 kg.

1.1.2 Biology of coat development and fibre growth

The coat of mammals affords protection against physical damage and environmental events such as temperature variations and precipitations. The mechanical, physical and chemical properties of the different types of hairs forming the coat, and the composition and the structure of the coat all play a role in this protection. Coat composition and structure are modified periodically, so that hairs are replaced and the coat adapts to seasonal climatic changes.

1.1.2.1 Changes in coat composition and structure

In general, there are two main types of hair in the coat, long and coarse guard hairs of the outer coat that provide mechanical protection, and short and fine down hairs of the inner coat that provides the thermal protection. The guard hair are produced by primary hair follicles usually organized in trio groups (Carter, 1943). Secondary follicles appearing within the trio groups produce the down hair.

There are two types of secondary follicles. The epidermal follicles originate from the primitive foetal epidermis as primaries until the first sign of epidermal keratinization. As the keratinized epidermis is not able to produce more new follicles, the subsequent secondaries are formed by branching from existing epidermal follicles (Hardy and Lyne, 1956). These derived follicles with their original epidermal follicle constitute a compound hair follicle. The hairs of derived follicles pass through the epidermis in the common hair canal developed by the generating epidermal follicle. The number of derived follicles varies according to season, and provides additional downs in the winter coat (Rougeot et al, 1984). Hair follicle development of different species is shown in Table 1.1.

Table 1.1: Hair follicle development in different species of fibre producing animals.

	Rabbit	Goat		Sheep	
Hair genesis	Angora	Cashmere	Angora	Primitive	Merino
Onset (foetus)	Day 18	Day 60			
End (post-natal)	2-3 monhs	3-6 months		Birth	
Hair density					
Primaries / group	5	3-5	3-5	3	3
Follicles / group	40-70	10-30	15-35	6-10	45-75
Derived / compound	3-5	1-3	1-3	0	6-8

1.1.2.2 Replacement of hair and fibre growth

There are variations in fibre growth between mammals and specially those that have been selected for fibre or fur production. Types of fleeces vary from a typical double coat to a single coat in which all fibres are essentially similar in their physical characteristics.

In the typical double-type coat, such as in Angora rabbit, Cashmere goat and most of fur-bearing animals including mink, hairs are replaced periodically. The pattern of growth of individual follicles can be divided in 3 main phases, anagen (active fibre growth), catagen (follicle regression) and telogen (resting phase) (Chase, 1954). Shedding of the previously grown fibre tends to occur about the onset of anagen so that at least one hair is in general always present in a follicle. Duration of anagen is constant while duration of telogen can be modified by photoperiodic manipulations, hormones, traumatism and plucking. Thus, a hair may be unchored in the skin by its club root for several weeks without growing. Pattern of hair growth is different in Angora rabbit, Cashmere goat, mink and moulting sheep, but changes in the coat are mainly controlled by seasonal variations in day length.

In mink, two moults, one in spring, one in autumn are observed. Each one progresses over the body according to a specific gradient. Spring moult begins on the muzzle in mid-April and extends towards the tail to give the summer coat. Autumn moult from late August occurs progressing from the tail to the muzzle and gives the winter coat. Summer coat is characterized by a low number of derived hair follicles (12-14 per compound follicle) and the winter coat by a higher number (17-20) (Rougeot and Thébault, 1983). Spring and autumn moults are mainly controlled by increasing and decreasing days (Bissonnette, 1939; Duby and Travis, 1972; Martinet et al., 1984) .

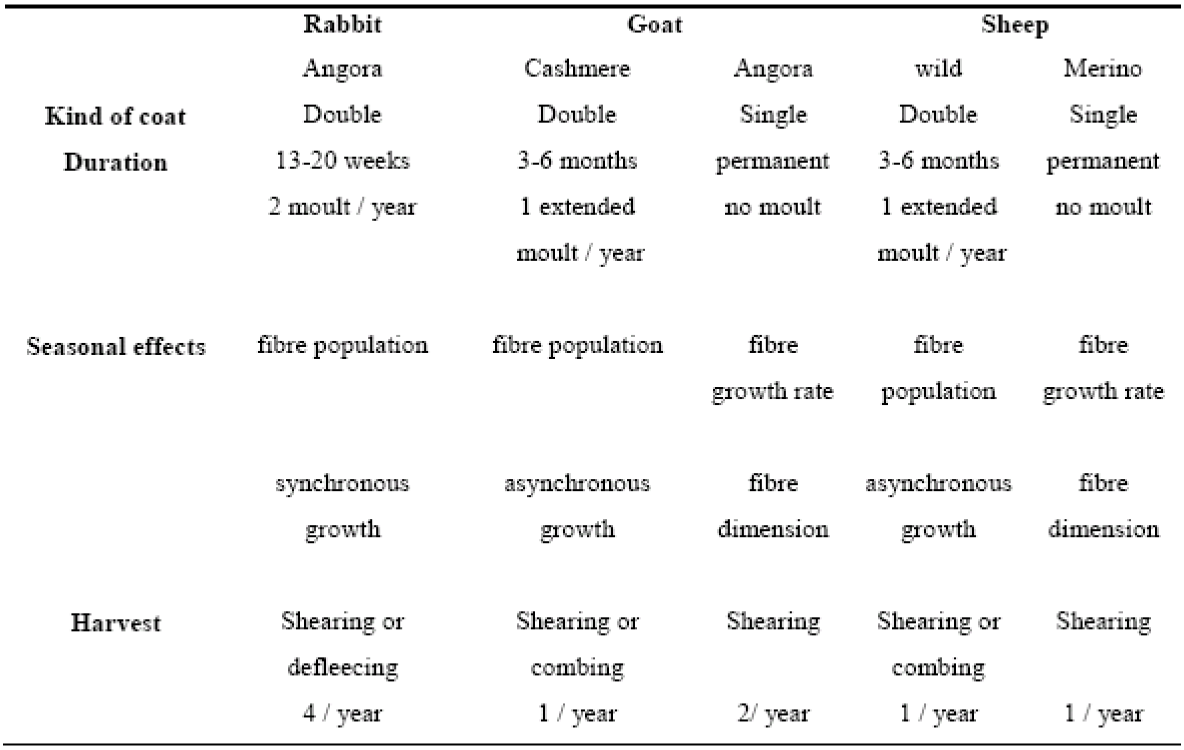
In the Angora rabbit, the different types of hair grow during 12 to 20 weeks. Without any manipulations, moults can be observed in the spring and the autumn, but in commercial farming, Angora wool is harvested at regular intervals by plucking in the French breed or by shearing in the German breed. According to the season and whatever the harvest method, variations in the fibre population are observed. In spring, a part of derived hair follicles regresses to the hair germ stage or disappears without replacing their downs. They are only renewed in the autumn, so that hair density is 20 to 30% higher in winter than in summer (Rougeot and Thébault, 1983).

In goats and sheep, the pattern of fibre growth ranges from a visible moult in the spring with a lesser moult in the autumn in double coat breeds such as Soay sheep and cashmere-producing goats, to apparent continuous growth in single coat breeds such as Merino sheep and Angora goat.

In double coat breeds, primaries are replaced as they are shedding in spring and summer maintaining a covering over the animal, while replacement of secondaries may not occur for 1 to 3 months after shedding. The seasonal pattern of down production in Soay sheep (Ryder, 1978) and cashmere goats (McDonald et al., 1987) begins around the summer solstice and ceases near the winter solstice albeit some subsidiary cycles have been be observed during spring in cashmere goats (Nixon et al., 1991). At the end of the fiber growth, cycle down length is quite similar or longer than guard hair. Thus in double coat breeds, pattern of hair growth is controlled by day length (Rougeot, 1961;Rougeot et al, 1984), and hair density as measured by secondaries/primaries ratio is low in summer and high in winter (Ryder, 1973; McDonald et al., 1987).

In single coat breeds such as Angora goat or modern Merino sheep, fibres grow apparently in a continuous pattern. However, most of the breeds exhibit seasonal cycle of fibre growth with a maximum rate in summer and a minimum one in winter. The amplitude is less pronounced in modern Merino sheep than in Angora goats and most other sheep breeds (Margolena, 1974; Ryder, 1978). The seasonal cycle in fibre growth is associated with concomitant changes in mean fibre diameter, mean fibre volume and growth rate of fibre length (Woods and Orwin, 1988). This seasonal cycle of fibre growth, and occasional fleece shedding, in modern single coat breeds, therefore appears to be a vestige of the moulting cycle of primitive and double coat breeds (Ryder, 1978). Some characteristics of fibre growth of different species are shown in Table 1.2.

Table 1.2: Fibre growth in different species of fibre producing animals.



	Rabbit	**Goat**		**Sheep**	
	Angora	Cashmere	Angora	wild	Merino
Kind of coat	Double	Double	Single	Double	Single
Duration	13-20 weeks 2 moult / year	3-6 months 1 extended moult / year	permanent no moult	3-6 months 1 extended moult / year	permanent no moult
Seasonal effects	fibre population	fibre population	fibre growth rate	fibre population	fibre growth rate
	synchronous growth	asynchronous growth	fibre dimension	asynchronous growth	fibre dimension
Harvest	Shearing or defleecing 4 / year	Shearing or combing 1 / year	Shearing 2/ year	Shearing or combing 1 / year	Shearing 1 / year

1.1.3 The Angora rabbit

The Angora rabbit (Oryctolagus cuniculus) is a species of the order Lagomorpha and is descended from the European wild rabbit. Angora rabbit fibre is categorised in the luxurious speciality fine animal fibre group along with mohair, cashmere and alpaca. The coat of the Angora rabbit is made of three main kinds of hair: bristles, awns and down fibres. Composition of the fleece in Angora rabbit is similar to the normal rabbit, but its structure is modified by the three kinds of hair that are much longer. The angora fibre is about three times longer than the normal hair rabbit. Extension of the active phase of hair growth (anagen) from 5 to 7 weeks in normal rabbits to 12 to 16 weeks in Angora rabbits is at the origin of the unusual length of the coat of Angora rabbit (Rougeot and Thébault, 1983; Rougeot et al., 1984) as it is for mice (Pennycuik and Raphael, 1984). The Angora character is due to a pair of autosomal recessive genes in mice and rabbit. Evidence was reported that mice deficiency in fibroblast growth factor 5 (*fgf5*), produced by gene targeting are of angora phenotype, and that the natural angora mutation corresponds to a large deletion of the *fgf5* exon 1, and part of upstream sequences in the mouse (Hebert et al., 1994; Sundberg et al., 1997). Recently, (Mulsant et al., 2004) suggested that as in mice a defect in the *fgf5* gene may be the cause of the rabbit angora phenotype.

Angora is almost exclusively used in the carded chain, either in drapery, or in hosiery. These two uses led to the selection of two strains of Angora rabbit. One, the German strain, intended to produce a woolly fleece, fine, with a minimum of bristles, is bred mainly in China, South America and central Europe. The other, the French strain, intended to produce bristly Angora, well adapted to the wool clothes industry, is mainly bred in France.

In the French angora rabbit, the hair is collected every 90 to 100 days by depilation when the follicles reach the resting stage and before hair starts falling, which would cause felting and reduces its value. All the hairs have, at the time of depilation, the same duration of growth, but the lengths differences (speed of growth faster of the bristles), that is to say 10 cm and 6,5 cm for the bristles and the downs after 14 weeks of growth, respectively. The diameter of the downs is low, about 15 µm with little variability, contrary to the coarser bristles, nearly 50 µm with variation from 30 to 80 µm. From 1980, French breeders have been using a depilatory fodder sold under the name Lagodendron® (Société Proval, 27 rue de la gare de Reuilly, 75012 Paris). With careful use of this product, rabbits can be plucked more quickly, easily, and less stressfully.

In the German Type, the hair is cut with scissors or electric or manual shears. Since the 1980s, scissors is the more common technique in China, while shearing is more common in Central Europe and South America.

Hair-weight production has long been the sole focus in Angora rabbit selection. These genetic improvement efforts in France and Germany have produced highly similar acceleration of hair growth. At the experimental production unit of INRA in France the annual output of does rose from 885 g/year in 1980 to 1 086 g/year in 1986, a phenotypic gain of 31 g/year. Animals tested at the *Neu-Ulrichstein Hesse Centre* in Germany gained in productivity from 400 g/year in 1945 to 1 350 g/year in 1986: a phenotypic gain of 32 g/year. Production in the French and German commercial sectors lagged slightly behind these figures with an estimated annual production per doe of 1000 g/year under French and 1200 g/year under German production conditions (Lebas et al., 1997).

There are major gaps in China by province and by production systems. For does the figures range from 261 g/year (unspecified Chinese strain, 1985) to 815 g/year (Lebas et al., 1997). Production conditions, particularly feeding, are highly influential because German rabbits under Chinese conditions are, according to the literature, producing from 422 to 820 g/year.
The fleece of Angora rabbit is grade in approximately five grades during harvest. These grades for France are:

- WAJ1 including long > 6 cm for down and bristle
- WAW1 includes long and woolly wool
- WAW2 includes short wool < 6 cm for down
- C.F.W. clean, felted wool
- 1D.W dirty wool

China likewise uses five grading lines but due to coat type differences grade fibre on the basis of fibre length and coat structure with less emphasis on the variation within the fleece. There are no nationwide classing standards for Angora fleeces in China, with the classing requirements being determined by the growers and the markets they are supplying into at the time of shearing. An example of Chinese wool lines are:

- First grade 5 cm single coated fleece
- Second grade 3 to 4 cm single coated fleece
- Third grade 6 cm or longer double coated fleece
- Forth grade 4.5 to 5 cm double coated fleece
- Fifth grade 3 to 4 cm double coated fleece

Homogeneity, compression and resilience are some of the quality traits of angora fibres that have been defined by Rochambeau et al. (1991). Homogeneity has been calculated as the ratio of WAJ1 to TFW and expressed as a percentage. Compression is the resistance of 10 g of angora wool (cm) under 1 kg of weight. Resilience is the height of the mentioned wool sample after taking of the weight (See appendix II).

1.2 Non-genetic factors influencing wool production

In Angora rabbit, the main principal non-genetic factors influencing fibre growth that can be altered by farmers' management decisions are harvest number or age, sex, reproduction, the harvest method, and seasonal influences. The most important, judging by weight at each harvest is the interval between two harvests. This effect is attenuated when considering annual output. Because of the birth season effect, the observed seasonal effect is the result of a birth season effect and a harvest season effect when the harvest number is constant.

1.2.1 Animal factors

Wool production is influenced by the age and sex of animals, and by reproduction in the doe.

1.2.1.1 Age or harvest number

The number of harvest is important (at least at the first harvest) for all rabbit strains and for the second and third harvests in French strains. In French Angora, the young rabbits still produce woolly fur, even after depilation at seconds and third harvests. The total weight of wool harvested in the French breed increases rapidly up to the fifth harvest (Rougeot et al., 1984; Rochambeau et al., 1991; Allain et al., 1999). Total fleece weight at the first harvest is about five times lower than that observed at the fourth or fifth harvest (Thébault and Rochambeau, 1988). Effect of harvest number on wool production of Angora rabbits are shown in Table 1.3.

Table 1.3. Effect of the number of harvest on wool production in Angora rabbits.

Traits	Harvest number					Reference	Remarks
	1	2	3	4	> 4		
Live weight (g)	1461	3075	3460	4063	-	Thébault and Rochambeau 1988	Females
Fleece weight (g)	35	149	200	242	-		
Age (week)	8	21	26	40	-		
Live weight (g)	1430	2919	3463	3815	4099	Rochambeau et al, 1991	Females
Fleece weight (g)	35	152	203	233	248		
Age (week)	8	21	26	40	54		
Live weight (g)	-	-	-	-	-	Allain et al, 1996	Females
Fleece weight (g)	33.45	150.86	200.20	228.76	235.67		
Age (week)	-	-	-	-	-		
Live weight (g)	1246	2707	3208	3344	-	(Eiben, 2000)	Females and males
Fleece weight (g)	17.8	114	178	172	-		
Age (week)	8.5	20	32	44	-		
Live weight (g)	1030	3450	3960	4450	5150	(Fu-chang et al., 2000)	German Angora Rabbit, Females, N=50
Fleece weight (g)	-	187.2	238.0	250.4	247.2		
Age (week)	8	20	32	44	56		
Live weight (g)	1655	2784	3262	-	-	(Jaitner et al., 1988)	German Angora Rabbit, males
Fleece weight (g)	32.8	101.4	138.5	-	-		
Age (week	9	17	24	-	-		
Live weight (g)	1549	2800	3371	-	-	(Jaitner et al., 1988)	German Angora Rabbit, Females
Fleece weight (g)	31.7	110.8	-	-	-		
Age (week)	9	17	25	-	-		

If a comparison is made on the elements of the quality of the fleece of the first five harvests, the first two ones are different. On the other hand the three following harvests are rather similar. There are harvest number differences on mean diameter of fibres. The highest bristle diameter is observed from the third to the fifth harvest, and the lowest from the seventh harvest. Bristle diameter observed at the sixth harvest is intermediate. The fineness of undercoat and coarse wool of male and female German Angora rabbits rose when age increased. The fineness of undercoat and coarse wool of male and female rabbits at 11 months was similar to adult rabbit fineness. Also coarse wool ratio increased when age rose from 5 to 11 months (Fu-chang et al., 2000).

In sheep and goats, fibre production and fleece characteristics are influenced by age. Fibre growth rate increases from birth to a maximum at 3 to 4 years of age after which it declines (Summer and Bigham, 1993). The effect is similar for many sheep breeds (Bigham et al., 1978) cashmere-producing goats (Gifford et al., 1990) and angora goats (Stapleton, 1997). In Merinos, during the declining phase of wool production there is a progressive decline in the density of active follicles and a reduction in fibre volume. Although mean fibre diameter increases there is a relatively greater reduction in staple length. Colour, handle and washing yield also deteriorate, crimp frequency falls and crimp abnormalities increase. Tabbaa et al. (2001) studied effect of age on fleece characteristics of yearling (14–20 months) and mature (28–84 months) Awassi ewes and showed that greasy fleece weight (corrected for body weight) increased with age. Fleeces from F1 ewes from the three wool breeds of Finn sheep, Combo-6, and Borolo Merino and the two hair breeds of St. Croix and Barbados were evaluated by (Bunge et al., 1996). They estimated effect of age from two to 5-year-old F1 ewes by best linear unbiased estimates (BLUE). Age of ewe had a significant effect on fleece weight ($P<0.05$). Fleece weights increased with age, peaked at 3 years of age, and then decreased. Actual staple length decreased as age increased to 4 years of age and then increased in 5-year-old ewes. Two-year-old ewes produced fleeces with a smaller ($P<0.05$) fibre diameter than ewes of the other ages. Age of ewe had no significant effect on proportion of coloured or kemp fibres.Sinha and Singh (1997) noted a high and positive correlation between 3-month weight and wool yield in Muzaffarnagri lambs.

As the goats aged, body weights increased, clean mohair production decreased, and fibre diameter and medullated fibre content increased (Lupton et al., 1996). Allain and Roguet (2003) showed that age of animal have a significant effect on greasy weight of Angora goats. As it rapidly increased (+1.1Kg) from the first shearing at 6 months of age to the third shearing at 18 months of age. In their study, mean fibre diameter increased from 18 months to 30 months of age and over (+1.7). In cashmere goats, weight of down and fibre length declined significantly every year from 2 to 6 years of age (Zhou et al., 2003).

1.2.1.2 Sex

In Angora rabbits, the weight of the fleece was greater in females than males by about one standard deviation for harvests with a harvest number greater than three. The adult females weighed 4100 g and produced 250 g wool every 14 weeks (Rochambeau et al. 1991). The mean guard hair diameter as measured from the third to the sixth harvest is significantly higher in females than in males, respectively 54.1 and 49.5 microns (Allain et al., 1992). The sex factor was very important at the second harvest. It explained 20% of the variation, in favour of female animals (Rochambeau et al., 1998). In German Angora rabbit, annual wool yield of adult females was 4.22% more than that of adult male rabbits (Fu-chang et al., 2000). Production increases when the influence of androgen hormones decreases. Males have less homogeneity, shorter bristle and longer down hair. Sex difference in French and German strain angora rabbits ranges 5-20%, 0-15% respectively, depending upon the breed.

The males hava shorter bristles and longer downs than females when lengths were measured on rabbits whose harvest number was between two and four. In males the length of bristles is 3 to 4 mm shorter and that of down is 2 to 3 mm longer than in females. Males have different fleeces from those of females; they are less homogeneous with longer down hairs and shorter bristles (Rochambeau, et al. 1991). A sex difference in bristle diameter has been observed. The mean guard hair diameter as measured from the third to the sixth harvest is significantly higher in females than in males, respectively 54.1 and 49.5 µm (Allain et al., 1992).

The sex factor is very marked in the French strain: male rabbits produce 20 percent less hair. This is not so true for the German strain, where the literature reports a difference from zero to 15 percent, with most citing a figure of 10 percent less for male rabbits. Live weight is irrelevant, except during the growth period, where it is related with the harvest number (first, second, etc.). The sex factor is less of distinction and is weaker in the German than in the French strain but males do show a more marked tendency towards felting.

In contrast, the wool production of the females is reported to be higher than in males in German purebred rabbits and German X French crossing. The difference amounted 12,4 % (Szendro, 1992).

In sheep, rams tend to produce more wool than wethers and ewes, due mainly to their greater size and the better feeding given to rams. Differences between wethers and ewes, once the effects of reproduction in ewes are allowed for, are probably small. Fibre diameter was slightly greater in rams than in ewes with the difference between the sexes increasing with age.

In cashmere goats, sex effect on production traits in the yearling and adult animals varied. Male goats produced more down hair (765 vs. 522g) with a little coarser (14.9 vs. 14.5 µ) and longer fibres (10.7 vs. 8.9) and were heavier in body weight (55.7 vs. 32.4 Kg) than female goats. There were no significant differences in fibre diameter and length between male and female yearling, although obvious differences in combed cashmere weight and body weight were observed. In adult cashmere goats, year, age of goats and sex had a significant effect on cashmere production, fibre diameter, fibre length and body weight (Zhou et al., 2003).Sinha and Singh (1997) observed a significant effect of sex of lamb on 3- and 6-month body weight, and fleece weight, in favour of males. In Angora goats, Allain and Roguet (2003), reported that at each shearing, males produce a heavy greasy fleece weight with a coarser fibre (+1.5µm), a higher coefficient of variation of fibre diameter (2.7 %) and better score values than their female counterparts.

1.2.1.3 Reproduction

Thébault and Rochambeau (1988) studied the effect of physiological condition of female and showed that lactating does produce less wool (-36g) than does, which had not been mated. The effects of littering and suckling on wool production were estimated by difference between females, which had and had not produced litters. An experiment was conducted by

Umesh et al. (2004) in Germany Angora rabbits to evaluate the effect of different parities on their biological and production performances. Parity had significant ($P<0.05$) effect on the doe weight at kidding, weight of progeny up to 84 days and wool yields at first and second shearing. Gestation and especially lactation reduce hair production by one-third in Angora rabbits.

In sheep, there can be substantial reductions in wool growth rate during both the latter half of pregnancy and early lactation. Overall, reproduction usually reduces annual fleece growth of ewes by 10-14 %; the greatest reduction being for ewes rearing twins. Increased feed intake can compensate for the effects of pregnancy and lactation on wool growth in low-producing sheep, but not in high-producing ones. It is concluded that increased competition for essential nutrients, perhaps one or more amino acids, between the wool follicles on the one hand and foetal and mammary tissue on the other, was the most likely cause of reduced wool growth. In cashmere and Angora goats, it has been shown that kidding and lactation affect live weight and fibre production in both types of goats, but the magnitude of the effect depends on breeding strategy and time of kidding and lactation. Weight loss during lactation was lowest when kidding occurred at the time of high pasture availability in spring. Fibre production decreased when the last 2 months of pregnancy and the 1st month of lactation coincided with the fibre growth cycle (Robertson et al., 1992).

1.2.2 Environmental factors

1.2.2.1 The harvest method

Angora wool is harvested either by shearing or by plucking. The latter method is used mainly in France. In the French rabbit, the wool yield at plucking is higher than with shearing (Schlolaut, 1980). The higher mean fibre diameter of downs (14.1 µm) and awns (23.3µm) in the plucked French Angora wool compared to the values of the shorn German fleeces (down: 12.4 µm; awn: 21.7 µm) are related to the harvesting method (Herrmann et al., 1996). The harvest procedure is fundamental to distinguish between bristly hair obtained by depilation and woolly hair obtained by shearing.

French farmers who want to produce a bristly grade of angora wool, used to make luxurious clothes, e.g., pullovers and shawls, which have a fluffy appearance, use plucking. Genetic selection aims to increase the number and the dimensions of bristles but the harvest process is also very important in determining the woolly or bristly quality of the fleece (Thébault and Vrillon, 1994). The harvest technique is an important factor, for French strain, shearing reduces adult doe productivity by about 30 percent.

1.2.2.2 Seasonal effects

As it is shown in the previous sections, the growth of hair or wool is a cyclic process, during which the follicles pass through three main phases (i) *anagen*, the phase of active fibre growth, (ii) *catagen*, during which the follicle regress, fibre growth ceases, and a ‘brush’ or ‘club’ end forms on the fibre, (iii) *telogen*, a resting phase. The loss of the previously grown hair, termed moulting or shedding is usually delayed until anagen of the next cycle, but some fibres may be retained for longer periods. Reproduction and fibre growth traits of different species are affected by season. In reproduction traits, primitive breeds of sheep are highly seasonal, but seasonality reduced in modern wool breeds. In double coat species such as cashmere goats, primitive sheep and Angora rabbit, fibre growth has a high seasonality, but in single coat species such as angora goats and Merino sheep, seasonality is much less important. We consider effect of season under two effects, one relative to the season of birth and the other, harvest season.

1.2.2.2.1 Birth season

Fleece parameters are influenced by the season in which the animals are born. The total yield of adult angora rabbits born in winter is significantly greater than that of those born in summer. The season of birth have a slight positive (8%) on total fibre weight for animals born in winter, and on first harvest fibre weight for animals born in autumn and winter (Rochambeau, et al. 1998). This difference is also present in the quality parameters such as structure and bristle diameter, and consequently the tautness (Thébault and Vrillon, 1994). The effect of the birth season was significant only for compression (Rochambeau, et al, 1991). Allain et al. (1992) showed that there is a birth season effect on the diameter of guard hair. The highest diameter in their study was observed in does born in winter and the difference between the extreme seasons is approximately 0.75 standard deviation.

In sheep, the performance of Corriedale ewes lambing in June-July (winter) was compared with that of ewes lambing in Sep.-Oct. (spring). Season of lambing had no significant effect on greasy or clean fleece weights, fibre length, fibre diameter, clean wool yield or lamb body weight, but there were significant differences in wool yield between lambs born in winter and spring (Oliveira and Figueiro, 1980). In Muzaffarnagri sheep there is no difference between wool yield in lambs born in October-November and those born in March-April (Sinha and Singh, 1997).

1.2.2.2.2 Harvest season

Fleece weight. Summer fleeces are lighter (-12%) than winter fleeces in female French angora rabbits (Thébault and Rochambeau, 1988). Rougeot and Thébault (1983) with survey on seasonal variations of wool traits concluded that the weight of the angora wool is minimal in summer (20 % of the annual production), maximum in autumn (26.8%) and in winter (27.6 %) and intermediate in spring (25.5). Shearing yield is higher in winter than in summer. When wool is removed by plucking, there appears to be a greater seasonal influence on the yield than in the case with shearing (Schlolaut, 1980). Most of the studies demonstrated a high seasonal effect from 35% of the fleece weight in unselected lines to 8 % in the most selected lines. The season of maximum fleece growth is always the autumn and winter. The lowest growth rate is seen during the summer. However the seasonal effect decreased with the harvest number. The relative difference between winter and summer harvests was around 30% for the first and second harvest, around 14% for the third and the fourth and only 9 %for subsequent adult harvest (Rougeot et al., 1984). The harvest season explained 10% of the variation. Spring harvest favoured the total fleece weight and the first harvest fibre weight (Rochambeau, et al. 1998).

The S/P (Primary lateral + secondary / primary central) ratio is the most important parameter in seasonal variation in fleece weight and is the lowest in summer in the Angora rabbit. The peak is in autumn, although there is no significant difference between this value and that in winter (Thébault and Vrillon, 1994).

Hair length. The harvest season also modifies the length of the wool. This effect is more noticeable for down than for bristles. Consequently, down hairs grow higher in the lock in winter than in summer (Rochambeau, et al., 1991). The adverse effect of summer conditions is greater on down fibres than on bristles. Bristles are about 10% longer in winter; while down hairs are 19 % longer (Thébault et Vrillon, 1994).

Hair diameter. Allain et al. (1992) observed an effect of the harvest season on mean bristle diameter in which the lowest diameter was observed in fleece harvested in winter. No large variation in hair diameter has been found between the different seasons (Thébault et Vrillon, 1994). However, this slight variation was statistically significant and hair diameter was always largest in spring.

Homogeneity, compression, resilience and structure. Thébault and Vrillon (1994) showed that homogeneity is greater in winter and autumn. Compression is lower in summer. No seasonal variation has been noted in resilience. Structure is low in summer, though tautness is better during the summer months. This is thought to be a mechanical consequence of the changes in structure i.e. the bristle ratio and bristle diameter. Rochambeau et al. (1991) showed that bristly fleeces compressed more than woolly fleeces and they relaxed less. The same difference in behaviour between summer fleeces, and winter fleeces was observed. In addition, winter fleeces, as in the case of bristly fleeces, were heavier and more homogeneous than were summer fleeces and woolly fleeces.

In sheep and goats, there is a significant seasonal effect on fibre production. In angora goats, the highest fleece weight was observed at autumn shearing (+0.12) (Allain and Roguet, 2003). Seasonal wool growth patterns are evident in Romney and the specific carpet wool breeds with summer wool growth rates two-to-three times greater than winter rates. In some studies, body weights and mohair production and quality of angora goats are all affected by season. These differences seem to be direct responses to the amount and quality of available forage. Wool and mohair shorn in autumn will be coarser, contain more medullation and have a higher tensile strength. Nevertheless, compared to Angora rabbit this effect is reversed as the highest fibre production on sheep and goats is always observed during summer.

To summarize about biology of fibre growth and non-genetic factors influencing wool production, Angora rabbits have some specific characteristics in comparison with other fibre-producing animals:

- Angora rabbits produce nearly 1 kg of wool that is nearly 0.25 of their body weight. The ratio of wool production to body weight is much lower than other species.
- Angora rabbit is a typical double coat species in which long coarse hair are desirable for making end uses products having a brushed appearance.
- In the Angora rabbit, the development of secondary follicles is continuing after birth until animals reach 50 % of their adult weight. In sheep and goats, the majority of secondary follicles develop before birth.
- Fibre production is less in male Angora rabbits than in females. The sex effect is reverse on sheep and goat.
- In Angora rabbits, fibre output is maximal in winter and minimal in summer while this effect is reverse in sheep and goats.

1.3 Genetic parameters of wool production

The maximum rate at which animals produce wool or hair, and the range of possible variation in several traits related to quantity and quality of fibre produced, is set by its genotype. There are definite differences between species and breeds of fibre producing animals in the capacity to grow wool and in various fleece characteristics. In sheep, Merinos, which have a much greater follicle density than down and long wool breeds, grow a similar mass of wool to the long wool breeds but considerably larger than the Down breeds.

Many characteristics of the fibre and follicle are highly heritable and significant changes can be made by selection for the desired characteristics. The heritability of wool traits such as greasy or clean wool weight, number of follicles per unit area of skin, S/P follicle ratio, fibre diameter, staple length and crimp frequency are in the range of 0.3-0.6. Many of these traits are correlated and account must be taken of this if it is desired to increase wool weight without altering various characteristics of the fleece.

The development of effective genetic evaluation and improvement programmes requires the knowledge of the genetic parameters (genetic variance of each trait and covariances among traits) for these economically important production traits. Accurate estimation of genetic parameters and in particular genetic correlations requires large across-generation data sets for each relevant population that are not always available. Pooling estimates from several populations may provide more reliable parameter estimates than those obtained from a single population if parameters remain stable. Rochambeau and Thebault (1990) reviewed genetic parameters for traits of Angora rabbit production and reported estimates of heritability from the literature. The traits covered in this section are those associated with wool production traits at different harvest numbers and live weight at various ages.

1.3.1 Heritability

Wool traits: Few studies have reported heritability estimates for wool traits in Angora rabbits and there was a considerable range in published heritability estimates for fleece weight at the various harvests.

The majority of studies estimated heritability of fleece weight in first to fifth harvests. The heritability values for fleece weight of Angora rabbit reported in literature ranged from 0.08±0.20 to 0.96±0.29 (Table 1.4). The most probable values estimated under a REML animal model ranged from 0.21 to 0.52 which are similar to the weighted mean heritability for clean fleece weight (0.36±0.02) in wool breeds of sheep (Safari et al., 2005).

Data on the 10 first shearing of 1119 Angora rabbits were analysed by (Magofke et al., 1994). The repeatability of hair production was 0.21 and 0.28 based on the 2nd-9th and the 2nd-10th shearing respectively; both values decreased when the first shearing was included. The heritability of hair production was 0.19, 0.27, 0.31, 0.33 and 0.26 respectively for the first, second, 3rd, 4th and 5th shearing. The heritability of body weight at 132 and 423 days was 0.21 and 0.33 respectively.

Estimations of heritability of quality traits in Angora rabbits are rare. Allain et al. (1996b) estimated the heritability of fleece traits in French Angora rabbits does that ranged from 0.15 to 0.25. Safari et al. (2005) reported lower heritability for fibre diameter in wool breeds of sheep (0.59±0.02). In addition, heritability for bristle and down length in Angora was lower than for staple length (0.46±0.04) reported for wool breeds of sheep (Safari et al., 2005).

In an experiment of crossbreeding, French Angora and New Zealand rabbits with a high coarse-wool percentage were crossed with German Angoras with a high wool yield. Individuals of the desired type were selected over 3 generations, to create a new strain, designated Su. The heritability of percentage of coarse fibres and wool yield were 0.13 and 0.29 in this strain (Shen et al., 1997).

Table 1.4: Estimates of heritability (± S. E.) with breed and reference for live weight and wool production of Angora rabbit

Heritability	Breed	Remarks[1]	Reference
Wool traits			
Fleece weight [2]			
First harvest			
0.65 - 0.90	G	-	(Jaitner et al., 1988)
0.20±0.12	G	-	(Caro et al., 1984)
0.40±0.02	F	REML	(Allain et al., 1999)
0.19	G	ROS	(Magofke et al., 1994)
0.44±0.15	G	REML	(Singh and Jilani, 2006)
0.96±0.29	G	ROS	(Katoch et al., 1999)
0.17	G	-	(Risam et al., 2005)
Second harvest			
0.15 – 0.44	G	-	(Jaitner et al., 1988)
0.23±0.12	G	-	(Caro et al., 1984)
0.31±0.03	F	REML	(Allain et al., 1999)
0.27	G	-	(Magofke et al., 1994)
0.40±0.20	G	REML	(Singh and Jilani, 2006)
0.25	G	-	(Risam et al., 2005)
Third harvest			
0.33	G	-	(Jaitner et al., 1988)
0.09±0.12	G	-	(Caro et al., 1984)
0.32±0.03	F	REML	(Allain et al., 1999)
0.31	G	ROS	(Magofke et al., 1994)
0.49±0.11	G	REML	(Singh and Jilani, 2006)
0.45	G	-	(Risam et al., 2005)
Fourth harvest			
0.60	G	-	(Jaitner et al., 1988)
0.08± 0.20	G	-	(Caro et al., 1984)
0.30	G	-	(Lin et al., 1995)
0.23	F	REML	(Allain et al., 1996a)
0.33			
0.21±0.24	G	REML	(Singh and Jilani, 2006)
0.14	G	-	(Risam et al., 2005)
Fifth harvest			
0.26	G	ROS	(Magofke et al., 1994)
0.26±0.13	G	REML	(Singh and Jilani, 2006)
0.11±0.10	G	ROS	(Katoch et al., 1999)
Annual wool yield			
0.52±0.10	G	REML	(Singh and Jilani, 2006)
Weight of quality J1			
0.23	F	REML	(Allain et al., 1996a)
Coarse rate			
0.13	G	-	(Lin et al., 1995)
Homogeneity			
0.18	F	REML	(Allain et al., 1996a)
Structure			
0.17	F	REML	(Allain et al., 1996a)
Bristle length			
0.25	F	REML	(Allain et al., 1996a)
Duvet length			
0.15	F	REML	(Allain et al., 1996a)

Compression			
0.19	F	REML	(Allain et al., 1996a)
Continu.			
Resilience			
0.12	F	REML	(Allain et al., 1996a)
Mean fibre diameter			
0.96±0.19	G	ROS	(Narayan et al., 1990)
0.85±0.14	G	ROD	(Narayan et al., 1990)
0.42	G	ROD	(Rawat et al., 1990)
Live weight traits			
Birth weight			
0.12	G	-	(Lin et al., 1995)
Weaning weight			
0.64±0.18	G	-	(Caro et al., 1984)
1st harvest			
0.47±0.15	G	-	(Caro et al., 1984)
0.93	G	-	(Jaitner et al., 1988)
0.27±0.02	F	REML	(Allain et al., 1999)
2nd harvest			
0.64 - 0.73	G	-	(Jaitner et al., 1988)
0.72±0.19	G	-	(Caro et al., 1984)
0.34±0.02	F	REML	(Allain et al., 1999)
3rd harvest			
0.10	G	-	(Jaitner et al., 1988)
0.67±0.20	G	-	(Caro et al., 1984)
4th harvest			
0.29±0.22	G	-	(Caro et al., 1984)
0.64±0.02	F	REML	(Allain et al., 1999)
Adult			
0.42±0.02	F	REML	(Allain et al., 1999)
Litter weight at birth			
0.41±0.07	G	REML	(Anshul et al., 2006)
0.10±0.10	G	REML	(Singh and Jilani, 2006)
0.38±0.17	Russian, British and G	-	(Gaur et al., 1991)
0.81±0.22	Russian, British and G	-	(Gaur et al., 1991)
Litter weight at weaning			
0.30±0.06	G	REML	(Anshul et al., 2006)
0.59±0.16	G	REML	(Singh and Jilani, 2006)
Mortality			
0.08±0.06	G	Preweaning mortality	(Anshul et al., 2006)
0.07±0.02	G	-	(Samber et al., 1998)

[1] ROS, regression of offspring on sire ; ROD, regression of offspring on dam; REML, restricted maximum likelihood estimation

[2] In Angora rabbits, greasy fleece weight and clean fleece weight are nearly the same trait. Therefore, we cannot differentiate between clean and greasy fleece weight that the authors mention in sheep wool

Some negative value of heritability of fibre diameter in Angora rabbit have been reported negative (-0.16) (Rawat et al., 1990). In these cases estimates fall outside the parameter space.

Body weight: The following live weights have been included as defined: birth weight, weaning weight, live weight at first, 2nd, 3rd, 4th harvest, adult weight, and litter weight at birth and weaning. The reported estimates of heritability for growth traits varied markedly among harvest numbers and authors as they ranged from 0.10 to 0.93 (Table 1.4). Here too, most estimates have not been obtained under a REML animal model. Moreover, high values are probably overestimated due to confusions between direct additive effect and maternal effects. Safari et al. (2005) calculated the weighted mean of heritability for growth traits of sheep that ranged from 0.15 to 0.41. They showed that the mean heritability for weight at birth and weaning are similar, and then the heritability increased with age from weaning to post weaning and adult weights.

1.3.2 Phenotypic and genetic correlations

Available estimates of correlations between traits of Angora rabbit have been summarised in Table 1.5. The genetic correlations between first yield and cumulative yields were positive in a study on German Angora rabbits (Katoch et al., 1999). There is a lack of data on genetic parameters of quality of Angora fibres. The genetic correlation between percentage of coarse fibres and wool yield was 0.13 in the Su strain (Shen et al., 1997).

There is no estimate of the genetic correlation of fibre diameter with fleece weight in Angora rabbits. In sheep, the genetic and phenotypic correlations for fibre diameter and greasy fleece weight (0.36 and 0.31, respectively) and clean fleece weight (0.28 and 0.25, respectively) are moderate and positive (Safari et al., 2005). These mean estimates of the correlations were generally similar to those reviewed by Fogarty (1995).

Table 1.5: Genetic (± S.D.) correlations between traits of Angora rabbit.

Trait 1[A]	**Trait 2[B]**	**Genetic correlation**	**Breed [B]**	**Reference**
Wool traits				
1	2	0.42	G	(Jaitner et al., 1988)
1	3	0.33	G	(Jaitner et al., 1988)
2	3	0.26	G	(Jaitner et al., 1988)
1	2	0.37±0.06	F	(Allain et al., 1999)
1	3	0.32±0.04	F	(Allain et al., 1999)
1	4	0.39±0.04	F	(Allain et al., 1999)
1	5	0.22±0.02	F	(Allain et al., 1999)
2	3	0.68±0.06	F	(Allain et al., 1999)
2	4	0.87±0.04	F	(Allain et al., 1999)
2	5	0.78±0.04	F	(Allain et al., 1999)
3	4	0.83±0.04	F	(Allain et al., 1999)
3	5	0.94±0.03	F	(Allain et al., 1999)
4	5	0.87±0.02	F	(Allain et al., 1999)
Live weights				
6	7	0.66	G	(Jaitner et al., 1988)
6	8	0.66	G	(Jaitner et al., 1988)
7	8	0.70	G	(Jaitner et al., 1988)
Wool and live weight				
1	6	0.59	G	(Jaitner et al., 1988)
1	7	0.43	G	(Jaitner et al., 1988)
1	8	0.30	G	(Jaitner et al., 1988)
1	6	0.63±0.21		(Caro et al., 1984)
2	6	0.49	G	(Jaitner et al., 1988)
2	6	0.09±0.34	G	(Garcia F and Magofke, 1982)
2	7	0.51	G	(Jaitner et al., 1988)
2	8	0.30	G	(Jaitner et al., 1988)
2	7	0.97±0.10	G	(Caro et al., 1984)
3	6	0.02±0.70	G	(Garcia F and Magofke, 1982)
3	6	0.24	G	(Jaitner et al., 1988)
3	7	0.29	G	(Jaitner et al., 1988)
3	7	0.95±0.49	G	(Garcia F and Magofke, 1982)
3	8	0.40	G	(Jaitner et al., 1988)
3	8	0.70±0.37	G	(Caro et al., 1984)

[A] Trait codes. Wool traits : total fleece weight at first harvest, 1 ; second harvest, 2; third harvest, 3 ; fourth harvest, 4 ; fifth harvest, 5. Live weight : first harvest, 6 ; second harvest, 7; third harvest, 8.

[B] Breed : French, F ; German, G.

There is a close correlation between live weight and the quantity of wool harvested at the first harvest (Rochambeau et al., 1991). Its importance appears to decrease afterwards (Rochambeau, 1988).

With the exception of the first harvest, genetic correlations between total fleece weight and live weight are low and not significant. The parameters reported by Allain et al. (1999) indicate that in the French Angora rabbit breed no improvement of fleece weight production can be obtained by selection on live weight. These results are in contradiction to observations made on the German breed (Caro et al., 1984).

Larger animals produce more wool compared to smaller animals, but the relative wool production began to decrease if animals are heavier then 4.2 Kg (Nurminen, 1997). At the first shearing, the quantity of wool produced was found still to have some dependence on body weight. At the second, third, and fourth shearing the influence of live weight decreased gradually, wool yield then being determined primarily by genetic background (Eiben, 2000). (Rochambeau et al., 1994) in a survey on non genetic factors on fur quality found that heavier rabbits at eight and twelve weeks give more mature furs at slaughter, and these furs have longer downs and a better compacity.

In sheep, genetic correlations among weaning, post-weaning and adult weights are very high ranging from 0.75 to 0.93 (Safari et al., 2005).

The genetic and phenotypic correlations between live weight at various ages and fleece weight of Angora rabbit were positive and generally moderate in magnitude (Table 1.5). Our results in this aspect are similar to the estimates of Safari et al. (2005) in sheep. In Columbia sheep, (Hanford et al., 2002) calculated positive correlations for fleece weight with birth and weaning weight 0.21 and 0.18, respectively. In Angora rabbit, there were high and positive genetic correlations between the weight of long and bristly wool (quality WAJ1), total fleece weight and homogeneity (0.89 and 0.65) respectively, as well as between fibre length and staple structure measured on the back and haunch (Allain et al., 1996b) . In German Angora rabbit, the genetic correlations of hair production in the 1st, 2nd, 3rd, 4th and 5th shearing with total production were 0.16, 0.45, 0.67, 0.52 and 0.71 respectively, and those of body weight at 132 days with hair production in the 1st, 2nd and 3rd shearing were 0.33, 0.89 and 0.63 (Magofke et al., 1994).

1.3.3 Major genes and QTL

There is an intense and increasing interest in the study of genes of major effect on wool production and quality traits. Identifying genes of major effect offers the opportunity to improve production efficiency, product quality and product diversity, through utilising them in breeding programs, developing transgenic lines and by developing therapeutic agents that can be used to alter fibre attributes by altering gene expression. The opportunity exists to utilise our knowledge of major genes that influence the economically important traits in wool sheep. Genes with Mendelian inheritance have been identified for many important traits in wool sheep. Of particular importance are genes influencing pigmentation, wool quality and the keratin proteins, the latter of which are important for the morphology of the wool fibre. Gene mapping studies have identified some chromosomal regions associated with variation in wool quality and production traits. Quantitative trait locus affecting fleece weight, staple length, fibre diameter and CV of fibre diameter have been identified in sheep (Ponz et al., 2001; Allain et al., 2006). More recently, putative QTL for coefficient of variation of fibre diameter, kemp and medullated fibre content and staple length were found in the Angora goat (Cano et al., 2007). The challenge now is to build on this knowledge base in a cost-effective way to deliver molecular tools that facilitate enhanced genetic improvement programs for wool sheep (Purvis and Franklin, 2005).

1.3.4 Conclusion

There is a large variation in the reported genetic parameters of Angora rabbits. One reason for this variation is the estimation method. In some studies, estimates of variances are unbiased but fall outside the parameter space, e.g. they can be negative. For example, heritability of mean kit weight and fibre diameter in Angora rabbit has been reported -0.11 (Gaur et al.,

1991) and -0.16 (Rawat et al., 1990), respectively. The estimation of heritability for litter weight with mixed animal model are more reasonable, e.g. (Ferraz et al., 1992). Otherwise, some estimations of heritability for fibre traits are very high which were obtained by least square methods, for example h2 of 0.96 for fibre diameter of Angora fibre (Narayan et al. 1990).

In summary, in utilisation of genetic parameters from literature it must be aware of the methods that have been implicated. Specially, there is a distinguishable difference between reported parameters with least square and REML methods.

2 Direct Response

RÉSUMÉ

Afin d'explorer la variabilité génétique de la production de laine et d'autres caractères quantitatifs, une expérience de sélection divergente pour le poids total de toison a été effectuée chez le lapin Angora français durant 8 cohortes de sélection de 1994 à 2001. Des analyses préliminaires ont montré que la production de poils lors des 2 premières récoltes étaient très différentes et devaient être analysées séparément. Il en a été de même pour la production de poils chez les males. En conséquence les analyses ont été réalisées sur la production de poils de 669 femelles nées entre 1994 et 2001 et ayant produit une toison de la 3ème à la 12ème récolte de poils. Les caractères de production étudiés ont été : le poids total de toison, le poids de chacune des deux qualités de poils jarreux (WAJ1) et laineux (WAW1), l'homogénéité de la toison (HOM) ou le rapport de la quantité de poils jarreux sur le poids total de la toison, le poids corporel aux âges de 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16), et 20 semaines (LW20) et puis de 9 semaines avant chaque épilation (9LW). Une analyse des facteurs non génétiques a été réalisée à l'aide d'un modèle d'analyse de variance à effets fixes en utilisant la procédure GLM du logiciel SAS. Les effets fixes significatifs ensuite retenus pour l'analyse génétique ont été: l'année de naissance (8 niveaux de 1994 à 2001), le numéro de récolte (10 niveaux de 3 à 12), la saison de naissance (4 niveaux), la saison de récolte (4 niveaux) et le stade physiologique des femelles (3 niveaux : femelle ayant mis bas, femelle inséminée n'ayant pas mis bas et femelle non mise à la reproduction). Les paramètres génétiques et les tendances génétiques ont ensuite été estimées en utilisant un BLUP appliqué à un modèle d'animal à l'aide du logiciel AsReml. Les variables relatives à la production de poils mesurées à chacune des récoltes de toison de la 3ème à la 12ème ont été analysées selon un modèle avec répétabilité et incluant le poids corporel 9 semaines avant la récolte comme covariable. Cela n'a pas été le cas pour les variables décrivant le poids corporel entre les ages de 4 et 20 semaines.

Les héritabilités estimées des caractères TFW, WAJ1, WAW1, HOM, LW4, LW8, LW12, LW16, LW20 et 9LW sont respectivement de 0.38±0.03, 0.30±0.03, 0.10±0.02, 0.06±0.02,

0.30±0.04, 0.09±0.08, 0.14±0.09, 0.32±0.10, 0.39±0.10 et 0.45±0.06. De fortes corrélations génétiques et phénotypiques entre TFW et WAJ1 (0.98 ± 0.01 et 0.89 ± 0.01, respectivement) ont été observées. Par contre la corrélation génétique entre TFW et 9LW était faible (0.26 ± 0.12). Les résultats ont montré qu'une sélection divergente pour le poids total toison a permis d'obtenir une différence de trois écarts types génétiques entre les lignées haute et basse après huit cohortes de sélection. La sélection pour le poids total de toison a amélioré de manière significative le poids de poils jarreux (WAJ1) qui a résulté d'une forte corrélation génétique positive (0.98) entre TFW et WAJ1. Chez le lapin Angora français, une toison de haute qualité ayant une bonne aptitude à fabriquer un fil « fleuffé » est caractérisée par un poids élevé de qualité WAJ1 et une forte homogénéité de la toison. Il est important de noter qu'une sélection pour le simple critère facilement mesurable du poids total de toison a un effet bénéfique général sur WAJ1 et HOM.

L'héritabilité estimée du poids total de toison lors de la première (TFW1) et la deuxième (TFW2) est similaire aux valeurs observées lors des épilations de 3 à 12. La corrélation génétique entre le poids total de toison lors des épilations 3 à 12 et TFW1 est proche de zéro, Par contre une forte corrélation génétique entre TFW2 et TFW (0.76) a été observée. L'analyse de la réponse à la sélection a montré qu'aucune réponse n'a été observée sur le poids de toison en 1ère récolte (TFW1). Par contre, une forte réponse équivalente à celle observée pour les récoltes 3 à 12 a été observée sur le poids de toison en 2ème récolte.
D'une part, ces résultats indiquent que la production de poils à la première épilation (TFW1) est un caractère différent de celui observée lors des épilations suivantes, ce qui était attendu sachant que le développement des follicule pileux n'est pas terminé chez le lapin à l'age de 8 semaines où a lieu la première épilation.

D'autre part, la corrélation génétique élevée entre le poids total de toison aux épilations de 3 à 12 et TFW2 ainsi que la réponse à la sélection sur TFW2 offre la possibilité de sélectionner les lapins Angora français pour le poids total de toison dès la seconde récolte.

2.1 Divergent selection for fleece weight in French Angora rabbits: Non-genetic effects, genetic parameters and response to selection

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Divergent selection for fleece weight in French Angora rabbits: Non-genetic effects, genetic parameters and response to selection

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Abstract

In order to explore genetic variability of wool production and other quantitative traits, an 8-cohort divergent selection experiment for total fleece weight (TFW) was carried out in French Angora rabbits. Studies were made on the wool production of 669 female rabbits born between 1994 and 2001 and having produced wool from the third to 12th harvests. The aim of the selection experiment was to obtain two divergent lines (low and high) on total fleece weight. The studied traits included total fleece weight, weight of the two qualities of wool (WAJ1 and WAW1), homogeneity (HOM), live body weight at ages of 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16), and 20 (LW20) weeks and then 9 weeks before each harvest (9LW). A preliminary analysis of non-genetic factors was done with the GLM procedure. The genetic parameters and genetic trends were analysed using a BLUP animal model. Heritability estimates for TFW, WAJ1, WAW1, HOM, LW4, LW8, LW12, LW16, LW20 and 9LW were 0.38, 0.30, 0.10, 0.06, 0.30, 0.09, 0.14, 0.32, 0.39 and 0.45, respectively. Genetic and phenotypic correlations between TFW and WAJ1 were high (0.98 ± 0.01 and 0.89 ± 0.01, respectively). There was a low genetic correlation between TFW and 9LW (0.26 ± 0.12). After eight cohorts of selection, the divergence between the lines was approximately three genetic standard deviations. Selection for total fleece weight had a generally beneficial effect on fleece quality.

Keywords: Angora rabbit; Bristle; Body weight; Divergent selection; Fleece weight; Genetic responses; Wool quality

1. Introduction

The French Angora rabbit breed has a fleece with well-differentiated guard hair (Rougeot and Thébault, 1983) and produces long and bristly wool. Such bristly fleeces are valuable because of their aptitude to produce a fluffy yarn used for certain luxury knit products(Rougeot and Thébault, 1984). World Angora production was approximately 8000 metric tons in 2000 (Schlink and Liu, 2003).

The opportunity for selection on a trait depends on the amount of additive genetic variation in a trait. Realised heritability has been traditionally estimated by using either a directional or divergent selection design (Hill, 1972). Mixed model methodology and computational resources, however, allow the inclusion of data on all generations and relationships by using an animal model, which has become the method of choice to analyse selection experiments (Sorensen and Kennedy, 1986).

In order to explore the genetic variability of wool production and other quantitative traits in the Angora rabbit, a divergent selection for a trait experiment on total fleece

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weight was undertaken. The experiment began in 1994 and, by 2001, two large cohorts were available from the high and low lines. There is little information on genetic parameters of wool quality in Angora rabbits. This paper reports non-genetic factors affecting wool production and live weights as well as genetic parameters, direct and correlated responses in the lines, measured in female French Angora rabbits over 8 years of a divergent selection experiment.

2. Materials and methods

2.1. Animals

Data were obtained from the Angora experimental rabbit farm of INRA (*Institut National Recherche Agronomique*) at Le Magneraud, France. The experiment took place in a naturally lighted semi-open building with no heating and no forced ventilation. Rabbits were fed a commercial pelleted diet. Allain et al. (1999) described the management, reproduction and housing circumstances of these animals.

Eight hundred ninety-six rabbits out of a total of 3567 animals born in the herd with full pedigrees recorded were measured. Studies were made of the wool production of 669 female Angora rabbits born between 1994 and 2001 under a divergent selection experiment that was initiated in 1994. French Angora bucks are known to produce 20% less wool than does (Rochambeau et al., 1991). Moreover since the Angora doe's capacity to foster appears to be limited, French breeders carry out selection at birth according to sex, so that only newborn does and a few bucks are kept (Rougeot and Thébault, 1983). Thus the number of males available was low and statistically insufficient for use in the study. Therefore, only data from females were analysed in the present work.

The aim of the selection experiment was to obtain two divergent lines on total fleece weight (TFW). A high line and a low line were made up of 80 females and 20 males each. Rabbits were distributed between the lines in order to have the same demographic structure and the same distribution of genetic values. Generations were overlapping. The renewal after selection was composed each year of 36 females and 5 males, alive at the second harvest in each line. The selection criterion was the total fleece weight of the does measured for the third and later harvests. During the selection experiment, genetic values were estimated with a BLUP applied to an animal model using MODANIM software (Poivey, 1986). The evaluation of the animals was done each year. Heritability and repeatability were set to 0.31 and 0.51, respectively. Twenty does and five bucks having the highest and the lowest genetic values in the high and the low lines respectively were used for the renewal. The does were inseminated a few days after harvests between the third and the seventh harvest, then after each one. Individual does were limited to six daughters and one son used as replacements. The males born 1 year were used the following year for reproduction. Each of the five bucks was replaced by one of its sons. This pattern of selection was followed for the 8-year duration of the experiment.

2.2. Traits

The young rabbits were sexed at birth and most of the males were eliminated. In this way the size of the litters were reduced to less than six rabbits just after birth. They were weaned 4 weeks later. They were plucked for the first and second times at the ages of 8 and 21 weeks, respectively. Thereafter they were plucked at regular intervals every 14 weeks.

During each wool harvest, the fleece was sorted and graded in five different classes, according to quality: Class 1: clean, unfelted, long and bristly fibre, from the back, the sides and the rump of the rabbit (WAJ1); Class 2: clean, unfelted, long and woolly fibre, from the breast and the belly of the animal (WAW1); Class 3: clean, unfelted and short (<6 cm) fibre, from the legs of the rabbit, Class 4: clean and felted fibre, from the neck and the tail of the animal; Class 5: dirty fibre, from the belly of the rabbit. Homogeneity (HOM) was calculated as the ratio of WAJ1 to TFW, expressed as a percentage. Live body weight at ages of 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16), and 20 (LW20) weeks were collected. Thereafter animals were weighed at regular intervals 9 weeks before each wool harvest (9LW).

2.3. Statistical analyses

2.3.1. Testing of fixed effects

From preliminary analysis, the dataset was separated into three subsets according to the harvest number: one for each of the first two harvests and one for the third to the 12th harvests. Only fibre data of the third to the 12th fleece harvests were analysed. The least square means method with the GLM procedure was utilised to determine the significance of the fixed effects and covariate.

2.3.2. Estimation of genetic parameters and breeding values

All analyses for genetic parameters and breeding values were carried out with ASReml (Gilmour et al., 2002). In selection experiments with overlapping generations, a mixed model approach shows considerable

Table 1
Number of records (N), mean and standard deviation (S.D.) for the studied traits: total fleece weight (TFW), weight of bristly wool (WAJ1), weight of woolly wool (WAW1), homogeneity (HOM), live body weight at 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16), 20 (LW20) weeks of age and 9 weeks before harvest (9LW)

Trait	Unit	N	Means	S.D.
Fibre traits				
TFW	g	3351	214.3	57.2
WAJ1	g	3351	149.3	46.8
WAW1	g	3351	30.7	15.3
HOM	%	3351	69.1	9.3
Live body traits				
LW4	g	792	597.9	122.6
LW8	g	736	1364	232.8
LW12	g	700	2174	294.1
LW16	g	681	2732	334.0
LW20	g	630	3003	313.6
9LW	g	2925	3802	474.0

advantages over the least-squares estimator (Sorensen and Kennedy, 1986). The method enabled the inclusion of different fixed effects, covariate and random effects in the model for each trait. For fibre traits, a series of bivariate model analyses were first run to estimate covariance components, which were subsequently applied to a multi-trait model to derive genetic and phenotypic correlations among traits. Finally, a multi-trait model was included for TFW, WAJ1, WAW1 and HOM. The following linear mixed model for a multivariate analysis of TFW, WAJ1, WAW1 and HOM traits was used:

$$\boldsymbol{Y}_i = \boldsymbol{X} i\boldsymbol{\beta}_i + \boldsymbol{Z}_i\boldsymbol{a}_i + \boldsymbol{W}_i\boldsymbol{p}_i + \boldsymbol{e}_i$$

Where

N is the total number of animals,
N_i is the number of animals measured for the ith trait,
$\boldsymbol{Y}_i$ (N_i) is a vector of animal records for the ith trait,
$\boldsymbol{\beta}_i$ (f_i) is a vector of fixed effects for the ith trait consisting of:

- A covariate effect of 9LW on TFW, WAJ1 and WAW1 traits,
- Year (8 levels) from 1994 to 2001,
- Harvest number (10 levels) from the third to the twelfth harvest,
- Birth season effect (4 levels),
- Harvest season effect (4 levels),
- Reproduction (3 levels: females which had litters and females which had been inseminated or not) from the third harvest onwards.

$\boldsymbol{a}_i$ (N) is a random vector of direct additive genetic effects of animals for the ith trait,
$\boldsymbol{p}_i$ (N_i) is a random vector of permanent environmental effects of animals for the ith trait.

A bivariate analysis between 9LW and TFW was undertaken according to the above linear mixed model but without an effect of harvest season for 9LW and covariate for TFW.

For LW4, LW8, LW12, LW16 and LW20, a set of bivariate analysis between body weight and TFW was undertaken. The linear mixed model included the same fixed and random effects as above without covariate for TFW. The vector of significant fixed effects for LW4, LW8, LW12, LW16 and LW20 consisted of Year (8 levels) from 1994 to 2001; Birth season (4 levels) except for LW4; Age of dam effect (6 levels) for the LW4 trait only; Number of weaned rabbits (6 levels; 1, 2, 3, 4, 5 to 7 and more than 7). A random vector of a common litter environmental effect of animals for LW4, LW8, LW12, LW16 and LW20, was included.

Breeding values for all the traits were obtained as solutions from the best linear unbiased prediction analysis of the ASReml package. Then the means of the estimated breeding value (EBV) for all traits were calculated per cohort of animals born the same year and per selected line.

3. Results and discussion

3.1. Means and standard deviations

Means and standard deviations (S.D.) for total fleece weight (TFW), weight of bristly wool (WAJ1), weight of woolly wool (WAW1), homogeneity (HOM) and live body weights are given in Table 1.

3.2. Non-genetic effects

Significance levels of fixed effects for fibre traits and 9LW are shown in Table 2. In this study the total weight

Table 2
Significance levels of fixed effects for total fleece weight (TFW), weight of bristly wool (WAJ1), weight of woolly wool (WAW1), homogeneity (HOM) and live body weight 9 weeks before harvest (9LW)

Traits	Fixed effects					Covariate
	Year	Harvest number	Birth season	Harvest season	Reproduction	9LW
TFW	***	***	***	***	***	***
WAB	***	***	***	***	***	***
WAW	***	***	***	***	***	***
HOM	***	***	*	***	***	ns
9LW	**	***	***	ns	***	

*** $P<0.001$; ** $P<0.01$; * $P<0.05$; ns: non-significant.

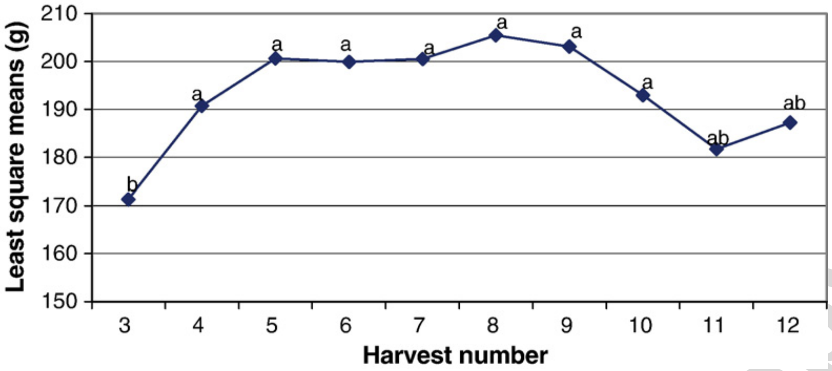

Fig. 1. Effects of harvest number on fleece weight. Dots with unlike letters differ ($P<0.05$).

of harvested wool increased rapidly from the third to the fourth harvests, remained high from the 4th to the 9th harvest and decreased thereafter (Fig. 1). The observed increase of total fleece weight from the third to the fourth harvest, and then the decrease of total weight of wool in the last three harvests, were similar to earlier results (Rochambeau and Thébault, 1990). An important birth season effect was observed on TFW, WAJ1 and WAW1. The animals born in the summer produced less wool than those that were born in other seasons. The effect of the season of birth, previously demonstrated on hair production in the vole (Lee and Zucker, 1988) and on wool production in angora rabbits (Thébault et al., 1992) was confirmed in the present study.

There was a clear harvest season effect with a higher wool production in the winter than in the other seasons for TFW and WAJ1. The quantity of wool produced varied with the harvest season with a maximum in the winter in agreement with previous observations indicating that the seasons of maximum fleece growth were always the autumn and winter (Caro et al., 1984; Thébault et al., 1992). Rougeot and Thébault (1983) in a study on seasonal variation of wool traits concluded that the weight of the angora wool is minimal in the summer, maximum in the autumn and in the winter and intermediate in the spring.

Table 3
Significance levels of fixed effects for live body weight at 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16) and 20 (LW20) weeks of age

Traits	Fixed effects			
	Year	Birth season	Number of kits weaned	Age of dam
LW4	***	ns	***	***
LW8	***	***	***	
LW12	***	***	***	
LW16	***	***	***	
LW20	***	***	***	

*** $P<0.001$; ns: non-significant.

The values of TFW, WAJ1, WAW1 and HOM in does that had a litter between two harvests were the smallest ($P<0.01$). Does that had been inseminated artificially without producing a litter had a smaller TFW and WAJ1 than does that had not been inseminated ($P<0.05$). The depressive effect of reproduction on live weight and TFW observed in does producing a litter was similar to that found in a previous study (Rochambeau et al., 1991). The difference in wool production between females that had or had not been inseminated can be explained by pseudo pregnancy induced by the hormonal treatment used with artificial insemination.

Significance levels of fixed effects on live body weight traits up to 20 weeks of age are reported in Table 3. Year, birth season and litter size weaned effects were significant on LW8, LW12, LW16 and LW20 traits. For LW4, the effects of year, litter size weaned and age of dam were significant.

3.3. Heritabilities and correlations

Table 4 shows the current estimates of phenotypic and genetic parameters for fibre traits. Heritability estimates for TFW were in agreement with other estimates, ranging from 0.31 to 0.42 (Allain et al., 1999; Lin et al., 1995). Youzhang and Pin (1997) obtained heritability estimates of 0.30 and 0.13 for total wool

Table 4
Heritability (bold), genetic (above diagonal) and phenotypic (below diagonal) correlation estimates (±standard deviations) for total fleece weight (TFW), weight of bristly wool (WAJ1), weight of woolly wool (WAW1) and homogeneity (HOM)

Traits	TFW	WAJ1	WAW1	HOM
TFW	**0.38±0.03**	0.98±0.01	0.94±0.05	0.40±0.12
WAJ1	0.89±0.01	**0.30±0.03**	0.86±0.07	0.58±0.10
WAW1	0.40±0.02	0.08±0.02	**0.10±0.02**	0.12±0.19
HOM	0.21±0.02	0.60±0.02	−0.47±0.02	**0.06±0.02**

Table 5
Estimates of heritability, genetic and phenotypic correlations (±standard deviations) from bivariate analysis between total fleece weight (TFW) and live body weight at 4 (LW4), 8 (LW8), 12 (LW12), 16 (LW16), 20 (LW20) weeks of age and 9 weeks before harvest (9LW) from the third harvest

Trait 2	h^2 TFW	h^2 trait 2	r_g	r_p
LW4	0.35±0.05	0.30±0.04	−0.04±0.17	0.04±0.04
LW8	0.35±0.05	0.09±0.08	−0.12±0.28	0.06±0.04
LW12	0.35±0.05	0.14±0.09	−0.02±0.23	0.07±0.04
LW16	0.35±0.05	0.32±0.10	0.10±0.17	0.06±0.04
LW20	0.35±0.05	0.39±0.10	0.09±0.16	0.07±0.04
9LW	0.35±0.05	0.45±0.06	0.26±0.12	0.34±0.03

r_g: genetic correlation; r_p: phenotypic correlation.

production and percentage of coarse fibres in Angora rabbits, respectively. Genetic and phenotypic correlations between TFW and WAJ1 were positive and highly favourable. WAJ1 is an important economical trait in angora production but its measurement is more difficult and subjective than TFW and the heritability estimate of WAJ1 is lower than that of TFW. Heritability estimates for WAW1 was low and there is no other result in the literature for comparison of this trait.

Heritability, phenotypic and genetic correlation estimates from bivariate analysis of TFW and live weights are shown in Table 5. In these analyses, TFW had a little lower but non-significant heritability estimate than when estimated from multivariate analysis using 9LW as a covariate. The heritability estimate for 9LW was high and in agreement with previous results (Allain et al., 1996, 1999). In Chinese angora rabbits, Lin et al. (1995) reported a heritability estimate of 0.43 for live weight. Caro et al. (1984) reported a high genetic correlation (0.70) between body weight and wool production at third shearing in the German breed. Rochambeau (1988) observed a positive relationship between fleece weight and live body weight only in the first harvest with a significant phenotypic correlation. Thébault et al. (1992) also showed that fleece weight increases with body weight up to 4 kg. In our study, phenotypic and genetic correlation estimates between TFW and body weights were not significantly different from zero, except between TFW and 9LW, where a low genetic correlation estimate (0.26) was observed.

3.4. Direct and correlated responses

Direct and correlated responses to selection for TFW on fibre traits over the 8 years of selection are presented in Fig. 2. In the low line, mean breeding value of TFW per cohort of animals born the same year decreased sharply from 1995 to 1997, was stable between 1997 and 1999 and then decreased again. On the contrary, in the high line, mean breeding value for TFW increased

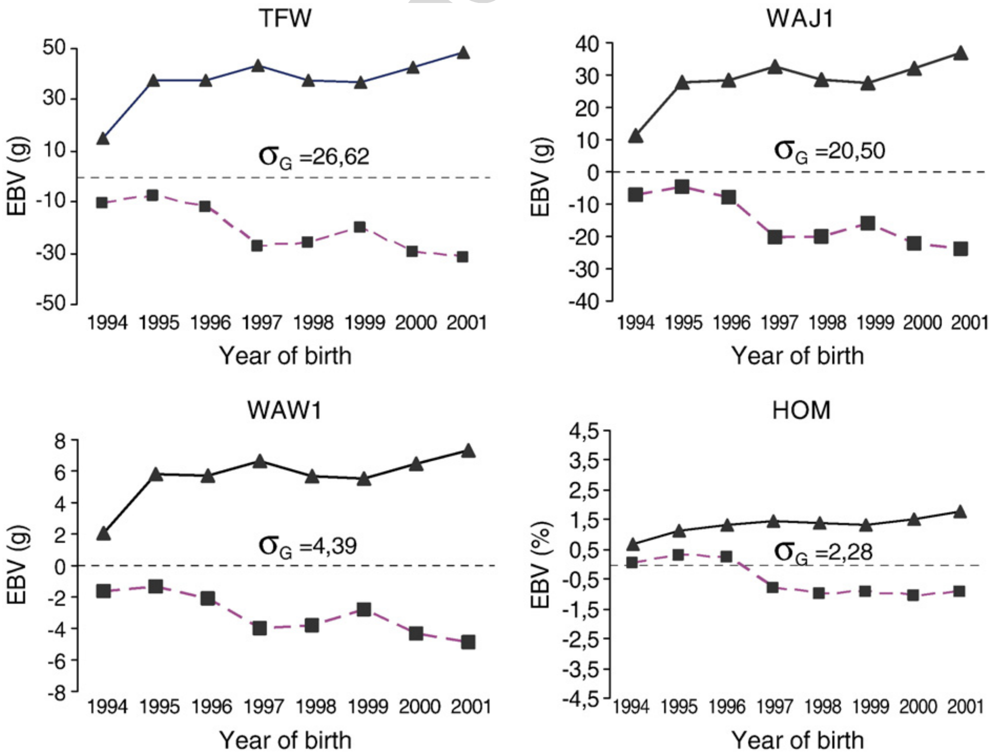

Fig. 2. Change of mean breeding value estimates (EBV) of total fleece weight (TFW), bristly wool (WAJ1), woolly wool (WAW1) and homogeneity (HOM), over the 8 years of selection for both the high (▲) and low (■) lines. Genetic standard deviation (σ_G) is given for each trait.

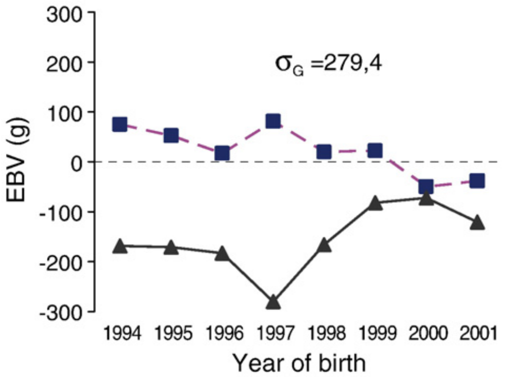

Fig. 3. Change of mean estimated breeding value (EBV) for live body weight 9 weeks before harvest over the 8 years of selection between the high (▲) and low (■) lines. Genetic standard deviation (σ_G) is given.

sharply until 1995 and then slightly up to 2001. Substantial response was achieved through selection for TFW, with a divergence between the high and low lines in the mean breeding value of 80.95 g or 3.04 genetic standard deviations after 8 years of selection. Significant correlated responses to selection on TFW were also observed on other fibre traits and a divergence of 2.96, 2.78 and 1.21 genetic standard deviations were obtained for WAJ1, WAW1 and HOM, respectively. Thus a selection for TFW, a simple and easy criterion to measure, is very efficient to improve WAJ1 which is an important economical trait in French angora wool production.

Correlated response to selection for TFW on 9LW is shown in Fig. 3. In the initial cohort, a difference in mean breeding value estimates of 9LW was observed between the two lines in favour of the low line. Such a difference cannot be explained and could be due to a random sampling effect when the divergent selection experiment was initiated. After 8 years of selection for TFW, the difference in the mean breeding value of 9LW between the two lines decreased over years and was close to null at the end of the experiment. This result indicates that, as expected in regard to genetic parameters, an increase in live body weight was obtained by selection for total fleece weight.

In the literature, there are no results about selection experiments for wool traits in the Angora rabbit. In other species, nearly all of the existing divergent selection studies in livestock science have been done on sheep. Bray et al. (2005) with a divergent selection experiment for wool growth rate, showed that sheep selected for high estimated breeding value produced more wool per day than sheep selected for low breeding value (on average 32.5 versus 17.7 g/day clean wool, respectively; $P < 0.05$). Responses to selection for yearling fleece weight and live weight were studied in the Romney sheep on two selection lines, one selected for fleece weight and the other for live weight, and a control line (Johnson et al., 1995). Direct responses to selection, derived from deviations from the control line, were 1.20 kg and 11.9 kg for fleece weight and live weight respectively, *i.e.* about 2.5 phenotypic standard deviation for both traits. In sheep, as in angora rabbits in the present study, important genetic progress could be made by selecting for wool traits.

4. Conclusion

Selection for high and low total fleece weight was successfully performed in Angora rabbits and a divergence of three genetic standard deviations was observed between the high and low lines after 8 years of selection. Selection for TFW significantly increased WAJ1 which resulted from the highly positive genetic correlation between TFW and WAJ1. It is important to note that selection for easily measurable total fleece weight has a general beneficial effect on fleece quality. These genetically diverse lines are suitable for subsequent detailed studies of biological and physiological changes of the different fleece components brought about by selection on total fleece weight. A high quality fleece having a good ability to produce a fluffy yarn was characterised by a high weight of quality WAJ1 and high fleece homogeneity. All these characteristics were observed on the high line indicating that selection for total fleece weight results in an improvement of the quality of the fleece.

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2.2 Direct response of selection for total fleece weight at harvest number of 3-12 on total fleece weight at first and second harvest

Introduction

From preliminary analysis, the dataset was separated into three subsets according to the harvest number: one for each of the first two harvests and one for the third to the 12th harvests. Here fibre data of the first and second harvests were analysed seperately. Previous studies have been shown that TFW in first and second harvests is different trait from higher harvests (Thébault et al., 1992).

Material and methods

The least square means method with the GLM procedure was utilised to determine the significance of the fixed effects. All analyses for genetic parameters and breeding values were carried out with ASReml (Gilmour et al., 2002).

The following linear mixed model for a bivariate analysis of TFW at first (TFW1) or second harvest (TFW2) and TFW at 3-12 harvests (TFW3_12) was used:

$$\mathbf{Y}_i = \mathbf{X}i\,\boldsymbol{\beta}_i + \mathbf{Z}_i\,\mathbf{a}_i + \mathbf{W}_i\,\mathbf{p}_i + \mathbf{e}_i$$

Where

N is the total number of animals,

N_i is the number of animals measured for the ith trait,

$\mathbf{Y}_i$ (N_i) is a vector of animal records for the ith trait,

$\boldsymbol{\beta}_i$ (f_i) is a vector of fixed effects for the ith trait consisting of:

- Year (8 levels) from 1994 to 2001,
- Harvest number (10 levels) from the third to the twelfth harvest for TFW3_12,
- Birth season effect (4 levels),
- Harvest season effect (4 levels) for TFW3_12,

- Reproduction (3 levels: females which had litters and females which had been inseminated or not) from the third harvest onwards for TFW3_12,

$\mathbf{a}_i$ (N) is a random vector of direct additive genetic effects of animals for the ith trait,

$\mathbf{p}_i$ (N_i) is a random vector of permanent environmental effects of animals for the ith trait.

Breeding values for all the traits were obtained as solutions from the best linear unbiased prediction analysis of the ASReml package. Then the means of the estimated breeding values (EBV) for all traits were calculated per cohort of animals born the same year and per selected line.

Results and discussion

Means and standard deviations (SD) for TFW1, TFW2 and TFW3_12 are shown in Table 2.2.1. Significance levels of fixed effects for fibre traits and 9LW are shown in Table 2.2.2.

Table 2.2.1 Number of records (N), mean and standard deviation (SD) for the studied traits: total fleece weight at first harvest (TFW1), total fleece weight at second harvest (TFW2), total fleece weight at 3rd to 12 harvests (TFW3_12).

Trait	Unit	N	Means	SD
TFW1	g	762	31.31	8.56
TFW2	g	669	143.80	34.02
TFW3_12	g	3351	214.3	57.20

Table 2.2.2 Significance levels of fixed effects for the studied traits: total fleece weight at first harvest (TFW1), total fleece weight at second harvest (TFW2), total fleece weight at 3rd to 12 harvests (TFW3_12).

Traits	Fixed effects				
	Year	Harvest number	Birth season	Harvest season	Reproduction
TFW1	***	-	***	ns	-
TFW2	***	-	***	ns	-
TFW3_12	***	***	***	***	***

*** $P < 0.001$; ns: non-significant.

Results of analyse bivariate of TFW1, TFW2 and TFW3_12 without covariate are shown in Table 2.2.3. Heritability of TFW at first and second harvest was similar to its values observed at harvests of 3-12. Genetic correlation between TFW3_12 and TFW1 is close to zero and indicates that wool production at first harvest is a different trait from that of following harvests. Similar to our results, genetic correlation between birthcoat and clean fleece weight in superfine Merino sheep was reported essentially zero and it concluded that birthcoat do not increase economic gains when included in the selection criteria (Kemper et al., 2003). In French Angora rabbits the high genetic correlation between TFW3_12 and TFW2 proposes the possibility of selection at this harvest for TFW.

Response to selection on TFW1 and TFW2 are shown on Figure 2.2.1. There is not response to selection at first harvest while response to selection at second harvest was similar to that observed for harvests of 3-12. These observations confirms that TFW1 is a different trait which was expected as hair follicle development in the rabbit is not complete at 8 weeks of age when occurs the first harvest. Rougeot et al. (1984) studying the the development of the coat in the growing angora rabbit from birth indicated that the number of derived hair follicle increased in the growing animal from 10-12 at birth to 50-70 at the age of 20 weeks when occurs the second harvest. They concluded that the multiplication of derived hair follicles was independent of age but occurs up to a weight of 2 kg which was reached between 8 and 14 weeks depending on the growing potential of animals.

Table 2.2.3: Estimates of heritability, genetic and phenotypic correlations (± standard deviations) from bivariate analysis between total fleece weight at harvests of 3-12 (TFW3_12) and of fist (TFW1) and of second (TFW2)

Trait 1	Trait 2	h^2 Trait 1	h^2 Trait 2	r_g [1]	r_p
TFW3_12	TFW1	0.35±0.05	0.36±0.08	0.01±0.11	0.14±0.03
TFW3_12	TFW2	0.33±0.05	0.38±0.08	0.76±0.10	0.34±0.03

[1] r_g : genetic correlation; r_p: phenotypic correlation

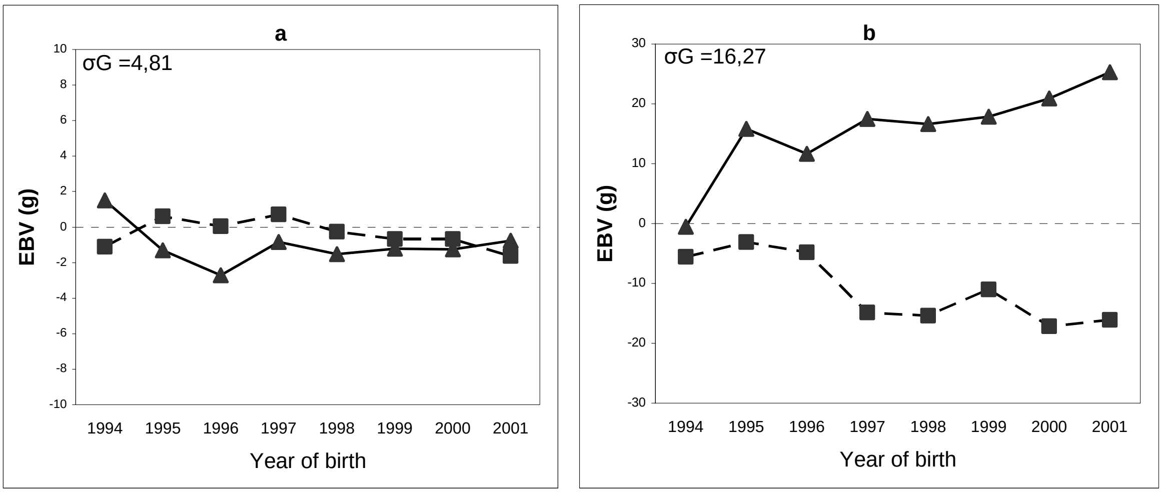

Figure 2.2.1: Change of mean breeding value estimates (EBV) of total fleece weight at first harvest (a) and at second (b) harvests over the eight years of selection for both the high (▲) and low (■) lines. Genetic standard deviation (σ_G) is given.

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3 CHARACTERISTICS OF ANGORA RABBIT FIBER USING OPTICAL FIBER DIAMETER ANALYSER

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Résumé

Pour la laine de mouton et le mohair produit par la chèvre angora, le diamètre moyen des fibres est l'une des caractéristiques les plus importantes déterminant la transformation et l'utilisation des fibres par l'industrie textile et par conséquent le prix des laines et du mohair sur le marché international. Des méthodes récentes, rapides, précises et efficaces de la mesure du diamètre des fibres basée sur la méthodologie *Optical Fiber Diameter Analyser* (OFDA) ont été mises au point. Ces méthodes sont largement utilisées pour déterminer les caractéristiques de la laine et du mohair, mais à notre connaissance, peu d'études ont été réalisées pour évaluer cette méthodologie sur la fibre angora. L'objectif de cette étude a été de décrire les caractéristiques de l'Angora à l'aide de la méthodologie OFDA et d'analyser la variabilité des caractéristiques des fibres de la toison de 2 lignées divergentes de lapin angora français sélectionnées pour le poids total de toison.

L'expérience a été réalisée sur un total de 349 prélèvements de toison effectués sur 60 lapins Angora français issues de 2 lignées divergents pour le poids total de toison. Les échantillons de toison ont été prélevés sur 30 animaux femelles de chacune des 2 lignées divergentes lors des récoltes de poils effectuées lors des 6 premières récoltes de poils à savoir, respectivement, aux ages de 8, 21, 35, 49, 63 et 77 semaines. Les prélèvements ont été analysés selon la méthodologie OFDA à l'aide d'un OFDA100. Les mesures suivantes ont été obtenues : le diamètre moyen des fibres, le coefficient de variation du diamètre des fibres, le facteur de confort ou proportion de fibres dont le diamètre est inférieur à 30µm, la finesse de filature, le degré de courbure moyenne des fibres, l'écart-type de ce degré de courbure des fibres, l'opacité moyenne des fibres, le pourcentage de fibres médullées, le diamètre moyen le long

de la fibre mesuré sur une longueur de 200µm avec un pas de 2µm et l'écart type de ce diamètre le long de la fibre. Les caractéristiques ont été analysées selon un modèle mixte avec l'animal comme effet aléatoire et les effets fixes suivants : groupe de sélection, saison de récolte et numéro ou age de récolte. Des corrélations ont ensuite calculées entre les caractéristiques OFDA des fibres de la toison, le poids total de toison et la compression, une caractéristique textile de la toison mesurée par la hauteur de 10g de poils soumis à une pression de 3kg dans une chambre cylindrique.

Les caractéristiques OFDA de la fibre angora qui ont été observées sont les suivantes : un diamètre moyen de 14,6µm avec un CV du diamètre de 42%, un facteur de confort de 98%, un degré de courbure moyen de 40,1 °/mm, une opacité moyenne de 46%, un taux de fibres médullées de 1,7%, un diamètre moyen le long de la fibre de 15,4 µm et un écart type moyen de ce diamètre le long de la fibre de 6,2 µm.

Alors que chez l'angora, toutes les fibres sont médullées, le taux de fibres médullées observé à l'OFDA à partir de la mesure de l'opacité des fibres est très faible, entre 0.1 à 7.3 %. Cette mesure de l'opacité qui permet d'apprécier la médullation de la laine de mouton et du mohair n'est pas adaptée et doit être redéfinie ou faire l'objet d'une calibration spéciale pour évaluer le degré de médullation et/ou la taille de la moelle des fibres angora.

Toutes les caractéristiques OFDA de la fibre angora ont évolué de manière significative avec l'age de l'animal. Le diamètre moyen, le CV du diamètre, le diamètre moyen le long de la fibre et le degré de courbure des fibres ont augmenté avec l'age de l'animal jusqu'à la 3ème récolte à l'age de 35 semaines, puis n'ont plus évolué entre la 3ème et la 6ème récolte. Par contre le facteur de confort ou proportion de fibres ayant un diamètre inférieur à 30µm a diminué entre la 1ère et la 3ème récolte puis s'est stabilisé.

Un effet significatif de la saison de récolte a été observé sur certaines caractéristiques des fibres. En été, nous avons observé un diamètre moyen des fibres et un diamètre moyen le long de la fibre plus faible, mais un CV du diamètre des fibres plus élevé. Le degré de courbure des fibres le plus faible a été observé en automne.

Des corrélations positives ont été observées entre le poids total de toison, le diamètre moyen, Le CV du diamètre et le degré de courbure des fibres.

La méthodologie OFDA est une alternative intéressante pour évaluer le diamètre des fibres, le coefficient de variation de diamètre de fibre et le taux de jarres par la détermination du facteur de confort.

ABSTRACT: An experiment was conducted to describe the characteristics of Angora rabbit fiber using optical fiber diameter analyser (**OFDA**). A total of 349 fleece samples were collected from 60 French Angora rabbits. Recorded measurements of OFDA were: mean fiber diameter, CV of fiber diameter, comfort factor, spinning fineness, mean fiber curvature, SD of fiber curvature, mean opacity of fibers, percentage of medullated fibers, mean fiber diameter along length, and SD of fiber diameter along length. The main effects included in the mixed model were fixed effects of group, harvest season, and age and a random effect of animal. Correlations among total fleece weight, compression and OFDA measurements were calculated. Mean fiber diameter was lower than the fiber diameter along length. Mean percentage of medullated fibers was very low and ranged from 0.1 to 7.3%. The mean comfort factor was 97.5% and ranged from 93.3 to 99.8%. The mean fiber curvature was 40.1 deg/mm. The major changes in Angora fleece characteristics from 8 to 105 wk of age were an increase in fiber diameter, CV of fiber diameter, mean fiber diameter along length and curvature, and a decrease in compression and comfort factor. The effect of harvest season was significant on some fiber characteristics. Mean fiber diameter and the mean fiber diameter along length had a positive correlation with total fleece weight. The OFDA methodology is a method to evaluate fiber diameter, CV of fiber diameter, and bristle content through measuring of comfort factor. However, OFDA is not adapted for measuring opacity or size of medulla or both in Angora wool and needs a new definition or a special calibration. The spinning fineness should be redefined and adapted for Angora rabbits.

Key words: Angora, fiber characteristics, rabbit, wool

INTRODUCTION

Because average fiber diameter determines processing performance and end-use of wool, it is one of the most important characteristics that determine the market price of wool. More rapid, accurate, and efficient methods of measuring fiber diameter are therefore of considerable interest for animal fibers (Qi et al., 1994) and are widely used to determine the quality of wool and mohair. Angora rabbits produce fibers called Angora which belongs to luxury animal fibers category. The projection microscope method for measuring fiber diameter in Angora rabbits has been used in some studies (Rougeot and Thébault, 1983; Rougeot and Thébault, 1989; Qi et al., 1994; Thébault and Vrillon, 1994; Olmez and Dellal, 2002; Risam et al., 2005). However, differences among studies were observed due to the influence of fiber properties. The Angora rabbit fleece is made of different kinds of medullated fibers that have a variable cross section shape between and along the fiber. A rapid method for measuring cross section characteristics of the different fiber types of the Angora rabbit fleece has been proposed (Allain and Thébault, 1996). However, this method is not widely used because it required a skilled operator and was time consuming. The optical fiber diameter analyser (**OFDA**) is capable of providing an acceptable estimation of fiber characteristics in mohair (Lupton and Pfeiffer, 1998), wool (Baxter et al., 1992; Cottle et al., 1996; Peterson and Gherardhi, 1996; Baxter, 1998; Allain and Thebault, 2000; Allain and Thébault, 2000), and cashmere (Peterson and Gherardhi, 1996; Herrmann and Wortmann, 1997). Allain and Thébault (2000) showed that OFDA may also be a promising system for accurate and rapid estimation of Angora wool quality. However, to our knowledge, no comprehensive profile of fiber properties of Angora using OFDA has been published. The objective of this study was to describe the characteristics of Angora wool using OFDA. A secondary objective was to investigate the variability of the quality of Angora wool according to the age and the harvest season.

MATERIALS AND METHODS

Animals and Fiber Sampling

The population background, production, management, and selection procedure were previously described in detail by (Rafat et al., 2007a). Briefly, in order to explore genetic variability of Angora wool production and other quantitative traits, a divergent selection experiment for total fleece weight was carried out in French Angora rabbits during 8 yr beginning in 1994. The aim of the selection experiment was to obtain 2 divergent lines (low and high) based on total fleece weight in order to measure direct and correlated responses to selection. From the last cohort born in 2001, 360 fleece samples were collected from 30 females of each selected line. All animals were white and were born from January to November 2001. For each animal, total fleece weight was recorded and a fleece sample from the back was taken at 8, 21, 35, 49, 77, and 105 wk of age. The mean BW of animals at these ages were 1.3, 3.1, 3.4, 3.7, 3.9, and 3.9 kg, respectively.

This experiment was licensed under the guidelines of the French Ministry of Agriculture and the National Committee of Animal Experimentation for animal research.

Fiber Measurements

All samples (n = 349) were tested on OFDA4000 at BSC Electronics Pty. (Ltd., Ardross, 6153 Western Australia). For measurements of each Angora wool sample, between 50 and 100 mg fiber snippets were obtained at random by cutting fleece samples of Angora wool with a guillotine at about 2 to 3 cm from the base of the whole staple. Snippets are short pieces of fiber (typically around 0.8 to 2 mm long) which have been cut to measure fiber diameter and related properties. Snippets were processed according to the procedure outlined in the International Wool Textile Organization test method (IWTO-47, 1995). The OFDA was calibrated using standard wool tops and set to measure 4,000 snippets. Several measurements of OFDA were made (Table 1) : mean fiber diameter, CV of fiber diameter, comfort factor, spinning fineness, mean fiber curvature, SD of fiber curvature, mean opacity of fibers, percentage of medullated fibers, mean fiber diameter along 200 µm of length (diameter along length) and SD of mean diameter along length.

Definition of Angora Wool Quality and its Relationship with Fiber Diameter

Quality parameters considered in French Angora wool (Rochambeau et al., 1991) includes homogeneity [ratio between the bristly hair weight (a positive characteristic) and total fleece weight. Bristly hair is the part of the fleece usually harvested from the back and the sides of the Angora rabbits having a high content of long and coarse fibers. In wooly hair (usually harvested from the breast and the belly) there is a low content of guard hair]; compression and resilience (measured on a 10 g sample of Angora wool harvested from the rabbit haunch and submitted under a pressure of 3 kg inside a smooth walled, graduated cylinder of 43 mm diameter. Compression is the height of compressed wool inside the cylinder. Resilience is the height of the wool when the pressure is removed; structure (ratio of the down length to the bristle length); and tautness or roughness (assessed subjectively by handling the smoothness of coat on the sides of the rabbit. This quality is desirable to the French processing industry and is estimated by the breeder on a scale of 1 to 5. This is a “bristle index” resulting from several characters including bristle diameter, bristle ratio, and coat structure. Cloth woven from wool with a high roughness index has a desirable fluffy look).

Fiber diameter has close relationship with the quality characteristics of Angora wool. Compression was measured on all samples to study the probable correlation between compression and OFDA measurements. For definithin of comfort factor see Table 1.

Table 1. OFDA4000[1] measurements included in this study

Measurement	Definition
Mean fiber diameter, µm	Average of all fiber diameter measurements (n = 4000) taken on the samples
CV of fiber diameter, %	The CV of all fiber diameter measurements taken from the sample
Comfort factor, %	Comfort factor is the percentage of fibers greater than 30 microns subtracted from 100 percent.
Spinning fineness, µm	A measure of the performance of the fiber when spun into yarn by combining the measurements of the mean fiber diameter and the CV. The formula used by OFDA4000 was proposed by(Butler and Dolling, 1992) according to an original theory from (Martindale, 1945)). In practice, the spinning fineness is equivalent to the mean fiber diameter when the CV is 24%.
Fiber curvature, deg/mm	A measure of the angle formed by 200µm fiber long arc and extra polled to 1mm long arc. The greater the curvature is, the finer the crimp is.
Mean fiber opacity	Average of all fiber opacity measurements taken on the sample. Opacity is the relative capacity of a fiber to obstruct transmission of light when it is scanned under both dark and bright field image
Medullated fiber content, %	The percentage of fiber opacity measurements that were above 94%.
Mean fiber diameter along length, µm	Average of all fiber diameter measurements taken along 200 µm fiber length each 2 µm
SD of mean fiber diameter along length	The S.D. of all fiber diameter measurements taken along 200 µm fiber length each 2 µm

[1] OFDA4000: the first instrument to directly measure diameter, length and hauteur of fibres in aligned form. Suitable for wool, animal and synthetic fibres.

Statistical Analyses

Traits were tested for normal distribution. An important application of mixed linear models is in the analysis of repeated measures data (Littell et al., 1998; Wang and Goonewardene, 2004). Therefore, mean fiber diameter, CV of fiber diameter, spinning fineness, comfort factor, mean fiber curvature, and diameter along length were analyzed with a mixed model that included a random effect of animal. The model was:

$Y_{ijklm}=\mu+G_i+S_j+A_k+r_{ijkl}+e_{ijklm}$

Y_{ijklm} was the trait, µ was the general mean, G_i was the selected group of the animal (low and high), S_j was the season of harvest (j=1, 4), A_k was the age at harvest (k=1, 6), r_{ijkl} was the random effect of animal, and e_{ijklm} was the random residual term. The MIXED procedure of SAS (SAS Inst., Inc., Cary, NC) was used for these analyses. The CORR procedure of SAS was utilized to calculate correlation coefficients between selected characteristics.

RESULTS AND DISCUSSION

Descriptions

Basic measures for fiber and fleece characteristics are presented in Table 2. The measured mean fiber diameter, CV of fiber diameter, diameter along length, and fiber curvature of Angora wool samples had a distribution near to normal (data not shown).

The spinning fineness was greater than mean fiber diameter and diameter along length. Allain and Thébault (2000) measured 40 samples of Angora wool from 1 yr old rabbits and reported 14.7 ± 1.1 µm and 35.7 ± 5.6 % for fiber diameter and CV of fiber diameter, respectively. These data are similar to our results. The difference between spinning fineness and mean fiber diameter resulted from a high CV of fiber diameter and the presence of desirable coarse bristles in the Angora wool. Thus, it was predicated that spinning yield of Angora wool be lower than sheep wool. The present definition of spinning fineness for sheep wool may be not useful or should be redefined for Angora wool.

Table 2. Basic statistics for fiber and fleece characteristic measurements in the French Angora rabbit[1]

Trait	n	Mean	SD	Minimum	Maximum
Total fleece weight, g	343	177.7	88.4	18.0	378.0
Compression, mm	321	28.1	2.6	20.0	37.0
Mean fiber diameter, µm	349	14.6	1.2	11.6	18.3
CV of fiber diameter, %	349	40.4	7.0	26.0	61.9
Comfort factor, fibers ≤ 30µm, %	349	98.0	1.0	93.3	99.8
Spinning fineness, µm	349	17.5	2.1	13.1	24.7
Mean fiber curvature, deg/mm	349	40.1	10.8	18.0	68.0
SD of fiber curvature, deg/mm	349	30.4	6.9	15.0	49.0
Mean opacity of fibers, %	349	46.0	6.0	31.5	61.0
Percentage of Medullated fibers, %	349	1.7	1.2	0.1	7.3
Mean fiber diameter along 200 µm length, µm	349	15.4	1.3	11.8	19.7
SD of mean fiber diameter along 200 µm length, µm	349	6.2	1.4	3.2	10.9

[1] See Table 1 for a definition of fiber characteristics. These samples have been collected at different ages. Data presented as averages over all

Mean fiber diameter along length was 5% greater than mean fiber diameter (15.4 and 14.6 µm, respectively). The S.D. of mean fiber diameter along (a measure of the uniformity of fiber diameter) indicated a large variability of the mean fiber diameter along (6.2 µm or 40.2%). In sheep, along fiber length variation in diameter is lower and ranged from 10 to 16% (Notter et al., 2007). In Angora rabbit, the pattern of fiber growth is not permanent and a new hair growth produces a “tip-end” fiber after each harvest. This could explain the high along fiber length variation in diameter in Angora rabbit compared to the sheep. Nevertheless, our results of fiber diameter and diameter along length confirm the large variability between and along fibers in Angora rabbit.

Mean percentage of medullated fibers was very low and ranged from 0.1 to 7.3%. This result was unexpected because when Angora wool characteristics are observed using the cross-section methodology (Thébault et al., 1995), all fibers have at least 1 medulla canal (Figure 1). By considering the measured range of fiber diameter (more than 8 µm), it was expected that all fibers would be distinguished as medullated fibers by OFDA (the percentage of medullated fibers would be close to 100). This was not the case such that the opacity threshold for medullated fibers may need to be redefined for Angora wool compared to the threshold used for sheep wool and mohair. Alternatively, the result could be interpreted as only showing the most medullated and opaque fibers which are the ones visible to the eye, rather than strictly showing 100% of the fibers as medullated which may not be a useful measure.

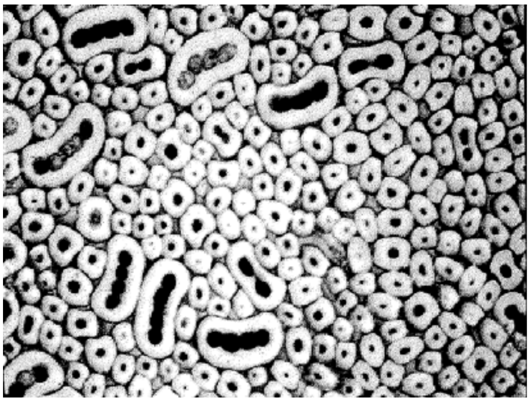

Figure 1. Cross section images of a whole lock in the proximal region of Angora wool.

Medullated fiber content is an important selection criterion for Angora goats (Allain and Roguet, 2006) and certain breeds of sheep. Some sheep breeds (Drysdale) were specifically developed for high medullated fiber content (Lupton and Pfeiffer, 1998). In Angora wool production, the incidence of medullation is not very important because, in contrast to other fiber-producing animals, all fibers are desirable. However, size and number of medulla canals are an important criteria to identify different kinds of fibers constituting the Angora rabbit fleece. Thus, a new definition and calibration of OFDA must be developed in order to measure medullation in Angora wool.

The mean comfort factor was 97.5% and ranged from 93.3 to 99.8%. Bristles or coarse fibers are desirable fibers which play an important role in determining Angora wool quality (Rougeot and Thébault, 1989). Thus, measurement of the percentage of fibers having a fiber diameter greater than 30 µm is an important criteria determining

Angora wool quality. As proposed by Allain and Thébault (2000), comfort factor of OFDA, or conversely prickle factor, can be a good indirect estimation of bristle content. In fleece testing, prickle factor is an early attempt to characterize the tendency for coarser fibers to produce irritations on the skin. Essentially, fibers over 30 µm in diameter tend to bend less and produce a painful “poking” sensation on the skin’s surface. With more than 5% of the total number of fibers, the effect tends to be quite noticeable. Hence, the prickle factor is the percentage of fibers above 30 µm (SGS, 1996).

The mean fiber curvature of Angora (40.1 deg/mm) was less than reported results for wool. Values of 74.2 ± 4.8 deg/mm and 21.0 µm were observed for top curvature and diameter, respectively, for wool (Brims, 2003). In Targhee ewes, fiber curvature was reported 97.0 ± 11.3 deg/mm with fiber diameter of 21.9 ± 11.3µm (Notter et al., 2007). In cashmere goats, the range of 47.5 to 77.6 deg/mm was reported for fiber curvature in different ages and nutrition levels (McGregor, 2003). In Alpaca, 33.6 ± 7.0 deg/mm was reported for fiber curvature in the samples with fiber diameter of 27.8 ± 5.4 µm (Lupton et al., 2006). In the same species, fiber curvature in samples with fiber diameter of 28.1 ± 6.0 µm was reported 27.8 ± 10.6 deg/mm (McGregor, 2002). The significant role of fiber crimp in determining wool and mohair processing performance has been demonstrated (Smuts et al., 2001). A good relationship was found to exist between the OFDA curvature and staple crimp/wave frequency for both wool and mohair. No published information is available for this trait in Angora rabbits. In furred and furless white New Zealand does, fiber curvature has been reported (38.5 ± 2.0 and 47.5 ±1.8 deg/mm, respectively; (Rogers et al., 2006). These findings and our results suggest that fibers in rabbits are less crimped than in sheep or goats.

Harvest Season and Age Effects

The 2 groups of Angora rabbits were produced from a divergent selection experiment on total fleece weight. No effect of selection group was observed on mean fiber diameter, CV of fiber diameter, comfort factor, curvature, and fiber along length.

Effect of harvest season was significant on the fiber diameter, CV of fiber diameter, comfort factor, and diameter along length (Table 3). Diameter of down is smallest in summer (Thébault and Vrillon, 1994) which is similar to our results of fiber diameter and diameter along length (Table 3). Effects of the harvest season on comfort factor and diameter along length have not been reported previously. Comfort factor has been suggested to be indirect estimation of both traits of bristle content (Allain and Thébault, 2000) and secondary to primary follicle ratio (Rafat et al., 2007b). In the present study, low comfort factor was observed in summer when secondary to primary follicle ratio was low and bristle content was high, as shown in other studies (Rougeot and Thébault, 1983; Rafat et al., 2007b). This result confirms that comfort factor is an important characteristic describing quality of Angora wool.

Table 3. Least square means for effects of harvest season and age on French Angora wool

	Fiber characteristic[1]				
Item	Mean fiber diameter	CV of fiber diameter	Comfort factor	Fiber curvature	Diameter along length
Harvest season					
Winter	14.9^{a}	40.4^{a}	97.9^{b}	40.3	15.7^{a}
Spring	14.7^{a}	40.8^{a}	97.9^{b}	40.5	15.6^{a}
Summer	14.3^{b}	42.1^{a}	97.9^{b}	40.1	15.1^{b}
Autumn	14.7^{a}	38.9^{b}	98.2^{a}	38.8	15.5^{a}
Age, wk					
8	14.0^{b}	32.9^{d}	98.7^{a}	24.9^{c}	14.3^{d}
21	14.0^{b}	37.5^{c}	98.7^{a}	40.5^{b}	14.8^{c}
35	15.2^{a}	40.9^{b}	97.9^{b}	42.4^{ab}	15.7^{b}
49	14.8^{a}	43.9^{a}	97.6^{bc}	44.1^{a}	15.6^{b}
77	15.0^{a}	43.7^{a}	97.6^{c}	42.6^{ab}	16.3^{a}
105	14.9^{a}	44.3^{a}	97.3^{c}	45.1^{a}	15.9^{a}

[1] See Table 1 for a definition of fiber characteristics. [a, b, c, d] Within an effect class and a column, LS means without common superscripts differ ($P < 0.05$).

A significant effect of age was observed on the fiber diameter, CV of fiber diameter, comfort factor, fiber curvature and diameter along length. Mean fiber diameter, CV of fiber diameter, diameter along length and mean fiber curvature increased with age. In contrast, comfort factor decreased with age (Table 3). Mean fiber diameter increased after 21 wk of ages but remained unchanged thereafter. Mean fiber curvature of Angora wool increased between 8 and 21 wk of age and then remained unchanged. Variations of fiber characteristics of Angora rabbit according to age have not been previously reported.

In Angora goats, similar observations of age effect on fleece weight and mohair fiber characteristics have been described (Allain and Roguet, 2003, 2006). There is a slight increase of fiber diameter of Merino sheep from 3 to 12 mo of age (Francis et al., 2000). In llamas, both fiber diameter and greasy fleece weight increase with age (Frank et al., 2006). In another study, with increasing age of the Alpaca, the fiber diameter increased whereas proportion fibers < 30 µm decreased (Wuliji et al., 2000). An effect of age on fiber characteristics of sheep was found, but differences in fiber diameter, comfort factor, and spinning fineness were low between 2 and 5 yr of age (Notter et al., 2007). In contrast to our results in Angora wool, fiber curvature in Alpaca at 1 yr of age was about double that recorded at ages of 2 yr and greater (McGregor, 2006).

Correlations

Table 4 contains correlations among total fleece weight, compression, and OFDA measurements. Mean fiber diameter had a negative relationship with comfort factor and a high positive relationship with diameter along length. Mean fiber diameter and diameter along length positively correlated with total fleece weight. Similarly there is an undesirable additive genetic correlation of 0.51 between fiber diameter and fleece weight in Targhee sheep (Notter and Hough, 1997).

A plot of curvature versus fiber diameter and diameter along length illustrates negative relationships between fiber curvature and fiber diameter and diameter along length. The magnitude of these correlations were smaller than, but in the same direction as, that reported for Angora wool (Rogers et al., 2006). In cashmere goats, increasing fiber diameter was associated with decreasing fiber curvature measured by OFDA (McGregor, 2003). The curvature measurement is generally positively associated with crimp frequency and, through a generally accepted positive association between crimp frequency and fineness, is usually negatively associated with fiber diameter and total fleece weight (Fish et al., 1999). In our study, a positive correlation was observed between total fleece weight and fiber curvature. Before any standardization of fiber curvature measurement using OFDA, work is required to determine appropriate calibration, sampling, preparation and testing procedures (Fish et al., 1999). No relationship was detected between fiber curvature and compression ($P = 0.73$), but fiber curvature increased at high CV of fiber diameter.

This study described Angora wool characteristics with OFDA methodology and its variations according to age and season in 2 divergently selected groups for total fleece weight in French Angora rabbits. The major changes in Angora wool characteristics from 8 to 105 wk of age were a decrease in compression and comfort factor, an increase in fiber diameter, CV of fiber diameter, diameter along length and fiber curvature. The effect of harvest season was significant on some fiber characteristics. Previously no widely used method was available for measuring fiber diameter on Angora wool. Allain and Thébault (2000) showed that measurements of cross section characteristics is the adequate methodology to determine fiber quality in the Angora rabbit, but such methods are not widely used as they still are time consuming and expensive. The OFDA methodology allows evaluation of important Angora wool characteristics such as fiber diameter, CV of fiber diameter, or bristle content through measuring of comfort or prickle factor. However, the OFDA methodology is not adapted for measuring opacity or size of medulla in Angora wool and needs a new definition or a special calibration. Data generated in this study could be used to establish the levels of opacity corresponding to fine, slightly medullated Angora wool and, coarse, heavily medullated fibers. Another parameter, spinning fineness should be redefined and adapted for Angora wool. Similarly, more studies are needed using curvature measurements on Angora wool.

Table 4. Correlation coefficients between total fleece weight, compression, fiber characteristic[1] and measurements of optical fiber diameter analyser in Angora rabbit fleeces

Item	Compression	Fiber diameter	CV of fiber diameter	Comfort factor	Fiber curvature	Diameter -along
Total fleece weight	-0.22	0.34	0.37	-0.32	0.47	0.48
P value	0.01	0.01	0.01	0.01	0.01	0.01
N	321	343	343	343	343	343
Compression		-0.13	-0.11	0.15	-0.02	-0.17
P value		0.02	0.04	0.01	0.73	0.01
N		321	321	321	321	321
Fiber diameter			0.19	-0.62	-0.25	0.94
P value			0.01	0.01	0.01	0.01
N			349	349	349	349
CV of fiber diameter				-0.75	0.47	0.30
P value				0.01	0.01	0.01
N				349	349	349
Comfort factor					-0.10	-0.66
P value					0.08	0.01
N					349	349
Fiber curvature						-0.11
P value						0.04
N						349

[1] See Table 1 for a definition of fiber characteristics.

The samples have been collected at different ages. Correlations have been calculated on averages over all.

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4 DIVERGENT SELECTION FOR TOTAL FLEECE WEIGHT IN ANGORA RABBITS: CORRELATED RESPONSES IN WOOL CHARACTERISTICS

RÉSUME

Une expérience de sélection divergente pour le poids total de toison a été réalisée chez le lapin Angora en vue d'étudier la réponse directe à la sélection ainsi que les réponses corrélées sur les composantes de la toison. Les données de 669 femelles issues de 8 cohortes de sélection nées entre 1994-2001 et ayant produit ensemble un total de 2 923 récoltes de toison ont été analysées afin de mesurer les réponses corrélées à la sélection. Les composantes de la toison étudiées ont été : les dimensions des poils (longueur des duvets et des jarres, diamètre moyen des fibres et diamètre des jarres), le facteur de confort ou proportion de fibres dont le diamètre est inférieur à 30 µm, la compression, la résilience, et le rapport du nombre de follicules pileux secondaires et primaires latéraux par follicule pileux primaire central (S/P). Une analyse des facteurs non génétiques a été réalisée à l'aide d'un modèle d'analyse de variance à effets fixes en utilisant la procédure GLM du logiciel SAS. Les effets fixes significatifs ensuite retenus pour l'analyse génétique ont été: l'année de naissance (8 niveaux de 1994 à 2001), le numéro de récolte (10 niveaux de 3 à 12), la saison de naissance (4 niveaux), la saison de récolte (4 niveaux) et le stade physiologique des femelles (3 niveaux : femelle ayant mis bas, femelle inséminée n'ayant pas mis bas et femelle non mise à la reproduction). Les paramètres génétiques et les tendances génétiques ont ensuite été analysés en utilisant un BLUP modèle animal à l'aide du logiciel VCE. Les 8 caractères décrivant les composantes de la toison ont été analysées selon un modèle multi caractères à 9 variables incluant TFW la variable sélectionnée.

Les héritabilités estimées des différentes composantes de la toison varient de 0.06 pour la longueur des duvets à 0.39 pour le diamètre des jarres. De fortes corrélations génétiques (supérieures à 0.70) ont été observées entre les longueurs des jarres et des duvets (0.75), entre la compression et la résilience (0.85), entre le diamètre des jarres et la longueur des duvets (0.80) et entre le diamètre moyen des fibres, le facteur de confort et le rapport S/P.

En réponse à la sélection pour le poids total de toison, nous avons observé :

- une amélioration de 0.92, 0.21 et 0.55 écart type génétiques respectivement pour la longueur des jarres, le facteur de confort et le rapport S/P ;
- aucune réponse corrélée sur la longueur des duvets
- une diminution de 1.00, 1.31, 0.38 et 0.50 écarts types génétiques pour respectivement la compression, la résilience, le diamètre des jarres et le diamètre moyen des fibres.,.

En conclusion, la sélection pour augmenter le poids total de toison s’est traduite par une amélioration des composantes qualitatives et quantitatives de la production de poils chez le lapin Angora français.

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Divergent selection for total fleece weight in Angora rabbits: Correlated responses in wool characteristics

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Abstract

An experiment was carried out to study direct and indirect responses to selection in the Angora rabbit. There were two selection lines, one selected for high fleece weight and the other for low fleece weight. Data from 669 female rabbits born in 1994–2001 and having produced a total of 2923 harvest of wool were analysed to quantify the correlated responses to selection. By 2001, there had been eight cohorts of selection. The correlated responses analysed included compression, resilience, fleece quality traits (bristle and down length, average fibre diameter, comfort factor, bristle diameter) and secondary to primary follicle ratio (*S*/*P*). Genetic correlations were obtained by restricted maximum likelihood techniques. In response to selection, a positive difference of 0.92, 0.21 and 0.55 genetic standard deviation were observed for bristle length, comfort factor and *S*/*P*, respectively. No correlated response was observed on down length while negative differences of 1.00, 1.31, 0.38 and 0.50 genetic standard deviations were observed for compression, resilience, bristle diameter and average fibre diameter, respectively. Selection for increasing total fleece weight results in an increase of qualitative component traits of wool production in the French Angora rabbit. The quantitative traits were examined in the first (published) part of the paper.

Keywords: Angora rabbit; Bristle; Divergent selection; Down; Fibre diameter; Follicle; Wool

1. Introduction

Angora rabbit fibre is categorised in the luxurious especially fine animal fibre group along with mohair, cashmere and alpaca. After wool and mohair, Angora fibre production is the third largest fibre industry in the world. Angora rabbit production in France was estimated to be approximately 2000–3000 rabbits with an annual production of 2 tonnes of fibre in 2005 (personal communications with the Union of French Angora Rabbit Breeders).

Selection for total fleece weight was successful in sheep (Wuliji et al., 2001; Bray et al., 2005), in goat (Merchant and Riach, 2003; Bai et al., 2006) and in French Angora rabbit (Rafat et al., 2007). It is unclear, however, whether a higher fleece weight is associated with an increase in other fleece characteristics (length, diameter, compression and secondary to primary follicle ratio) of Angora rabbits. In sheep, Morris et al. (1996) found an unfavourable

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correlated response in mean fibre diameter when selecting for high fleece weight. In a companion paper, Rafat et al. (2007) presented results of a divergent selection experiment on total fleece weight in French Angora rabbits. The first results indicated that an important direct response on total fleece weight was obtained on the two divergent lines. A divergence of three genetic standard deviations on both total fleece weight and weight of the bristly wool was observed between the high and low lines after 8 years of selection. An increase in live body weight was also obtained by selection for total fleece weight. The objective of this paper was to evaluate the correlated responses to selection for fleece characteristics.

2. Materials and methods

2.1. Animals

The animals came from a divergent selection experiment on total fleece weight described by Rafat et al. (2007). Studies were made on the wool production of 669 female Angora rabbits born between 1994 and 2001 under a divergent selection program to assess direct and correlated responses. There were 3567 animals in the pedigree file. The aim of the selection experiment was to obtain two divergent lines for total fleece weight. The selection criterion was the total fleece weight of the does measured for the third and later harvests. The selection method was based on a BLUP procedure using a repeatability animal model. The management, reproduction and housing conditions of these animals have been previously described (Allain et al., 1999; Rafat et al., 2007).

2.2. Traits

The rabbits were plucked for the first and second times at the ages of 8 and 21 weeks, respectively. Thereafter they were plucked at regular intervals every 14 weeks until the 12th harvest. The data of the 3rd to 12th harvests for each cohort were utilised in this study. At each harvest, total fleece weight (TFW) was recorded. The live body weight (9LW) was measured 9 weeks before each harvest. At the fifth and seventh harvests from cohorts of 1994 to 2000, and at the 3rd to 12th harvests from the last cohort born in 2001, the following variables were recorded: compression, resilience, the length of bristles (BL) and downs (DL) measured on locks taken from the haunch. The first two measurements were used to judge the quality of the fibre (Allain et al., 1999). Compression and resilience were measured according to the method of de Rochambeau et al. (1991).

On animals born in 2001 and issued from the last selected cohort, additional biological samples were made at the fifth and the seventh harvests (Table 1). Two wool samples were taken from the haunch. The first sample including all kinds of fibre was obtained to determine average fibre diameter (AFD) and comfort factor (CF, percentage of fibres ≤30 μm) according to the Optical Fibre Diameter Analyser (OFDA) methodology (IWTO-47, 1995). The second sample was obtained by extracting bristles by hand from a total lock in order to determine bristle diameter (BD) according to the cross section methodology (Allain and Thébault, 1996). Skin samples were taken from the back by biopsy 5 weeks after the fourth and the sixth harvest to determine the primary to secondary hair follicle ratio within the hair follicle group. Details of the methodology of skin histology and S/P ratio measurement are described by Rougeot and Thébault (1983). Because of the shrinkage of skin specimens during histological procedures, there is a strong case for using the relative density of primary and secondary follicles expressed by the S/P ratio to overcome the difficulties of making an accurate estimate of total population of wool follicles (Abouheif et al., 1984).

2.3. Statistical analysis

2.3.1. Testing of fixed effects

The least squares method of the GLM procedure (SAS, 2001) was utilised to determine the significance of the fixed effects and covariate. TFW was analysed with a model that initially included year and season of birth, harvest season, harvest number and reproduction as fixed effects and 9LW such as a covariate. BL, DL, compression and resilience were analysed with the same

Table 1
Number of records (*N*), means and standard deviation (SD) of the means for the studied traits

Trait	Unit	*N*	Means	SD
Total fleece weight [a]	g	2923	213.27	56.60
Bristle length [b]	mm	1171	101.93	9.41
Down length [b]	mm	1170	67.04	8.78
Compression [b]	mm	1165	26.52	2.64
Resilience [b]	mm	1165	60.08	5.33
Bristle diameter [c]	μm	149	46.41	3.45
Average fibre diameter [c]	μm	157	14.91	0.94
Comfort factor [c]	%	157	97.85	0.83
Secondary to primary follicle ratio [c]	–	102	48.18	10.32
Live weight before wool harvest [a]	g	2923	3802.1	473.99

[a] This trait was measured at all fleece harvests of all cohorts.
[b] This trait was measured at all harvests of the last cohort, and fifth and seventh harvests from previous cohorts.
[c] This trait was measured at the fifth and seventh harvests of the last cohort.

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Table 2
Significance levels of fixed effects for the studied traits[a]

Traits	Fixed effects					Covariate
	Year	Harvest number	Birth season	Harvest season	Reproduction	9LW
TFW	***	***	***	***	***	***
BL	***	*	*	**	ns	
DL	***	***	**	**	ns	
Compression	***	**	ns	***	ns	
Resilience	***	**	ns	**	ns	
BD				*		
AFD				*		
CF				*		
S/*P*				*		

[a] TFW: total fleece weight; BL: bristle length; DL: down length; BD: bristle diameter; AFD: average fibre diameter; CF: comfort factor; *S*/*P*: secondary to primary follicle ratio; 9LW: live weight at age of 9 weeks before wool harvest.
*** $P<0.001$; ** $P<0.01$; * $P<0.05$; ns: non-significant.

model without the covariate. BD, AFD, CF and *S*/*P* were analysed with a model including the harvest season effect (Table 2).

2.3.2. Estimation of genetic parameters and breeding values

The estimates of variance components for different variables were obtained by using VCE, a multivariate restricted maximum likelihood (REML) variance component estimation program with an animal model (Groeneveld, 1998). Genetic parameters were estimated according to a multivariate analysis including the nine traits studied: TFW, BL, DL, compression, resilience, BD, AFD, CF and S/P. The following multivariate linear mixed model was used:

$$\mathbf{y}_i = \mathbf{X}_i\mathbf{b}_i + \mathbf{Z}_i\mathbf{a}_i + \mathbf{W}_i\mathbf{p}_i + \mathbf{e}_i$$

where

$\mathbf{y}_i$ ($\mathbf{K}_i$) is a vector of $\mathbf{K}_i$ observations collected for the *i*th trait,

$\mathbf{b}_i$ ($\mathbf{f}_i$) is a vector of fixed environmental effects for the *i*th trait consisting of:

- a covariate effect of 9LW on TFW,
- year effect (8 levels; from 1994 to 2001) on TFW, BL, DL, compression and resilience,
- harvest number effect (10 levels; from the 3rd to the 12th harvest) on TFW, BL, DL, compression and resilience,
- birth season effect (4 levels) on TFW, BL and DL,
- harvest season effect (4 levels),
- reproduction effect (three levels: females which had litters and females which had been inseminated or not) on TFW.

$\mathbf{a}_i$ (N) is a vector of direct genetic effect for the *i*th trait; N is the total number of animals in the pedigree,

$\mathbf{p}_i$ (N_i) is a random vector of permanent environment to all observations from a given animal for the *i*th trait; N_i is the number of animals measured for the *i*th trait,

$\mathbf{e}_i$ ($\mathbf{K}_i$) is a random vector of residual for the *i*th trait.

$\mathbf{X}_i$, $\mathbf{Z}_i$ and $\mathbf{W}_i$ are known design matrices.

Table 3
Heritability (bold) and genetic correlations±standard deviations from multiple-trait analysis for the studied traits[a]

	TFW	BL	DL	Compression	Resilience	BD	AFD	CF	*S*/*P*
TFW	**0.35±0.03**	0.37±0.07	0.20±0.08	0.05±0.08	−0.07±0.08	0.16±0.06	0.02±0.07	0.12±0.09	0.04±0.10
BL		**0.15±0.02**	0.75±0.09	−0.15±0.10	−0.04±0.12	0.55±0.09	0.04±0.13	0.34±0.14	0.07±0.16
DL			**0.06±0.02**	0.12±0.12	0.30±0.14	0.80±0.09	0.39±0.19	−0.12±0.17	−0.46±0.19
Compression				**0.10±0.02**	0.84±0.06	0.39±0.09	−0.10±0.13	0.38±0.14	0.14±0.16
Resilience					**0.08±0.02**	0.72±0.09	−0.13±0.15	0.17±0.17	0.05±0.18
BD						**0.39±0.05**	0.07±0.12	0.01±0.17	−0.18±0.15
AFD							**0.32±0.08**	−0.63±0.12	−0.88±0.11
CF								**0.15±0.05**	0.86±0.11
S/*P*									**0.17±0.06**

[a]TFW: total fleece weight; BL: bristle length; DL: down length; BD: bristle diameter; AFD: average fibre diameter; CF: comfort factor; *S*/*P*: secondary to primary follicle ratio.

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Breeding values for all the traits were obtained as solutions from the best linear unbiased prediction analysis of the last covariance matrices at convergence. Then the means of the estimated breeding value (EBV) for all traits were calculated per cohort of animals born the same year and per divergent selected line.

3. Results and discussion

3.1. Genetic parameter estimates

Table 3 shows the heritability estimates of, and genetic correlations between total fleece weight and wool characteristics. Heritability estimates for BL, DL, compression and resilience were smaller than those reported earlier in Angora rabbits (Allain et al., 1996a). Genetic correlations between the total fleece weight and both bristle and down length were low to moderate and positive. The genetic correlation between bristle and down length was high and positive. Heritability estimates for BL, DL, compression and resilience were low to moderate, ranging from 0.06 to 0.15. All these results were in agreement with earlier observations (Allain et al., 1996b). In cashmere goats, Bai et al. (2006) reported a significant positive correlation between fleece weight and fibre length.

High and positive genetic correlations were observed between compression and resilience. These two important fleece characteristics are used to determine fleece bristlyness. Bristly fleeces from Angora rabbits are valued because of their ability to produce a fluffy yarn used for certain luxury knit products. Bristly fleeces compress more and relax less than woolly ones (de Rochambeau et al., 1991).

Heritability estimates for BD, AFD, CF and *S*/*P* were moderate to high. The heritability of *S*/*P* in the present study was low compared to estimates by Abouheif et al. (1984) in sheep and Ma et al. (2005) in cashmere goats, but in agreement with the lower value of the estimate by Mortimer (1987) in Merino sheep. The high and positive genetic correlation of CF with *S*/*P* and the high and negative genetic correlation between AFD and S/P suggest the possibility of using either AFD or CF instead of *S*/*P*. Measurement of AFD and CF by OFDA methodology is rapid, easier and less expensive than the measurement of the *S*/*P* ratio from a skin sample after a histological treatment. Up to now, there are no literature available describing genetic parameters of fibre diameter and hair follicle density in Angora rabbits.

3.2. Genetic correlated responses on other fleece traits

The means of breeding value estimates per year of birth are plotted in Fig. 1 for BL, DL, compression and resilience. Response on total fleece weight and correlated responses on other fibre traits observed on the 2001 animal cohort. In response to the divergent selection experiment on total fleece weight, positive differences of 0.92, 0.21 and 0.55 genetic standard deviations were observed for bristle length, comfort factor and *S*/*P*,

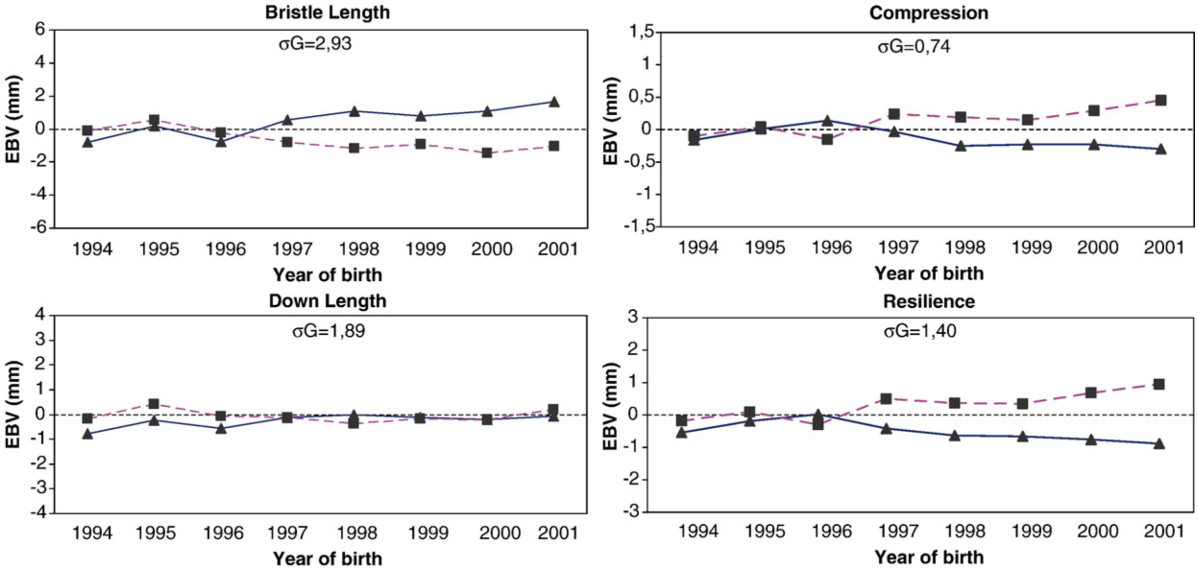

Fig. 1. Change of mean breeding value estimates (EBV) of bristle length, down length, compression and resilience, over the 8 years of selection for both the high (▲) and low (■) lines. Genetic standard deviation (σ_G) is given for each trait.

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respectively. There was no effect on down length while negative differences of 1.00, 1.31, 0.38 and 0.50 genetic standard deviations were observed for compression, resilience, BD and AFD, respectively. No results about correlated responses to selection on total fleece weight or on fleece characteristics in Angora rabbits have been published. It is important to observe that selection for total fleece weight has a general beneficial effect on fleece quality. A high quality fleece having a good aptitude to produce a fluffy yarn is characterised by a high weight of first class quality, high fleece homogeneity and long bristles (Thébault and de Rochambeau, 1988). These characteristics were observed in the high line as described previously for weight of first class quality and fleece homogeneity (Rafat et al., 2007) and in this study for length of bristles. Thus, selection for total fleece weight results in an improvement of the quality of the fleece. Similarly, Bai et al. (2006) suggested that selection for cashmere weight is very effective in the cashmere goat, which has led to the slow genetic progress of fibre length due to its genetic correlation with cashmere weight. In another study, Redden et al. (2005) concluded that selection for increased mean cashmere weight results in a reduction in fleece quality and value.

Compression and resilience were also affected by selection and a decrease in both traits was observed in the high line. Similarly, a gradual decline in resistance to compression was noted over 9 years of selection of good quality wool or finer wool in Merino sheep (Ventner, 1980). Resistance to compression is related to fibre crimp and fibre diameter (McGregor, 2006). In our study estimates of genetic correlations were positive between BD and both compression and resilience.

4. Conclusion

Selection for total fleece weight significantly increased bristle length, secondary to primary follicle ratio and comfort factor and decreased compression, resilience, bristle diameter, and average fibre diameter. These changes resulted from moderate to high genetic correlations between total fleece weight and bristle length, and between fibre dimensions (BL, DL, AFD, and BD) and secondary to primary follicle ratio, comfort factor, compression and resilience. Thus, selection for increasing total fleece weight results in an increase of both quantitative and qualitative traits of wool production in the French Angora rabbit. Measurement of total fleece weight is simple and easy at the farm level. Selection for this trait has positive effects on fleece characteristics such as bristle length, follicle population and fibre diameter.

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5 DEMOGRAPHY AND GENEALOGY: GENETIC DESCRIPTION OF A DIVERGENT SELECTION EXPERIMENT IN ANGORA RABBITS WITH OVERLAPPING GENERATIONS

Résume

Les objectifs principaux de ce chapitre sont d'une part de décrire la démographie et la structure génétique de deux lignées de lapins Angora français conduites en générations chevauchantes lors d'une expérience de sélection divergente. Il s'agit d'autre part de décrire les effets d'une augmentation de la consanguinité pendant l'expérience de sélection divergente. Il s'agit enfin d'analyser la différentielle de sélection sur le poids total de toison, caractère qui constituait le critère de sélection.

La longévité productive des femelles a été analysée à l'aide du *kit* de survie selon un modèle de Weibull incluant les effets fixes suivants: le groupe de sélection (2 niveaux), la consanguinité (4 niveaux correspondants aux quartiles de la distribution des coefficients de consanguinité au sein de chaque cohorte de sélection) ainsi que 2 effets dépendants du temps : la saison de récolte (37 niveaux de l'hiver 1995 à l'hiver 2001), le statut reproductif de la femelle à chaque récolte (3 niveaux: pas de reproduction, femelle inséminée ou femelle ayant mis bas).

Aucune différence significative entre les lignées basses et haute n'a été observée sur la longévité productive de femelles. Des effets significatifs des deux effets dépendants du temps (saison de récolte et statut reproductif) et de la consanguinité ont été observés. Les animaux les plus consanguins ont un facteur de risque de 30% supérieur à celui des autres classes ayant un moindre coefficient de consanguinité.

L'intervalle moyen entre générations a été de 562 et 601 jours respectivement dans les lignées basse et haute, soit un nombre de générations de 3.90 et 3.64, respectivement. Des effets significatifs de l'année de la naissance et de la lignée de sélection intra année de naissance sur l'intervalle entre générations ont été observés. Les intervalles de génération ont diminué de manière significative de 1995 à 2000 et plus rapidement dans la lignée haute que dans la lignée basse.

Le nombre de filles dans la lignée haute a été très variable. Le nombre d'animaux par génération a été plus élevé en lignée haute que dans la lignée basse. Chaque mâle a laissé en moyenne trois filles à la génération suivante (2.52 dans la lignée basse, 3.24 en lignée haute). Dans les deux lignées la population de 2001 a été crée à partir de environ 8 ancêtres efficaces de la population initiale.

La consanguinité dans la lignée haute a toujours été plus élevée que dans la lignée basse. L'effet du consanguinité a été significatif uniquement sur le poids total de toison et le poids vif. Les animaux les moins consanguins ont produit un poids total de toison plus élevé que les autres. L'augmentation de la consanguinité pendant l'expérience a eu un effet négatif sur le poids total de toison. La description démographique et la structure génétique ont montré que la gestion des reproducteurs a été très similaire au cours des 8 années dans les deux lignées divergentes. Les différentielles de sélection observées ont été inférieures à celles prévues initialement en raison des règles de gestion des reproducteurs adoptées afin de limiter l'augmentation de consanguinité.

Les différentielles de sélection sur le poids total de toison et la réponse corrélée sur le poids corporel ont été analysées à partir de la valeur génétique estimée (EBV) a posteriori des candidats à la sélection et des parents théoriques et réels. Les parents théoriques ont été définis intra lignée comme étant les 5 mâles et les 20 femelles ayant les valeurs génétiques les plus élevées ou les plus faibles respectivement pour la lignée haute et la lignée basse. Les différentielles de sélection réalisées et théoriques ont été calculées comme la différence de valeur génétique entre les candidats à la sélection et respectivement celles leurs parents réels et celles des parents théoriques. L’analyse de la relation entre les valeurs génétiques estimées du poids total de la toison et du poids corporel au cours de l’expérience suggère d’émettre une hypothèse sur la mise en œuvre de two mécanismes différents. Dans un premier temps jusqu’en 1997, les valeurs génétiques pour le poids corporel ont diminué dans la lignée haute lorsque la valeur génétique pour la production de poils augmentait et vice versa dans la lignée basse. Ensuite après 1997, les valeurs génétiques du poids corporel et du poids total de toison ont évolué dans le même sens dans les deux lignées. Ainsi dans un premier temps, les animaux ont utilisé préférentiellement leurs réserves corporelles pour la production de poils alors que lors de la seconde période, l’augmentation du poids du corps et par conséquent de la surface de la peau a permis le progrès génétique sur la production de poils

Abstract

The main aim of this chapter were i) to describe the demography and the genetic structure in two divergent selected lines of French Angora rabbits with overlapping generations, ii) to describe the effects of an increase of inbreeding during an experiment of divergent selection, iii) to analyse the differential of selection on selection criterion of total fleece weight. A study of longevity with the survival kit showed that there was not significant difference between low line (LL) and high line (HL) in a number of live animals. Significant effects of both time dependant effects: year-harvest season and reproduction were observed. An significant effect of inbreeding ($P<0.05$) was also observed with a 30 % higher risk factor in the highest class of inbreeding coefficient compared to other classes. The means of generation intervals were 562 and 601 days in LL and HL, respectively. The number of generations for LL and HL were 3.9 and 3.64, respectively. The effects of birth year and line within birth year on generation intervals were significant. Generation intervals decreased significantly from 1995 to 2000 ($P<0.05$). The number of daughters in HL was very variable. The number of animals per generation was higher in HL than in LL. Each buck has left nearly three daughters to the next generation (2.52 in LL, 3.24 in HL). In both lines, the effective number of ancestor genomes still present in the genetic pool of the generation was around 8 from the reference population of 1995 to that of 2001. Inbreeding in HH was always higher than in LL. The effect of inbreeding was significant ($P<0.05$) only on total fleece weight and live weight. The animals with the lowest inbreeding category produced a higher total fleece weight ($P<0.05$) than the others. The description of demography and the genetic structure in this study showed that in the two divergent lines, the similar management of reproducers was done during 8 years of selection.

5.1 Introduction

Parameters derived from the probability of gene origin are very useful for describing a population structure after a small number of generations and the gene origin approach may be used in selection experiments analysis (Rochambeau et al., 1989).

Owing to the fact that selection experiments with rabbits are generally carried out in separated generations, it is interesting to achieve a demographic analysis in a population that has been selected in overlapping generations. Moreover, most natural and artificial populations have overlapping generations. In addition, breeding organisations are interested in utilising overlapping generation.

Hill (1974) showed that in a population with discrete generations, the pattern of response can be described and predicted adequately by just the mean performance of the group of animals born in the current generation; but with overlapping generations it is necessary to describe the performance of all age groups present in the population at any time.

In chapter 2, observations from the divergent selection experiment on total fleece weight in Angora rabbits were described without explaining the reasons of variations in the genetic trends. Here we describe the selection differential in which the posterior estimated breeding value (EBV) of selection candidates, theoretical and real parents will be compared.

The main aim of this chapter were i) to describe the demography and genetic structure in two divergent selected lines of French Angora rabbits with overlapping generations, ii) to describe the effects of an increase in inbreeding during an experiment of divergent selection and iii) to analyse the selection differential for the selection criterion total fleece weight (TFW) and for the correlated response of live body weight (LW).

5.2 Materials and methods

5.2.1 Longevity

The total number of live animals in the first wool harvest was 1114 and decreased to 942 (236 male, 675 female) in the second wool harvest. In French Angora rabbit production, bucks are maintained in the herd only for the purpose of reproduction and they do not have any role in the production of wool. Therefore, longevity was studied only for female animals and the variable analysed was the total number of harvest during the life. The numbers of live females according to birth year and harvest number are shown in Table 5.1. If a female was still living after the twelfth harvest, its record was censored. For females born in 1999 and 2000, their records were also censored if the animals were still living after the eighth and the fifth harvest respectively, due to limited number of cages in the experimental unit. Longevity data were analysed using the ‘Survival kit’, a set of FORTRAN programmes(Ducrocq, 1994). The fixed effects included in the model were the selection group (2 levels: low and high lines), inbreeding class (4 levels: quartiles of the inbreeding coefficient distribution within each cohort), the year-season of harvest (37 levels from winter 1995 to winter 2001), the reproduction status (3 levels: no reproduction, females inseminated and females with litters).The two latter effects were assumed to be time dependant with changes at each harvest. The Weibull programme (Ducrocq et al., 1988) was used to fit the data. Likelihood ratio tests of fixed effects were obtained by comparing the full model with reduced models explaining one effect at a time.

Table 5.1: Number of female animals used for estimation of longevity.

Birth Year	**Group**	**Harvest Number**											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1995	Low	52	51	48	45	40	38	32	31	26	21	15	13
	High	52	49	47	40	32	29	26	22	19	17	15	11
1996	Low	42	42	41	39	32	29	27	23	24	19	16	11
	High	38	37	36	31	30	22	18	11	11	8	6	6
1997	Low	41	22	21	21	20	20	17	14	12	12	11	7
	High	50	40	33	30	27	25	21	19	14	11	8	8
1998	Low	51	42	41	34	29	26	21	16	15	8	4	1
	High	49	46	42	38	32	29	29	26	12	9	6	5
1999	Low	64	45	42	34	29	26	22	12				
	High	64	54	51	44	42	40	29	18				
2000	Low	38	29	26	23	15							
	High	49	38	31	29	22							
2001	Low	89	83	76	69	62	55	44	33	22	18	14	7
	High	101	97	89	82	73	62	50	39	34	29	25	13

5.2.2 Pedigree information

To characterise the structure of the population, the following parameters were analysed:
(1) Generation interval: This is the average age of parents at the birth of their useful offspring. We computed this for the four pathways (buck-son, buck-daughter, doe-son and doe-daughter) using birth dates of animals together with those of their bucks and does. The effects of the year of birth and the selected line within year were studied with GLM procedure of SAS (2001). This parameter has been calculated for parents of 942 animals (male and female) alive in the second harvest.

(2) The probability of gene origin was calculated from pedigree information using ENDOG v3.2 (Gutierrez and Goyache, 2005) and PEDIG (Boichard, 2002) softwares. The following statistics were computed: number of ancestors, effective number of ancestors and number of ancestors explaining 50 percent of the genetic variability. Size of population, base population

(one or more unknown parents) and the number of animals in the reference population were 1250, 55 and 1195, respectively.

The expected marginal contribution of the ancestors contributing the most in the whole population was computed with ENDOG software according to (Boichard et al., 1997) and using the whole known pedigree dataset as the reference population. However, to compute the effective number of ancestors (f_a) we used as the reference population the animals born in each year.

(3) Effective population size (Ne) is defined according to Wright (Wright, 1931) as the number of individuals that would give rise to the calculated rate of inbreeding if they bred in the manner of the idealised population. Ne of a population was estimated in two ways. As a first estimation, Ne_f was calculated from the evolution of the inbreeding coefficient (Nei and Tajima, 1981):

$$\hat{N}e_f = \frac{g}{2\Delta\hat{F}}$$

Where g is the number of cohorts (8) divided by generation intervals –therefore g is the number of generation-, and $\Delta\hat{F}$ is the relative rate of increase of inbreeding from initial population to the last cohort.

For a second estimation, Ne_h was calculated through the parameters of familial structure according to (Hill, 1972) as follows:

$$\frac{1}{Ne_h} = \frac{1}{16ML}\left[2 + V_{mm} + 2\left(\frac{M}{F}\right)C_{mmmf} + \left(\frac{M}{F}\right)^2 V_{mf}\right] + \frac{1}{16FL}\left[2 + \left(\frac{F}{M}\right)^2 V_{fm} + 2\left(\frac{F}{M}\right)C_{fmff} + V_{ff}\right]$$

Where M and F are, respectively, the numbers of adult males and females with offspring and L the average (in year) of the generation intervals calculated for the four pathways. The parameter V_{mm} (V_{mf}) is the variance of the number of male progeny from a male (female) parent, and V_{mf} (V_{ff}) is the same variance for female progeny. Let the covariance of the number of male and female progeny from each male parent be C_{mmfm} and from each female be C_{fmff}.

5.2.3 Inbreeding

The individual inbreeding coefficient (F) defined as the probability that an individual has two identical alleles by descent was computed for each animal using the FORTRAN program *vanrad* from PEDIG software (Boichard, 2002). Previous experimental work has shown that inbreeding depression tends to be linear with respect to the level of inbreeding (Falconer, 1981). To confirm this applied generalisation, inbreeding of the animal was categorised into 4 discrete categories (Table 5.2). Category assignments were based on the quartiles of the distribution of inbreeding within each cohort. Total fleece weight, LW, bristle length (BL), down length (DL), bristle diameter (BD), mean fibre diameter (FD) and secondary to primary follicle ratio (SP) were analysed by least squares procedures (SAS, 2001) using the effects of inbreeding category and fixed effects. Live weight was considered as a covariate for TFW analysis. Live weight analysed by the same model without covariate. Fixed effects of above traits were the same as described previously (Rafat et al., 2007a; Rafat et al., 2007b).

Table 5.2: Four discrete categories of inbreeding (I) for each year of birth.

	Categories			
Year of birth	1	2	3	4
1994	I <= 0.01680	0.01680 < I <= 0.02513	0.02513 < I <= 0.03045	0.03045 < I
1995	I <= 0.02711	0.02711 < I <= 0.04785	0.04785 < I <= 0.07454	0.07454 < I
1996	I <= 0.03194	0.03194 < I <= 0.05661	0.05661 < I <= 0.09105	0.09105 < I
1997	I <= 0.05183	0.05183 < I <= 0.07425	0.07425 < I <= 0.08269	0.08269 < I
1998	I <= 0.07483	0.07483 < I <= 0.08339	0.08339 < I <= 0.10181	0.10181 < I
1999	I <= 0.09005	0.09005 < I <= 0.10181	0.10181 < I <= 0.12638	0.12638 < I
2000	I <= 0.12134	0.12134 < I <= 0.13262	0.13262 < I <= 0.14676	0.14676 < I
2001	I <= 0.12621	0.12621 < I <= 0.14545	0.14545 < I <= 0.15186	0.15186 < I

5.2.4 Differential of selection

We described EBV for candidates of selection, theoretical parents and parents. In each year all live animals during the 6 months-period from first April of the current year backward to first October of the previous year were considered as candidates of selection. Theoretical parents were defined as the 5 males and 20 females that had the best and the worst EBV for TFW in the HL and LL, respectively. The parents were animals that were utilised as breeding animals during the experiment. The realised differential was calculated as EBV of the parent minus those of candidates of selection. The theoretical differential was calculated as the EBV of the theoretical parent minus those of candidates of selection. Numbers of animals for each of the mentioned animals are shown in Table 5.3.

Table 5.3: Number of candidates of selection and parents. Number of theoretical parents was 25 including 5 male and 20 female in each year.

	Year							
	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Candidates								
Low								
Male	16	14	13	22	10	17	23	19
Female	106	106	63	83	68	69	77	68
Σ	122	120	76	105	78	86	100	87
High								
Male	16	16	9	14	21	22	26	24
Female	107	99	40	66	64	49	98	91
Σ	123	115	49	80	85	71	124	115
Parents								
Low								
Male	5	5	5	2	8	10	9	11
Female	9	15	13	6	18	22	19	27
Σ	14	20	18	8	26	32	28	38
High								
Male	4	6	5	3	8	11	7	10
Female	5	16	15	5	16	25	18	26
Σ	9	22	20	8	24	36	25	36

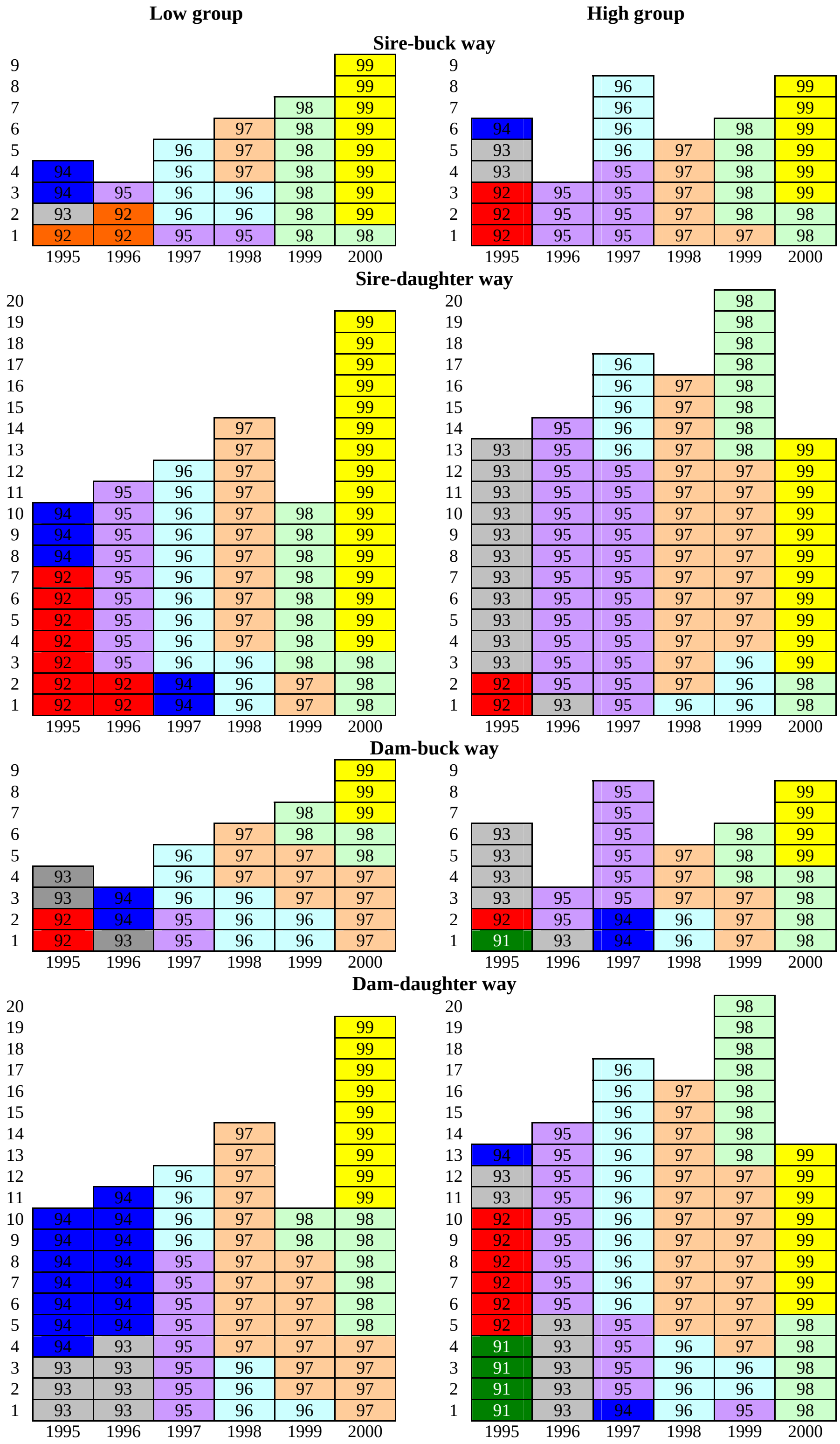
5.3 Results and discussions

5.3.1 Longevity

There was no significant difference between LL and HL in number of live animals. Significant effects of both time dependant effects: year-harvest season and reproduction were observed. An significant effect of inbreeding ($P<0.05$) was also observed with a 30 % higher risk factor in the highest class of inbreeding coefficient than in the other classes.

5.3.2 Generation intervals

The distribution of year of birth of reproducers in 4 ways of sire-buck, sire-daughter, dam-buck and dam-daughter are shown in Figure 5.1. Reproducers of each cohort have the parents which have been born during nearly last three years. In the last cohorts, reproducers become younger. Generation intervals for the four pathways are shown in Figure 2.2. In LL, the decrease was not uniform through pathways and during the two last years, parents of females remained relatively more aged. In contrast, in HL the decrease was uniform. The means of generation intervals were 562 and 601 days in LL and HL, respectively. There were 8 cohorts (1994-2001), and then the number of generations for LL and HL were 3.90 and 3.64, respectively.



Low group

High group

Sire-buck way

Low group

	1995	1996	1997	1998	1999	2000
9						99
8						99
7					98	99
6				97	98	99
5			96	97	98	99
4	94		96	97	98	99
3	94	95	96	96	98	99
2	93	92	96	96	98	99
1	92	92	95	95	98	98

High group

	1995	1996	1997	1998	1999	2000
9						
8			96			99
7			96			99
6	94		96		98	99
5	93		96	97	98	99
4	93		95	97	98	99
3	92	95	95	97	98	99
2	92	95	95	97	98	98
1	92	95	95	97	97	98

Sire-daughter way

Low group

	1995	1996	1997	1998	1999	2000
20						
19						99
18						99
17						99
16						99
15						99
14				97		99
13				97		99
12			96	97		99
11		95	96	97		99
10	94	95	96	97	98	99
9	94	95	96	97	98	99
8	94	95	96	97	98	99
7	92	95	96	97	98	99
6	92	95	96	97	98	99
5	92	95	96	97	98	99
4	92	95	96	97	98	99
3	92	95	96	96	98	98
2	92	92	94	96	97	98
1	92	92	94	96	97	98

High group

	1995	1996	1997	1998	1999	2000
20					98	
19					98	
18					98	
17			96		98	
16			96	97	98	
15			96	97	98	
14		95	96	97	98	
13	93	95	96	97	98	99
12	93	95	95	97	97	99
11	93	95	95	97	97	99
10	93	95	95	97	97	99
9	93	95	95	97	97	99
8	93	95	95	97	97	99
7	93	95	95	97	97	99
6	93	95	95	97	97	99
5	93	95	95	97	97	99
4	93	95	95	97	97	99
3	93	95	95	97	96	99
2	92	95	95	97	96	98
1	92	93	95	96	96	98

Dam-buck way

Low group

	1995	1996	1997	1998	1999	2000
9						99
8						99
7					98	99
6				97	98	98
5			96	97	97	98
4	93		96	97	97	97
3	93	94	96	96	97	97
2	92	94	95	96	96	97
1	92	93	95	96	96	97

High group

	1995	1996	1997	1998	1999	2000
9						
8			95			99
7			95			99
6	93		95		98	99
5	93		95	97	98	99
4	93		95	97	98	98
3	93	95	95	97	97	98
2	92	95	94	96	97	98
1	91	93	94	96	97	98

Dam-daughter way

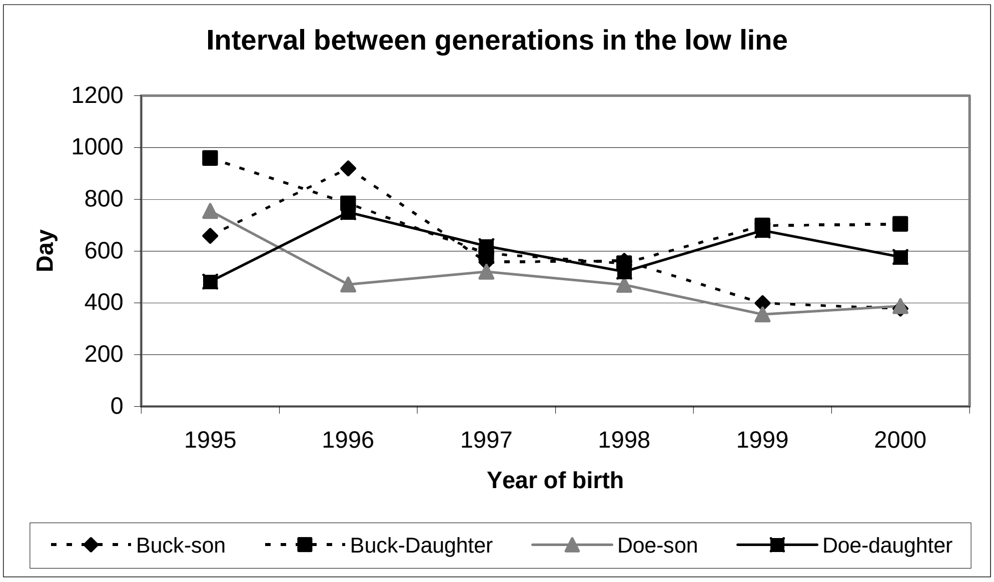
Low group

	1995	1996	1997	1998	1999	2000
20						
19						99
18						99
17						99
16						99
15						99
14				97		99
13				97		99
12			96	97		99
11		94	96	97		99
10	94	94	96	97	98	98
9	94	94	96	97	98	98
8	94	94	95	97	97	98
7	94	94	95	97	97	98
6	94	94	95	97	97	98
5	94	94	95	97	97	98
4	94	93	95	97	97	97
3	93	93	95	96	97	97
2	93	93	95	96	97	97
1	93	93	95	96	96	97

High group

	1995	1996	1997	1998	1999	2000
20					98	
19					98	
18					98	
17			96		98	
16			96	97	98	
15			96	97	98	
14		95	96	97	98	
13	94	95	96	97	98	99
12	93	95	96	97	97	99
11	93	95	96	97	97	99
10	92	95	96	97	97	99
9	92	95	96	97	97	99
8	92	95	96	97	97	99
7	92	95	96	97	97	99
6	92	95	96	97	97	99
5	92	93	95	97	97	98
4	91	93	95	96	97	98
3	91	93	95	96	96	98
2	91	93	95	96	96	98
1	91	93	94	96	95	98

Figure 5.1: The distribution of year of birth of reproducers in 4 ways of sire-buck, sire-daughter, dam-buck and dam-daughter. The reproducers of each cohort that has been born in the same year are shown with different colour.



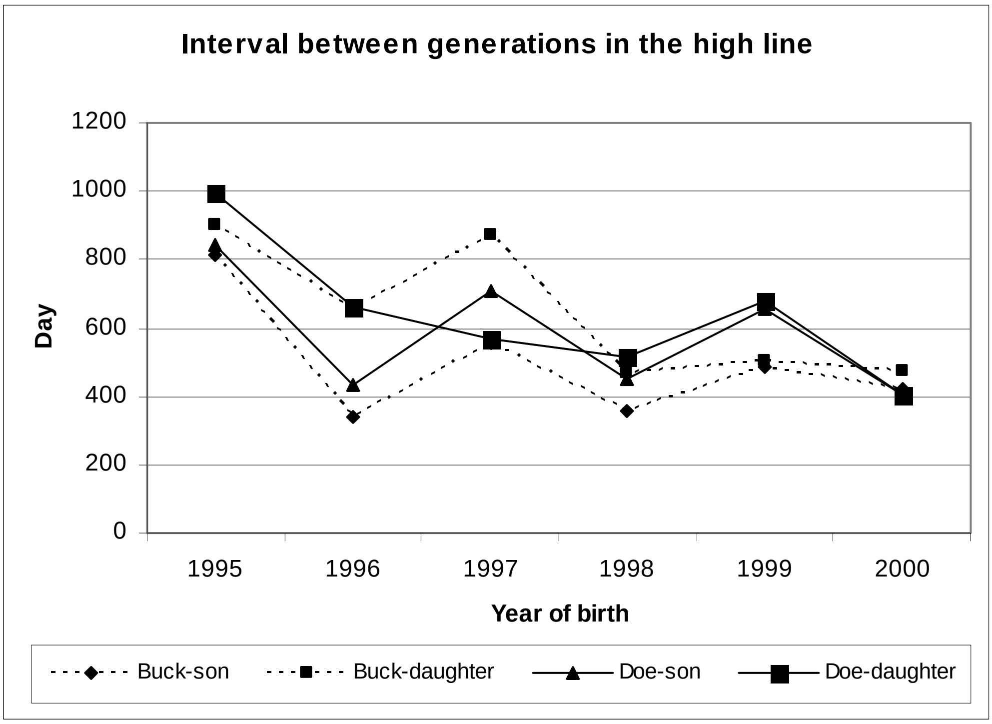
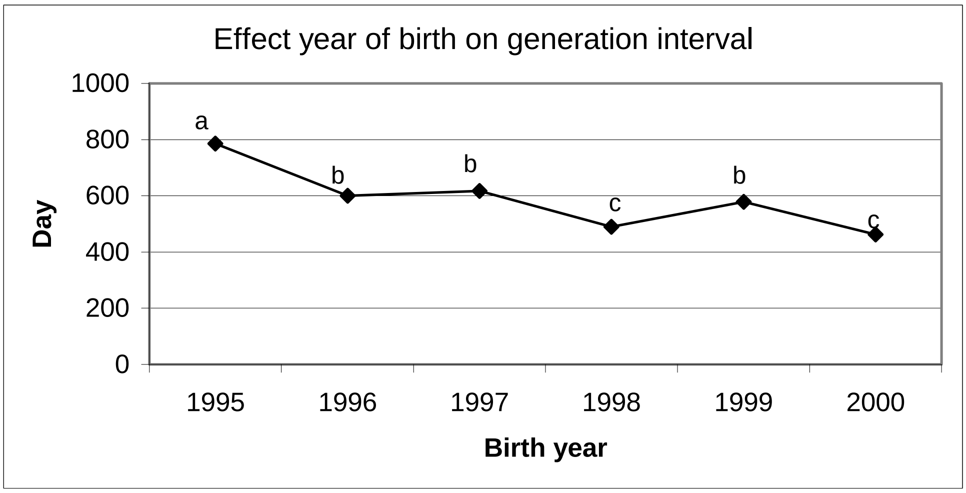
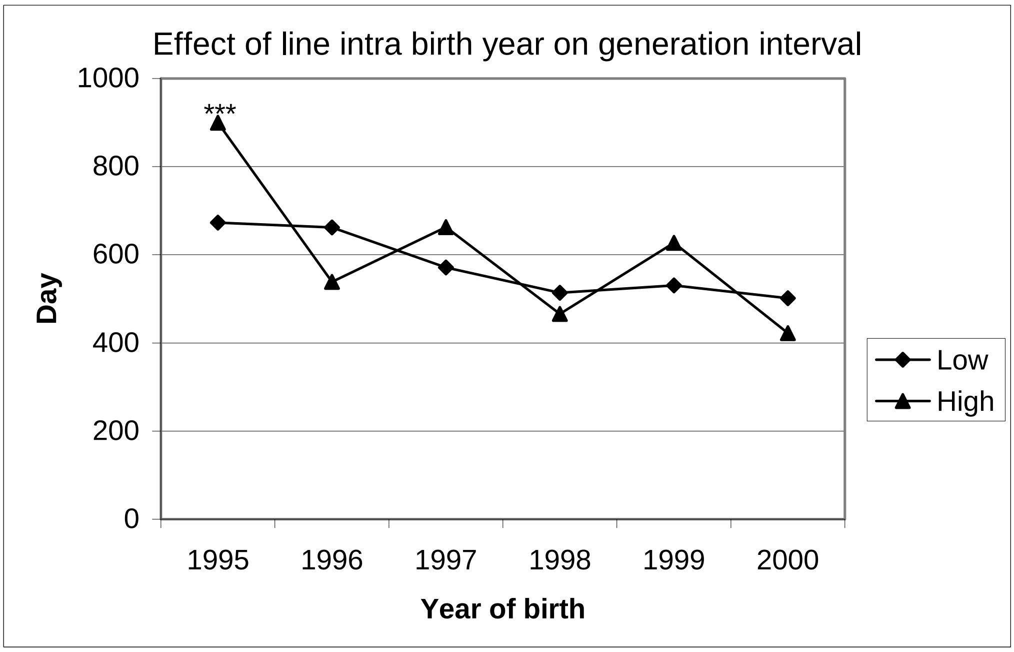


Figure 5.2: Generation intervals for the four pathways in the pedigree of the two lines of Angora rabbits.

The effects of birth year and line within birth year were significant (Figure. 2.3.). Generation intervals decreased significantly from 1995 to 2000 ($P<0.05$). The difference between LL and HL was not significant except for animals born in 1995 where HL animals were more aged than LL ones ($P<0.05$).



a, b, c significant difference *($P<0.05$)*



*** $P<0.01$ between two lines

Figure 5.3: Effect of year of birth and line intra year of birth on generation intervals.

Due to selection, offspring of young parents had an above-average breeding value. Long-term genetic contribution of the youngest age classes were therefore higher than expected from the age class distribution of parents, and generation interval was shorter than the average age of parents at birth of their offspring. Bijma and Woolliams (1999) showed that due to an increased selective advantage of offspring of young parents, the generation interval decreased with increasing heritability and selection intensity. There are not any references on generation intervals in the Angora rabbit. Data described for meat rabbits in the literature, show a generation interval value much smaller than in the present study. Ramon et al. (1992) analysing a synthetic meat strain and Rochambeau et al. (1992), analysing a Rex rabbit strain, obtained an average generation interval of 0.88 and 1.04 years respectively.

5.3.3 Effective population size

Table 5.4 shows the family size of both lines. The number of daughters in the high line was very variable. The number of animals per generation was higher in HL than in LL. Each buck has left nearly three daughters to the next generation (2.52 in LL, 3.24 in HL). Each doe has left about two daughters (1.54 in LL, 1.72 in HL). The variance of family size was higher in HL than in LL.

Table 5.4: Family size in the low and high lines.

	Means		**Variance**	
	Low	High	Low	High
Number of sons per buck	1.10	1.28	0.71	0.99
daughters per buck	2.52	3.24	5.51	10.19
Covariance daughters/sons per buck	-	-	0.73	0.54
Number of sons per doe	0.67	0.69	0.53	0.56
daughters per doe	1.54	1.72	1.35	1.64
Covariance daughters/sons per doe	-	-	-0.21	-0.18

The observed inbreeding effective population size Ne_f and the observed familial structure effective population size Ne_h do not converge to the same measure of effective population size ($Ne_f=47$ and $Ne_h=31$ for LL; $Ne_f=29$ and $Ne_h=33$ for HL). Genetic variability seems to be better maintained in LL than in HL. The effective population size of LL (Ne_f) is larger.

5.3.4 Probability of gene origin

Tables 5.5 and 5.6 summarise the expected contribution of the ancestors explaining 50% of genetic variability in both lines. In both lines, the total number of major ancestors remains steady and the effective number of ancestors still present in the genetic pool was around 8 from the reference population of 1995 to that of 2001. In LL, one male (92243) contributed the most in all reference populations except in 1996 and 1997. In HL, four different males contributed the most for all reference populations but one male was the main ancestor in 1994, 1997, 1999 and 2000 cohorts.

5.3.5 Inbreeding

Figure 2.4 shows the increase of inbreeding (F) in 942 live animals at second harvest per year of birth. Inbreeding in HH was always higher than in LL. Least square means of studied traits are shown in Table 5.7. The effect of inbreeding level was significant ($P<0.05$) only on TFW and LW. The animals with the lowest inbreeding coefficients produced a higher TFW ($P<0.05$) than the others. On LW, the significant effect of inbreeding was variable and no tendency with an increase of inbreeding was observed. There was a decrease in BL, DL, BD, FD and SP with an increase of F during 4 categories, but these differences were not significant.

In sheep, a decline in fleece weight for an increase of inbreeding has been observed (Ercanbrack and Knight, 1991) and thus is in agreement with our result. Wiener et al. (1994) showed that inbreeding of the individual significantly and linearly reduced fleece weight in sheep.

Table 5.5: Parameters characterising the genetic variability of low and high reference populations (animals born from 1994 to 2001 and with both parents known) based on pedigree information.

	Reference population [a]															
	Low								High							
	1994	1995	1996	1997	1998	1999	2000	2001	1994	1995	1996	1997	1998	1999	2000	2001
Number of animals in the reference pop.	28	65	53	32	60	63	48	106	11	63	47	59	56	77	57	124
Number of ancestors	14	15	13	12	14	14	13	12	6	18	14	12	15	17	13	15
Effective number of ancestors (fa)	7	9	7	6	8	9	8	8	4	7	7	7	7	8	8	8
Number of ancestors explaining 50%	3	4	3	3	3	4	3	3	2	3	3	3	3	3	3	3
Expected contribution of the ancestor contributing the most, *(ancestor)*	30,4% *(92243)*	20,0% *(92243)*	23,6% *(95110)*	28,1% *(96024)*	21,5% *(92243)*	22,5% *(92243)*	23,1% *(92243)*	22,7% *(92243)*	36,4% *(92203)*	27,8% *(93015)*	22,3% *(95077)*	21,1% *(92203)*	25,9% *(97033)*	19,1% *(92203)*	18,9% *(92203)*	20,5% *(93015)*

a Each time a particular population have been chosen such as the reference population, i.e., low group, cohort 1994; low group, 1995 et …

Table 5.6: Expected contributions (%) of the ancestors explaining 50 % genetic variability in the each reference population

				Reference population							
				Low							
N	Animal	Sex	Birth	1994	1995	1996	1997	1998	1999	2000	2001
1	89047	male	1989	_	11,6	_	_	_	_	_	_
2	89076	female	1989	_	13,5	_	_	_	_	_	_
3	91105	male	1991	9,8	_	_	_	_	_	_	_
4	92153	male	1992	10,7	_	_	_	_	_	_	_
5	92211	male	1992	_	_	_	_	_	9,4	_	_
6	92221	male	1993	_	11,5	17,0	_	15,0	_	_	_
7	92243	male	1992	30,4	20,0	16,3	20,3	21,5	22,5	23,1	22,7
8	93147	female	1993	_	_	_	11,7	_	_	_	_
9	95110	male	1995	_	_	23,6	_	_	_	_	_
10	96024	male	1996	_	_	_	28,1	16,1	13,0	15,6	15,0
11	96084	male	1996	_	_	_	_	_	14,4	16,0	16,5
	Σ			**50,9**	**56,6**	**56,9**	**60,1**	**52,6**	**59,3**	**54,7**	**54,2**
				High							
1	92077	male	1992	_	_	_	16,5	_	_	_	_
2	92203	male	1992	36,4	15,6	_	21,1	_	19,1	18,9	18,2
3	92420	male	1992	_	_	_	_	_	_	_	13,4
4	93015	male	1993	_	27,8	21,8	_	_	18,7	18,3	20,5
5	93034	female	1993	22,7	_	_	_	_	_	_	_
6	93057	female	1993	_	9,5	_	16,5	_	_	_	_
7	95017	male	1995	_	_	_	_	15	13,9	13,9	_
8	95021	male	1995	_	_	13,8	_	_	_	_	_
9	95077	male	1995	_	_	22,3	_	13,4	_	_	_
10	97033	male	1997	_	_	_	_	25,9	_	_	_
	Σ			**59,1**	**52,9**	**57,9**	**54,1**	**54,3**	**51,7**	**51,1**	**52,1**

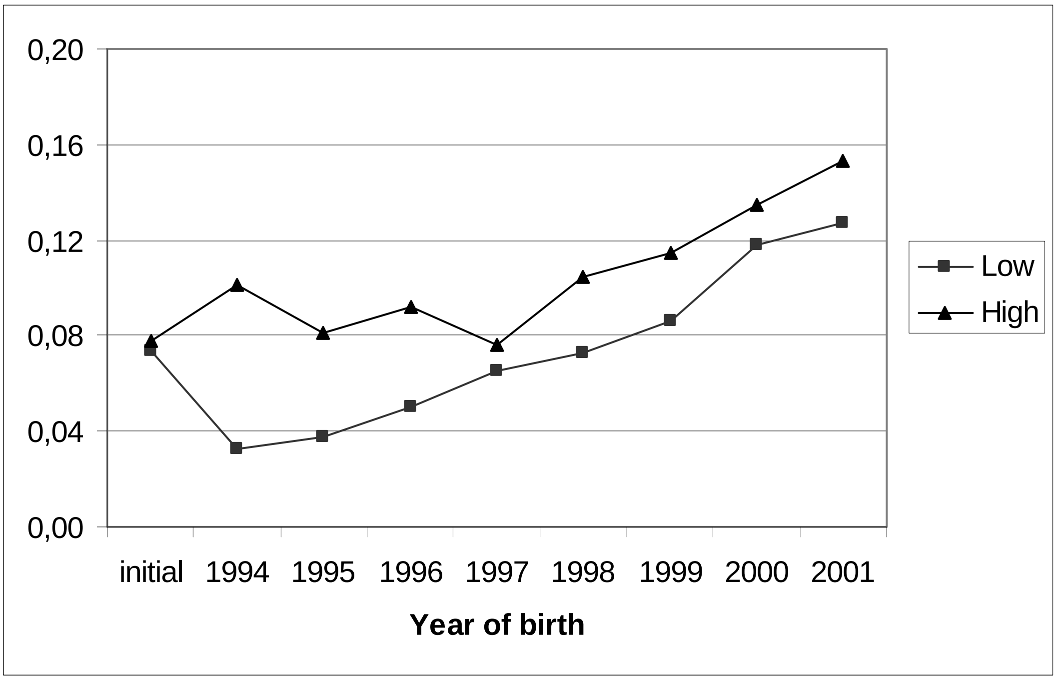


Figure 5.4: Increase of inbreeding (F) in 942 live animals at second harvest by year of birth.

Table 5.7: Least square means for effect of inbreeding level on total fleece weight (TFW), live weight (LW), bristle length (BL), down length (DL), bristle diameter (BD), mean fibre diameter (FD) and secondary to primary follicle ratio (S/P)

	TFW		**LW**		**BL**	**DL**	**BD**	**FD**	**S/P**
	1994-2001	**2001**	**1994-2001**	**2001**	**1994-2001**	**1994-2001**	**2001**	**2001**	**2001**
Quartiles									
1	195,0^{a}	227,5^{a}	3940^{a}	3810^{ab}	97,3	62,51	46,63	14,86	49,83
2	187,9^{b}	208,7^{b}	3862^{b}	3836^{ab}	96,8	62,38	45,22	15,15	48,53
3	187,6^{b}	191,4^{c}	3932^{a}	3809^{b}	96,1	62,44	45,96	15,18	45,12
4	184,0^{b}	202,1^{bc}	3969^{a}	3949^{a}	96,5	61,42	46,04	15,47	42,87

$^{a, b, c}$ Within each column, least square means without common superscripts differ ($P < 0.05$).

5.3.6 Differential of selection

We studied the differential of selection by comparing the posterior EBV of the candidates, theoretical parents and parents. Figure 5.5 shows EBV of TFW in the candidates of selection, parents and theoretical parents and Figure 5.6 shows the realised and theoretical differential of EBV for TFW within each line. In HL, we observed a maximum differential of selection in year 1995; then it decreased until 1999 and peaked in 2000. The evolution of the genetic level of the candidates of HL is explained by that of the differential. In HL little or no deviation existed between the theoretical and realized differential. In LL, the theoretical differentials was stronger and especially more constant. On the contrary, the realised differential did not follow theoretical differential except in 1997 and 1998. Evolution of the genetic level of the candidates was again explained by that of the differential.

Figure 5.7 shows EBV of LW in the candidates of selection, parents and theoretical parents and figure 5.8 shows the differential of EBV for LW within each line. In HL, the candidates were always lighter. The realised differential was positive at the beginning and at the end of experiment. At the beginning the theoretical differential went to the same direction and at the end there was no more theoretical differential. A realised differential of LL was nearly zero while theoretical differential was negative at the beginning and in the end of experiment.

Selection for animals with high EBV for TFW caused to select animals with low EBV for LW. In HL, animals with high EBV of TFW had low EBV of LW. In LL, when animals with low EBV of TFW have been selected, they had higher EBV of LW than HH. It seems that there were two different mechanisms explaining the relations between wool and body weights over the experiment.

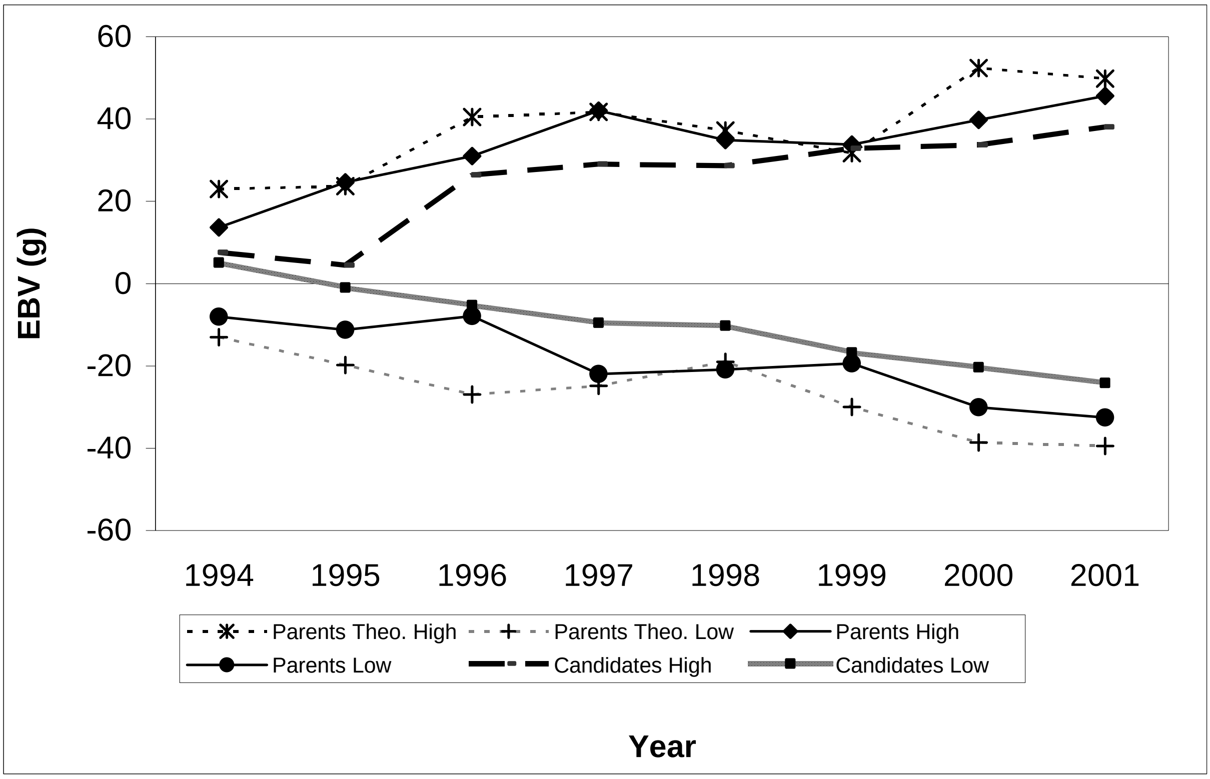


Figure 5.5: Estimated breeding value (EBV) of TFW in the candidates of selection, parents and theoretical parents. **Year**: for candidates, **year** is the date from first day of October until first day of April of the next year; for parents, **year** is the year of birth

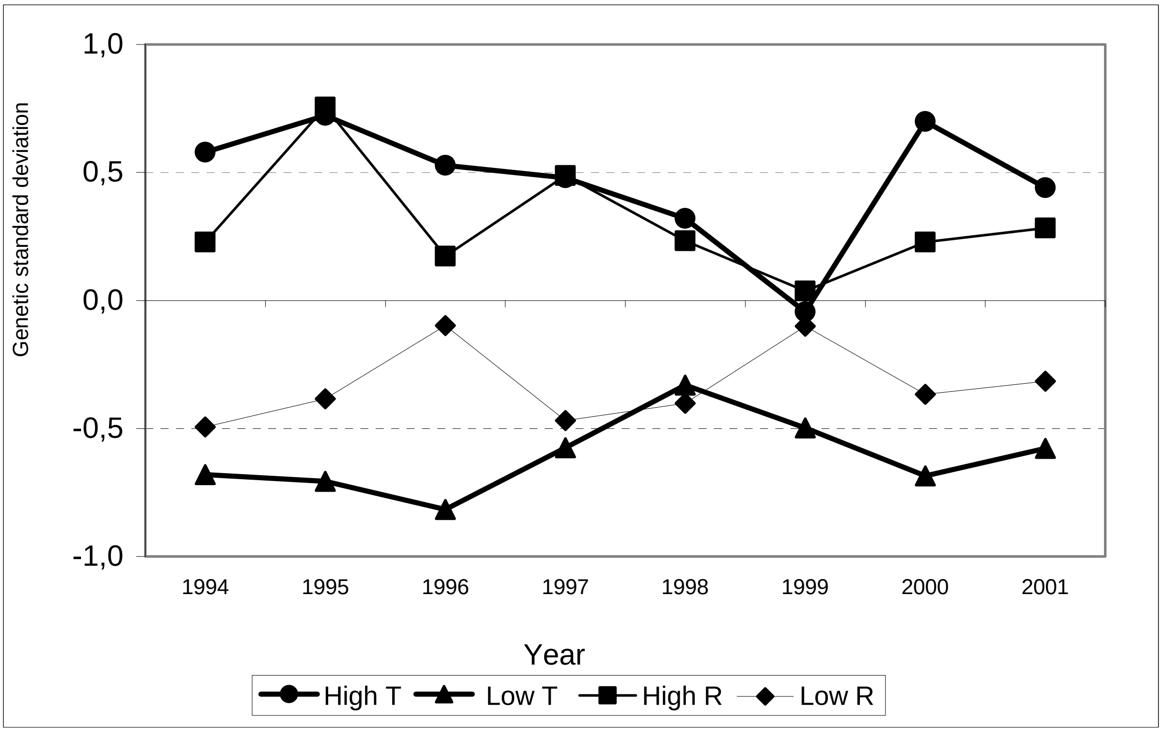


Figure 5.6**:** Theoretical and realised differential[1] of estimated breeding value for total fleece weight within each year[2]. [1] Realised differential (R) = Parents-andidates; Theoretical differential (T) =Theoretical parents-candidates. [2] Year: year for candidates is the date from first day of October until first day of April of the next; year for parents is the year of birth.

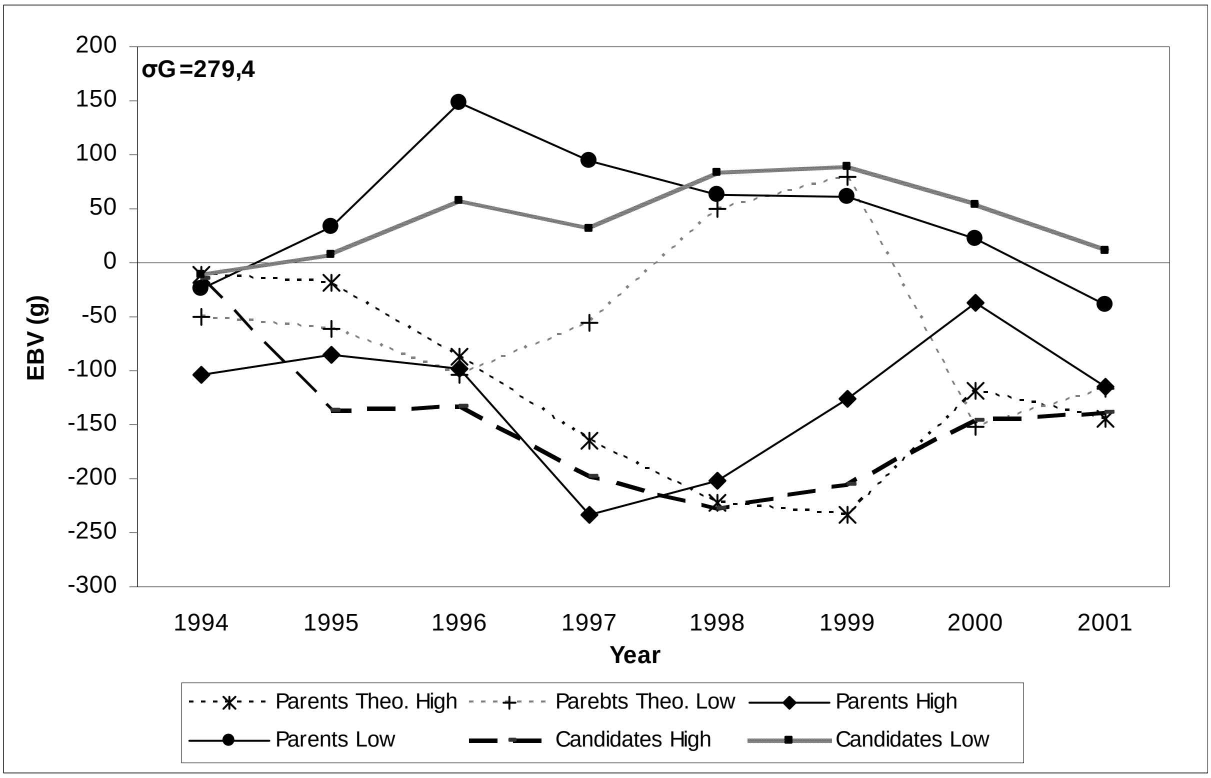


Figure 5.7: Estimated breeding value (EBV) of live weight in the candidates of selection, parents and theoretical parents. **Year**: for candidates, **year** is the date from first day of October until first day of April of the next year ; for parents, **year** is the year of birth

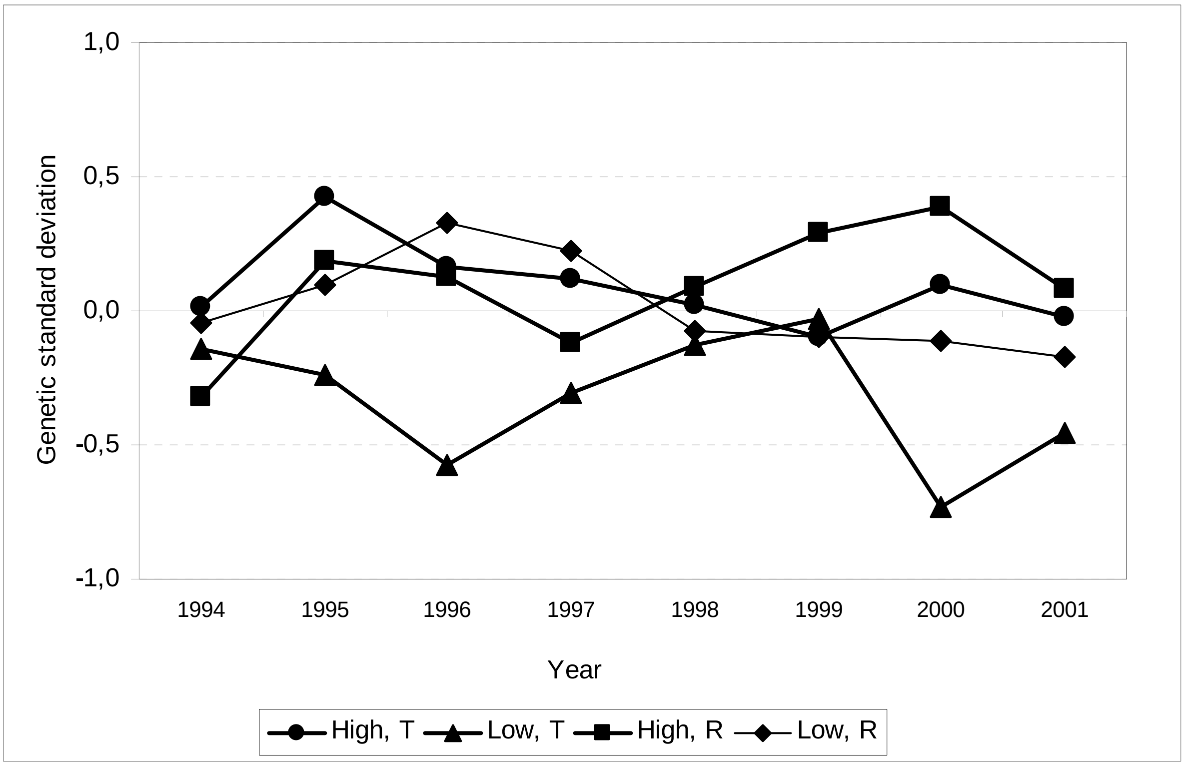


Figure 5.8: Theoretical and realised differential[1] of estimated breeding value for body weight within each year[2]. [1] Realised differential (R) = Parents-candidates; Theoretical differential (T) =Theoretical parents-candidates.[2] Year: year for candidates is the date from first day of October until first day of April of the next; year for parents is the year of birth.

An hypothesis supported by the observation of variations in EBV of TFW and LW from a period of time from 1994 until 1997 and thereafter. In the first period, EBV of LW decreases in HH with increasing of EBV of TFW, while EBV of LW increases in LL. After the year of 1997, in the second period, EBV of LW increased in HL and decreased in LL. During the second period, the effect of body surface is important while in the first one, rabbits with high EBV for TFW utilised their body reserves efficiently to produce wool. The similar phenomenon has been reported in sheep by Li et al. (2006). Adams et al. (2006) showed that there is a negative genetic correlation between fleece weight and subcutaneous fat depth in Merinos and animals with high EBV of clean fleece weight had 20 % less fat in their body. In sheep, there is evidence that selection for an even rate of wool growth throughout the year may also affect muscle and fat metabolism (Adams et al., 2006). Negative genetic correlation between -0.20 and -0.44 have been observed between follicle density and live weight (Adams and Cronje, 2003). Increased fibre growth rate requires an increase in protein synthesis rate in the skin, which in turn may affect whole body protein turnover rate and the sensivity of tissues to insulin (Adams and Cronje, 2003). Lee et al. (2002) found a genetic correlation of 0.40 between fibre diameter and digestible organic matter intake under field condition, and suggested that selection for reduced fibre diameter could decrease feed intake. In our study we had not the data of feed intake and we did not measured fibre diameter in all of animals. Therefore it is not possible to compare the results that have been found in wool sheep with results of Angora rabbit. In the second period, after the year of 1997, EBV of LW increases in HL and decreases in LL indicating that effect of body surface is important. It seems there is an interaction between two physiological mechanisms. After the year of 1997, relationship between TFW and LW has been changed.

5.3.7 Conclusion

During the 8 years of selection, they were only slight differences in the management of the two divergent lines. Generation intervals and inbreeding increase were lower in LL than in HL The increase of inbreeding during the experiment had a negative effect on total fleece weight.

The relationship between estimated breeding values of total fleece weight and body weight was studied and a hypothesis for the observed results proposed. The observed selection differentials were lower than expected due to the breeding animal management rules in order to control inbreeding increase. There was more genetic potential for exploitation during the experiment of divergent selection, but the inbreeding management caused that we can not benefit of this potential.

6 Conclusion

RÉSUMÉ

Cette thèse analyse une expérience de sélection divergente sur le poids de la toison chez le lapin Angora. Cette expérience clos trente années de recherches conduites par l’INRA sur l'amélioration génétique de cet animal. L'analyse a porté sur les récoltes de poils d'ordre supérieur à deux, chez les femelles. Un modèle à répétabilité a été utilisé pour analyser les récoltes successives d'un animal. Les analyses démographiques et génétiques ont montré que les souches hautes et basses ont été conduites de la même manière pendant 8 ans. La sélection sur le poids de la toison a été efficace et la différence entre les souches atteignait 3 écarts types génétiques pour la dernière cohorte. Cette sélection s'est accompagnée d'une amélioration du poids de la première qualité de poil (WAJ1) et de l'homogénéité (HOM). Il semble que les femelles qui produisent le plus de poils aient un poids corporel inférieur aux femelles qui produisent peu de poils. Par ailleurs, la sélection pour le poids de la toison s'est accompagnée d'une augmentation de la longueur des jarres, du rapport S/P et du facteur de confort. Dans le même temps, la compression, la résilience, le diamètre des jarres et le diamètre moyen des fibres ont diminué. L'utilisation d'un OFDA a permis de décrire de nouvelles caractéristiques de la toison du lapin Angora, comme le diamètre des fibres et son coefficient de variation. Ces souches constituent un matériel de choix pour étudier les conséquences biologiques d'une telle sélection.

Notre thèse apporte des résultats originaux avec tout d'abord l'estimation des progrès génétiques réalisés après une experience de sélection divergente sur le poids de la toison chez le lapin Angora. La réponse sur les composantes quantitatives et qualitatives de la toison a aussi été étudiée. Ensuite, nous avons utilisé une méthode originale (OFDA) de mesures des diamètres des poils. Cette méthode permet notamment d'estimer beaucoup plus rapidement le rapport S/P. Le lapin Angora est un exemple intéressant d'animal à double pelage chez lequel on cherche à augmenter à la fois les jarres et les duvets.

Cette thèse ouvre plusieurs perspectives qui nécessitent de nouveaux travaux de recherche. Le modèle à répétabilité est simple à utiliser mais un modèle à régression aléatoire permettrait de mieux modéliser les récoltes de poils successives. Par ailleurs, l'estimation des paramètres génétiques, puis celle du progrès génétique n'est pas optimale. L'incertitude qui pèsent sur les premières estimations n'est pas prise en compte dans la seconde étape. Les méthodes MCMC couplées à une approche bayésienne permettent d'inférer la distribution a posteriori de la réponse à la sélection. Ensuite les liaisons complexes entre le poids de toison et le poids corporel nécessitent d'être approfondies ; nous faisons l'hypothèse que le fonctionnement métabolique des animaux de la souche haute est différent de celui de la souche basse. Enfin cette thèse montre aux producteurs comment accroître la poids de la toison dans une population de lapin Angora conduite en générations chevauchantes.

The Angora rabbit is exploited to produce a fleece, which is then valued by the textile industry. The genetic improvement and the breeding of this animal have been studied by INRA for more than thirty years and this thesis was the last research work of INRA on Angora rabbit. To analyze the efficiency of selection on the total fleece weight and the correlated response on the other characters, an experiment of divergent selection began on this trait on 1994. After 8 years of divergent selection, a herd of females of the high line and a herd of females of the low line has been created in 2001. These animals entered production and they produced more than 12 wool harvests. Objectives of the experiment of selection divergent were to assess genetic parameter estimates for TFW and correlated traits; and to get an experience on management of a population of angora rabbits under selection with overlapping generations.

The thesis was begun with construction of necessary data files. After adjustments of incorrect data, for finding a model for genetic analyse, factors of variation were studied. Among fixed effects, number of harvest was the most important. The main question in that first phase of the study was: which harvest number can be considered such as an adult fleece? Results showed that i) wool production in the first and second harvests must be considered separately from higher harvest numbers; ii) production data of male and female belongs to two different populations and only data from females were analysed in the present work. In the description phase, levels of each variable were distinguished. Some of them needed to be gathered for following steps of analysis. For example, the number of weaned rabbits regrouped to fewer levels because to avoid classes with a too weak effective to be statistically significant Normality of traits has been studied for possibility the use of ANOVA.

After definition of fixed effects, the genetic analysis was made. There were two types of variables: repeated and unrepeated variables. For estimation of genetics parameters, in this study the repeatability model was used in which wool harvests from 3rd until 12th have been considered as a repeated trait. The repeatability model has been employed for the analysis of data when multiple measurements on the same trait are recorded on an individual (Interbull, 2000). In this model, the phenotypic variance comprises the genetic (additive and non-additive) variance, permanent environmental variance and temporary environmental variance. For an animal, the repeatability model usually assumes a genetic correlation of unity between all pairs of records, equal variance for all records and equal environmental correlation between all pairs of record. In practice, some of these assumptions do not hold in the analysis of real data (Mrode, 2005). For using of the repeatability model, firstly, wool harvest numbers from 3 to 12 were considered as separated traits and genetic correlations between them were estimated. All of them being higher than 0.70 (data not shown), the repeatability model was considered as acceptable. As there were 12 different traits describing the quantity and the quality of wool production at each harvest reaching convergence when estimating genetic parameters was not possible. Furthermore, as no traits were measured at each wool harvest on all animals, traits were analysed in three datasets. The first one includes 4 traits: TFW, WAJ1, WAW and HOM; the second one a group of bivariate analyses with TFW and one of each of the body weights measured in the young age before the second wool harvest, and the third one included nine traits: TFW, BL, DL, COM, RES, FD, BD, CF and SP (with 9LW such as covariate for TFW) always measured on the fifth and the seventh wool harvest..

Demography analysis and genetic description helped us for a better understanding of selection process during time and over generations. Description of demography and the genetic structure in this study showed that in the two divergent lines, the similar management of reproducers has been done successfully during 8 years of selection. The increase of inbreeding during experiment had negative effect on total fleece weight.

Selection for high and low total fleece weight was successfully performed in Angora rabbits and a divergence of three genetic standard deviations was observed between the high and low lines after 8 years of selection. There was more genetic potential for exploitation during the experiment of divergent selection, but the inbreeding management caused that we can not benefit of this potential. Selection for TFW significantly increased WAJ1 that resulted from the highly positive genetic correlation between TFW and WAJ1. It is important to note that selection for easily measurable total fleece weight has a general beneficial effect on fleece quality as the WAJ1 quality is the highest valuable part of the fleece of the French angora rabbit. These genetically diverse lines are suitable for subsequent detailed studies of biological and physiological changes of the different fleece components brought about by selection on total fleece weight. In French Angora rabbit, the traits of WAJ1 and HOM are among the most important quality traits. A high quality fleece having a good ability to produce a fluffy yarn was characterised by a high weight of quality WAJ1 and high fleece homogeneity. Our results showed that with selection for TFW, there is a positive and large response on WAJ1 and HOM, because of their genetic correlations with TFW. This positive effect indicates that selection for TFW do not have a deleterious effect on quality traits. All these characteristics were observed on the high line indicating that selection for total fleece weight results in an improvement of the quality of the fleece.

When traits are genetically correlated (i.e., breeding values for those traits are correlated), selection solely on one will result in a correlated change in the second. Such a change in the unselected character is called a correlated response. The relationship between estimated breeding values of total fleece weight and body weight was studied and a hypothesis for the observed results was proposed. When we select the animals with maximum EBV of TFW in HL, they have a lower EBV of LW in comparison to LL in which animals have been selected for minimum of EBV of TFW.

Selection for total fleece weight significantly increased bristle length, secondary to primary follicle ratio and comfort factor and decreased compression, resilience, bristle diameter, and average fibre diameter. These changes resulted from moderate to high genetic correlations between total fleece weight and bristle length, and between fibre dimensions (BL, DL, AFD, and BD) and secondary to primary follicle ratio, comfort factor, compression and resilience. Thus, selection for increasing total fleece weight results in an increase of both quantitative and qualitative traits of wool production in the French Angora rabbit. Measurement of total fleece weight is simple and easy at the farm level. Selection for this trait has positive effects on fleece characteristics such as bristle length, follicle population and fibre diameter.

By using the OFDA (Optical Fibre Diameter Analyser) methodology, some new characteristics of Angora fibres were described which are interesting to use in description of Angora wool. This part of the study described precisely Angora fibre characteristics measurements with OFDA methodology and its variations according to age and season in two divergent selected groups for total fleece weight in the French Angora rabbit. The major changes in Angora wool characteristics from 8 to 105 weeks of age were a decrease in compression and CF, and an increase in FD, CVFD, FDA and CURV. Effect of harvest season was significant on some fibre characteristics. The OFDA methodology is an interesting alternative to evaluate important Angora fibres characteristics such as fibre diameter, CV of fibre diameter or bristle content through measuring of comfort or prickle factor. However, OFDA is not adapted for measuring opacity and/or size of medulla in Angora fibre and needs a new definition or a special calibration for doing this. Another parameter, spinning fineness needs to be redefined and adapted for Angora. Similarly, more studies must be done for using curvature measurements on Angora fibre.

Our work contributes to the research in two areas, which are estimation of genetic parameters with multivariate models of best linear unbiased prediction of breeding value and theoretical investigation of selection in populations with overlapping generations.

These genetically diverse lines are suitable for subsequent detailed studies of biological and physiological changes of the different fleece components brought about by selection on total fleece weight. This positive effect indicates that selection for TFW do not have a deleterious effect on quality traits. All these characteristics were observed on the high line indicating that selection for total fleece weight results in an improvement of the quality of the fleece.
Our results showed that with selection for TFW, there is a positive response on WAJ1 and HOM, because of their genetic correlation with TFW.

6.1 How do we improve the state of art?

Estimated genetic parameters have given us a relatively precise prediction for expected responses to selection. Such estimates are population-specific and are often relevant to one generation of selection, despite their frequent use across a wide range of populations and for many rounds of selection. Selection experiments, where selection has been based on a single trait, have been used rarely in Angora rabbit. The major aim of this thesis was to check the prediction that selection response be effective. Much of studies that estimated genetic parameters in angora rabbits were not from selection experiments. Moreover, Utilisation of BLUP animal model in this thesis gives more results that are reliable.

In Merino sheep, genetic parameters for most traits associated with wool production and quality have been precisely estimated from a large number of studies. However, realised responses to selection in wool-quality traits have been less extensively studied in Merinos. This thesis gives knowledge of these subjects in Angora rabbits.

An IWTO method (IWTO-8-89) is defined for determining fibre diameter and percentage of medullated fibre in wool and other animal fibres, by using a projection microscope. Nevertheless, this method is time consuming, not widely used for measuring fleece composition or fibre diameter in angora and not very precise, as most angora fibres are medullated and the fibre cross section shape is not circular. Allain (http://www.macaulay.ac.uk/europeanfibre/effnnew1da.htm) has proposed that OFDA apparatus might to be tested for angora. Number of samples, number of measured fibres per each sample and number of measured traits in our OFDA part of study is more complete than rarely similar studies. Moreover, our measurements with OFDA may be help to find an objective instrumental measurement of angora in practice.

Also, the measurement of S/P ratio is long, expensive and time consuming and it requires histological treatment and analysis of skin samples. Our results have shown that an indirect measurements of S/P ratio derived from OFDA parameters such as AFD and/or CF could be achieved and thus providing an easy and rapid criteria for improving wool traits in Angora rabbits and other fibre-producing animals by extension.

Most estimates of genetic parameters for wool production were concentrated on Merinos. These breeds are owning a single coat without any medullated fibres. Among double-coat animals such as cashmere goats, only inner-coat or downs are economically important. In the Angora rabbit, all types of fibres within the fleece have economic value and from this viewpoint, this animal has an exclusive situation among double-coat animals. In fibre-producing animals, we are interesting to obtain genetic parameters of fibres that are produced by secondary follicles. Exceptionally in Angora rabbit, traits of bristles, such as diameter and length, are important in genetic studies.

Limitations in multiple trait mixed model: During our genetic analysis, we utilised a set of analysis to cover all of the recorded traits. These analyses included a 4 and 9 multi trait analyses between wool traits and several set of bi-variable analyses between TFW and one of the body weights. Arriving to a convergence with all of the traits in the same time was not possible. Also, it is necessary to say that all of the traits were not recorded for all of the animals.

6.2 Perspectives

Subsequent to this thesis there are some research directions that deserve to be investigated.

Repeatability model. The basic assumption of the repeatability model utilised in this thesis was that repeated measurements were regarded as expression of the same trait over time. For an animal, the repeatability model usually assumes a genetic correlation of unity between all pairs of records, equal variance for all records and equal environmental correlation between all pairs of record. In practice, some of these assumptions do not hold in the analysis of real data (Mrode, 2005). For using of the repeatability model here, firstly we estimated genetic correlations between different harvest numbers of 3-12 and all of them were more than 0.70 (data not shown). The main advantages of this model are its simplicity, fewer computation requirements and fewer parameters compared to a multivariate model.

A next step would be the use of the random regression models in the comparison to the repeatability model in order to evaluated the bias between the two models. Random regression models can typically be used when a trait is expressed repeatedly, e.g. over time such as our study that each animal have 1-12 record of TFW. If the random effects are modeled as a function of time, then both the variance as the covariance between expressions at different times are modelled as a continuous function.

MCMC: A natural application of animal models has been predictions of the genetic means of cohorts, for example, groups of individuals born in a given time internal such as a year or a generation. These predicted genetic means are typically computed as the average of the BLUP of the genetic value of the appropriate individuals. From these, genetic change can be expressed as, for example, the regression of the mean predicted additive genetic value on time or on appropriate cumulative selection differentials. In common with selection index, it is assumed in BLUP that the variances of the random effects or ratios thereof are known, so the predictions of breeding values and genetic means depend on such ratios. This, in turn, causes a dependency of the estimators of genetic change derived from ‘ animal’ models on the ratios of the variances of the random effects used as ‘priors’ for solving the mixed-model equations. This point was first noted by Thompson (1986) who showed that an estimator of realized heritability given by the ratio between the BLUP of total response and the total selection differential leads to estimates that are highly dependent on the value of heritability used as ‘prior’ in the BLUP analysis. In view of this, it is reasonable to expect that the statistical properties of the BLUP estimator of response will depend on the method with which the ‘prior’ heritability is estimated. The problem of exact inference about genetic change when variances are unknown has not been solved via classical statistical methods (Sorensen et al., 1994). However, this problem has a conceptually simple solution when framed in a Bayesian setting, as suggested by Sorensen and Johansson (1992). Application of the Bayesian approach to the analysis of selection experiments yields the marginal posterior distribution of response to selection, from which inferences about it can be made, irrespective of whether variances are unknown. In summary, the utilised methodology supposes that the genetic parameters (heritability and genetic correlations of the characters) are known. To appreciate the influence of the uncertainty, which presses on the genetic parameters on the answer to the selection, future work could consist in studying a methodology MCMC (Monte Carlo Markov Chain) to estimate simultaneously the genetic parameters and the response to selection. This methodology supplies besides a distribution a posterior with studied parameters.

OFDA: For decision about of genetic improvement of Angora rabbit, we need to get more information about requirements of the textile industry about angora fibre characteristics, specially the traits that can be easily distinguished by OFDA.

Relationship between total fleece weight and body weight : The consequence of selection for TFW on BW in Angora rabbit under various nutrition rations needs to be cleared in future researches. Hypothesis is that the animals with high potential of wool production have different requirements of nutrients in comparison of low potential animals. In other words, the intake of rabbits selected for increased fleece weight may be greater than of those selected for reduced fleece weight. Efficiency of production of wool to food in these two genotypes also might be studied.

Applications for rabbit wool producers: This thesis provides the available data on genetic and phenotypic relationships between fleece weight, WAJ1, WAW1, HOM and live weight, and on genetic relationships between fleece weight, fibre diameter, BL, DL, BD, and SP, that could be applied practically by rabbit wool producers. Selection for increased TFW does not result in a reduction of WAJ1 or length of bristle. Also, the demographic analysis in a population that has been selected in overlapping generations may be interesting for breeding organisations which utilise overlapping generation in practice. Knowledge of the demographic structure of Angora population under selection is useful for the subject elaboration of a genetic programme.

Appendix I

Nouveau chapitre de la thèse

Valorisation des compétences

Analyse d'une expérience de sélection divergente pour le poids total de la toison chez le lapin angora

Directeur de thèse: Hubert DE ROCHAMBEAU

Directeur labo: Edouardo MANFREDI

Laboratoire: Station d'Amélioration Génétique des Animaux

Mentor: Robert MARTINEZ – Cabinet PROGRESS

Thèsard:
Seyed Abbas RAFAT

Le contexte :

La laine Angora est une fibre textile « kératinisée » (issue de protéine fibreuse), produit à partir de poils longs de lapin Angora. Cette fibre est une "des fibres spéciales dites de luxe", incluant notamment le mohair, le cachemire et l'alpaga. Ces laines spéciales représentent seulement 3 % de la production brute de laine dans le monde, mais leur prix peut être 10 à 30 fois supérieur à celui de la laine de mouton.

Le lapin angora est exploité pour produire une toison, valorisée ensuite par l’industrie textile. L’INRA (Institut National de la Recherche Agronomique) étudie l’amélioration génétique du lapin Angora depuis plus de trente ans.

La recherche scientifique étudie la possibilité d’augmenter la production de laine de lapin Angora par la génétique. Il est intéressant, pour les éleveurs de lapin Angora de savoir quels sont les caractères héréditaires. Pour analyser l’efficacité d’une sélection sur le poids total de la toison et la réponse corrélée sur les autres caractères (longueur, diamètre, résistance etc …), nous avons effectué une expérience de sélection divergente (2 lignées différentes, haute et basse) sur ce caractère. Les résultats de cette sélection ont été analysés pendant ma thèse.

Ma thèse dans ce contexte :

Mon sujet de thèse est inclus dans le projet global de « Variabilité génétique des caractères et gestion des populations » de notre équipe. La production de fibre angora est la troisième plus grande industrie de fibre animale dans le monde après la laine et le mohair.
Au regard de la concurrence publique et internationale, les résultats pourront être utiles pour des éleveurs de lapins Angora en France (peu) et surtout en Chine, en Inde et en Turquie.

Compétences scientifiques et techniques:

L’équipe phanères de la SAGA est la seule équipe de recherche en France qui travaille sur la biologie de la production de fibres et de fourrures chez les animaux. Cette unité a réalisé quelques découvertes sur les fibres de lapin Angora.
Des outils modernes en informatique, statistiques et génétique quantitative ont étés mis à la disposition du projet.

Moi dans ce contexte :

J’ai travaillé 10 années comme chercheur/enseignant sur les fibres des animaux à l’université et obtenu un diplôme de DEA. J’ai donc souhaité poursuivre mes études et mes travaux sur ce sujet en réalisant une thèse. Travailler sur ce sujet au sein d’une équipe de chercheurs m’a beaucoup intéressé, et je voulais rejoindre l’équipe de Daniel Allain et H. De Rochambeau, que je connaissais depuis quelques années, à travers leurs publications scientifiques. J’ai tout d’abord émis quelques propositions sur la manière de traiter ce sujet de thèse, puis j’ai contacté Monsieur Mark Brims (BSC Electronics) en Australie pour solliciter sa participation à notre projet. Il a accepté de mesurer gracieusement un ensemble de 480 échantillons de mèche d’angora.

Déroulement, gestion et coût de projet :

Conduite du projet

Principales étapes : Mon sujet de thèse comportait 3 phases successives de difficulté croissante :

- J’ai réalisé une bibliographie sur les facteurs de variation de la production de poils chez le lapin angora en comparaison avec d’autres espèces, le mouton et la chèvre principalement.

- Dans le même temps je me suis formé sur le logiciel SAS (Statistical Analysis System), puis j’ai réalisé des mesures complémentaires sur les échantillons biologiques, recueillis au cours de l’expérience. Ils étaient essentiellement constitués de mèches de poils (2/animal en récolte 5 et 7) et de coupes histologiques de peaux (2/animal de la cohorte 2001 en récolte 5 et 7).
- Ensuite j’ai constitué les fichiers nécessaires à l’analyse.
- La troisième phase a consisté à analyser la réponse de la sélection sur le caractère d’intérêt et sur les autres caractères mesurés. Cette méthodologie supposait que les paramètres génétiques (héritabilité et corrélations génétiques des caractères) soient connus.

Des Réunions avec le directeur et le responsable scientifique avaient lieu régulièrement deux fois par mois. Nous avons également eu des réunions du comité de thèse avec la participation de E. Manfredi, A. Ducos, C. Robert et J. Bouix.

Evaluation et prise en charge du coût du projet :

Tableau 1. Coût de projet

Ressources Humaines		Prise en charge
	Thésard	750 * 12mois * 3 ans =27 000 € + 45% charge=39 150 €
	Directeur	6 heures/mois *11mois * 3 an ~ 1,5 mois 1,5 mois * 4.000 + 45% = 8 700 €
	Responsable scientifique	8 heures/ mois * 11 mois * 3ans ~ 2 mois 2 * 3.500 + 45 % = 10 150 €
	Techniciens (INRA Le Magneraud)	1 tech. * 2(h/j) * 30 J *12 mois * 10 ans ~ 52 mois 52 mois * 1.500 € + 45 %= 113100 €
	Technicien (INRA Toulouse	1 tech. * 1 mois * 1500 €+ 45 %= 2 175 €
Matériels	Les animaux	670*50€=33 500
	Alimentation et vétérinaire	130 g de pellets par jour * 670 animaux*365 jours * 3 ans= 95 375 Kg *0.20 €/Kg=19 075 €
	Histologie	1.000€
	Mesurer diamètre des fibres (OFDA)	245*4€=980 €
	Total	**227 830 €**

Compétences :

Les compétences scientifiques acquises :

Génétique quantitative, application du modèle linéaire, estimation des composantes de variance valeur génétique, sélection. Métrologie des fibres et histologie quantitative de la peau

Les compétences techniques :

Les logiciels SAS, VCE, ASReml, PEDIG, ENDOG, Survival kit.

Techniques de mesures caractéristiques des fibres d'animaux

Langages informatiques : Fortran, Perl

Compétences personnelles :

Gestion de projet :

- **Oral :** Analyse D'une Expérience De Sélection Divergente Pour Le Poids Total De La Toison Chez Le Lapin Angora, 7ème Séminaire des Thésards, station d'amélioration génétique des animaux, INRA centre de Toulouse, 2005

- **Ecrit :** Rafat, S.A., H. de Rochambeau, R.G. Thébault, I. David, S. Deretz, M. Bonnet, B. Pena-Arnaud and D. Allain, Divergent selection for total fleece weight in Angora rabbits: Correlated responses in wool characteristics, *Livestock Science*, *In Press, Corrected Proof*, *Available online 30 March 2007,*

- Rafat, S.A., D. Allain, R.G. Thébault and H. de Rochambeau, Divergent selection for fleece weight in French Angora rabbits: Non-genetic effects, genetic parameters and response to selection , *Livestock Science, Volume 106, Issues 2-3, February 2007, Pages 169-175*

- S. A. Rafat, H. de Rochambeau, M. Brims, R. G. Thébault, S. Deretz, M. Bonnet, and D. Allain (2007) Characteristics of Angora fibre using optical fibre diameter analyser. *Submitted to Journal of Animal Science*

Langues (Reading, Writing, Speaking) :

Farsi : (fluent, fluent, fluent)
Turc : (fluent, fluent, fluent)
Français : (functional, functional, functional)
Anglais : (fluent, functional, functional)

Résultats:

Pour le laboratoire:

- Ce projet constitue le dernier projet d'analyse sur le lapin angora en France. L'INRA avait pour objectif de connaître, après trente ans de recherche sur le lapin angora, quelle était la progression des résultats obtenus par voie génétique.
- Ce projet a constitué une recherche originale sur ce sujet. En termes de bibliographie, il n'existait aucun résultat publié sur les paramètres génétiques de qualité de la laine Angora.
- Le laboratoire SAGA s'est intéressé à l'utilisation de nouvelles méthodes de génétique quantitative pour l'analyse des données disponibles. Cela permettra le développement et l'application des méthodes plus performantes de statistique dans les domaines de la génétique des animaux.

Pour l'économie :

- Quelques résultats utiles et pratiques sont issus de ces travaux et feront l'objet de conseils utiles aux éleveurs de lapin angora en France, en Turquie, en Inde et en Chine

Pour moi-même :

- Le lapin Angora a constitué pour moi un modèle d'animal utile pour développer un travail de recherche et expérimenter des procédés scientifiques sur des fibres animales. À l'avenir je pourrai utiliser ces outils et méthodes dans ma carrière de chercheur sur d'autres espèces : le mouton et la chèvre, producteurs de laine, de cachemire et de mohair.

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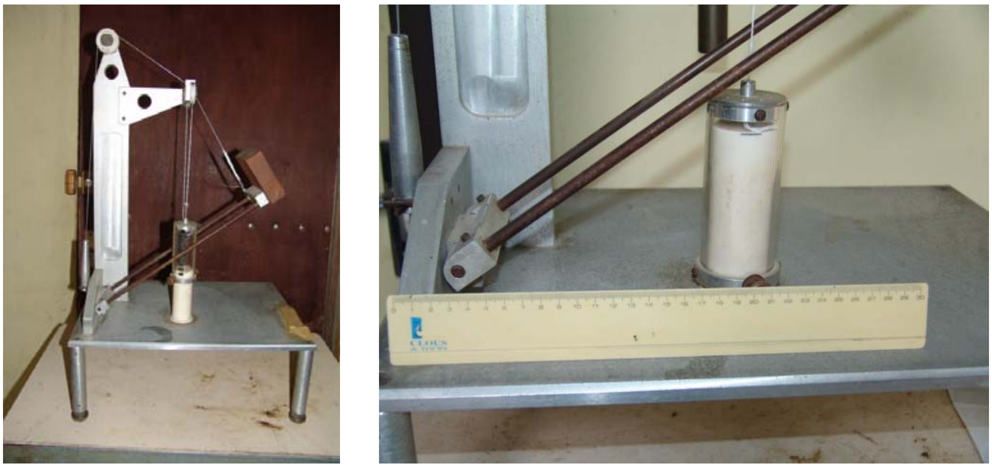
Appendix II

Measurement of compression and resilience



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