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Genetic improvement for alpaca fibre production in the Peruvian Altiplano: the Pacomarca experience

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Summary
Pacomarca is an experimental ranch founded by the INCA group to act as a selection nucleus from which basic genetic improvement of alpaca fibre can spread throughout the rural communities in the Peruvian Altiplano. State-of-art techniques in animal science, such as performance recording or assisted reproduction including embryo transfer, are applied to demonstrate their usefulness in the Altiplano conditions. Pacomarca has developed useful software (Paco Pro) to carry out the integral processing of production and reproduction data. Mating is carried out individually, and gestation is diagnosed via ultrasound. Breeding values estimated from a modern genetic evaluation are used for selection, and embryo transfer is applied to increase the selection intensity. However, the objective of Pacomarca goes beyond, extending its advances to the small rural communities. Training courses for farmers are organised while searching for new ways of improving the performance of alpacas both technically and scientifically.

Keywords: *alpaca, fibre, genetic improvement, Peruvian Altiplano*

Résumé
Pacomarca est un ranch expérimental créé par le groupe INCA en tant que noyau de sélection pouvant répandre les bases de l'amélioration génétique pour la fibre d'alpaga dans toutes les communautés rurales du haut-plateau péruvien. A Pacomarca, on applique des techniques de pointe de la zootechnie, comme le contrôle des performances ou la procréation médicalement assistée, y compris le transfert d'embryons, pour démontrer leur utilité dans les conditions productives du haut-plateau. Pacomarca a élaboré un logiciel (Paco Pro) utile à entreprendre l'élaboration intégrale des données sur la production et sur la reproduction. Les accouplements sont réalisés de façon individuelle, la gestation est diagnostiquée par le biais de l'échographie, les valeurs génétiques, estimées par des techniques modernes d'évaluation génétique, sont utilisées pour la sélection, et le transfert d'embryons est appliqué pour accroître le taux de sélection. Cependant, l'objectif de Pacomarca va au-delà de ces activités et vise à transmettre ces progrès aux petites communautés rurales. On organise des cours de formation pour les agriculteurs tout en cherchant de nouvelles façons d'améliorer la performance des alpagas du point de vue technique ainsi que scientifique.

Mots-clés: *alpaga, fibre, amélioration génétique, Altiplano péruvien*

Resumen
Pacomarca es un rancho experimental fundado por el grupo INCA para actuar como un núcleo de selección que permita extender la mejora genética de la fibra de alpaca en el altiplano peruano. En Pacomarca se aplican técnicas estándar en producción animal, como el control de rendimientos o la reproducción asistida incluyendo la transferencia de embriones, para demostrar su utilidad en las condiciones productivas del altiplano. Pacomarca ha desarrollado una aplicación informática (Paco Pro) que permite una gestión adecuada de la información productiva, reproductiva y genealógica necesaria para llevar a cabo un programa de mejora genética: los apareamientos se llevan a cabo de forma individualizada, la gestación se diagnostica mediante ecografía, los méritos genéticos estimados mediante modernas técnicas de evaluación genética se usan para la selección de reproductores y la transferencia de embriones se utiliza para aumentar la intensidad de selección. En todo caso, el objetivo de Pacomarca se cumple esencialmente organizando periódicamente cursos de formación para miembros de pequeñas comunidades rurales del altiplano en los que se produce la diseminación de sus avances en manejo, reproducción y producción de la alpaca resultado de las experimentaciones realizadas en Pacomarca.

Palabras clave: *alpaca, fibras, mejora genética, Altiplano Peruano*

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Introduction

Within the four South American camelid species of llamas, guanacos, alpacas and vicuñas (Kadwell *et al.*, 2001), the alpaca is the most numerous. With a population of 3.5 million in Peru, representing 75% of the world's total, the alpaca provides the main means of sustenance for thousands of families in the high Andes. Other countries which breed alpacas are mainly Bolivia and Chile in South America, and, after exportation, New Zealand, Australia, the United States, and Canada.

Thousands of rural Peruvian families raise flocks of alpacas at elevations of more than 4000 m above sea level among impressive landscapes where the daily temperature ranges between −15°C and 20°C. They do what has been done for thousands of years, shearing the animals and selling their fibre every year, to provide their families with their principal income.

There are two breeds of alpaca: the Huacaya and the Suri (Wuliji *et al.*, 2000). The Huacaya are the most numerous type in Peru, representing 93% of the population; their hair has relatively short fibres which are dense, curly and voluminous. Hair covers almost all of the body, and only the face and lower parts of the legs have a covering of short fibres. Suri alpacas have long, straight hair which is silky and exceptionally lustrous. If Suri fleece is allowed to grow, it can sweep the floor and drape like curtains. This type of Suri is called "Wasi", and it has been used in the past to protect the herds.

Under the current usual management, alpacas are shorn with knives or shears, usually once a year between November and April. The colour of the fibre is variable; up to 22 colours have been defined which range from white to black through greys, fawns and browns. The fibre is classified manually according to its fineness and sorted into the qualities shown in Table 1. One animal will have all of the qualities in different percentages throughout its body. Therefore, meticulous manual sorting is necessary to separate the different qualities, colours and lengths. The finer qualities have more value in the international market, so finer alpacas have higher market value. The names of these quality classes do not necessarily reflect the age of the animals or other phenotypic characteristics. The appellation 'Baby', for example, is applied to products (tops, yarns, cloth etc.) where the average fibre diameter is 22.5 µm. The fibre used to obtain this quality does not necessarily come from baby animals; it could easily come from an adult animal with a very fine coat.

Table 1. Alpaca fibre categories according to textile industry (Inca tops super-fine alpaca).

Category	Fibre diameter (µm)
Royal alpaca	19.5
Baby alpaca	22.5
Super-fine alpaca	25.5
Huarizo	29
Coarse	32
Mixed pieces	>32

There is increasing international interest in the study and production of fine alpaca fibre (Wuliji *et al.*, 2000; Frank *et al.*, 2006; Lupton *et al.*, 2006; McGregor, 2006). In the last 45 years alpaca fibre has become thicker, warning about the need of establishing a genetic selection program. The low educational level of alpaca farmers makes the implementation of a bottom-up initiative difficult, and it is only conceivable with the joint efforts of public administration and market operators. This was the initial reason that led the INCA Group to found its ranch known as Pacomarca, that today is one of the most important sources of genetically improved Alpacas in the Altiplano.

Pacomarca

Origin

Pacomarca (Figure 1) is an experimental farm run by the INCA Group in the department of Puno since 1992. It occupies approximately 1500 ha (3706 acres) and lies at an altitude of 4060 m (13 320 ft) above sea level on the Altiplano. The farm raises approximately 2050 selected alpacas. The objective of the INCA Group was to try to reverse the tendency to abandon alpaca raising, that was occurring in Peru. Pacomarca S.A. decided on its own initiative to undertake a project to recover the fineness of the alpaca fibre produced in Peru. This effort is also a continuation of the original work of the Sallalli farm, located at the foot of the Sabancaya Volcano, which was destroyed when the volcano erupted some years ago. The site is appropriately located in the high Andean plains (Altiplano) with an easily accessible location, that is close to the main alpaca-raising areas, electricity supply, land area sufficiently large to be able to grow crops, a water supply and title deeds in legal order.

The initial genetic stock was composed of animals selected and bought according to the information available from the

Figure 1. A panoramic view of the Pacomarca Ranch.

purchasing fibre activity of the INCA Group during 50 years. Animals were individually identified from the beginning. Software called "Paco Pro" was developed to manage all of the information generated by the herd in order to administer animal performance, mating and health. This data set now consists of about 2.5 million records of variable nature.

The Pacomarca experimental ranch (Figure 1) is considered the leading genetic improvement center in Peru, and its influence in the Alpaca breeding and scientific world is proving essential for the future of this precious resource in its native country. The final goal is to act as a resource from which basic genetic improvement can be spread throughout rural communities in the Peruvian Altiplano.

Objectives

Even though the original aim of the ranch was to develop a population with high genetic value, the day to day running of the ranch taught their managers about several other perspectives of alpaca production and other objectives were discovered which could be carried out at the ranch. Some of them are summarised as the following:

1. to carry out a genetic selection scheme to improve fibre quality;
2. to learn management practices which help to better commercialise alpaca fibre;
3. to teach successful management practices to the farmers on small surrounding farms;
4. to become a farm which acts as a selection nucleus; and
5. to research genetics, reproduction and other animal sciences.

Performance recording

Today the organisation of performance recording reaches many of the daily practises carried out on the ranch. Animals are sheared every year which registers their performance, and a sample of wool is taken from the animal rib cage and sent for analysis in the laboratory. The animals are also periodically weighed and measured, and the mating is always individually carried out in specific boxes and the gestation is controlled by scan. Veterinary treatments are also carefully noted. All of the information is gathered in the data set managed by the Paco Pro software. This information covers the following:

- pedigree with identifications of individual, father and mother, birth date and sex;
- individual mating information, pregnancy tests and births;
- individual performance of fibre diameter, standard deviation, comfort factor and coefficient of variation;
- individual performance of the different fibre qualities of the fleece;
- individual shearing performance by corporal zones;
- individual heights and weights at different ages;
- disease registration and medical treatments;
- registering their origin and culling with destination and causes of culling; and
- defects.

In addition, Paco Pro registers the phenotype traits of the individual alpaca. The type traits, that are assessed using subjective scores from 1 (poor) to 5 (excellent) by expert classifiers, include the following:

Density scores the amount of follicles per square millimeter. The fleece is sampled at three locations (shoulder, mid-point and rump) by manual pressing and assessing the amount of fleece the hand can grab at once.
Crimp scores the number of fibre waves per centimeter. Crimp includes amplitude and frequency: amplitude is the height of the wave as measured from the crest to the trough and frequency is the number of waves for a given measurement. The trait we are looking for is high frequency and medium amplitude. Only Huacaya alpacas are scored for crimp.
Lock structure scores the formation of individual fibres into groups. A "lock score" includes the lock definition from the skin out to the tips of each lock, the independence of the locks from each other and the density and heaviness within the lock. We are looking for uniform independent locks throughout the body. Only Suri alpacas are scored for lock structure.
Head assesses the biometrical relationship between the head and the shape of the alpaca. The alpaca must have a small rounded head. The main areas of evaluation are the ears and snout. An animal with a score of 5 will have a short snout and proportional ears, giving the appearance of a rounded head.
Coverage scores the presence or absence of fibre in the alpaca extremities and head. A coverage score of 5 indicates much fibre in the extremities, potentially even covering the toes and the head to the point of producing wool blindness. A score of 1 designates an open face and very little fibre on the legs.
Balance scores the overall appearance of the alpaca: how the animal looks as a whole, including the proportionality of the body, neck, limbs and head.
Comfort factor is the percentage of fibres with a diameter below 30 μm.

Example of information extracted from the data set

We include brief examples of the information extracted from the Pacomarca data set, after a superficial analysis.

- Although the age of the parents at the birth of their offspring is an average of 6.2 years, the generation interval defined in the same way (but only for the animals that were selected as parents) is only 4.7 years, revealing the rapid replacement strategy adopted at the ranch.

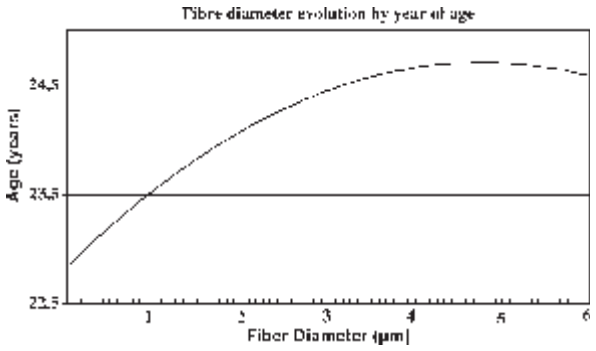

Figure 2. Mean values of the fibre diameter regarding age. Note: FD = 22.8 + 6.6×10^{-2} M − 5.72×10^{-4} M^2, where FD is the fibre diameter (µm) and *M* is the age (months).

- Factors affecting the fibre traits are the age, breed, colour, and month and year of shearing; sex, lab or body region have no significant effect.
- Factors affecting the weight and length of fleeces are the age, breed, and month and year of shearing, but not the sex.
- Only the age and the month and year of data recording affect the weight and height of animals.
- Fibre diameter increases with age. After fitting all other effects, the mean values of the fibre diameter regarding age in years are presented in Figure 2.
- Least squares estimates of the fibre traits within sex, breed, corporal region and month and year of shearing are provided in Tables 2 and 3.

Table 3. Number of animals (*N*), least squares means of fibre diameter (FD), standard deviation of fibre (SD), comfort factor (CF) and coefficient of variation (CV) within categories of month and year of shearing.

Month	Year	*N*	FD	SD	CF	CV
February	2001	85	19.88	4.10	94.23	19.88
August	2001	6	21.11	3.09	94.70	3.13
January	2002	106	20.76	4.96	94.48	20.76
October	2002	192	21.69	5.61	91.01	24.35
November	2002	7	24.22	5.40	87.30	22.51
December	2002	686	22.68	5.43	90.60	23.92
August	2003	121	21.13	5.08	94.07	24.03
September	2003	818	21.35	5.07	93.97	23.78
November	2003	9	23.33	5.49	90.00	23.34
December	2003	222	23.47	5.34	88.88	22.76
January	2004	103	20.60	5.00	94.23	24.33
June	2004	14	24.85	5.96	83.24	24.85
November	2004	139	19.31	4.72	96.55	19.31
December	2004	191	24.27	5.95	84.91	24.46
January	2005	198	23.13	5.17	89.47	23.13
May	2005	12	18.70	4.73	97.58	18.70
September	2005	259	21.61	5.44	92.14	25.03
October	2005	954	24.66	5.70	84.06	23.00
November	2005	52	18.74	4.77	96.60	18.74
March	2006	20	22.09	5.10	87.93	23.53
May	2006	159	21.08	5.63	93.09	21.08
June	2006	243	23.27	5.65	85.92	23.27
July	2006	104	21.98	5.46	89.50	21.98
August	2006	40	20.23	5.41	94.72	20.23
September	2006	1188	25.87	6.12	78.06	25.87
October	2006	8	24.81	5.71	84.22	22.71

Outstanding advances

Inca shearing method

The experience of the INCA Group in buying fibre throughout Peru showed that an important economic loss was due to practical lack of care at shearing, that is a management practice carried out once a year, usually in October.

Many farmers with a very low number of animals carry out shearing with the most rudimentary practices, such as using glass, tins or scissors in the best cases, and harming the animals. Moreover, disordered shearing and wool packing lead to heavy waste in a posterior treatment of the fleece. Alternatively, a correct ordered shearing practice allows a quick classification of the fleece, saving costs in personal and mechanical resources.

Pacomarca has developed a shearing protocol called “Inca esquila” (Figure 3) which allows better performance of the animal and thus a better price for the fleeces of the animals. It is described in several steps:

1. Clean the shearing area.
2. Clean the animal with a brush to eliminate all debris.
3. Separate the fleece into three parts: blanket, neck and pieces.
4. Stretch one side of the animal on the mat; place the dumbbells on the four legs of the animal.
5. Shear the belly and skirts first and separate them in a plastic bag.
6. Shear the animal from the belly to the back without the neck, and turn the animal to shear the other side without damaging the fleece.
7. Take the sheared fleece to a table and clean and take out any guard hair.
8. Put plastic in the middle of the fleece before folding it.
9. Wrap the fleece “drum” style.

Table 2. Number (*N*) of animals, least squares means of fibre diameter (FD), standard deviation of fibre (SD), comfort factor (CF) and coefficient of variation (CV) within categories of breed, sex and corporal region of sample.

	N	FD	SD	CF	CV
Breed					
Huacaya	4718	22.82	5.27	89.03	23.12
Suri	1232	24.47	6.46	82.17	26.32
Sex					
Male	1068	22.39	5.50	88.60	24.52
Female	4882	23.34	5.52	87.39	23.62
Region					
Rib cage	4854	23.41	5.55	86.65	23.69
Thigh	548	21.96	5.36	92.26	24.12
Shoulder	548	22.21	5.44	91.51	24.27

Figure 3. The shearing protocol called "Inca Esquila".

10. Repeat the same procedure for the neck.
11. Put the three separate bags (skirts, neck and fleece) into one plastic bag.

The INCA shearing method allows better yield of finer qualities such as Royal Alpaca and Baby Alpaca at the classifying process, allowing a better return to the alpaca producers.

Paco Pro data processing software

Data processing software was needed since the start of the ranch. Pacomarca invested in developing Paco Pro software, that carries out the integral data processing of the management of the ranch. Paco Pro is thus a strategic software system for the control and management of alpacas. The program keeps production and genealogical information about the alpacas such as their unique identifier, parents, sex, colour, breed, date of birth, date of death and progressive records of fibre diameter, fibre production, mating, diseases, births and much more.

All of the information recorded about individual alpacas can be rendered individually or in a set. Several groups may be created in many different ways, taking into consideration the location, type of nutrition, hierarchy, breed, colour, age and other characteristics.

Paco Pro also has specialised search tools for each module to allow the best management system for the animals. It can identify and explore a specific animal, its relatives and its entire genealogical tree. In addition, the system has a base animal attributes search, a finesse search tool and a production tool with records like fleece weight or staple length. All of the recorded data allow for easy access to records of a single animal and help to identify the elite group.

This integrated information makes control of the mating campaign easy and allows the planning of individual matings, taking into consideration the performance of previous campaigns. As a result, it provides demographic statistics so that we can plan accordingly for the following campaign.

All of the individual records are linked with each other in a relational database and are ready to render the expected progeny difference of each animal, so that a proper ranking of the best genetic material of the ranch can be obtained.

Animal breeding program

Pacomarca animals are bred according to their performance. Since 2007 the company has had an agreement with the University Complutense of Madrid to carry out genetic evaluations of their animals. The filters incorporated in Paco Pro provide a data set which is almost completely free of errors and makes data processing and generation of precise genetic evaluation easy to complete.

Genetic evaluation is carried out mainly for fibre related traits, including mean diameter and variability, but other traits have been also essayed such as fleece weight, fibre length, shearing interval, textile value or morphological traits (Gutiérrez *et al.*, 2009).

The international Best Linear Unbiased Prediction (BLUP) methodology was chosen to obtain the expected progeny

Table 4. Estimated heritabilities (diagonal) and genetic correlations (above diagonal) for several fibre and type traits in the Pacomarca data set.

	FD	SD	CF	CV	DE	CR/LS	HE	CO	GA
FD	**0.428**	**0.774**	**−0.974**	0.135	0.001	**−0.250**	**−0.201**	0.068	−0.080
SD		**0.459**	**−0.826**	**0.725**	−0.125	**−0.410**	−0.064	0.132	−0.017
CF			**0.306**	**−0.239**	−0.009	**0.284**	0.156	−0.105	0.046
CV				**0.369**	**−0.212**	**−0.395**	0.124	0.151	0.070
DE					**0.221**	**0.704**	**0.226**	**−0.073**	**0.234**
CR/LS						**0.339**	**0.345**	0.087	**0.367**
HE							**0.379**	**0.757**	**0.942**
CO								**0.418**	**0.809**
GA									**0.158**

Note: FD, fibre diameter; SD, standard deviation; CF, comfort factor; CV, coefficient of variation; DE, density; CR/LS, crimp (Huacaya) or lock structure (Suri); HE, head; CO, coverage; GA, general appearance.

differences of the individuals within breed. Previous estimation of genetic parameters is always mandatory, and the range of estimated heritabilities at the Pacomarca ranch allows for optimism. A sample of heritabilities in fibre and type traits (Cervantes *et al.*, 2009) estimated by restricted maximum likelihood using the VCE program (Neumaier and Groeneveld, 1998) is provided in Table 4.

The BLUP evaluation accounts for some non-genetic effects such as the sex of the animal, the coat colour and the month and year of shearing, allowing isolation of the additive genetic value. The influence on the animal which is not of genetic origin (the permanent environmental effect) is also removed. The breeding values are accompanied by a value measuring their reliability, allowing ranch managers to carry out an appropriate genetic selection. To our knowledge, this is the only Alpaca ranch in the world with a genetic value for each of its animals.

Embryo transfer

After the genetic evaluation experience, Pacomarca acquired the ability to identify its best animals. However, a quick genetic response is limited by the number of their offspring. In a natural way, only one cria is born for each female and year. If embryo mortality is also considered, then only one offspring is expected for each two fertile females.

To face this limitation, Pacomarca started an assisted reproduction program by means of embryo transfer. The males and females with the best breeding values are selected. Up to six embryos (average of four) are obtained from each elite female and transferred to females with high maternal abilities. In this way each elite female can provide a mean of four offspring yearly. Table 5 provides a summary of the data for 2009 concerning embryo transfer, showing 68% successful pregnancies by embryo transfer this year. Pregnancy is diagnosed by means of ultrasound regardless of whether the mating was natural or via embryo transfer.

Farmers training program

The small Andean farmers are the beneficiaries of technical and scientific advances achieved in Pacomarca. The training farmers program (Figure 4) has been enthusiastically accepted by farmers in Peru and other countries. Communities and organised groups spend time at the ranch attending specialised courses with the aim of transferring all advances. The improvement of the managing practices of these farmers will consequently help improve the entire textile world.

Table 5. Summary of embryo production in the 2009 campaign.

	Number	%
Donor females	31	
Recipient females	145	
Flushes	131	
Collected embryos	101	77.10
Transferred embryos	101	77.10
Gestations	69	68.32

Figure 4. Pacomarca's breeding training program.

Future advances

The successes obtained by Pacomarca in just a few years have provided increasing encouragement which leads to new objectives. Some of them are the following:

- To monitor animals that are transferred to other farmers in order to know if the improvement accomplished at Pacomarca is maintained in other places.
- To incorporate animals of other farmers into the performance recording, particularly those with genetic relationships with the animals of the ranch.
- To investigate the high heritabilities found in the fibre traits which suggest the presence of genes with major effects. An initial objective in this sense would be to locate the carriers of such genes and select them, but a deeper molecular search of these hypothetical genes is not ruled out.
- To carry out a genetic evaluation using a technique known as canalisation, that is thought to reduce the variability (SanCristobal *et al.*, 1998; Gutiérrez *et al.*, 2006), and to compare the resulting breeding values with BLUP breeding values to assess the possibility of replacing the traditional BLUP technique.
- To innovate breeding and operational techniques in order to increase the economic output of these animals.

Pacomarca is thus becoming the most important selection nucleus in Peru, but extending its advances to the rural community is still dependent on the educational level. Additional efforts are needed in this area.

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