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Breeding Management Practices, Maternal Behaviour, and Reproductive Performance in Camelids

Doctoral thesis

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Declaration

I hereby declare that I have completed this thesis entitled **Breeding Management Practices, Maternal Behaviour and Reproductive Performance in Camelids** independently, all texts in this thesis are original, and that all information sources have been quoted and acknowledged by means of complete references. I also confirm that this work has not been previously submitted, nor is it currently submitted, for any other degree, to this or any other university.

In Prague ....

Name of the student……………….

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Abstract

Although camelids (*Camelidae*) significantly contribute to human nutrition and livelihoods in the tropics and subtropics, the lack of studies focusing on their reproductive efficiency, reproductive management, and maternal behaviour limits the understanding of their reproductive performance under various conditions. South American camelids (SACs) contribute significantly to the Andean ecological and cultural heritage. However, pastoralists face economic and climatic challenges in mountainous areas, which makes SAC husbandry more difficult. This thesis aimed to critically review and synthesize the current knowledge on reproductive management and husbandry techniques used in dromedary camels and domestic SACs, with a focus on their reproductive performance and maternal behaviour. The partial objectives were to characterize the husbandry practices of farmers raising SACs in Ecuador and Peru, analyse the differences between the herds in these two countries, and assess the influence of farmers' gender and the length of SAC farming experience on the breeding techniques used. This thesis also aimed to characterize and compare the nursing behaviour of alpacas kept under traditional conditions in the Andean region and on farms in Central Europe. Lastly, to document the occurrence of allonursing in domestic SACs. To achieve this, 102 SAC farmers completed a questionnaire, and 1,899 nursing bouts of alpacas (*Vicugna pacos*) were observed in the Andes and Central Europe. Although the primary purpose of SACs farming was for fibre and meat production, several differences in husbandry practices can be seen between Andean farmers. The farming experience of SAC farmers was longer in Peru, where larger alpaca herds and the keeping of llamas (*Llama glama*) as supplementary activity were more common than in Ecuador. Women were more often involved in SACs farming than men, and the mean farming experience for women was significantly higher than for men. The main problem in the husbandries mentioned by the farmers were external and internal parasites and the lack of pasture in the dry season. The alpaca nursing behaviour in the Andes and Central Europe showed markable similarities under two completely different locations, despite different environments and management, especially in the initiation by cria and termination by the dam. However, significantly less frequent sniffing of crias by dams in the Andes was observed. Allonursing was not observed in the Andes but occurred rarely in Central Europe (n=5); however, 18.6 % of surveyed Andean farmers reported that they observed allonursing in their herds. These findings enhance the understanding of alpaca maternal care and may help improve farm management and animal welfare. Research of alternative feed sources for SACs and

proper pasture management in the Andes could help farmers mitigate husbandry problems, increase reproductive efficiency, and face issues linked to climate change challenges.

Keywords: allonursing; alpacas; dromedary camel; nursing behaviour; reproductive performance; South American camelids

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AFC	Age of first calving
AFS	Age of first service
DESCOSUR	Centro de Estudio y Promoción de Desarrollo
ESPOCH	Escuela Superior Politécnica de Chimborazo
FAOSAT	Food and Agriculture Organization Corporate Statistical Database
GLM	Generalised Linear Models
INIA	Instituto Nacional de Innovación Agraria
m a. s. l.	Meters above the seas level
MIDAGRI	Ministerio de Desarrollo Agrario y Riego
OIF	Ovulation inducting factor
SACs	South American camelids
WA	Weaning age

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1 Introduction and Literature review

Camelids play an important role in the livelihood of many populations worldwide. Both SACs and camels play significant roles in rural areas (Markemann and Zárate, 2010; Faraz et al., 2023). They serve as a good source of meat and milk, and their other products, such as fibre, have grown in popularity outside their place of origin (Vilá and Arzamedina, 2022). The members of the camelid family are well-adapted to harsh conditions; for example, they have calluses on their feet, which allow them to move in more challenging terrain such as mountains, rocks, or hot sand (Puschmann et al., 2013). Furthermore, they have lower requirements for water or food than other domestic animals. Due to their digestive system physiology, they can also utilize low nutritionally dense feed and poor vegetation (Laudadio et al., 2009).

However, the husbandry and breeding of camelids are challenging in the places of their origin, and the reproductive efficiency of camelids is often inferior due to some of their reproductive peculiarities, which are mismanaged (Brown, 2000; Mayouf et al., 2014). Camelids are bred as seasonal breeders in the places of their origin and exhibit induced ovulation (Kalla et al., 2008; Aguilar et al., 2014; Berland et al., 2016). With the older age of first breeding and relatively long gestation period, their reproductive management is challenging (Kaufmann, 2005; Njanja and Oba, 2011). Also, the maternal and suckling behaviour of SACs has not been studied.

1.1 Biological and Ecological Characteristics of Camelids

1.1.1 Characteristics of camelid species

Some authors have divided the Old World camelids into three species, two of which are domesticated and used as husbandry animals (Plasil et al., 2016). It is the dromedary camel (*Camelus dromedarius*), the one-humped camel, that dominates the arid African and Arabian Peninsula regions (Bekele et al., 2018; Burger et al., 2019) and the Bactrian camel (*Camelus bactrianus)* with two humps, traditionally bred in colder regions of East Central Asia, China and Mongolia (Wilson, 1984; Faye and Konuspayeva, 2023). The third camel species is the wild Bactrian camel (*Camelus ferus),* which belongs to the critically endangered animals (Hare, 2008; Yadamsuren et al., 2012).

The dromedary camel population has grown steadily over the past 10 years, from approximately 28.9 million to more than 38.5 million in 2022 (FAO, 2022). Despite their marginal number compared to other domestic livestock species, the annual dromedary camel population growth rate is faster than that of cattle and sheep populations (Faye and Bonnet, 2012). Major regions of dromedary camel production include Africa and Asia (Kadim et al., 2008; Eisa and Mustafa, 2011; Nagy et al., 2013); however, camels are also well-represented in zoological gardens and private farms internationally (Baum, 2011). Figure 1 shows the dromedary camel population growth in major regions during the past 40 years. In the hot, arid areas of the tropics and subtropics, dromedary camels play an important role in the livelihood of the local pastoralists (Tura et al., 2009; Simenew et al., 2013). Camels are particularly suitable for production under arid conditions, as their digestive system allows for the utilization of poor-quality nutrition, with a broader feeding selection compared to cattle grazing a variety of grasses, bushes, and trees (Laudadio et al., 2009).

There is also a population of more than one million feral dromedary camels in Australia (NT.GOV.AU, 2024). They were brought to the country in the 19th century and expanded to many regions because of the variable conditions during the year. The feral dromedaries cause significant changes to the natural ecosystem (Lethbridge et al., 2010).

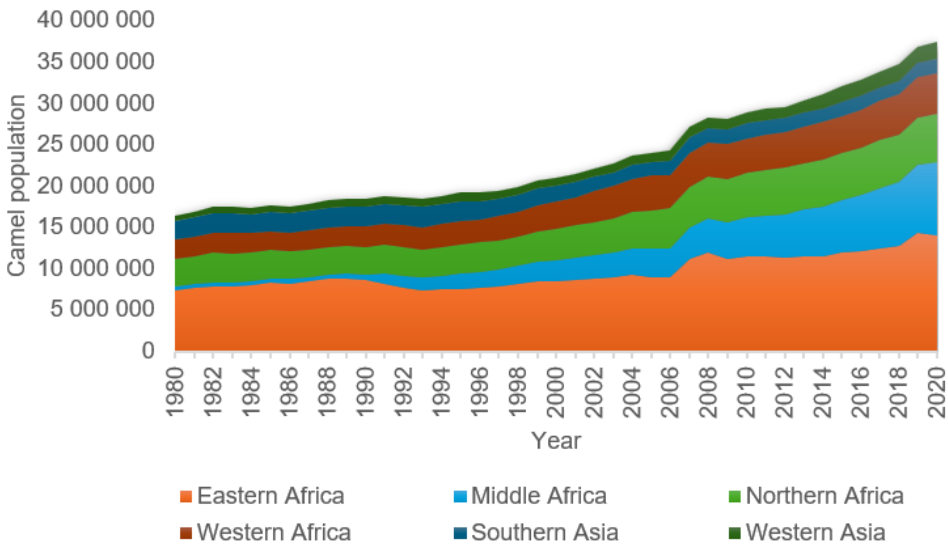

Figure 1. Dromedary camel population growth in major regions between 1980 and 2020 (Marešová et al., 2023 unpublished work).

There is a lack of studies focused on the Bactrian camels, thus the thesis is focused mainly on dromedary camels.

The husbandry of the New World camelids is a part of the traditional way of life of the Andean pastoralists. The SACs are well-adapted to the harsh climatic conditions of the mountainous regions and can be used in high-altitude environments (Markemann and Zárate, 2010). Two domesticated SAC species are found mainly in Peru and Bolivia - llamas (*Llama glama*) and alpacas (*Vicugna pacos*) (Rodriguez and Quispe, 2007). The SACs have been important animals for the local farmers for centuries. The domestication of wild camelid species started around the year 5000 BC in Argentina and Chile (Cartajena et al., 2007; Cartajena, 2009) and in Peru around the year 4000 BC (Kent, 1982; Moore, 1988; Mengoni-Goňalons and Yacobaccio, 2006).

There are two breeds of alpacas – Huacaya, with short fleece, which has an equal length over the body, and Suri, with longer fleece, which hangs parallel to the body (Antonini et al., 2004; Lupton et al., 2006). The Huacaya type is the main alpaca type bred in Andean countries; about 85% to 90% of alpacas are of this type (Quispe et al., 2009; Rogue Gonzáles and Olmachea Valdéz, 2012). There are also three breeds of llamas - Qara, Chaku and Intermedio (Ayala Vargas, 2018; Vargas et al., 2021). Alpacas reach 80 to 90 cm in the neck, while llamas reach up to 150 cm in the neck and are the highest and strongest SACs (Cardelino and Mueller, 2005). The domestic SACs arose from the wild SACs species, which include the vicuñas (*Vicugna vicugna*) and guanacos (*Lama guanicoe*), and as shown in the Figure 2, they are found mainly in Chile, Bolivia, Argentina, and southern Peru (Wheeler, 1995; Yacobaccio, 2021). Whether the SACs are domesticated or wild, they contribute greatly to the Andean region's overall cultural heritage and can be found in the natural reserves of the Andean countries (Vilá & Arzamendia, 2022).

The majority of the population of alpacas is located in Peru, where the total number has increased from 3.69 million to 5.6 million in the last 15 years (MIDAGRI, 2023, FAOSTAT, 2023). On the other hand, the number of llamas is decreasing in Peru, from 1.27 to 1.07 million (MIDAGRI, 2023). According to FAOSTAT (2023), there is currently no data about the alpaca and llama populations in Ecuador, although the estimated number of alpacas in the country is approximately 6,000 and the estimated number of llamas 10,000 (Germana Cavero et al., 2016; Vilá and Arzamendia, 2022). In the past years, SACs have almost been extinct in Ecuador. Thus, few studies focused on their husbandry or data summarizing their breeding success (Germana Cavero et al., 2016). However, the trend to protect and support their breeding has started, and SACs have recently been brought back to the Ecuadorian mountains (Rosenthal, 2008). Vicuñas were successfully reintroduced to Ecuador in 1987, and they are now present in the Chimborazo Fauna Production Reserve in central Ecuador (Cárdenas et al., 2021).

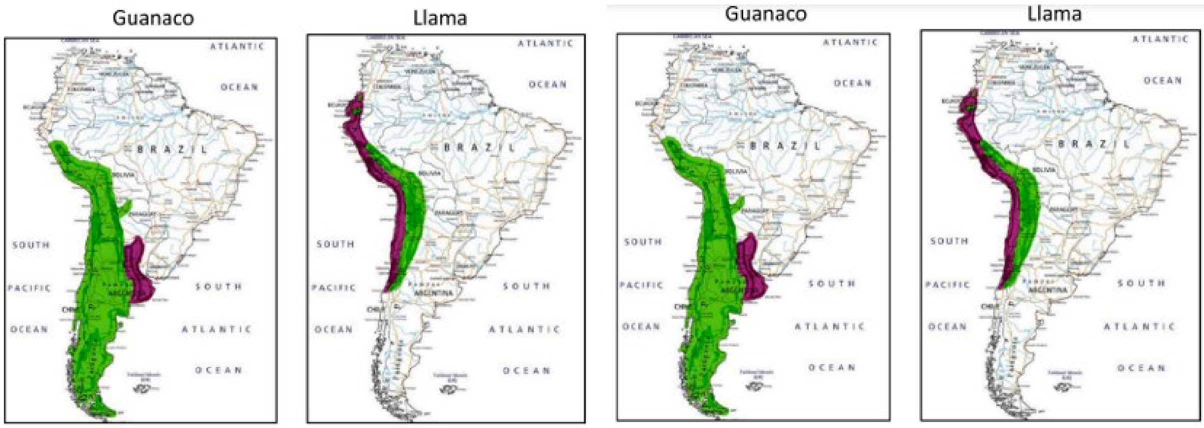

Figure 2. Distribution of four SACs species in South America, comparison of the current placement (green colour) and pre-Hispanic placement (purple colour) of the species (Miranda-de la Lama and Villarroel, 2023)

1.1.2 Ecological and cultural roles of camelids

The ecological and cultural contribution of camelids is irreplaceable. Camelids are animals used by breeders in rural areas for many purposes. Dromedary camels in the tropics and subtropics are used for milk production (Seifu, 2019; Nagy et al., 2022), particularly within East African regions, including Ethiopia and Kenya (Tadese et al., 2014; Yosef et al., 2015; Bekele et al., 2018), and North Africa, including Egypt and Sudan (El-Malky et al., 2018; Morshedy et al., 2020; Mostafa et al., 2020). There are also growing camel milk industries in other countries, such as the Arabian Peninsula (FAO, 2022), Australia, the Canary Islands (Faye, 2020), and European countries as well (Faye, 2022). One of the main reasons why milk production is still the most common use of dromedary camels is that it serves as a source of food security in arid and semi-arid areas (Faraz et al., 2023). It is also a good source of vitamin C (Farah et al., 1992; Zhang et al., 2005) and minerals, and thus has health benefits for humans (Konuspayeva et al., 2022). However, dromedary camels are not only utilized as a source of milk in these areas (Faye, 2020), but they are also bred for meat and fat production (Megersa et al., 2008; Abdussamad et al., 2011; Kadim et al., 2022) and used for transport and racing (Ali et al., 2009), and as a social or cultural prestige (Gebissa, 2015). For example, camels are usually part of the family heritage in Tunisia (Letaief and Bedhiaf-Romdhani, 2022).

With their well-adapted body, camels fit perfectly into the local habitat (Burrows, 2018). As an invasive species, they cause many problems to the natural environment on the Australian mainland and affect other local animals, the farmers, and the Aboriginal people (Edwards et al., 2010). Box et al. (2016) found that although the number of feral camels increased in Australia, the mortality of the local trees is on the same level. However, the problem of feral camels in the habitat is that they affect plant growth.

SACs husbandry is a typical part of the life of pastoralists in the Andean region. Llamas and alpacas do not cause soil erosion or uproot the plants like other domestic ungulates and can effectively use the pasture possibilities of the mountainous habitat of "antiplano" (Aygala Vargas, 2018), which is characterized by high altitudes of around 4,000 meters, low temperatures of 3 to 8 degrees Celsius and plains with a low occurrence of trees (Catorci et al., 2014; La Frenierre and Mark, 2017). Although they are well-adapted to these harsh conditions, slight differences exist among the species and types. Alpacas can be bred in the more humid habitat of the Andes, while llama husbandry is more suitable for dry environments (Iňiguez, 1998). Suri alpacas are not adaptable to the high Andean environment like the Huacaya type (Fernandez-Baca, 1994). A herd of alpacas (Huacaya breed) is shown in Figure 3.

SACs husbandry is important for the local farmers, and it brings many opportunities for women farmers, who are often involved and contribute to the local economy (Germana Cavero et al., 2016). SACs are used as multi-purpose animals, but meat and fibre are the most important objects for their breeding (Miranda-de la Lama and Villarroel, 2023). The meat utilization provides food security to the mountainous areas in the South American countries (Paz et al., 2012; Action, 2013). Rural families in the Andean highlands are often dedicated to SACs husbandry, which is mostly the main or the only source and strategy of their livelihood (Westreicher et al., 2007). They are usually bred by the local communities, where all the members contribute to their husbandry and animal production during the year (Aguilar et al., 2014).

Fibre production is the most important purpose for alpaca farmers, and the optimal fibre characteristics are used as selection criteria (Markerman and Zárate, 2010). Alpaca fibre is appreciated for its fineness, softness, and warmth (Cardellino and Mueller, 2009). It does not contain lanolin, and it does not need to have chemical treatments. Many studies focused on the quality and the improvement of SACs fibre (Lupton et al., 2006; Peréz-Cabal et al., 2011; Soroko et al., 2019; Cruz et al., 2023). Although the alpaca fibre quality is high, finer fibre is sheared from vicuñas (Quispe et al. 2009). Due to the high quality of their fibre, vicuñas were almost extinct because of the hunting for their coats in the last century (Yacobaccio, 2009). The fibre from llamas or guanacos is not utilized for fibre production due to its lower quality characteristics (Mueller et al., 2015). Llamas thus represent a source of sustenance (meat), and in past years, farmers used them as pack animals for extended travels in poorly accessible areas (Markemann et al., 2009). However, with the increase in road construction and better connections, this purpose is unimportant nowadays (Iňiguez and Alem, 1996). In Europe, alpacas are used only for breeding and fibre production or as pets (Wolfthaler et al., 2020).

Figure 3. Herd of alpacas (Huyacaya breed) in Peru (Marešová, Peru, 2022)

1.1.3 Reproductive biology of camelids

The reproductive anatomy of camelids will be briefly described in this chapter for the overall review of the topic. The reproductive organs of camelid males are similar to that of other domestic animals, like boars (El-Wishy, 1988). The testicles reach approximately 15g to 17g in adult alpacas (Bravo, 1995) and 57g in dromedary camels (Sumar, 1985). The left testicle is slightly larger than the right one (Sumar, 1985). However, testicle size can vary during the non-breeding and breeding season, and the testicles are bigger when rut occurs (El-Wishy, 1988a; Samatar et al., 2022), from 57g to 109g, respectively (Sumar, 1985). The height of the testicles depends also on the body height of the camelid. Thus, it is considered to be variable (Sumar, 1985). The scrotum is similar to those of pigs or dogs and not like cattle (Yagill, 1985). According to Johnson (1989) and Tibary and Vaughan (2006), no seminal vesicles are present in SACs, and neither are they present in camels (Ali et al., 1978). However, camelids have got H-shaped prostate, bulbourethral gland, urethra, and ampulla ductus, and their penis is a fibroblastic type (Sumar, 1985; EL-Wishy, 1988a; Tibary and Vaughan, 2006). In young and immature SACs, the penis is adhered to the prepuce until puberty occurs (Sumar, 2000). In dromedary camels, the penis in erection is 35 to 40 cm long (Sumar, 1985), but it can reach up to 60 cm (Leese, 1927).

The reproductive organs of camelid females are similar to other domestic ungulates, with similarities with horses (Yagil, 2006) or sows (Sumar, 1996). Ovaries are globular, typically red to pink in colour, and their weight is usually 4g in the non-breeding season (El-Wishy, 1988) and up to 8g in the breeding season (Wilson, 1984). The standard follicle size is between 5 and 12 mm in alpacas, and in llamas, the average size is slightly smaller (Sumar, 1985). The oviduct in camels reaches 14 to 30 cm (Srikandakumar et al., 2003). The uterus of SACs and camels has two horns separated by a septum (Arthur et al., 1986; Srikandakumar et al., 2001). The left horn is slightly larger, which is a possible consequence of pregnancies primarily in the left horn in camelids (El-Wishy, 1988; Arthur et al., 1986; Al-Eknah et al., 2001). The uterine horns are connected with the well-presented uterine body (Monaco et al., 2024). Three spiral folds are presented in the alpacas´ cervix and five in the dromedary camel´s cervix, which is short, around 3.6 mm (Srikandakumar et al., 2001). The uterus of SACs is Y-shaped (Smith, 1994), while in dromedary camels, it is T-shaped (Srikandakumar et al., 2001). The camelids have a diffuse epitheliochorial type of placenta (Abd-Elnaeim et a., 1999). The oviduct in camels is 17 to 28 cm long (Novoa, 1970; Wilson, 1984). The length of the vagina is around 13 to 15 cm in alpacas (Fowler, 1989; Sumar, 1985) and 14 to 30 cm in dromedary camels (Srikandakumar et al., 2001). The udder of camelids has four quarters covered with black skin (Wilson, 1984).

Due to their unique reproductive physiology, the reproduction of camelids differs from other domestic ungulates. Apart from other domesticated species like cattle (*Bos taurus*), sheep (*Ovis aries*), or pigs (*Sus domesticus*), camelid females undergo induced ovulation, which is typically seen in cats (*Felis catus*) or rabbits (*Oryctolagus cuniculus domesticus*) (Silva et al., 2020). Although ovulation usually starts after the copulation process, it is induced chemically by the activity of Ovulation-inducing factor (OIF), which was confirmed in alpaca (Kershaw-Young et al., 2012) and camel sperm (Silva et al., 2017; Al-Fatlawy and Baiee, 2018; Ratto et al., 2019). This is against the previous theory that ovulation is induced by copulation mechanically. For the onset of the ovulation, the copulation is possibly not necessary, while the OIF is presented in the female's body system (Berland et al., 2016). Nevertheless, more investigation into this topic is necessary for more specific results and a deeper understanding of the OIF purpose and influence on camelid females' ovulation (Silva et al., 2017).

Also, camelid females do not present the typical oestrus cycle well (Ghallab et al., 2024). SACs females' oestrus cycle is not fully ended, and it is combined by the regular continued stage of oestrus while there is not a presence of the breeding male, with the stage dioestrus - of non-acceptance of the male (San Martin et al., 1968; Fernandez-Baca et al., 1970a). The oestrus period in SACs varies from 30 to 90 days (England et al., 1971). In dromedary camel females, the oestrus cycle is also really variable according to studies by Musa et al. (2006), with shorter periods of 12 days or with more extended periods of 30 days (Alfuraiji, 1999).

The oestrus cycle of camelids females is characterized by the presence of follicular waves, as reported in alpacas (Tibary and Vaughan, 2006), Bactrian camels (Njikjou et al., 2009) or guanacos (Riveros et al., 2010). The luteal phase is often missing in non-mated females because the corpus luteum is not presented without mating (Elias et al., 1984). Females can undergo ovulation while reintroducing themselves to the breeding male after a long time or while other stimuli are present (Bravo and Sumar, 1989). However, spontaneous ovulation can be seen in non-lactating dromedary camel females (Nagy et al., 2005; Manjunatha et al., 2012), alpacas (Bravo and Sumar, 1989), or llamas (England et al., 1971). The camel females' age influences folliculogenesis, as Ashour et al. (2017) reported, where the highest number of follicles was seen in females of 6 to 10 years. Small follicles are presented on ovaries during the non-breeding season (Vyas et al., 2004; Ali et al., 2008).

1.1.4 Reproductive seasonality

Although camelids can reproduce during the whole year, they are known as seasonal breeders (Vyas et al., 2004). That allows them to give birth to the optimal conditions of the area (Kalla et al., 2008; Al-Bulushi et al., 2019; Cruz et al., 2020). The breeding seasonality is mainly used for domestic SACs in the Andean countries where the reproductive season lasts from December to March (Smith et al., 1994; Markemann and Zárate, 2010) or April (Sumar, 2000; Vaughan, 2011) when the rainy season occurs in the Andes (Montenegro et al., 2010). In vicuñas, the breeding season occurs in the shorter time from March to May (Vila and Cassini, 1994). In the rainy season, the nights are warmer, and due to the rains, there are more feeding possibilities on the pasture, which increases the chance of cria survival (Cruz et al., 2015; Cruz et al., 2020). However, the breeding season does not influence the number of follicles in SACs (Bravo and Sumar, 1989). Therefore, in zoological gardens and private farms outside their origin countries, the SACs can reproduce throughout the year (Bravo and Sumar, 1989). However, their reproductive activity has a noticeable peak (Johnston, 1988).

Also, the breeding season in dromedary camels mainly occurs within the rainy season of the area due to the higher amount of available fodder and nutrition (Merkt et al., 1990; Abdussamad et al., 2011). For most arid countries, the primary reproductive months for mating are from November to March, as reported in Oman (Musa et al., 2000), or until April, as reported in Algeria (Deghnouche et al., 2018), and from July to August in some parts of Ethiopia (Simenew et al., 2013). Although seasonal breeding depends on factors such as climate conditions, rainfall, or temperature (El-Harairy et al., 2010), it has some benefits in camelids´ husbandry. Cooler periods of the year are preferred for calving, to decrease the risk of abortion, and to ensure adequate feed intake of the female, thus yielding and improving the quality of the milk (Tibary and El-Allali, 2020).

1.2 Reproductive behaviour of camelids

The reproduction in camelids is accompanied by visible behavioural changes, especially in the males, as described by many authors (Yagil et al., 2006; Ali et al., 2009; Padallino et al., 2015). Males in a rut are usually very aggressive towards other animals in the herd or the farmers, making the mating problematic (Pushman et al., 2013; Miller and Fowler, 2014). Flehmen response and the secretion of poll glands are also visible during the rut (Padallino et al., 2015). The signs of heat in the females are not so massive as in camel males and are presented by the submissive behaviour towards the male, more frequent vocalization, or urination (Merkt et al., 1990; Padalino et al., 2015). Other females not in the heat at that moment reject the male by spitting or kicking (Mahla et al., 2015). However, the signs of oestrus often do not correspond to the presence of the dominant follicle (Vyas and Sahani, 2000). Sometimes, the signs of oestrus are not as visible, as seen in the study of Musa and Abusinena (1978). That was contrary to the study of Joshi et al. (1978), who observed obvious signs of oestrus. With the combination of the behaviour not corresponding with the phase of the dominant follicle presence and the fact that most of the males prefer mating with more submissive females, the determination of the correct mating time in camelids is quite tricky for the breeders (Vyas and Sahani, 2000). The copulation process in camelids is performed in the sternal position (typical for copulation) and is quite long. It varies from 20 to 25 minutes, up to 65 minutes in SACs (Barry et al., 1971; Vaughan et al., 2003) and 5 to 20 minutes in dromedary camels (Al-Hazmi, 2000). After the copulation, camelid males usually fall on the side (Yagil and Etzion, 1980).

1.2.1 Maternal behaviour

The mother-young relationship plays a crucial role in the early life of newborn offspring in ungulates. It provides several benefits to the young, such as feeding, source of immunoglobulins through colostrum, predator protection, habits, and social bonding (Sarno and Franklin, 1999; Cassinello, 2001). The maternal behaviour varies across the species and is not usually visible until parturition. Therefore, even if there are differences between the animals, females try to find a suitable location with a low risk of predator attack to give birth (Marchand et al., 2021). After the parturition, a stronger mother-young bond begins to form. There are two categories of the social bond between the mother and the young: the hiders and followers (Lent, 1971). The family of camelids belongs to the follower type (Ralls et al., 1986), and the term "cria" is used for the SAC offspring (Aguilar et al., 2014). For the follower type, the vocalization is more frequent than for hiders. Thus, the mothers can easily recognize their offspring at longer distances (Torriani et al., 2006).

The signs of the most frequent maternal care behaviour are seen during the first weeks after parturition. After birth, the dams attempt to orient the young towards the teats more and to the antiparallel position (opposite to the dam), which makes the recognition by sniffing easier (Nath et al., 2016). Identifying the cria by sniffing by the dam is important in both the wild and captivity in SACs (Zapata et al., 2009). The newborn animals usually stand up within 2 hours after birth and begin following mothers within the first 24 hours (Massicot, 2006). Camelid females never lick their offspring, only sniffing is observed. The reason for the absence of licking is unknown (Pushmann et al., 2013). The mother-young relationship is usually formed by touching each other's noses, by grunts from both and by rubbing (Tibary et al., 2014).

The intensity and development of maternal care is affected by the mother's experience. Usually, the multiparous females were more successful and showed maternal care more and earlier (Green, 1990; Birgersson and Ekvall, 1994; Cameron et al., 2000; Hammadi et al., 2021), as seen in muskox (*Ovibos moschatus*; Tiplady, 1990) or buffalo (*Bubals bubalis*; Murphey et al., 1995). Less experienced females can wait longer for nursing because of the vigilance of the predators.

The nursing occurrence and duration are influenced by many factors, such as the wilderness or captive conditions (Manski, 1991), as seen in roe deer (Bongi et al., 2008) or giraffes (Gloneková et al., 2017). The calving in the wild is usually concentrated in better conditions in the year, with warmer climates or higher food resources. In comparison, the poorer conditions in other parts of the year can decrease the milk quality, and the females tend to reject the suckling young (Wronski et al., 2006). The dams in the wild can spend less time on maternal care due to the possibility of predator attacks (Therrien et al., 2007). Captive conditions offer a calmer environment with greater insight over the herd members and no predator risk so that the females can concentrate on nursing more (Andersen et al., 2000; Therrien et al., 2008; Pluháček et al., 2010). The conditions of captive farming positively affect the offspring's survival when the young does not suffer from a low frequency of nursing (Rubin and Michelson, 1994). Also, the dams cannot escape the offspring's suckling needs (Wronski et al., 2006).

1.2.2 Nursing and suckling behaviour

In ungulates, nursing is initiated mostly by the dam in the first weeks after birth. Dams often orient the young into an antiparallel position, i. e. dam and young are standing in opposite directions, which makes offspring recognition by sniffing easier (Packer et al., 1992; Gloneková et al., 2016). Nursing bouts initiated by the dam are also typically longer than when they are initiated by the young (Hejcmanová et al., 2011). When young become older, nursing is initiated mostly by them (Gauly et al., 2003; von Keyserlingk and Weary, 2007). Furthermore, different preferences of the side and nursing position were observed in ungulates. The young suckles from the left (from the mother's point of view) or the right side. Although the suckling side preference can be random, it can be affected by many factors. From the study of Komárková and Bartošová (2013), the horses (*Equus caballus*) suckle mainly from the right sight. This study focused on the role of the brain laterality, and it was found that this is probably due to the better function of the right hemisphere.

The other two nursing positions complicate the identification of offspring (Packer et al., 1992). When the young suckles at 90 degrees to the mother's body, it is called the perpendicular position (shown in Figure 4); when the young suckles from the back to the mother, it is the parallel position (Gloneková et al., 2017). Llamas prefer the antiparallel nursing position (Pouillon et al., 2001). The occurrence of perpendicular position is less frequent in older offspring (Villagrán et al., 2012). The perpendicular and parallel nursing position is seen when allonursing occurs (Brandlová et al., 2013; Gloneková et al., 2016; Gloneková et al., 2020).

The nursing duration seems to be shorter when the calf is older, as seen in fallow deer (*Dama dama*; Gauthier and Barrette, 1985), cattle (*Bos taurus*; Lidfors et al., 1994) or red deer (*Cervus elaphus*; Vasquez et al., 2004). The nursing frequency is the highest during the first month of the calf's life; after 6 months, there is a visible decrease. A similar trend of nursing duration was also observed in llamas (*Llama glama*; Gauly et al., 2003). Drábková et al. (2008) found no parity (experience) effects on the nursing duration. The sex of the young is a possible effect on the nursing duration, when the nursing tends to be longer in males, as it was seen in Derby eland (*Taurotragus derbianus*; Hejcmanová et al., 2011), red deer (*Cervus elaphus*; Drábková et al., 2008), giraffes (*Giraffa camelopardalis*; Gloneková et al., 2020b) or Bactrian camels (*Camelus bactrianus*; Brandlová et al., 2013). In contrast, studies of Cameron et al. (1999) or Pluháček et al. (2010) found that the nursing duration was longer for female calves.

The start of nursing is important because colostrum serves as the first source of immunoglobulins for the young (Silva et al., 2021). After birth, the newborn usually struggles to initiate suckling. When the young succeeds in suckling, it raises its tail (Aba et al., 2010). SACs dams initiate nursing by sniffing the cria when relaxing (Lama and Villarroel, 2023). The nursing duration can vary from 60 to 108 seconds in alpacas (Pouillon et al., 2001). The nursing duration in different positions is also different, as was seen in giraffes (Gloneková et al., 2021), and many factors influence it. When the nursing is initiated by the dam, it is longer (Hejcmanová et al., 2011). In contrast, the nursing duration is often determined by the dam, who is the main terminator of nursing (Wronski et al., 2006), when she leaves or drives the young away (Aba et al., 2010).

The nursing duration also varies during the offspring's age, with a longer duration in the first 3 months of its life (Hejcmanová, 2011). The predator strategy can affect the length of nursing in the first moths (Bongi et al., 2008). Less experienced dams seem to have less time for nursing, and their experience can affect the nursing duration. Nursing is more prolonged when the dam identifies the young by sniffing before (Gloneková et al., 2020b; Hejcmanová et al., 2011). Longer nursing was also seen in the antiparallel (Gloneková et al., 2021) than in the parallel position (Gloneková et al., 2017). Alpacas also prefer the antiparallel nursing position (Pouillon et al., 2001). The parallel position makes the identification of the young harder (Packer et al., 1992).

After a few months, the young prefer grazing, and weaning in dromedary camels is usually practiced at 8 or 9 months (Raziq et al., 2008; Raziq et al., 2011). The nursing duration can be affected by the female experience. The weaning age of 8 months was reported in alpacas, which had optimal body height in Peru (Aguilar et al., 2014). Weaning at 15 months in dromedary camels was reported by Albaba (2014). Although farmers practice weaning in rural areas, weaning is not controlled; it is done naturally.

Figure 4. Perpendicular nursing position (Marešová, Ecuador, 2021)

1.2.3 Allonursing in camelids

Allonursing behaviour occurs in some ungulate species. This behaviour has been observed in many domestic and wild ungulates, including giraffes (*Giraffa camelopardalis*; Gloneková et al., 2017), Plains zebras (*Equus burchellii*; Pluháček et al., 2011) or farmed guanacos (Zapata et al., 2010). It is the behaviour when the young suckles from a dam that is different from her own (Saito and Idani, 2018). It may depend on various factors, according to studies, such as the animal species, the social relations in the animal group, or the age and experience of the dam (Gloneková et al., 2016; Mota-Rojas et al., 2021).

However, it can have some advantages for the allosuckling young, which can compensate for the amount of milk, gain more weight, or obtain more immunoglobulins from the milk weight gain or compensation for missing nutrients in the mother's milk (Landete-Castillejos et al., 2000; Roulin, 2002; Zapata et al., 2010). Some studies tested the milk theft hypothesis for allosuckling when the young does not have enough amount of milk and tries to compensate it (Brandlová et al., 2013; Mota-Rojas, 2021). The young usually tries to compensate for the milk from the mother with a better physical condition (Brandlová et al., 2013; Roulin, 2002). On the contrary, some disadvantages for the young and the dam are connected with this behaviour, such as transmitting pathogens or hurting the young (Engelhardt et al., 2014; Mota-Rojas et al., 2021). Lastly, the allosuckled mother's filial young can struggle with less milk (Mota-Rojas et al., 2021).

Allonursing can be more frequent in less experienced dams, but this was not confirmed by Gloneková et al. (2016). In contrast, Roulin et al. (2002) and Olléová et al. (2012) observed that allonursing was accepted by older dams. Allonursing is more common for animals with more relations in herds (Roulin, 2002; Gloneková et al., 2016). Mota-Rojas (2021) stated the possible benefit of allonursing for the dam, which evacuates the milk when her young does not need it.

Moreover, the captive conditions can increase the frequency of allonursing (Packer et al., 1992; Pélabon et al., 1998). Allonursing duration was shorter than filial nursing duration in cattle (*Bos taurus*; Waltl et al., 1995), fallow deer (*Dama dama*; Ekvall, 1998), and red deer (*Cervus elaphus*; Vásquez et al., 2004). In giraffes, allonursing was observed more frequently in captivity than in the wild (Gloneková et al., 2016). This is similar to the common eland (*Taurotragus oryx*; Hejcmanová et al., 2011).

Although the allonursing was seen in other ungulates, such as dairy cattle (*Bos taurus*; Špinka and Illmann, 1992) or Plains zebra (*Equus burchellii*; Pluháček et al., 2011), the number of studies focusing on the allonursing behaviour in camelids is scarce. This behaviour has not been observed in dromedaries (Packer et al., 1992), but the attempts were seen in the study of Elmi (1989) conducted in Somalia. The successful allonursing was confirmed in Bactrian camels from Czech zoological gardens (Brandlová et al., 2013). According to this study, allonursing is the behaviour of milk theft when the young are in a lateral position. In other camelids species, allonursing was observed in wild guanacos in Argentina (Zapata et al., 2009a). It is the only one observed allonursing in the wild camelids, but probably it was a random occasion. According to Zapata et al. (2009b) allonursing is also the behaviour of milk theft in farmed guanacos. The compensation from allonursing was tested by Zapata et al. (2010), where the milk theft theory was tested, and the percentage of crias performing allosuckling was approximately 60% in tested farms. Allonursing may occur in dams with lower social status in the herd, which are tolerant of allonursing for increasing their social position (Packer et al., 1992). Dams may want to improve their position in the herd. This topic has not been well studied in camelids, and there cannot be final statements on this behaviour in this species.

1.3 Current challenges in management and reproductive performance of dromedary camels

A number of camel husbandry systems are currently utilized within the tropics and subtropics, from pastoral or nomadic systems (Ishag and Ahmed, 2011; Shuiep et al., 2014; Dowelmadina et al., 2015), transhumance or sedentary systems (Musa et al., 2006; Eisa and Mustafa, 2011; Ishag and Ahmed, 2011) to intensive systems (Eisa and Mustafa, 2011; Nagy et al., 2013). However, traditional pastoral camel management is still the primary husbandry system implemented for dromedary camel farming in the tropics (Asiimwe et al., 2020; Dowelmadina et al., 2015), particularly in Ethiopia (Wosene, 1991; Awoke and Ali, 2015), Nigeria (Vias Franck et al., 2009; Abdussamad et al., 2011) and Kenya (Kaufmann, 2005). Among other things, the focus also began to focus on more detailed knowledge of species, its protection (Vilá & Arzamendia 2022) and welfare, so that animals kept in large numbers have the best possible conditions for life (Lama & Villarroel 2023). Rateb et al. (2020) has also reported similar observations in dromedary camels.

1.3.1 Current status of research on female dromedary camel reproduction in the tropics and subtropics

The reproductive performance of female dromedary camels depends on various factors. Under the current husbandry and climatic conditions, camels tend to suffer poor fertility rates within arid areas (Kaufmann, 2005; Marai et al., 2009), despite their physiological adaptations that support reproduction in harsh environments (Skidmore, 2005). Puberty in dromedary camels usually occurs at the age of three years old in dromedary camel females and four years of age in males (Tibary et al., 2007; Ali et al., 2009; Raziq et al., 2011), with most females having their first calf when they reach four to six years old (Skidmore, 2005). As with other livestock, early breeding can result in a higher probability of abortions (Molash, 1990). However, the optimal age at first calving also depends on various factors other than physiological readiness, such as the economic situation and experience of the farmer (Ali et al., 2018). The age at first calving also influences the number of females in the herd, their replacement rate, and the number of culled animals per year (Lopez-Paredes et al., 2018).

Calving intervals are currently commonly used in the tropics to measure the reproductive performance of camels (MacGregor and Casey, 1999). Reported intercalving periods are approximately 24 months (Aujla et al., 1998; Mehta et al., 2007; Raziq et al., 2008), varying from 17.5 (Mostafa et al., 2019) to 51 months (Tibary et al. 2005) with maximum of 72 months (Tafesse and Tuffa, 2001). Gestation period lasts 12 to 13 months (Abbas et al., 2000; Kalla et al., 2008; Mehta and Sahani, 2009; Njanja and Oba, 2011) and a weaning age is 12 months (Benaissa et al., 2012; Awoke and Ali, 2015). However, reproductive performance is often very low in the pastoral systems (Tibary et al., 2005). According to Djellouli and Saint-Martin (1992) the calving rate in Tunisian herds is around 40% with the calf mortality up to 17%. High number of abortions was also reported in Niger (Abdussamad et al., 2011). The sedentary systems seem to have better reproductive performance (Bakheit et al., 2008) where shorter calving intervals are used and the female can give birth almost every year, when it has optimal feeding (Degen et al., 1987). Longer intercalving intervals are often seen in regions with higher annual temperature, but it is unclear if this is caused by the climate conditions or the management system (Tura et al., 2009; Awoke and Ali, 2015).

1.3.2 Husbandry and dromedary camel reproductive performance across the tropics and subtropics

Breeding management and animal husbandry factors, like the production systems used and breeding techniques practiced, play an important role in the reproductive efficiency of domestic animals. This is observed in dairy cows (Nath et al., 2010; Diskin and Kenny, 2016; Ibtisham et al., 2018) and sheep (Ali et al., 2020). Rateb et al. (2020) have also reported similar observations in dromedary camels. The camel reproductive performance in extensive pastoral herds is poor, caused by longer calving intervals and lower nutritional levels (Abbas et al., 1992; Bekele and Kebebew, 2002; Kaufmann, 2005). Furthermore, pre-parturition feeding management in pastoral systems is almost non-existent (Kalla et al., 2008; Yosef et al., 2015), and thus, females are unprepared for the upcoming lactation. The lack of milk in the udder often results in the calf's death by starvation (Musa et al., 2000). Low nutritional levels of primiparous females can also result in abortions (Nebel and McGilliard, 1993), which belong to the major reproductive problems in pastoral herds (Tibary et al., 2005). Poor camel reproductive management is an important factor that influences female camel fertility (Redding et al., 2013). However, pastoral farmers often do not have access to knowledge regarding reproductive diseases, detection of oestrus signs, or the correct parturition practices and interventions (Belina et al., 2021). Among the most common causes of reproductive failure are uterine and ovarian lesions and infections commonly caused by bacteria such as *E. coli*, *Staphylococcus*, *Chlamydia*, *Trypanosoma*, and *Salmonella* (Nabih and Osman, 2012). Reproductive disorders, like endometritis, can temporarily decrease milk production and the ability to successfully conceive during subsequent breeding, which then prolongs calving intervals (Derar et al., 2015; Ali et al., 2018; De Vries and Marcondes, 2020).

The inadequate health care provided, limited veterinary service available, and the use of unsuitable treatments for camels are commonly seen in pastoral herds (Redding et al., 2013; Belina et al., 2015). Because of the absence of veterinarians, breeders perform any interventions themselves, thus increasing the risk of zoonoses transmission through the handling of aborted materials (Wanjohi et al., 2012; Khalafala et al., 2017; Lamuka et al., 2017). Frequently, camels are mixed with other herds of livestock, like cattle, sheep, or goats which can also contribute to the transmission of diseases between the species (Abbas et al., 1992). However, there is a lack of studies focused on health problems in mixed herds. While camels seem to be less sensitive to infections than other livestock, they share the same pasture with (Nekoei et al., 2015), they seem to have a higher prevalence of brucellosis and pestivirus infections, thus being potential reservoirs (Al-Ruwaili et al., 2012; Saidi et al., 2018).

The abortion rates and calf mortality are extremely high under pastoral management but also the annual calf mortality (Tefera and Gebrehah, 2001; Awoke and Ali, 2015). The high calf mortality rates are further exacerbated by health problems, like diarrhea or hypothermia, which occur in the dromedary camel herds quite frequently (Al Mutairi, 2000; Mohammed et al., 2003; Megersa, 2014). The main causes of calf diarrhea are coccidian and bacterial infections, commonly associated with enteric pathogens such as *E. coli, Clostridium*, or *Cryptosporidium* (Kinne et al., 2002; Abraha et al., 2020), and viral infections caused by rotaviruses and corona viruses, which have been reported to contribute to the high calf mortality of dromedaries in Niger (Faye, 1997). The calf rearing techniques used in pastoral herds are likely to contribute towards the incidences of calf diarrhea, such the withdrawal of colostrum, or overfeeding and insufficient hygiene during the suckling period (Khanna et al., 1992; Megersa, 2014).

As reported for cattle, reproductive performance is highly affected by breeding methods and herd size (Lemma and Kebede, 2011). Breeding methods in camels are similar to those of other livestock; it can be managed and controlled, using hand mating, individual mating or artificial reproductive technologies, or unmanaged and natural as harem mating (Nagy and Juhasz, 2008; Holtgrew-Bohling, 2020). Hand mating is commonly described as the main practice of camel breeders (Abdussamad et al. 2011; Nagy and Juhasz, 2012). This type of mating can significantly affect reproductive performance because the proper recognition of females in oestrus is needed (Nagy and Juhasz, 2012). The male:female ratio is an important factor influencing reproductive performance, especially in regions (and/or production systems) with shorter breeding seasons. Together with the fact that long and repeated mating is often naturally occurring in camels (Abdulmohsen et al., 2018; Al-Bulushi at al., 2018), a higher male:female ratio can be a major limiting factor in camel reproductive performance. High frequency of mating or intensive semen collection negatively affects pregnancy rates and sperm quality in camels (Al-Bulushi et al., 2018).

Another common problem in dromedary camel reproductive management is that one breeding bull that originated from the herd is used often for many consecutive years (Köhler-Rollefson et al., 1991; Farah et al., 2004), likely leading to inbreeding depression and decreased fitness of offspring. As found by Awoke and Ali (2015) and Gebissa (2015), majority or all breeders in Ethiopia do not prevent mating of breeding bull with his mother, sisters, or daughters. Abdelhadi et al. (2011) reported in Sudan that almost 80 % of farmers practiced inbreeding deliberately to keep production qualities. Farmers are often not aware of the negative impacts of inbreeding (Bekele et al., 2018).

On the other hand, camels bred in sedentary or intensive systems achieve higher reproductive efficiencies and reproductive performances, due to the better reproductive techniques used, increased health care, higher nutritional level, and the management of environmental/climatic stressors (Bakheit et al., 2008; Deghnouche et al., 2018). While successful calving rates in pastoral management systems are generally low, at approximately 40% (Kaufmann, 2005; Babiker et al. 2011; Ahmad et al. 2012), under intensified systems, a calving rate of 80% is achievable (Abdel-Rahim et al., 1994; Nagy and Juhasz, 2008). This calving rate was reported also under extensive management systems by Raziq and Younas (2006). However, this data was published as a local report without detailed description of the data collection. Quite good calving rates (60%) can be achieved under traditional extensive breeding systems by using an optimum sex ratio (8 males for 100 females), as reported by Musa et al. (2000).

Intensive systems are often reported utilizing shorter calving intervals and earlier weaning ages, and thus a faster replacement rate of the animals in the herd (Köhler-Rollefson et al., 1991; Mohammed and Al-Mutairi, 2012). Bakheit et al. (2008) showed that, as with other livestock, improved feeding and care improves camel reproductive performance, with females under intensive management and good feeding calving almost every season when weaning occurs at 5 months of age (Babiker and El-Zubeir, 2014). Under these conditions, the calving interval can be shortened to 17 to 20 months (Gebissa, 2015; Mostafa et al., 2016). Camel females fed with supplementary feeding before parturition have shorter involution intervals (Morshedy et al., 2020) and go into the first postpartum oestrus sooner (Mostafa et al., 2020), thus their service periods are shorter (Abdel-Rahim et al., 1994; Diskin and Kenny, 2016), which may accelerate the next conception (Mostafa et al., 2020). Enhanced feeding in the last phase of pregnancy and during the onset of lactation increases the birth weight of calves (Hammadi et al., 2001), as in other livestock, such as cows (Mostafa et al., 2014). In addition, the higher supply of dietary fat can increase follicle size and the levels of supportive reproductive hormones in the blood (Ibtisham et al., 2018). Thus, female camels fed with supplementary feeds are typically able to reach higher conception rates (Hammadi et al., 2001; Mostafa et al., 2016). Even the simple supplementation of minerals in the form of salt blocks has a positive effect on lactation yield (Onjoro et al., 2006; Babiker and El-Zubeir, 2014).

Based on the current literature, it is difficult to interpret the effect of management on the length of the breeding season, due to large variations in the reported data. The mean length of breeding season under different types of management is between 4 to 6 months, but even whole-year reproduction was described under both intensive (Abdalla et al., 2015) and extensive management (Kalla et al. 2008). While poor infertility rates can be seen as the consequence of the farmers knowledge gap in dromedary camel reproduction physiology (Kuria et al., 2002; Rateb et al., 2020), infertility rates also increase with an increasing age of the camel female (Tibary and Anouassi, 1997). Together with this, the longer lifespan of the females can subsequently shorten the lifespan of surplus calves, because they cannot replace the females in the herds and are used for meat production at younger age, as it is practiced in cows (DeVries and Marcondes, 2020). Thus, careful consideration and management of camels under intensive systems is necessary to ensure economic efficiency. According to Ali et al. (2018), the herder/camel ratio and the farming experience are one of the major effects that influence the camel reproductive efficiency in Saudi Arabian herds. Factors affecting dromedary camel reproductive performance are summarized in Figure 5.

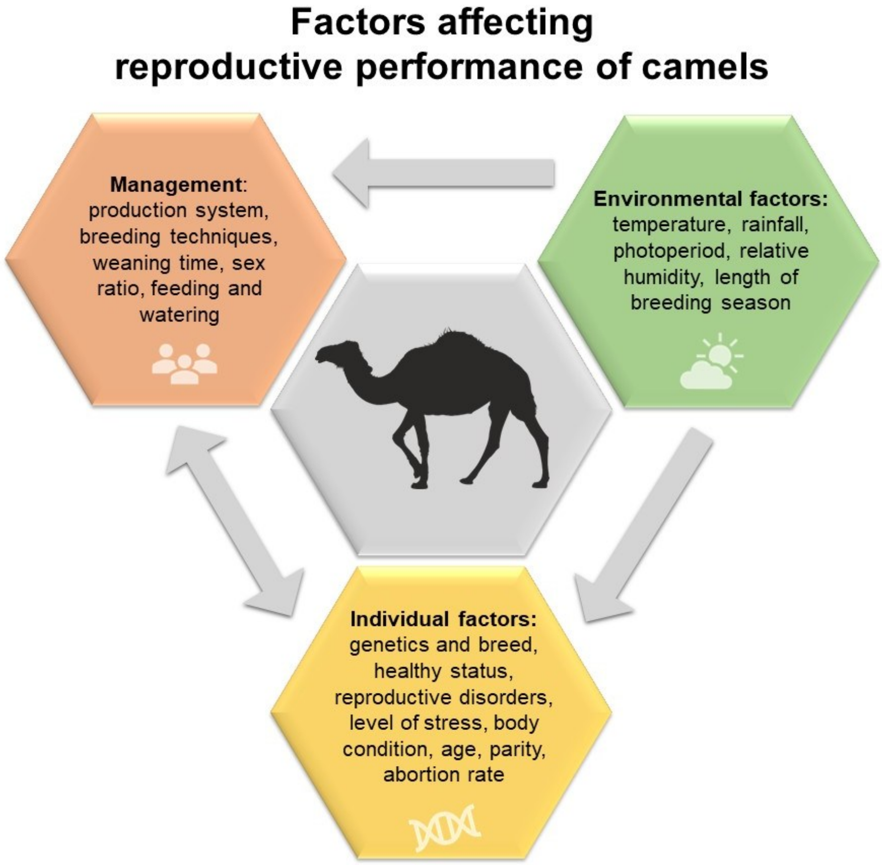

Figure 5. Factors affecting reproductive performance of dromedary camels (Marešová et al. 2023, unpublished work)

1.3.3 Climate and dromedary camel reproduction in the tropics and subtropics

Although dromedary camels are suitable for arid conditions (Laudadio et al., 2009), it does not mean that extreme climate does not affect their physiology, welfare, and reproductive performance. Nutritional status varies across the year due to climate changes, and it significantly affects the physiological responses of dromedaries (Amin et al., 2007; Babiker et al., 2011). In general, the successful reproduction of dromedary camels depends on various environmental factors. As camels are seasonal breeders (Bhakat et al., 2000; Shuiep et al., 2014), shorter days can influence camel breeding seasonality (Merkt et al., 1990; Ainani et al., 2018). Marai et al. (2009) observed a possible effect of climatic conditions on the start of the camel reproductive season linked with the photoperiod length. In milder weather conditions of the colder months, the number and size of the ovarian follicles increases (Musa and Abusineima, 1978), as does body weight and the size of testes in males. Thus, semen volume and number of spermatozoa are higher in the breeding season (Zeidan and Abbas, 2003), which typically occurs during the rainy season of the area (Gebrehiwet, 1998; Simenew et al., 2013; Shuiep et al., 2014). The occurrence of reproductive diseases also differs during the year, with a higher frequency occurring during the rainy season (Benaissa et al., 2015), which can be connected to the higher reproductive activity in this part of the year (Marai et al., 2009). However, when the current literature was consolidated, very high abortion rates (50%+) were reported for arid regions (Jaji et al., 2011; Waheed, 2019). This could be explained by high temperatures and limited resources of feed and water in arid regions. These conditions affect the nutrition and body condition of camels (Amin et al., 2007), making them more susceptible to diseases.

Infectious diseases, such as brucellosis and trypanosomiasis, may cause abortion rates of up to 70% in camels (Tibary et al., 2006; Hassani, 2021). In the case of brucellosis, geographical location, herd size, age of animals, and mixed rearing are considered risk factors in camels. A high prevalence has been reported in Sudan, Egypt, Saudi Arabia, and Nigeria (Dadar et al., 2022), and all of these countries are located in the arid climatic zone. In contrary, low prevalences in Niger were reported from Mahamadou Tanimoun et al., (2021). Based on the study of Selim et al. (2022), camels with poor body conditions had significantly higher prevalences of trypanosomiasis. Non-infectious causes of abortion, such as environmental factors, are currently not well-documented in camels.

In light of the increasing population of camels across various geographical regions and climatic zones, it is necessary to better understand the influence of the climate on reproductive performance of camels. Thus, research on this topic is essential.

1.4 Husbandry and reproductive performance of South American camelids

SACs' husbandry gradually became popular even outside the areas of their natural occurrence and spread widely to Europe, such as Switzerland, Germany, Austria (Wolfthaler et al., 2020), Oceania, and North America (Mirande de Lama and Villarroel, 2023). However, the SACs' husbandry brings many challenges to farmers in Andean regions and other countries (Gutiérrez et al., 2012).

Smith et al. (1994) stated that the puberty starts at 5 months in SACs. When the follicle activity starts, SACs can be bred at the age of one year (Fernandez-Baca et al., 1972; Sumar, 2000). Although early mating is possible, SAC females are usually not introduced to breeding until they are 2 years old (Aguilar et al., 2014). However, earlier pregnancies at 3 months have been seen (Vaughan and Tibary, 2006). The age of first mating depends on the feeding provided and thus the optimum body weight, which should be close to 2/3 of their adult body weight (Smith et al., 1994; Sumar, 2000). Llamas obtain their body weight later than alpacas, affecting their first breeding age (Smith et al., 1994). Vicuñas kept in captivity also start to show reproductive activity at the first year of age, but the average age of the first calving was seen at 3 years of age (Schmidt, 1975). The gestation length is also quite long in SACs, lasting around 11.5 months (Vilca et al., 2010; Vaughan, 2011). According to Hallowell (2019), the gestation length among the herds in South America can vary from 320 to 400 days. The birth rate in llama herds in Peru seems to be lower than in alpaca herds, with 46% and 60%, respectively, as reported in a study by Pizzaro et al. (2019). Pantoja et al. (2012) reported a higher birth rate of 78% in llama herds in Peru. In Bolivia, the reported birth rates between llamas and alpacas do not vary much, with 61% in llamas and 66% in alpacas (Rodriguez and Quispe, 2007).

1.4.1 Current status of research in SACs reproduction

Among the major problems in SACs reproduction are the high occurrence of abortions and cria mortality. Several studies were focused on the presence of parasitic diseases and higher occurrence of abortions (Knight, 1995; Tibary et al., 2012; Kapustka and Budzyńska, 2022). Most early losses occur within the first 30 days of gestation (Ratto et al., 2011). External parasites like ticks or scabies (in the Andean region called "sarna") and internal parasites *Fasciola, Haemonchus,* and *Taenia* contribute to economic losses in SAC husbandry (Paredez et al., 2009). In Switzerland, the primary cause of abortions in alpacas is *Coxiella burnetiid*, however, abortions are very rare (Rufli et al., 2021). Scabies can play an important role in the occurrence of problematic births and abortions. (Kapustka and Budzyńska, 2022). Also, *E. coli*, *Clostridium*, and *Streptococcus*, are common causes of cria mortality (Wilson et al., 2022; Whitehead, 2013). The most critical time for the cria is the first six weeks of life (Gomez-Quispe et al., 2022).

Offspring survival depends on various factors, including environmental conditions (Barrington et al., 2006), adequate amount of colostrum (Weaver et al., 2000), or good nutrition of its mother (Vaughan and Tibary, 2006). With good nutrition, alpaca female crias can reach the optimal mating body weight in the first year, but usually, poor management tends to postpone the mating to 2 years (Brown, 2000). Similar findings were observed by Rojas et al. (2021), who reported higher fertility and birth rates in alpaca herds in Peru after including feeding supplements. Bustinza et al. (1988) found that the cria survival rate in older females is higher than that of younger females. Alpacas, which were born earlier in the breeding season, had a higher survival rate than they were born later (Cruz et al., 2020).

SAC females usually conceive within three matings (Vaughan and Tibary, 2006). Thus, modern reproductive methods could be a practical step toward higher reproductive performance in SACs. Nevertheless, modern techniques in SACs reproduction in the Andean region are not so well reported. Artificial insemination was reported in the study of Huanca et al. (2004), and the valuable pregnancy rate of 60% showed the possibility of using it in SAC herds. However, according to Wurzinger and Guttiérrez (2022), artificial reproductive technologies are not well used in SACs herds in the Andes due to their low efficiency and high price. Thus, the technologies are usually for study purposes.

Another technique that could be utilized in SACs is embryo transfer. The first embryo collection in SACs was reported by Novoa and Sumar (1968) in the Peruvian highlands. Another embryo transfer in alpacas in South America was reported by Sumar (1996) and Morante et al. (2009). The pregnancy rate of 66% after the embryo transfer in alpacas in the USA was reported by Taylor (2000), while in Peru, the reported calving rate was only 40% (Sumar, 2008). The techniques of semen collection, such as electroejaculation and artificial vagina, can be used in SACs, but these methods did not have much success in the local areas (Vaugham, 2006; Huanca et al., 2009). There is a lack of studies on alpaca semen preservation techniques. Embryo transfer and embryo freezing can help preserve valuable species or animals with excellent characteristics (Del Campo et al., 1995; Sumar, 2008; Vásquez et al., 2011). However, Andean farmers often do not want to change their husbandry practices because they are afraid of trying new technology or they are not in a good economic situation to afford it (Bello-Bravo et al., 2024).

1.4.2 Management and husbandry of SACs in Andean countries

Research in SAC production systems is limited, and the studies are often focused only on the production sphere and are not involved in the herd structure, reproductive parameters, or genetic improvement. SACs are mainly found in southern Peru or Bolivia, with the highest concentration of domestic SACs husbandries (Vilca et al., 2010; Alguilar et al., 2014).

The SACs' husbandry is situated in regions with major poverty in Andean countries (Quispe et al., 2009). Most SACs are owned by the local communities, which are part of the poorest, so the management development would lead to more significant income for rural families (Paz et al., 2012; Kristjanson et al., 2007). Thus, the reproductive and productive efficiency in high Andean regions is usually very low. There are three common types of SACs husbandry systems used: small farms or communities, medium-sized producers, and companies (Fernandez-Baca, 2005; Pizzaro et al., 2019). Around 80% of alpaca farms in Peru belong to rural communities (Fernandez-Baca, 2005). The pasture is owned by the whole community, which is part of the poorest sector of the country, and the management funding is weak, and the animals belong to the families (Barrantes et al., 2018). In most situations, farmers are unable to use modern breeding technologies, which improve production (Quispe et al., 2009). The breeding programs of alpacas to improve reproductive management were officially established in Peru in 1994 by the Centre for Development Studies and Promotion - DESCOSUR (Iňiguez, 1998). Nevertheless, the local farmers are often scared or not interested in using the new technologies or do not have economic support to buy new treatments (Reyna, 2006; Bello-Bravo et al., 2024). In Bolivia, several breeding programs were done in the 90s (Iňiguez, 1998), but there is a lack of information about the results.

In Peru and Bolivia, the local systems of SACs breeding are mainly extensive or pastoral, and SACs herds are usually mixed with sheep, cattle, donkeys, or goats (Reyna, 2006; Quispe et al., 2009; Radolf et al., 2022). The mean size of the alpaca herd in Peru is about 50 animals (MINAGRI, 2017), but smaller herds of 20 animals can be found in poor regions (Fairfield, 2006; Gutiérrez et al., 2012). In smaller herds with fewer males, the problem of inbreeding occurs (Huanca et al., 2004; Reyna, 2006; Vilca et al., 2010). The husbandry systems depend on the animals' type, colour, age, or sex (Aygala Vargas, 2018). The herd of SACs is divided into groups of castrated males, which are used for transport or fibre production, breeding males (machos) and females (hembras) first-year bred or many years bred (Markemann and Zárate, 2010). In herds, there are also calves from birth to the weaning, called "cria," and young animals after the weaning to puberty (1.5 years for the females, 2 years for the males), called "tuis" (Aguilar et al., 2014; Aygala Vargas, 2018). One breeding male can serve 10 to 20 females in the herd, however the new male usually comes from the same herd (Vilca et al., 2010). The non-separated herds of males and females are also common in the Andes (Fernandez-Baca, 1993; Aguilar et al., 2014). However, the presence of the male in the same herd during the whole year can negatively decrease the male's libido (Sumar, 1996). Separating groups of males and females can increase breeding activity (Fernandez-Baca et al., 1972; Sumar, 1985).

When the SACs reach optimal body weight, they are selected for breeding based on several selection criteria (Brown, 2000). In Peru, the main selection criteria are the colour and uniformity of the fibre (Vilca et al., 2010; McGregor et al., 2012). Almost 80% of the Peruvian herds are white, favourable for the next steps in wool production (Quispe et al., 2009). The fibre fineness, length, and weight are evaluated characteristics for fibre production (Gutiérrez et al., 2009; Aguilar et al., 2014). However, llamas and alpacas are crossbred to obtain more fibre, but this decreases its quality (Reyna, 2006), as seen in 70% of herds (Carpio, 1991). Other selection criteria connected to the phenotype are the animal size and the presence of body defects (Wurzinger et al., 2008; Markemann and Zárate, 2010; Vilca et al., 2010). Breeding problems in the Andes include malformations caused by inbreeding, which are common in the SAC herds (Huanca et al., 2004; Vilca et al., 2010). Animals with blue eyes or short ears are also not included in the breeding process (Aguilar et al., 2014). Thus, in Peru, the pedigree and registers are more valuable in breeding selection (Gutierrez et al., 2012). The farmers also prefer males with good libido, active reproductive behaviour and good size of testicles (Markemann and Zárate, 2010; Vilca et al., 2010). Llamas are bred mainly for meat production (Aguilar et al., 2014). Thus, the important criteria for llamas are conformation and size (Gutiérrez et al., 2012; Wurzinger et al., 2018).

The rainy season in the Andes plays an important role in the SAC's farming, and many husbandry activities are connected to each part of the year (Figure 6). Fibre production contributes significantly to the SAC's farming sector. The shearing of the fleece is usually done in November for the females and the crias because of warmer temperatures and optimal feeding conditions during the rainy season (Quispe et al., 2009; Vilca et al., 2010; Condori Diaz, 2019).

The shearing of males is practiced in August to test their resistance to the cooler temperatures during winter (Espezüa, 2004). For the vicuñas, shearing is practiced during the spring (Quispe et al., 2009). It is called "Chaku," and it is presented as a celebration or ritual for the people in rural areas. Vicuñas are grouped by well-organized human chain and shorn (Vilá, 2015). The hybridization of alpacas and llamas with the hybrid called "Huarizo" is also practiced to gain more fleece weight, resulting in lower quality and fineness (Carpio, 1991). Towards the end of the rainy season in the Andes, humidity is at its highest, and the occurrence of diseases, like enterotoxaemia, is more frequent, as noted in South American alpacas (Cruz et al., 2020), which may affect abortion rates.

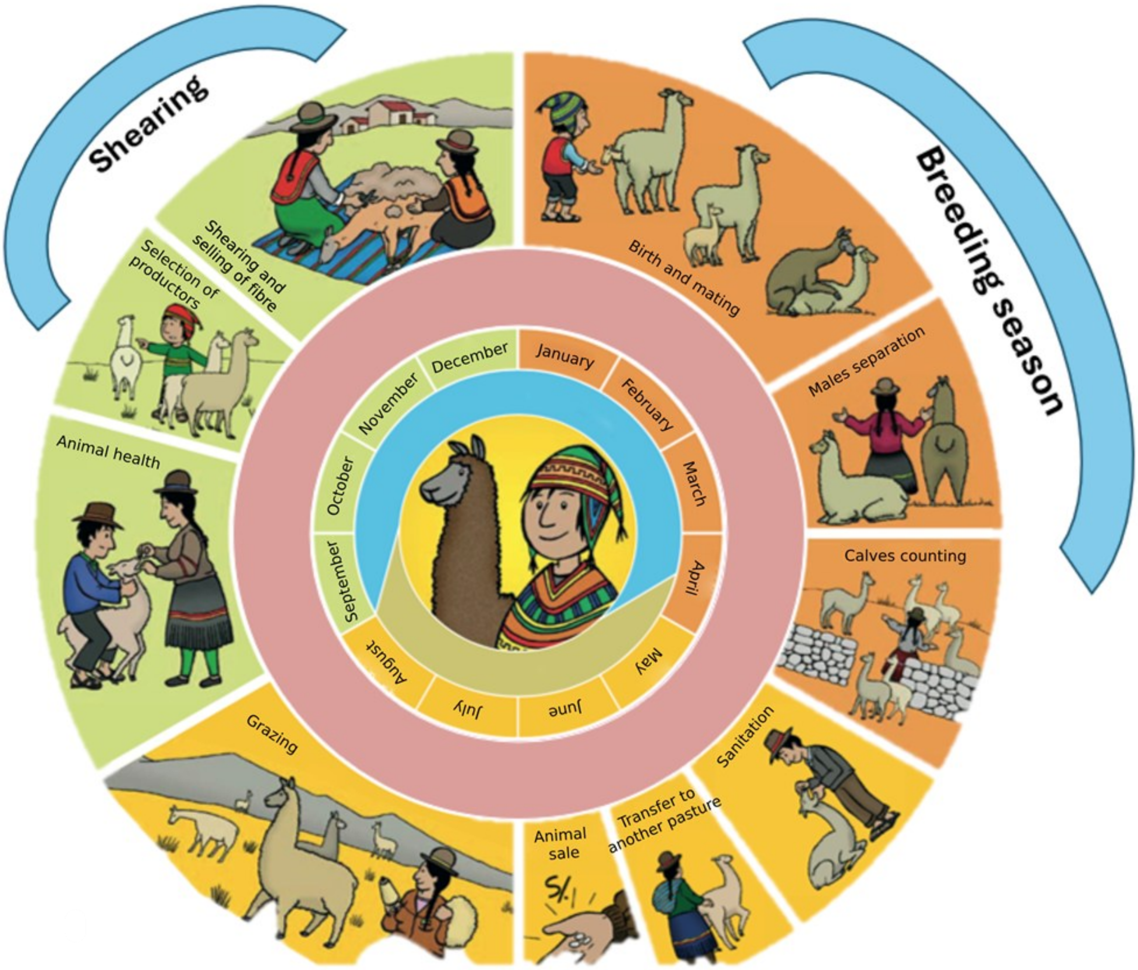

Figure 6. Calendar of SACs husbandry practices during the year (Marešová, 2024)

Breeding season starts in late November and ends in April in the Andes (Prince, 2016; Cruz et al., 2020). Some farmers separate the SACs' males and females during the year, allowing them to join only for the mating period in the rainy season (Rodríguez y Quispe, 2007). The herds of females include the crias until the age of one year. After one year, the young males are selected for breeding or meat production while the females stay in the herd (Wurzinger et al., 2008). In pastoral systems, the males often stay in herds with females throughout the year without separation, which causes uncontrolled mating (Wurzinger et al., 2008; Rodríguez and Quispe, 2007). The weaning is usually done at the age of 6 to 8 months, and when it is controlled, the udder protector can be used in smaller herds (Aygala Vargas, 2018; Wurzinger and Guttiérrez, 2022). However, the natural weaning done by the female is also seen across the SACs herds. In herds with more animals, it is necessary to separate the mothers with the crias from males to prevent abortions or aggressive behaviour toward the newborn crias (Aguilar et al., 2014).

The low reproductive efficiency in SACs is caused by many problems occurring in the husbandries. A high abortion rate and cria mortality rate of 50% during the first three months was reported in Peru (Fernandez-Baca et al., 1970b; Fernandez-Baca, 2005). High cria mortality occurs in SACs herds due to infectious diseases (Reyna, 2006; Vilca et al., 2010), especially during the increased humidity in the second half of the rainy season (Cruz et al., 2015). However, other factors, such as poor management knowledge, insufficient nutrition, low birth weight, or poor animal healthcare, influence cria survival greatly (Quispe et al., 2022). However, the lack of studies focused on the results of the breeding programs in Peru and other Andean countries makes understanding the cria rearing methods more difficult.

1.4.3 The SACs husbandry in European farms

The SACs husbandry has recently become incredibly popular in European countries (Gauly, 2018). Alpaca populations are increasing in Germany (Neubert et al., 2021; Wagner et al., 2023), the United Kingdom (D´Alterio et al., 2006), Austria (Stanitznig et al., 2016), Poland (Kapustka and Garbiec, 2022), or other countries. Although the number is still increasing in Europe, it is unsure how many animals there are. Alpaca farmers do not have to identify their alpacas; not all alpaca farms are officially registered (Neubert et al., 2021). The estimated number of alpacas in Germany is about 15,000, according to Gauly et al. (2018). There are about 45,000 registered alpacas in the United Kingdom and 15,000 unregistered (Middleton et al., 2024). Davis et al. (1998) reported that alpaca males are handled more often than llamas. Neubert et al. (2021) found in their survey that the majority of farmers in Germany started their alpaca breeding six years ago and have small farms of about 15 alpacas. The common herd in the UK is about 21 to 50 animals (Middleton et al., 2023). The SACs are grouped into at least three or four animals, with enough space for all animals in the group (Bromage, 2003; Gauly et al., 2018). Wagner et al. (2023) reported that half of the farmers participating in the survey used males from the same herd. The SACs herds can be handled with all-year pasture, which is possible in European weather conditions, while the enclosure with a shed is provided (Neubert et al., 2021). Also, hay is needed yearly, and minerals and vitamin D supplements in European farms are welcomed (Van Saun et al., 1998; Van Saun et al., 2014).

Alpacas in Europe are used as hobby animals for trekking and fibre production (Kriegl et al., 2005), as flock guardians (Matthews et al., 2024), or as therapy animals (Kapustka and Bustyńska, 2020). The shearing should be done yearly in alpacas (Zanolari et al., 2018). In European climate conditions, it occurs from May to June before high summer temperatures (Middleton et al., 2023). Usually, it is done in a lying position, but when the SACs are trained, they can stand during the shearing (Gunsser, 2013). Mixed grazing is observed on many European farms. However, there is a problem with parasite transmission (Franz et al., 2015). Among the major problems in SACs farming in Germany are internal and external parasites (Ballweber, 2009; Fowler, 2010). Endoparasites cause high economic losses in SACs farming (Cebra et al., 2013; Franz et al., 2015). The fertility in SACs is also very low in European herds (Van Saun, 2008). The females' first calving is usually about 3 years, and the calving usually occurs from June to August (Wagner et al., 2023). The farmers use sheep vaccines due to the lack of licensed vaccines for camelids (D´Alterio et al., 2006; Neubert et al., 2021). The vaccination helps to reduce mortality (Bentacor et al., 2009; Rosadio et al., 2012), and it should be done annually (Lopez, 2021). Although the SACs are increasingly popular in European countries, there are still gaps in their needs and care. Alpacas are often used for breeding up to the age of 16 years (Wagner et al., 2023). However, the number of information sources about SACs handling is increasing, which helps to provide an optimal level of welfare in the SACs farms in Europe (Kapustka and Garbiec, 2022).

2 Aims of the thesis

This doctoral thesis aimed to critically review and synthesise the current state of knowledge on reproductive management and husbandry techniques in camelids, with a particular focus on their reproductive performance and maternal behaviour in regions of their origin and also in European farms.

The specific objectives were as follows:

1. To systematically summarize and assess the current information available regarding reproductive performance in females of dromedary camels within the tropics, comparing the performance within various climatic zones, regions, and husbandry conditions.
2. To characterize the husbandry practices of farmers raising domestic South American camelids (SACs) in the Andean region (Ecuador and Peru).
3. To analyse the differences in husbandry techniques in SACs herds in Ecuador and Peru.
4. To assess the influence of farmer-specific data on the breeding techniques used.
5. To characterize and compare the nursing behaviour of alpacas kept under traditional conditions in the Andean region and on farms in Central Europe.
6. To document the occurrence of allonursing in domestic SACs.

3 Materials and methods

3.1 Descriptive analysis of existing studies about female dromedary camel reproductive performance in tropics

A comprehensive review of the available literature about the female dromedary camel reproductive management was performed between October 2019 and July 2022. Databases used included Web of Science, Scopus, Google Scholar, JSTOR, SpringerLink, ScienceDirect, and conference proceedings. Search keywords used included: “dromedary camel”, “*Camelus dromedarius*”, “camel reproduction”, “husbandry”, “management”, “camel pastoral management”, “camel reproductive management”, “camel breeding”, “camel reproductive parameters”, “calving interval”, “camel calves”. Studies focusing on assisted reproductive technologies were not included.

A total of 121 studies about camel reproductive management and performance were reviewed. The studies were subsequently grouped into six geographic regions assigned by the M49 standard (United Nations, 1999): Western, Northern, Eastern, and Middle Africa, and Western and Southern Asia. The greatest number of studies focused on dromedary camel reproductive performance have been conducted in Ethiopa, whilst studies in Western and Middle Africa, and Western Asia are mostly lacking.

Climatic conditions in areas of the studies were classified based on Köppen-Geiger climate classification updated by Kottek et al. (2006). Information was collected from all relevant studies (grouped per region) published between the years of 1980 and July 2022, and included data regarding breeding season, age of puberty, age at first service and first calving, calving interval, pregnancy length, calving rate, abortion rate, calf mortality, and weaning age. Studies which published information regarding at least two of the aforementioned parameters were selected for the generation of the summary tables and figures. Moreover, camel husbandry management, male/female ratio, mating practices and other relevant information were collected and summarized.

3.2 Study areas

3.2.1 South American farms – survey

Data about South American camelids was collected in their natural habitat of Andes. For this study the data collection was done in Ecuador and Peru from April to July 2021 and April to September 2022. The survey was supported with the collaboration with Escuela Superior Politécnica de Chimborazo (ESPOCH) in Ecuador and Centro de Estudios y promoción de Desarrollo de Sur (DESCOSUR) in Peru. The questionnaires were conducted in traditional Andean communities within the Chimborazo province in Ecuador, and the Arequipa, Puno, Apurímac and Cusco regions in Peru. All locations are approximately at altitude of 3000 to 4500 m a. s. l. Regions included to the questionnaires are shown in the Figure 7.

Figure 7. Ecuadorian and Peruvian regions included in the questionnaire study assessing husbandry practices in South American camelid systems

3.2.2 South American farms – observations

The nursing behaviour of alpacas (*Vicugna pacos*) was observed at two locations in the Andes. The observations took place on local farms and did not interfere with normal operations at these farms. Alpacas were observed during normal routine and the observers did not interact in any way with the observed animals. The observations were conducted with the support of the organizations (Chapter 3.2.1.)

3.2.2.1 Ecuador

Four herds in the Chimborazo province were chosen for observations (the community Chorrera Mirador, San Vicente de Tablillas, Liglig and Aňa Moyocancha). Each herd consisted of 40 to 60 alpacas. Herds contained 11, 11, 16, and 28 nursing dam-cria pairs. The observations of nursing behaviour were conducted in two periods: from 28th May to 20th July 2021 (autumn and winter, dry season) and from 15th April to 26th May 2022 (autumn, dry season).

In the observed alpaca herds, dams were kept together with males during the whole year and were usually mated for the first time at the age of 2 years. Weaning of crias took place at approximately 6.5 months after birth, and thus the crias were between 1 to 5 months old at the time of the observations. The herds were placed on the pasture during the day, usually from 8 am to 3 pm, and the observations of nursing behaviours were performed at this time when alpacas were on the pasture. Pasture size was approximately 100 ha. Water was provided by natural resources on the pasture. During the night, the animals were in small enclosures with a shed. They did not receive any supplementary feeding.

Herds were located with an average altitude of 3,900 m a. s. l. The annual rainfall of the Ecuadorian páramos is 1,000 to 3,000 mm or more (Fiallos et al., 2015) The average temperature is 0 to 12 °C with occurrence of freezing and snow (La Frenierre and Mark, 2017). The precipitation during the period of the observations was from 65 to 70 mm (La Frenierre and Mark, 2017). The weather conditions during the observations were variable, from sunny days to very rainy days.

3.2.2.2 Peru

One alpaca herd located in Pampa de Toccra (Arequipa province) was observed in Peru. This area is part of the Salinas y Aguada Blanca National Reserve. The herd had approximately 200 females from which approximately 100 had crias. The observations were conducted in two periods: from 16th June to 22nd June 2021 (winter, dry season) and from 4th June to 1st July 2022 (winter, dry season).

Dams with crias were separated from the males outside of the breeding season, and thus at the time of the observations. The weaning age was approximately 7.5 months. The crias were between 1 to 7 months old during the observation period. Males and females of both species are usually included into the breeding system at the age of 2 years old. Animals were on pasture of approximate size 150 ha from 8 am to 6 pm and they shared the pasture place with wild vicuñas, which were presented in this area. No water was available on the pasture during the day. During the night, animals were in an enclosure with a shed where the water was provided.

The herd was situated in an altitude from 4,400 to 4,500 m a. s. l. The annual precipitation varying from 350 to 450 mm is concentrated to the rainy season, which is from December and March (Montenegro et al., 2010). Observations took place during the dry season, and there was no rain during the observation period. The average annual temperature is 3 to 5 degrees Celsius (Catorci et al., 2014).

3.2.3 Central European farms - observations

3.2.3.1 Poland and Austria

The repeated observations of alpacas in Central Europe were conducted in one Austrian farm (Vöcklabruck district) and three Polish farms (in Pulawy, Ciechanów, and Crakow districts) from 29th June to 5th September 2022 (summer). Total herd sizes varied from 20 to 30 animals per herd, depending on the location, observational period, and herd management. Several dams gave birth during the observational period. In total, 35 dams-cria pairs, divided into 6 herds, were observed.

During the observations, the crias were between 1 and 14 months old. Dams with crias were separated from adult males. Animals were released on pastures usually between 7 and 9 am. The herds rotated between different pastures, each ranging in size from 0.14 to 0.27 ha. All animals had stables where they spent nights, the hottest parts of the day and if there was heavy rain. All animals had access to hay and fresh water.

Mean temperatures in Austrian and Poland during the observation period were around 18 and 20 °C, respectively, and monthly rainfall varied from 195 to 222 mm and from 60 to 92 mm, respectively (Climate-Data, 2025). The weather was mostly sunny with several rainy days during the observations. But there were extremely high temperatures (up to 33 °C) during few days of observations in Austria.

3.3 Data collection for husbandry practices of South American camelids in Ecuador and Peru

A semi-structured questionnaire for the survey across the SACs farmers was created. The questionnaire was written in Spanish and distributed in a paper-printed form by the author. The English version of the questionnaire is provided in the Appendix 1. In the questionnaire there was introductory section about the information about the farmer and the localization of the farm. It was followed by 15 questions about the SACs husbandry. 1 additional question was connected to the allonursing occurrence (Appendix 2). The personal data of the farmers were anonymised. The questionnaire was focused on three areas – characteristics of the respondents, animals and husbandry practices and breeding and reproductive management. Topics and types of survey questions used are shown in Figure 8.

The multiple-choice questions offered the respondents the option to select one or more answers from a preset list if options. The respondents had always a chance to select “other” and supplement their own answer, but due to the fact that this option was basically not used, these answers were not reflected in the data analysis and results. The quantitative questions enabled respondents to provide numeric answers. Finally, the questions based on a 3-point Linkert scale ranged from 1 = not important, 2 = secondary important, to 3 = priority/very important. Each question utilising the Linkert scale contained seven to nine items which were scored independently. For the questions about the animal selection into the breeding, the selection criteria for were chosen according to Markemann and Zárate (2010). Farmers could choose the criteria and write their own criteria, if there was not the option.

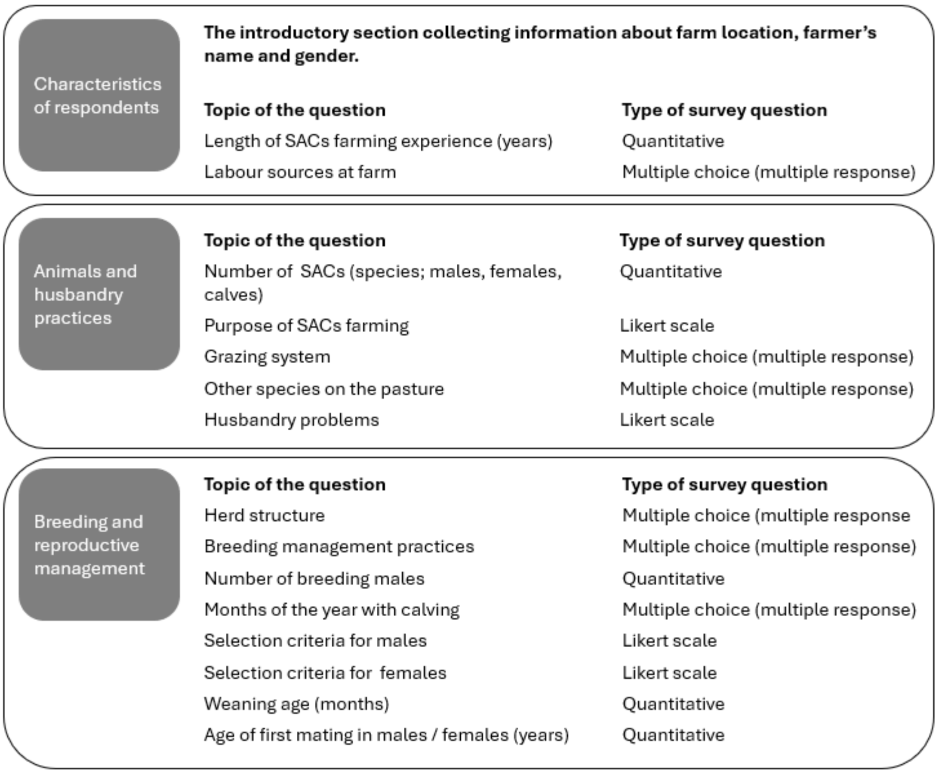

Figure 8. Summary of the questionnaire structure and types of survey questions used. (Marešová et al., 2023, unpublished work)

3.4 Data collection of nursing behaviour

The nursing data were collected using the all-occurrence sampling method (Šandlová et al., 2020) and by two observers (one in the Andes and one in Central Europe). The observers underwent joint training on observation of nursing behaviour before start of the research and they shared the same methodology of data collection.

When dams started nursing, the nursing duration was measured by a stopwatch. Nursing bouts longer than 5s were considered as successful (Gloneková et al., 2016). The termination of the nursing was considered after 10s of interruption (Brandlová et al., 2013). Initiator and terminator of nursing (dam/cria), sniffing by dam during nursing (yes/no) and way of initiation and termination were recorded for each nursing bout.. A detailed description of the behaviour before, during and after nursing is presented in Table 1. The position of suckling cria towards the nursing female was evaluated as parallel (animals standing in the same direction), antiparallel (animals standing in opposite direction) or perpendicular (cria standing from the side, ca. 90 degrees).

Table 1. Description of alpacas' behaviour observed before, during, and after nursing

Behaviour	Definition
Way of nursing initiation	
Approach	Animal approach by walk or run
Contact	Animal performed any physical contact with the second animal before nursing, mostly touching by nose or jumping on dam
Suckling continuation	Situation when cria terminated sucking and started a new bout longer than 10 seconds after, without any contact
Vocalization	Any sound produced before nursing
Other	Mostly standing up or following the second animal that participated in nursing
Sniffing behaviour during nursing	
Sniffing by the dam	Dam sniffs the cria's body
Way of nursing termination	
Stopping	Animal terminated the nursing/sucking without firm movement or interaction
Aggressive display	Kicking, spitting or pushing away
Scratching	Animal started to scratch instead of nursing/suckling
Lying down	Animal lay down on the ground
Disturbance	Animals were disturbed by an external factor

The observations were conducted at time ranges which were suitable for local farms and their management. They were conducted between 8am and 3pm in three Ecuadorian herds, the last herd was observed between 8 am and 1:30 pm. In Peru, observations were done between 8am and 5pm. In Central Europe, observations were done from 8am to 4pm. The herds were mostly observed without using binoculars, except for longer distances. Nursing behaviour was observed on pastures in the Andes. In Central Europe, the majority of the observations were conducted on the pastures as well. However, if a herd was enclosed for some part of the observational period due to weather conditions or herd management, the observations continued in stables.

The individual identification of animals and their relationships assessment were not mostly possible in Ecuador and Peru due to the high number of animals present in one herd, no individual marking, and very basic register system of the herds. So, all nursing bouts where just one cria was suckling were considered as filial nursing. Data about nursing bouts were collected from as many animals as possible but recoding of all nursing bouts was impossible because of the high number of dams in Peru. The individual identification of nursing animals in Central Europe was done and so name of nursing dam and suckling cria were recorded. Sex and age of suckling crias was also individually determined.

Lastly, 102 Ecuadorian and Peruvian farmers were asked personally if they noticed any occurrence of allonursing in their herds. This question was a part of the questionnaire about husbandry practices (Chapter 3.3).

3.5 Statistical analysis

3.5.1 Data analysis – questionnaires

The statistical analysis was performed in Statistica version 13 (TIBCO Software Inc. 2017). The means, SE, medians, maximum and minimum ranges were obtained by descriptive statistics. Since llamas were only kept by 11 respondents, the purpose of farming and breeding management was analysed for alpacas only. Frequency tables and Pearson Chi-square test were used for the comparison of the occurrence of categorical variables like country, gender of farmer, labour sources, length of SACs farming experience categorised to three groups (1 to 10 years; 11 to 30 years; 31 + years), grazing practices, and managed/non-managed reproduction. Data from the 3-point Linkert scales were treated 1) as categorical variables and tested by Pearson Chi-square test for differences between countries and farmers' gender; or 2) treated like ordinal data where the median was calculated and displayed in spider diagrams. Since the data did not show a normal distribution (Kolmogorov-Smirnov test, $p < 0.01$), non-parametric Mann-Whitney U or Kruskal-Wallis tests were used. To explore the relationship between length of farming experience and herd size or age of weaning, the Sperman correlation was used. The level of significance used throughout the analyses was $p < 0.05$.

The circular statistics for testing the seasonality of calving season in Peru and Ecuador were performed in Oriana, version 4.02 (Kovach Computing Services 2013). Herds were classified as managed or unmanaged in terms of mating. Managed herds were herds where males were introduced to herd just for limited time period for mating. In non-managed herds, males were present with females all year. Rayleigh Test with a significance level $p < 0.01$ was used for these analyses.

3.5.2 Data analysis – nursing behaviour

Just nursing bouts longer than 5 seconds were used for the data analysis. Nursing bouts identified as non-filial were not included in the data analyses because of their rare occurrence (n=5) so just nursing bouts which were considered as filial were analysed. Given the dataset size and data distribution, a normal distribution was assumed, and parametric statistical methods were applied. The statistical analysis was performed in Statistica programme, version 13 (TIBCO Software Inc. 2017). The level of significance used throughout the analyses was $p < 0.05$.

A dataset of crias aged 1 to 7 months from the Andes and Central Europe was used for the analysis of nursing behaviour and for comparison both locations. A dataset of crias of all ages from Central Europe, where the exact age and sex of crias were known, were utilised to test the effects of cria age and sex.

Categorical data like location (the Andes vs. Central Europe), nursing position, sniffing by dam, initiator and terminator of nursing, and way of initiation or termination were analysed by frequency tables and tested by Pearson's Chi-square test. Differences in nursing duration sorted by categorical variables mentioned above were tested by Student's t-test and ANOVA. No significant differences in nursing duration of alpacas in Peru and Ecuador were found ($t(923) = 1.64$, $p > 0,05$) so these data are presented together as location “Andes”. No significant differences in nursing duration of alpacas in Poland and Austria were found ($t(972) = 1.39$, $p > 0,05$) so these data are presented together as location “Central Europe”.

Generalised linear models (GLM) were utilized for testing of effects of location, position of cria, terminator, sniffing by dam, and their interactions on nursing duration. For GLM testing, the effect of cria age (treated as continuous variable) and sex were assessed, and nursing dam was used as a random effect. Initiator of nursing was not included in the model because almost all nursing bouts were initiated by the cria (see Results).

Cria age data were also categorised to 4 groups (1-2 months for crias up to 61 days old, 3-5 months for crias 62-152 days old, 6-12 months for crias 153-365 days old, and crias old 366 days or more) and used as a categorial variable to compare the mean nursing durations of crias in different age categories and to test the proportion of nursing bouts initiated or terminated by dams and way of initiation or termination.

4 Results

4.1 Descriptive analysis of existing studies about female dromedary camel reproductive performance in tropics

Number of studies reporting female dromedary camel reproductive performance according to country and region is summarized in Figure 9. Only 38 % of the studies focused primarily on dromedary camel reproductive performance, whilst the rest of studies focused on other topics but contained information about reproductive performance as well (Figure 10). The majority of studies were based on questionnaires and surveys with farmers (Figure 11). Breeding methods (natural harem mating, hand mating, artificial insemination, or other practices) were not described in more than half of the studies focusing on reproductive performance (n=24). Furthermore, among the published studies, parameters regarding the rearing of the calves are not commonly reported (Simenew et al., 2013; Mayouf et al., 2014; Vatankhah et al., 2019), and similarly, information about the occurrence of abortions is not well-reported or completely unknown in many tropical countries farming with dromedary camels (Elias et al., 1991; Fazal et al., 2017; Gherissi et al., 2020).

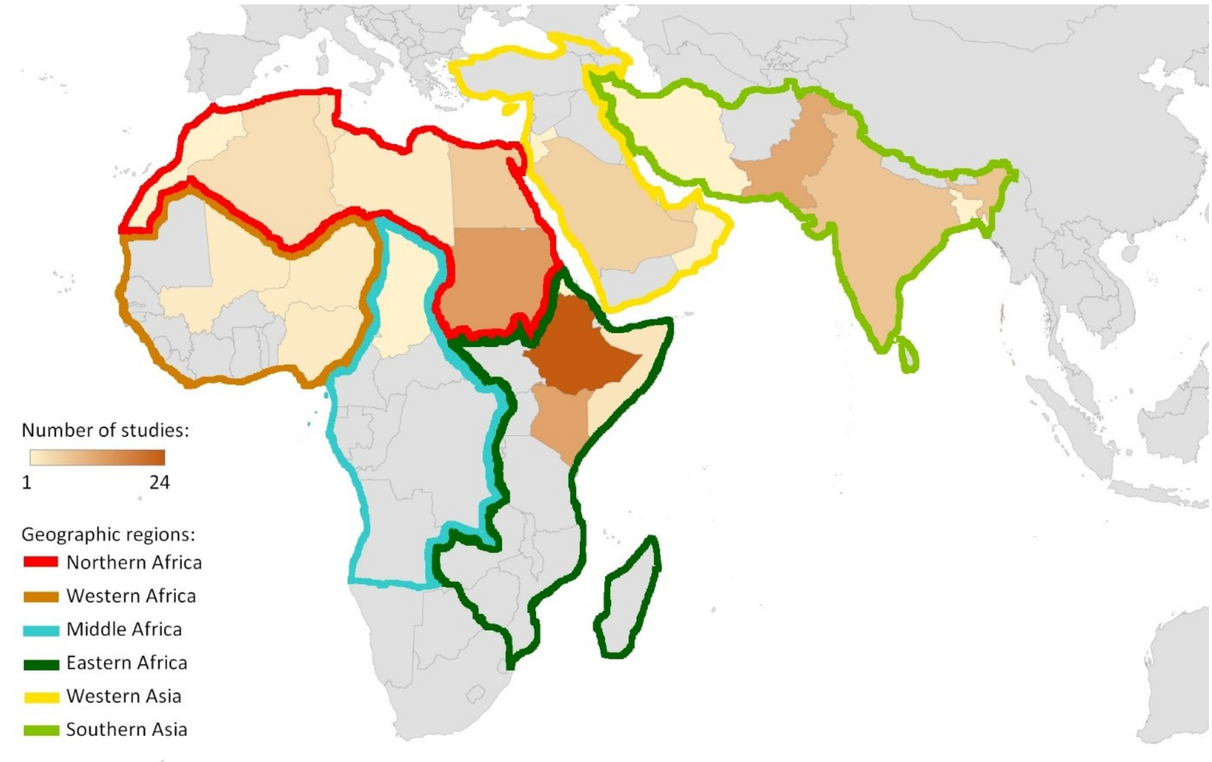

Figure 9. Number of studies reporting dromedary camel reproductive performance according to country and region (Marešová et al., 2023, unpublished work)

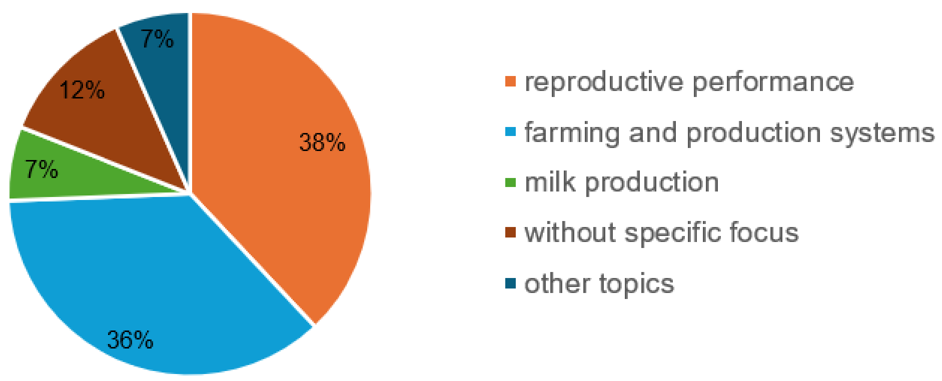

Figure 10. Summary of the main focus of the selected dromedary camel studies reporting reproductive performance data (n = 121). Studies “without specific focus” included general information about camels but did not focus on a specific topic. Studies under “other topics” were usually covering health, rearing of calves, reproductive hormones, feeding, marketing of products etc.

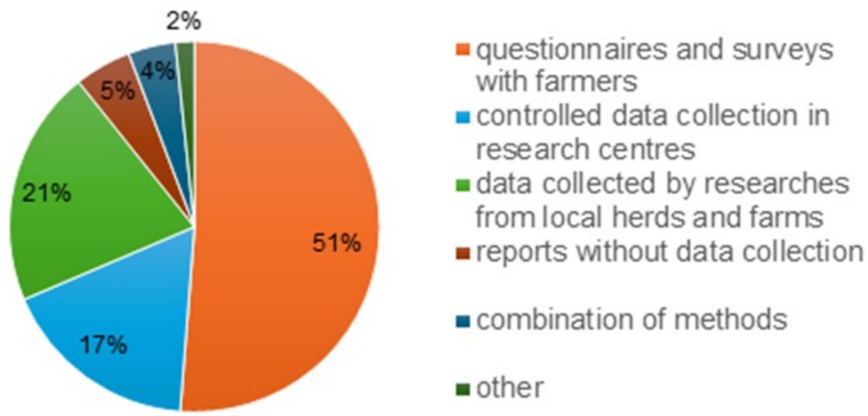

Figure 11. Summary of the main focus of the selected dromedary camel studies reporting reproductive performance data (n = 121). Studies "without specific focus" included general information about camels without focusing on a specific topic. Studies under "other topics" usually covered health, calf rearing, reproductive hormones, feeding, product marketing, etc.

Tables comparing the female dromedary camel reproductive parameters within the different climatic zones and husbandry systems are included in Appendix 3 - 5.

4.2 Husbandry practices of SACs in Ecuador and Peru

4.2.1 Characteristics of the farmers

Characteristics of respondents in both countries are shown in Table 2. Whilst gender was rather balanced for the overall data, in Ecuador, respondents were predominantly men with 1 to 10 years of farming experience, whilst in Peru, they were women with more than 31 years of farming experience. The owners of the animals themselves were the only person involved in the farming activities (i.e., did not employ the help of other family members or other labourers) in the most cases (Table 2), especially for Peruvian farmers (Pearson Chi-square: 31,8477, df=1, $p<0.0001$) and women farmers (63.3% for women vs. 24.5 % for men; Pearson Chi-square: 15,5756, df=1, $p<0.0001$).

Table 2. Characteristics of respondents and their distribution based on country, gender, length of SACs farming experience and labour sources

	Total		Ecuador		Peru	
Characteristics	**Number**	**Percentage**	**Number**	**Percentage**	**Number**	**Percentage**
Overall	102	100.0%	44	43.1%	58	56.9%
Gender of farmer						
Women	49	48.0%	7	15.9%	42	72.4%
Men	53	52.0%	37	84.1%	16	27.6%
Length of SACs farming experience						
1 to 10 years	44	43.1%	34	77.3%	10	17.3%
11 to 30 years	32	31.4%	10	22.7%	22	37.9%
31 + years	26	25.5%	0	0.0%	26	44.8%
Labor sources at farms						
Owner only	44	43.1%	5	11.4%	39	67.2%
All family members	35	34.3%	17	38.6%	18	31.0%
All adult family members	1	1.0%	0	0.0%	1	1.7%
Owner and paid workers	17	16.7%	15	34.1%	2	3.4%
Paid workers only	13	12.7%	10	22.7%	3	5.2%

Mean SACs farming experience (p < 0.0001) was significantly lower in Ecuador than in Peru. The most experienced were woman from Peru. See Table 3 for details.

Table 3. Distribution of a length of SACs farming experience in years and differences between countries, gender, and gender within countries (where means with different superscript letters are significantly different, p < 0.01).

	Number of farmers	Mean ± SE farming experience	Median farming experience	Minimum farming experience	Maximum farming experience	Statistical result
Overall	102	20.9 ± 1.96	15.0	1	70	
Country						
Ecuador	44	7.2 ± 1.20	3.5	1	25	Mann-Whitney U Test, U = 298, p < 0.001
Peru	58	31.3 ± 2.59	30.5	2	70	
Gender						
Women	49	28.9 ± 3.07	29.0	1	60	Mann-Whitney U Test, U = 727, p < 0.001
Men	53	13.5 ± 2.01	10.0	1	70	
Gender in country						
Women in Ecuador	7	$2.6^{a} \pm 0.57$	3.0	1	25	Kruskal-Wallis test, H (3, N=102) = 45.977, p < 0.001
Men in Ecuador	37	$8.1^{a} \pm 1.38$	4.0	1	4	
Women in Peru	42	$33.3^{b} \pm 3.10$	30	2	70	
Men in Peru	16	$26.1^{b} \pm 4.58$	20	3	60	

4.2.2 Herds size and composition

The size of the herds kept varied between the interviewed farmers (Table 4). All the interviewed farmers bred alpacas but farming llamas was not so common between the interviewed farmers (see Table 4). Llamas were kept by farmers who had a minimum of 15 years of SACs farming experience. More experienced farmers kept significantly larger herds of alpacas ($p < 0.05$, $\rho = 0.57$). Table 5 shows the mean number of females, males, and crias in SACs herds.

Table 4. Herds sizes according to country and SAC species, and differences between these (Mann-Whitney U Test)

	Number of farmers	Mean ± SE herd size	Median herd size	Minimum herd size	Maximum herd size	Statistical result
Overall	102	157.9 ± 21.10	87	6	1100	
Country						
Ecuador	44	54.6 ± 9.9	27	6	338	Mann-Whitney U Test, U = 325.5, p < 0.001
Peru	58	236.3 ± 32.89	143	34	1100	
Species						
Alpacas	102	151.1 ± 19.87	86	6	1100	Mann-Whitney U Test, U = 276.0, p < 0.01
Llamas	11	63.1 ± 34.15	35	3	393	
Species (country)						
Alpacas (Ecuador)	44	52.6 ± 8.70	27	6	250	Mann-Whitney U Test, U = 334.5, p < 0.001
Alpacas (Peru)	58	225.8 ± 30.98	143	34	1100	
Llamas (Ecuador)	1	88	88	88	88	Not applicable
Llamas (Peru)	10	60.6 ± 37.65	20.5	3	393	

Table 5. Mean ± SE numbers of males, females and crias and sex ratio in herds

	Males (M)	Females (F)	Crias	Sex ratio (M:F)
Alpacas	23.8 ± 4.42	89.84 ± 11.7	37.45 ± 5.52	1:7.17 ± 1.28
Llamas	10.73 ± 4.29	37 ± 21.82	15.36 ± 8.69	1:3.25 ± 0.59

4.2.3 Grazing system and husbandry problems

Extensive grazing was the most common form of grazing/feeding used (77.5%). 97.1% of farmers did not provide any supplementary feeding to their SACs. The majority of farmers (72.6%) used their pasture just for SACs and did not mix herds with other livestock. If other species of livestock were kept with SACs, these were sheep (27.5 %), cattle (10,8%), horses (2,9%), and donkeys (1.0%). No significant difference ($p>0.05$) was observed between countries in the above-mentioned practices. 29.4% of farmers used herdsmen for guarding the animals but Ecuadorian farmers used herdsmen significantly more frequently than Peruvian farmers (47.7 vs. 15.5%, Pearson Chi-square: 12,5029, df=1, p=0.0004). Internal and external parasites together with lack of pasture were noted by the majority of farmers as the most common serious problems for their farms (Table 6).

Table 6. Frequency of problems considered by South American camelid farmers in Peru and Ecuador as serious issues on their farm

Problems	Total		Ecuador		Peru		Difference between countries (p)
	Number	Percentage	Number	Percentage	Number	Percentage	
Internal parasites	59	57.8%	19	43.2%	40	69.0%	0.0075
External parasites	57	55.9%	17	38.6%	40	69.0%	0.0042
Lack of pasture	56	54.9%	19	43.2%	37	63.8%	0.0081
Infectious diseases	38	37.3%	12	27.3%	26	44.8%	0.0600
Technical handling problems	21	20.6%	12	27.3%	9	15.5%	0.1382
Administrative problems	20	19.6%	9	20.5%	11	19.0%	0.9321
Economic problems	20	19.6%	9	20.5%	11	19.0%	0.4085
Animal fertility	18	17.6%	10	22.7%	8	13.8%	0.3326
Congenital malformations of crias	12	11.8%	1	2.3%	11	19.0%	0.0052

4.2.4 Breeding and reproductive management

In Ecuador, 68.2% of the farmers (n=30) kept males and females together during the whole year while in Peru, 69.0% (n=40) of farmers kept males and females separately, and managed their breeding. The majority of farmers in Ecuador and Peru (75.0% vs. 100.0%, respectively) had more than 1 breeding male in their herds of females (Pearson Chi-square:

16,2527, df=1, p=0.000055). The mean number of breeding males at one farm significantly differed between Ecuador and Peru (2.59 and 8.17, respectively; Mann-Whitney U Test, U =497.5, $p < 0.00001$).

No significant difference (Pearson Chi-square, $p > 0.05$) in calving season in managed (with reproductive management) and non-managed herds was found. February and March were common months of calving (80.4% and 77.5% of respondents recorded these months, respectively). In non-managed herds, significant seasonality was observed in both countries, with the peak of the calving season in February (Rayleigh Test, p < 0,01). However calving seasons differed between Peru and Ecuador (Pearson Chi-square: 38.3477, df=11, p=0.000068). As shown in Figure 12, circular variance was higher in Ecuador than in Peru (0.726 vs. 0.137, respectively).

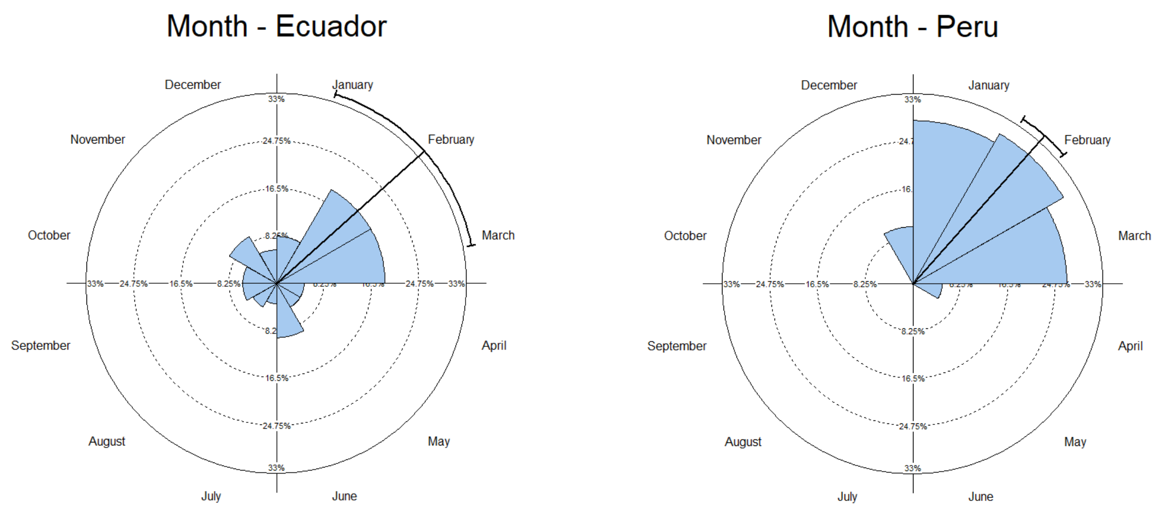

Figure 12. Distribution of cria births during the year (%) in non-managed SACs herds in Ecuador and Peru. Mean and confidence interval 95% are plotted.

The reported mean age at first mating in breeding females and males, and the weaning age of crias are presented in Table 7. The majority of farmers in Ecuador and Peru reported that they practice controlled weaning of crias (77.3% and 77.6%, respectively). However, only 35.3% of farmers in Ecuador and 13.3% of farmers in Peru separated crias from the herds after weaning. No significant correlation between the length of experience of the farmer and the age of first mating of their female or male animals was found. On the contrary, age of cria weaning correlated significantly ($p < 0.05$, $\rho = -0.43$) with the length of farmer's experience; more experienced farmers tended to choose to wean crias at an early age.

Table 7. Reproductive parameters and their differences between Ecuador and Peru (Mann-Whitney U Test)

	Overall	**Ecuador**	**Peru**	**U**	**p**
Age at first mating in females (years ± SE)	2.1 ± 0.05	2.1 ± 0.08	2.2 ± 0.07	1139.5	0.358
Age at first mating in males (years ± SE)	2.8 ± 0.06	2.6 ± 0.09	2.9 ± 0.08	961.0	0.034
Weaning age of crias (months ± SE)	8.9 ± 0.31	9.2 ± 0.66	8.6 ± 0.2	598.5	0.100

4.2.5 Selection criteria

From all 102 interviewed farmers, the main primary selection criteria for SACs males and females, respectively were size (83.3% and 81.4%), colour (82.4% and 88.2%), conformation (61.8% and 54.9%), and growth (55.9% and 52.9%). Median scores for all criteria for males and females in Ecuador and Peru are shown in Figure 13. No significant differences in section criteria were found between woman and man farmers, just women marked pedigree of females as primary criteria significantly more often than man (57.1 vs. 28.3%, respectively; Pearson Chi-square: 8,87793, df=2, p=0.0118).

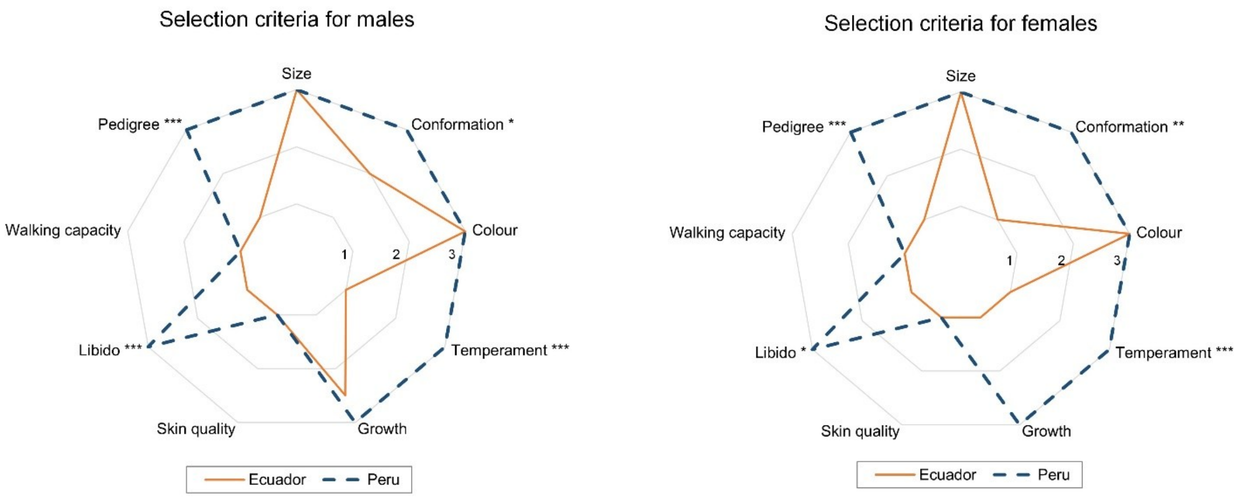

Figure 13. Median values of highly important (3) to non-important (1) male and female selection criteria according to the opinion of South American camelid farmers in Ecuador and Peru. Asterisks mark significant differences between countries (*p < 0.05, **p < 0.01, *** p < 0.001).

4.2.6 Purpose of SACs farming

92.2% and 86.3% of farmers scored fibre and meat production as the as the most important purposes of their alpaca farming activities, respectively. Figure 14 shows the median scores of the importance of different farming purposes in the two countries.

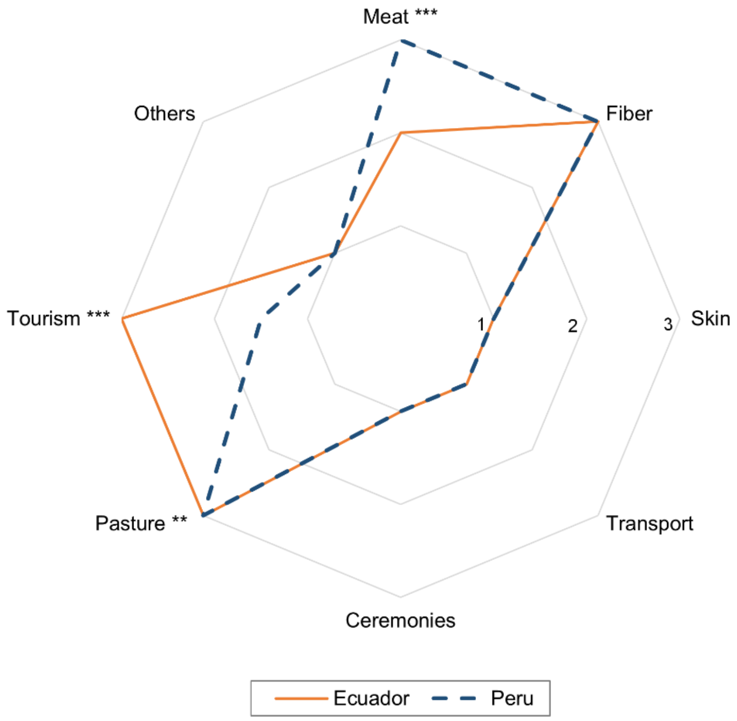

Figure 14: Median scores of importance of SACs farming purposes in Ecuador and Peru (3: very important – primary purpose, 2: important – secondary purpose, 1: – not important). Asterisks mark significant differences between countries (*p < 0.05, **p < 0.01, *** p < 0.001).

4.3 Nursing behaviour

4.3.1 Nursing Behaviour of Alpacas and Differences between Locations

Nursing was initiated more frequently by crias (99.14 % and 96.10 % of nursing bouts in the Andes and Central Europe, respectively) than by dams (χ^2 (1) = 18.51, p < 0.0001). Way of initiation was dependent on the initiator (χ^2 (4) = 303.73, p < 0.001). Crias initiated nursing mostly by approach, and dams mostly by vocalisation (Figure 15).

Nursing was terminated more frequently by dams (59.35 % and 51.85 % of nursing bouts in the Andes and Central Europe, respectively) than by crias (χ^2 (1) = 10.82, p < 0.01). Way of termination depended on the terminator (χ^2 (5) = 1222.38, p < 0.0001). Crias mostly just stop suckling, whilst dams ended nursing by moving away (Figure 16).

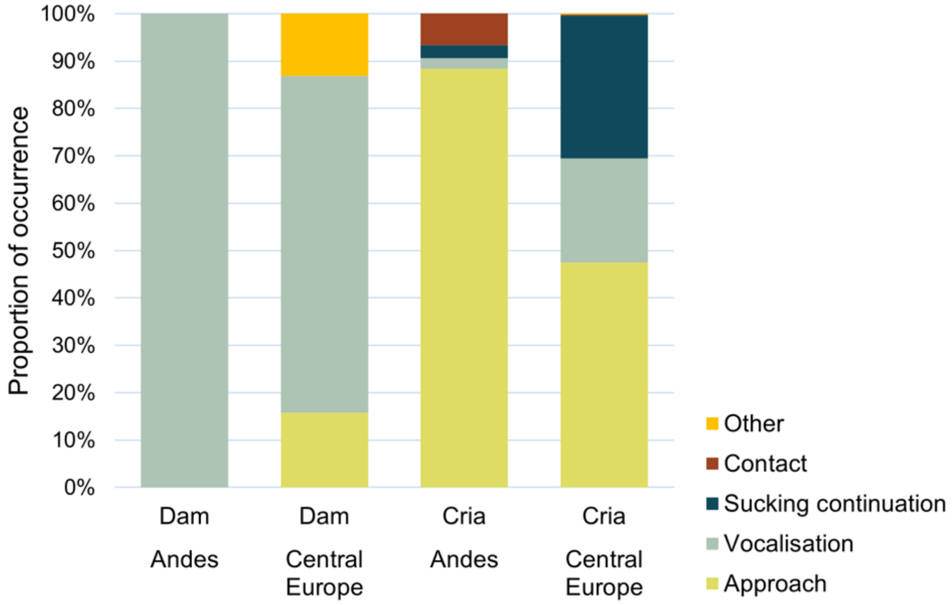

Figure 15. The way of nursing initiation divided by the nursing initiator and location

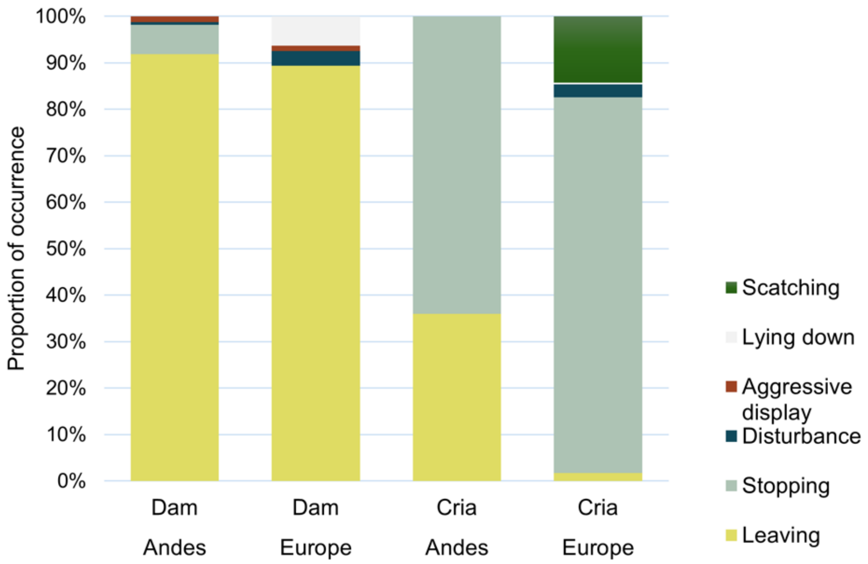

Figure 16. The way of nursing termination divided by the nursing terminator and location

Alpaca nursing duration in the Andes and Central Europe is presented in Table 8.

Table 8. Mean ± SE, median, minimum and maximum nursing duration in alpacas in the Andes and Central Europe.

	Number of nursing bouts	**Mean ± SE nursing duration (s)**	**Median nursing duration (s)**	**Minimum nursing duration (s)**	**Maximum nursing duration (s)**
Andes	925	96.96 ± 1.46	97	9	424
Central Europe	974	85.04 ± 1.87	87	5	300

Nursing duration was significantly shorter in Central Europe than in the Andes when tested without consideration of other factors like sniffing or nursing position (t (1897) = 4.99, $p < 0.0001$). However, the model revealed that the location (the Andes vs. Central Europe) itself was insignificant and interactions between location and sniffing by dam or location and position of cria played the most significant roles in nursing duration (GLM: F (14) = 41.92; $p < 0.0001$). See Table 9 for details.

Table 9. Factor affecting nursing duration analysed by GLM (n. s. = non-significant, p > 0.05).

Effect	**df**	**F**	**p**
Location	1	1.02	n.s.
Position of cria	2	7.01	$p < 0.001$
Terminator	1	19.69	$p < 0.0001$
Sniffing by dam	1	107.17	$p < 0.0001$
Location ´ Position of cria	2	6.78	$p < 0.01$
Location ´ Terminator	1	5.00	$p < 0.05$
Position of cria ´ Terminator	2	0.71	n.s.
Location ´ Sniffing by dam	1	149.57	$p < 0.0001$
Position of cria ´ Sniffing by dam	2	2.12	n.s.
Terminator ´ Sniffing by dam	1	2.22	n.s.

Nursing duration was not affected by the initiator in the Andes; however, it was significantly longer when initiated by the dam than by the cria in Central Europe (83.92 ± 1.91 vs. 112.45 ± 7.79 s, respectively; $t\ (972) = 2.97$, $p < 0.01$). As shown in Figure 17, mean nursing duration when terminated by dam was significantly shorter in both locations.

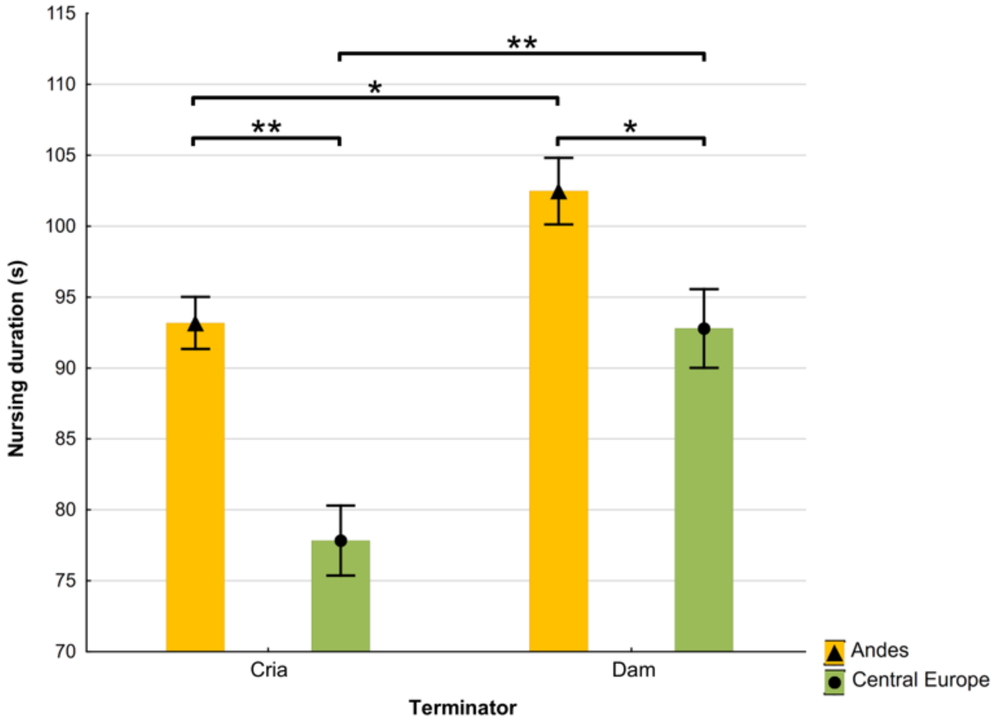

Figure 17. Mean ± SE nursing duration terminated by dams and crias in the Andes and Central Europe (asterisks mark significance level, ** p<0.01, ***p<0.001).

The preferred nursing positions of crias in the Andes and Central Europe were antiparallel (56.76 % and 52.26 % of nursing bouts, respectively) and perpendicular (42.38 % and 33.88 %, respectively). The parallel position was significantly less frequent ($\chi^2\ (2) = 117.18$, $p > 0.05$), especially in the Andes (0.86 % vs 13.86 % in Central Europe). Likewise, mean nursing duration was significantly shorter in the parallel position (Figure 18).

Dams sniffed crias during nursing significantly less often in the Andes than in Central Europe (45.95 % vs. 68.58 % of nursing bouts, respectively; ($\chi^2\ (1) = 99.52$, $p < 0.0001$)). Mean nursing duration was significantly shorter when the dam did not sniff the cria. However, when the dam sniffed the cria, no significant difference between locations in nursing duration was found (Figure 19).

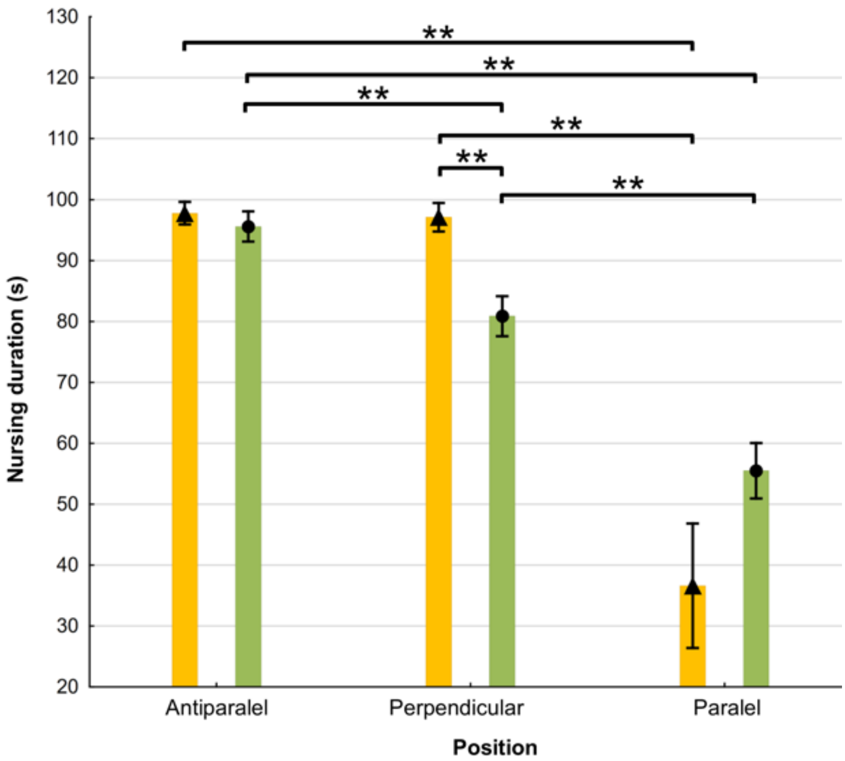

Figure 18. Mean ± SE nursing duration in the Andes and Central Europe divided by different nursing position

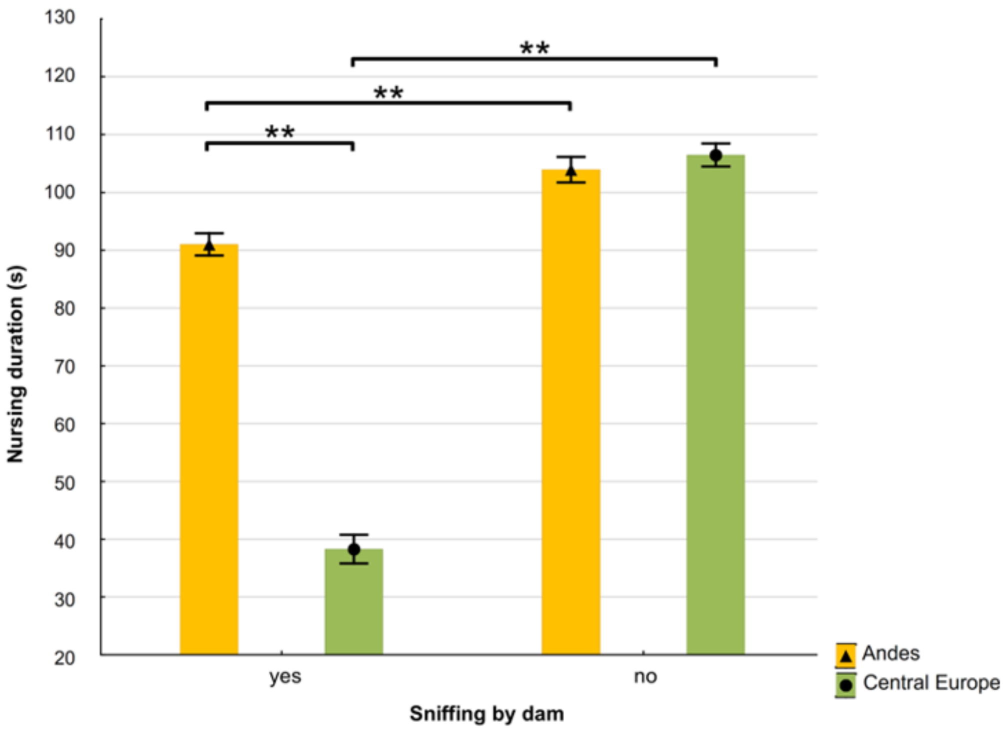

Figure 19. Mean ± SE nursing duration in the Andes and Central Europe divided by sniffing by dam. Asterisks mark significance level, *** p<0.001.

4.3.2 Effect of Cria Age and Sex

Cria age or sex did not significantly affect the proportion of nursing bouts initiated or terminated by dams. Way of initiation by crias was also not affected by the age of the cria. However, dams initiated nursing more often when they had crias of up to 2 months of age, and the nursing was initiated mostly by vocalisation (57.50 % from all cases when nursing initiated by dams; $p < 0.05$). Way of nursing termination of both, crias and dams did not significantly change with cria age. Sex did not play significant role in way of nursing initiation or termination. Mean nursing durations of crias in different age categories is presented in Figure 20.

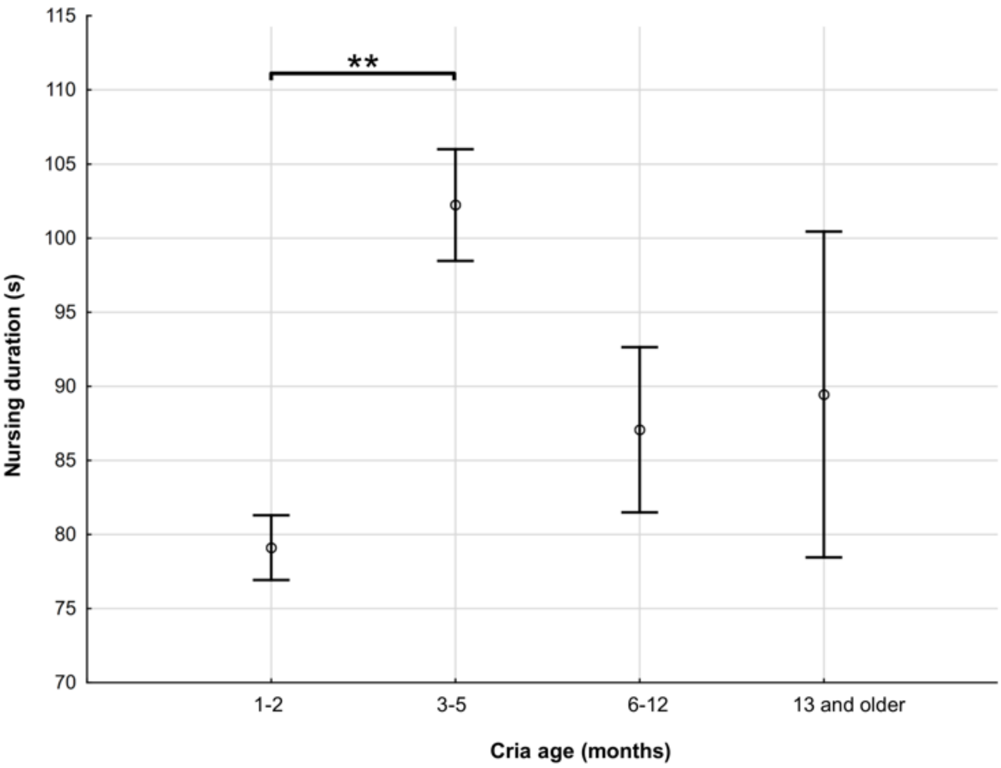

Figure 20. Mean ± SE nursing duration in different age categories of crias in Central Europe (asterisks mark significance level, ***p<0.001).

Model did not prove significant effect of cria age on nursing duration or its interactions with factors like nursing position, terminator nor presence of sniffing by dam (GLM: F (37) = 16.69; $p < 0.0001$). Nursing of female crias terminated by dams were significantly shorter than those terminated by female crias (t (656) = 3.50, $p < 0.001$). Detailed results are presented Figure 21 and Figure 22.

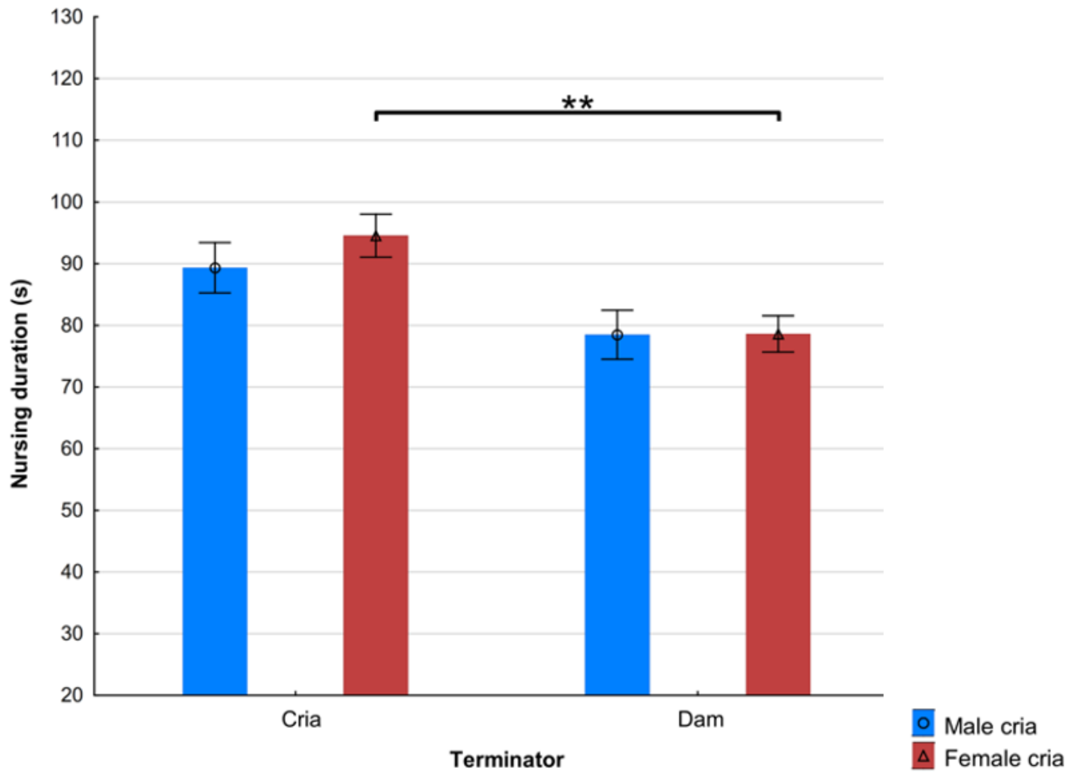

Figure 21. Mean ± SE nursing duration affected by terminator and cria sex

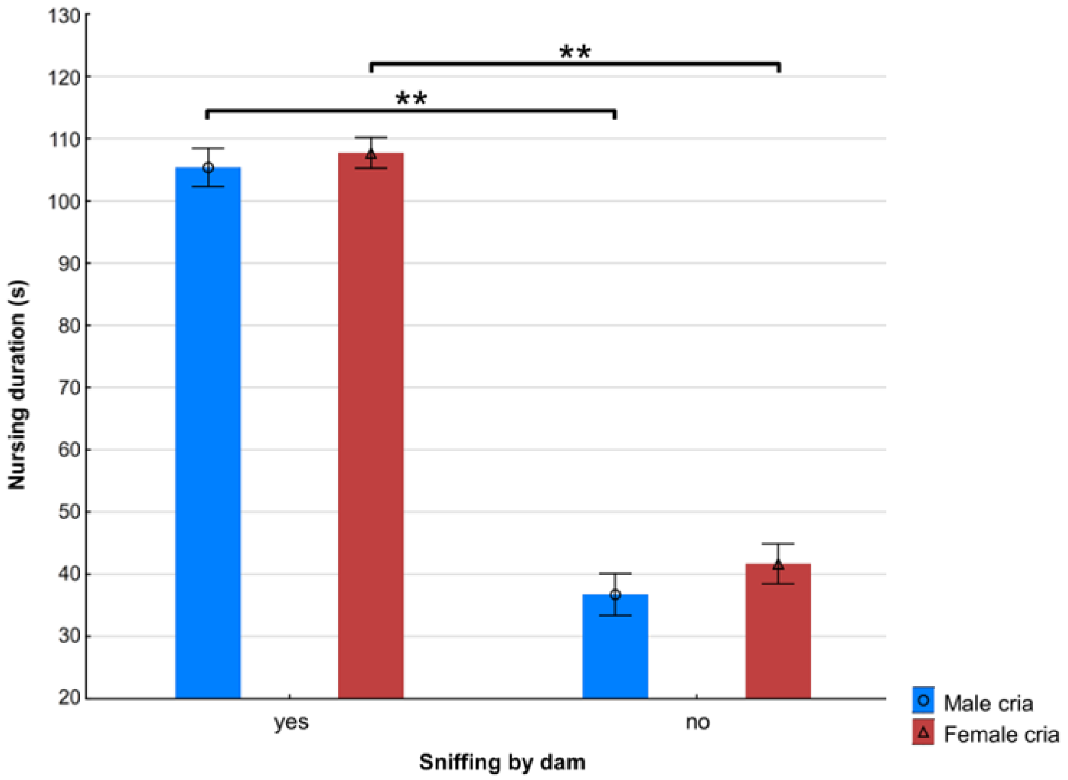

Figure 22. Mean ± SE nursing duration affected by sniffing by dam and cria sex. Asterisks mark significance level, *** p<0.001.

4.3.3 Occurrence of allonursing

Our observations did not prove the occurrence of allonursing in the Andes. The interactions of dams and some other (second) cria during nursing were observed only 8 times during the observations in the Andes, but none of those started to suck. It was seen 7 times in Ecuador and only once in Peru. The dam drove the other cria away and then sniffed the suckling cria. However, 19 out of 102 farmers (18.63 %) answered in the survey that they saw allonursing in their herds during the past years. Most of these farmers (n=18) were from Peru, while it was observed only on one farm in Ecuador

Allonursing was directly seen in Central Europe. Allonursing was confirmed in 0.38 % (n=5; 4 dams) of successful nursing bouts with a mean ± SE duration of 47.2 ± 39.5 seconds. All cases of allonursing were initiated by the cria, and the filial cria was suckling from the dam at the same time. All non-filial nursing bouts were complemented by sniffing the dam. The perpendicular position during the allonursing was observed in 80% of cases also terminated by the dam. Majority (80%) of allonursing bouts happened in stables. Moreover, nine attempts of crias' allosuckling were observed.

5 Discussion

5.1 Dromedary camel reproductive performance

Dromedary camels tend to suffer poor fertility rates in tropical and subtropical areas, mainly when reared in pastoral management systems (Zelek and Bekele, 2000; Kaufmann, 2005; Megersa et al., 2008). One particular challenge in addressing poor reproductive rates in dromedaries is the lack of herd record-keeping under the production systems utilized. The management affects calf survival, which is low in pastoral systems (Tefera and Gebrehah, 2001; Tura et al., 2009; Awoke and Ali, 2015). The high mortality rates could result from a combination of factors, including poorly developed calf-rearing techniques, breeding systems, and local climate conditions. The calf-rearing techniques used in pastoral herds are likely to contribute to the incidences of calf diarrhea, such as the early withdrawal of colostrum, overfeeding, and insufficient hygiene during the suckling period (Megersa, 2014; Abdel Fattah and Roushdy, 2016). Insight regarding the reproductive season and management, including the onset of puberty, age at first calving and other reproductive parameters within different production systems in tropical and subtropical regions can be important for ensuring successful gestations, lowering abortion rates, and improving calf survival. Moreover, in pastoral herds, mixed herds contribute to the transmission of diseases between the species (Abbas et al., 1992). However, there is a lack of studies focused on health problems in mixed herds. Health approaches to surveilling and managing the health of camels under these conditions should be identified after proper risk assessments.

Furthermore, higher milk production in intensive systems also leads to several health problems, including infertility, thus decreasing longevity (Pinedo and De Vries, 2010). In intensive systems, camel females may have a shorter lifespan, likely due to their intensive reproductive performance, as observed in domestic dairy cattle (Bielfeldt et al., 2006). However, there is a lack of information currently available on this topic, and thus, conclusions cannot be made in this regard. While poor fertility rates can be viewed as a consequence of the farmers' knowledge gap in camel reproduction physiology (Kuria et al., 2002; Rateb et al., 2020), infertility rates also increase with the increasing age of female camels (Tibary and Anouassi, 1997). Careful consideration and management of dromedary camels under intensive systems is necessary to ensure economic efficiency, balancing reproductive management with health, welfare, and production goals.

The challenging climatic conditions in tropical areas further exacerbate the camels' unique reproduction physiology and its effects on successful breeding management. It seems that there is a trend of fewer abortions in regions with lower temperatures, which was reported also by Tibary and En-Allali (2020). Longer intercalving intervals are also seen in regions with higher annual temperatures (Kaufmann, 2005; Kalla et al., 2008; Simenew Keskes et al., 2013). It is unclear if this is caused by the climate conditions or the management system due to the lack of information from these regions. However, when the current literature was consolidated, the highest abortion rates were reported for arid regions. This could be explained by high temperatures and limited resources of feed and water in arid regions. These conditions affect camels' nutrition and body condition (Amin et al., 2007), making them more susceptible to diseases. Based on the study of Selim et al. (2022), camels with poor body conditions had a significantly greater prevalence of trypanosomiasis. Calf mortality is high in the various climatic zones considered in this thesis, and thus, it could be expected that management could play a more important role than the climate in calf survival rates.

A proper description of the management or mating practices used is missing in many studies, limiting the broader interpretation of published results. However, the lack of information could be explained by the collection method of the studies, because only the studies with at least two reproductive parameters were included in the literature review and the descriptive analysis. Furthermore, mating practices were not described in more than half of the studies on reproductive performance. Although many studies are based on questionnaires with local camel farmers, many farmers do not maintain accurate and up-to-date records of their animals. Broader animal health care and workshops on new management techniques for farmers are crucial for suitable husbandry management.

5.2 Characterization of SACs husbandry in Ecuador and Peru

SACs husbandry belongs significantly to the way of life of the Andean pastoralists (Fernandez-Baca, 2005). However, not many studies on this topic are available. That is why this thesis brings unique data from Ecuador and Peru. Although the SACs husbandry is important for the local farmers (Paz et al., 2012; Miranda-de la Lama and Villarroel, 2023), variable husbandry techniques were reported in the survey conducted in these two countries. SACs breeding was more common in Peru than in Ecuador. This can be a consequence of the long SACs farming tradition in Peru, where these animals were used by the Incas (Vilá and Arzamendia, 2022) and where the domestication of SACs occurred around 5000 to 4000 BC (Kent, 1982; Moore, 1988; Mengoni-Goñalons and Yacobaccio, 2006). Moreover, in Peru, the highest alpaca population is found (MIDAGRI, 2023; FAOSTAT, 2023), while in Ecuador the data about the SACs population is not complete (FAOSTAT, 2023). The almost non-existent SACs husbandry in Ecuador in the past (Germana Cavero et al., 2016) can be a the reason why one third of Ecuadorian farmers started SACs farming just one year ago (according to the data from the year 2022). In contrast, the majority of Peruvian farmers started with SAC farming at childhood and spent their whole life in the husbandry. Finding an alpaca herd for the observation part of this study was more difficult in Ecuador than in Peru, further highlighting the limited SAC husbandry in Ecuador. However, in recent years, efforts have been made to reintroduce the SACs to the Ecuadorian páramos (Rosenthal, 2008). This was confirmed by the author's experience when she participated in a few development workshops for the SAC farmers supported by the collaborating university.

According to the results, there were more female respondents in the survey, suggesting that women can be more involved in SACs farming (Calle, 2023). Between the locations, there were significantly more women farmers in Peru than in Ecuador. The women also had more experience in SAC farming, corresponding with a previous study in the Andean region (Germana Cavero et al., 2016). Moreover, it was found that male farmers in Ecuador had lower mean experience in farming (Table 2), which can be a consequence of the lower historical distribution of SAC farming (Germana Cavero et al., 2016). The Ecuadorian respondents also mentioned the cooperating on SACs farming with the community members, which is similar to Sanchez's findings (2004). However, Peruvian farmers preferred handling the animals alone, which can result from being more skilled in the SACs farming.

As shown by this thesis, all interviewed farmers handled alpacas. This can be caused by the high number of alpacas, which are the most widespread camelids in South America

(MIDAGRI, 2022, FAOSTAT, 2023). According to MIDAGRI (2017a), the mean size of an alpaca herd in Peru is about 50 animals. However, in this survey, variable numbers of alpacas were reported, and the mean herd size was much greater. In poorer regions, smaller herds of 20 animals can be found (Fairfield, 2006; Gutierrez et al., 2012). This is more likely similar to the herds in Ecuador, where the mean size was smaller than in Peru. The results are supported by the significantly larger herds of more experienced farmers. When the herd is smaller, the problem of inbreeding can occur more often because the breeding male usually comes from the same herd (Reyna, 2006).

Based on the survey, alpaca herds are often mixed with sheep, horses, donkeys, llamas, and cattle. Other studies focused on the SACs breeding systems found mixed grazing commonly being used in the Andes (Nürnberg, 2005; Reyna, 2006; Markemann and Zárate, 2010; d'Apollonia et al., 2018; Radolf et al., 2022). The farmers can benefit from mixed grazing, which provides higher economic or food security (Sanchez, 2004; Radolf et al., 2022). On the other hand, mixed grazing can increase the risk of several pathogen or parasites transmission across the animal species (Chávez-Velásquez et al., 2005; Prince et al., 2016; Cruz et al., 2020). These pathogens can promote lower fertility success and increase the risk of abortions and cria mortality (Rosadio et al., 2012; Whitehead, 2013). According to Markemann and Zárate (2010), the mixed farming of alpaca and llama herds can lead to their hybridization and, thus, the decrease of the genetic pool of the animal species. But, as the results show, that llamas were bred by more experienced farmers with more than 15 years of experience, which can predict more suitable husbandry techniques being used in the husbandry. Nevertheless, alpaca and llama hybrids (huarizo) are often preferred for the higher fibre weight obtained (Carpio, 1991). However, due to the insufficient source of literature from the local husbandries, it cannot be determined if the breeding of the huarizo hybrid is deliberate or if it is a consequence of the farmers' insufficient knowledge.

Although big fibre companies exist in the Andes, the majority SACs farming belongs to the poorest population, and the pastoral system is the most common system used (Reyna, 2006; Quispe et al., 2009; Bello-Bravo et al., 2024). In Ecuador, the grazing system with a herdsman was more common than in Peru. It can be connected with the limited farming experience of the Ecuadorian farmers found in this survey or by Germana Cavero (2016). Parasites and lack of pasture were some of the main problems reported in this survey. The lack of pasture is a huge problem, especially in Peru, where the dry season lasts from April to November, and there is almost no rain (Montenegro et al., 2010). During the study in Peru, it did not rain at all, and the pastures were very dry.

SACs are multipurpose animals (Markermann and Zárate, 2010), but the main utilization from the survey was for fibre, meat, tourism, and skin. Fibre products are often farmers' only source of economic security (MIDAGRI, 2017a). This study confirmed the main purpose of fibre and meat in both countries (Figure 14). Thus, the SACs provide food security for the farmers (Paz et al., 2012). However, fibre products are often underrated, and the prices are lower than they should be. During the author's internship, a few workshops focused on fibre evaluation for the farmers. These workshops showed that farmers usually do not know how to count their salaries and the prices of alpaca fibre products.

The utilization of pack animals was also mentioned in the questionnaires. However, it was not the main purpose of SACs farming, which corresponds with Guttiérez et al., (2018) which also reported a decrease in this utilization in recent years. Better road construction development in distant communities can mean that SACs are used for transport less frequently. The preference for utilization of the SACs for tourism is seen in Ecuador more frequently, probably due to the easier generation of economic income. According to Aviles-Esquivel et al. (2018), recently, SACs are also kept as pets, with better adaptation to high altitudes. The variety of purposes of SACs farming is seen across the Andean husbandries. Further investigation in local areas is needed to understand the trends in SACs husbandry and to effectively support the farmers and achieve higher economic incomes.

5.3 Reproductive management of SACs

Reproductive management and modern reproductive techniques are often entirely absent in the Andes (Brown, 2000; Reyna, 2006), even though, it can significantly influence SACs reproductive efficiency (Sumar, 1996; Rojas et al., 2021). Local farmers often cannot try new techniques for economic or logistic reasons, or they are often apprehensive (Bello-Bravo et al., 2024). According to this survey, Peruvian farmers keep the males and females separated more often than in Ecuador. This could be connected with the lower experience of the SAC farmers in Ecuador or their limited knowledge. Nevertheless, other factors can also be involved, such as the size of the husbandry are, the number of animals or the economic situation of the farmers. The separation of the males can positively affect reproduction and sexual appetite, as found by Mammani-Cato et al. (2014), and can promote ovulation (Bravo and Sumar, 1989). The timing of all activities in SACs husbandry plays a significant role in reproductive efficiency, as reported also by Cruz et al. (2020). Even with the long gestation, it is possible to have one cria per year (Hallowell, 2019), but the proper management techniques must be implemented.

When the animals reach the optimum age and weight (Brown, 2000), they are selected for breeding or meat purposes. This survey observed that 80% of farmers select the animals according to their size and colour. The colour is a very important selection criteria, with regard to fibre production (Markemann and Zárate, 2010; McGregor et al., 2006). In Peru, most herds are white because this colour is preferred for fibre production (Quispe et al., 2009). Moreover, Peruvian farmers paid more attention to the animal pedigree, which can contribute to better fibre and meat characteristics (Aguilar et al., 2014), as reported also by the interviewed farmers. According to the results, the mean age at the first breeding of SACs females was 2.1 ± 0.53, which is much later reported by Sumar (1996) or Raggi (2005). Later selection for breeding can be a consequence of the limited grazing possibilities in the Andes and thus delays in reaching the optimal body weight necessary for breeding (Smith et al., 1994; Sumar, 2000; Aguilar et al., 2014). Moreover, based on the survey, the females are introduced to breeding later in Peru than in Ecuador, which can be again connected with lower feeding sources in the dry season. The males are usually selected for breeding at two or three years (Smith et al., 1994), as confirmed by the farmers in this survey.

Other reproductive parameters did not vary between the two countries. The mean weaning age of the crias was similar to other studies focused on SACs (Aygala-Vargas, 2018; Zárate, 2021); however, the more experienced farmers weaned the crias significantly earlier. In Peru, covering the udder to control the weaning is practiced (INIA, 2000), but herds without controlled weaning were also reported in this study. If the cria is not weaned, it can suckle the milk until one year and a half (Aygala-Vargas, 2018). This suggests that the farmer´s SAC farming experience could affect reproductive and productive efficiency. Efficiency could be improved by gaining knowledge from workshops, developing programs in alpaca reproduction in the country, and keeping more detailed registers of the animals.

The rainy season is preferred for reproductive activities in the Andes because of the warmer weather and more sources of pasture (Sumar, 2010; Cruz et al., 2015; Prince, 2016; Cruz et al., 2020). That is why the reproductive season in Peru coincides with the rainy season, and with occurring mainly from December to April (Prince, 2016; Cruz et al., 2020). The studies focusing on SACs breeding do not observe different reproductive seasons in Peru (Smith et al., 1994; Markemann and Zárate, 2010; Prince, 2016; Cruz et al., 2020). The occurrence of calving in Peru is consistent with these studies, while in Ecuador, the reproductive activity was reported throughout the year, with a peak during February and March (Figure 12). Calving throughout the year is possible in SACs (Vyas et al., 2004), potentially facilitating better opportunities and more efficient reproductive management of SACs in Ecuador. However, Peruvian farmers have observed that the rainy season has started later during the last twenty years (Mark et al., 2010). The present survey also reported that the change in the rainy season is one of the biggest issues, together with internal and external parasites. Pastoralists are facing shifts in precipitation patterns, which affect the quality and amount of fodder for animals (Postigo, 2020). According to Frezzato et al. (2020), it is evident that insufficient nutrition and parasites adversely impact SACs reproductive performance. However, monitoring systems for parasites are often not implemented in these areas. Supplementary feeding could also improve the situation. These are areas that researchers, local authorities, and future training initiatives for farmers should address.

5.4 Alpaca nursing behaviour

The SAC's nursing behaviour is not well studied. Pouillon et al. (2001) investigated the nursing behaviour only on six llama *(Llama glama)* dams. The results of this thesis found similar nursing behaviour in Central Europe and the Andes, although there are differences in climate conditions, pasture areas, and breeding practices. It can be assumed, that the SAC's nursing behaviour is not affected by these factors. The nursing was initiated mainly by the cria and terminated mainly by the dam in both locations. Dams initiated nursing only in crias younger than two months. When the crias became older, they were more active and initiated nursing more frequently (von Keyserlingk and Weary, 2007). When the dam initiated the nursing, she accompanied it with vocalization. The most common ways of initiation and termination of nursing are consistent with Aba et al. (2010). When the dam terminated the nursing, it was significantly shorter, which was similar to the observations of Wronski et al. (2006).

This study observed differences in nursing duration between the Andes and Central Europe. However, interactions between location and sniffing by a dam or location and cria position were identified as more important factors affecting the nursing duration. When the nursing was initiated by the dam in Central Europe, it was significantly longer, consistent with Hejcmanová et al. (2011). However, this pattern was not proved in the Andes. Possible factors that influence the nursing duration in the Andes are the dry season and the limited pasture abilities and feeding sources, especially in Peru (Bryant and Farfan 1984; Bryant et al. 1989). Thus, alpaca crias in the Andes are more dependent on nutrition from their mothers. Also, other factors such as the husbandry system, cria age, and cria sex can influence the nursing duration. Some studies found that nursing is longer in male giraffes (Gloneková et al., 2020b), deer (Drábková et al., 2008), or Bactrian camels (Brandlová et al., 2013). In contrast, studies by Cameron et al. (1999) and Pluháček et al. (2010) found that the nursing duration was longer in female calves. However, in this study, the effect of crias' sex was significant only in combination with other factors; female cria nursing was shorter when the dam terminated it.

The main nursing positions of alpaca nursing in the Andes and Central Europe were antiparallel and perpendicular. The same preference was observed in llamas (Poullion et al., 2001). The parallel position occurs with lower frequency in both locations, probably because this position makes recognition of the young more difficult for the dams (Packer et al., 1992). However, in Central Europe, this position was seen more frequently (13.86%) than in the Andes (0.86 %). The nursing duration of alpacas was significantly shorter in parallel position, which was seen in giraffes (Gloneková et al., 2017) and llamas (Pouillon et al., 2001). As found in this thesis, the duration of the nursing was significantly shorter without sniffing, which was observed in Giant eland (Hejcmanová et al., 2011) and giraffes (Gloneková et al., 2020b). This suggests that smell plays an important role in the identification of crias and maternal behaviour in alpacas (Pilarczyk et al., 2023). However, other factors such as the size of the pasture area, the number of animals per herd and higher disturbance by wild animals can play a role in the nursing duration in alpacas.

5.5 Occurrence of allonursing

The results showed that allonursing is present in alpacas. Although this behaviour was previously seen in other camelid species, like Bactrian camels (Brandlová et al., 2013) or farmed guanacos (Zapata, 2010), this behaviour was not previously described in domestic SACs. Allonursing attempts were observed in both locations, but all cases of successful allonursing were observed only in Central Europe. This behaviour in alpacas was much less frequent than reported in captive fallow deer (Pélabon et al., 1998) or river buffalo (Murphey et al., 1995). Zapata et al. (2010) also observed a higher frequency of allonursing in farmed guanacos in their study. This suggests that allonursing in alpacas is present but it is very rare. All cases of allonursing or allonursing attempts were initiated by the cria when the filial cria was simultaneously close to the dam. It is possible that the crias used the presence of the filial cria to increase the success of suckling (Brandlová et al., 2013), which supports the milk theft hypothesis (Gloneková et al., 2016), similar to guanacos (Zapata, 2009). This is consistent with giraffes, where non-filial calves only succeeded with the filial calf (Saito and Idani, 2018). However, in camels, calves were also successful without the filial calf (Brandlová et al., 2013). Nursing of non-filial crias without the simultaneous nursing of the filial cria was confirmed by Zapata (2009) in guanacos. In the work of Gloneková et al. (2016), the calves could also be nursed without the filial calf present. However, this was not seen in Central Europe where non-filial crias always joined the filial crias in nursing. The dam terminated the allonursing and the attempts in this study, consistent with Saito and Idani (2018).

Studies focused on allonursing also reported that the most common position during the allonursing is parallel (Bartoš et al., 2001; Olléová et al., 2012; Engelhardt et al., 2014) probably due to the more complicated recognition of the young (Packer et al., 1992). However, this study observed contradictory results where successful allonursing was seen mainly in the perpendicular position (80%). The parallel position was also observed in allonursing attempts in this study. However, detailed statistical analyses could not be applied due to the rare occurrence of allonursing in this study (n=5).

Although allonursing was not directly observed in the Andes, it cannot be completely ruled out due to the high number of animals in the herds, which makes identifying filial dam-cria pairs harder. As revealed by the questionnaires, some farmers reported that they had seen allonursing in their herds before. However, this behaviour also may have occurred in the small enclosures where alpacas were kept after the pasture and during hours when observations were not made. This assumption is also supported by observations in Central Europe where most allonursing cases were observed in stables. So, it can be deduced that smaller spaces with higher concentrations of animals, where dams are less likely to recognise the cria, will increase the incidence of allonursing (Vilagran, 2009).

Further and more detailed research of the nursing behaviour of domestic SACs, including 24-hour observations, can be recommended. Research on a question why allonursing occurrence is so rare in domestic alpacas when it was much more common in other camelids, like guanacos (Zapata 2009, 2010) or Bactrian camels (Brandlová et al., 2013) and which factors increase its incidence is also needed. The occurrence of allonursing can affect husbandry management significantly. Allonursing dams face higher nutritional needs (Zapata, 2010), and their crias could suffer from a lack of milk (Landete-Castillejos et al., 2000), meaning that supplementary feeding in such cases should be provided. On the other hand, allosuckling crias can improve their nutrition and gains (Zapata 2010) and when weaker or orphaned young are combined with dams which perform allonursing, they can be reared without artificial feeding (Haberová et al. 2012).

6 Conclusion

This thesis summarizes current knowledge about camelids´ reproductive performance and husbandry management. It is evident that reproductive performance is affected by several factors that often interact with it. Management factors, such as improper management techniques, poor nutritional conditions during gestation and lactation, and lack of health care have a large impact on the reproduction efficiency of camelids.

Substantial gaps in knowledge exist regarding the factors which may affect dromedary camel reproductive performance. Studies focused primarily on the female dromedary camel reproductive performance are limited, and fewer investigate the factors that could affect it. A proper description of the management and mating practices used is absent in many studies, limiting the broader interpretation of published results. Dromedary camels suffer poor fertility rates in tropical areas, mainly when reared in pastoral management systems. Their unique reproduction physiology and its effects on successful breeding management are further complicated by the challenging climate conditions in the tropics, such as annual rainfall, temperature, and the photoperiod, which influence almost every aspect of camel reproductive success. Management techniques in dromedary camel husbandries differ between the various production systems used, often resulting in lower reproductive performances in pastoral herds. High abortion rates and calf mortalities are further exacerbated by inadequate feeding during gestation and lactation, improper calf-rearing management, and poor health care. However, with the current state of knowledge, it is impossible to precisely attribute which factors affect specific reproductive parameters precisely. Additional research should be focused on further understanding the husbandry practices of camels under various production systems or local conditions. Moreover, research should also be focused on local knowledge regarding dromedary camel production within the tropics and subtropics to provide context-specific solutions for improving calving rates and survival whilst considering the longevity and health of breeding females.

SACs farming is essential for local farmers, but there are several differences in husbandry management in the Andean region. However, Ecuadorian and Peruvian farmers face the same problems, such as internal and external parasites and lack of animal pasture, which should be an area of focus for local organizations. Research on alternative feed sources for SACs, proper management of pastures, and effective handling of animal waste could help farmers mitigate these problems and face issues linked with climate change challenges. Since the results include a small number of farmers, further investigation of SACs farmers' needs and limitations is desirable in order to plan proper support in spite of the differences in farmers' gender and experience levels.

The results of this thesis contribute significantly to the understanding of maternal behaviour in alpacas and may help farmers monitor and evaluate the nursing behaviour of their animals. The alpaca nursing behaviour in the Andes and Central Europe showed remarkable similarities despite being in entirely different locations with different environments and management. The different husbandry management does not affect the species' maternal and nursing behaviour like it influences the reproductive performance. However, the influence of environmental and management factors on alpacas' nursing behaviour requires further investigation. The first occurrence of allonursing in domestic SACs was confirmed in Central Europe. Although this behaviour was not observed in the Andes through direct observation, the presence of allonursing was confirmed by local farmers. These findings showed that allonursing occurs not just in the wild SACs but also rarely in domestic SACs. Further research on specific factors affecting the occurrence of allonursing is recommended.

Future studies focused on camelids' reproductive performance should be conducted in regions such as Middle and Western Africa, where literature regarding this topic is limited and dromedaries are increasing, and the other Andean countries, where research focused on SACs is almost completely absent. Therefore, future research should focus on the detailed monitoring of breeding management practices in cooperation with local farmers and establish a proper experimental design of a monitoring system of specific factors affecting reproductive performance in camelids.

7 References

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8 Appendices

List of appendices

Appendix 1: SACs husbandry questionnaire

Husbandry and breeding practices of South American camelids in Ecuador and Peru, and the impact of country, gender, and farming experience thereon

Tropical Animal Health and Production

Jana Marešová, Tersia Kokošková, Tamara Fedorova*

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Informed consent for questionnaire survey

Author: Ing. Jana Marešová

Dear Madam, Sir,

I am writing to you with a request to participate in a research study that we are conducting at the Faculty of AgriSciences, Czech University of Life Sciences, that aims to obtain data on:

South American husbandry techniques and management, the purpose of your farming, the selection criteria, and the main problems in your husbandry

Your participation consists of filling out a questionnaire that will take approximately 8-10 minutes. The questionnaire is anonymous, so your personal data will not be published anywhere.

The information obtained through the questionnaires will be used exclusively for scientific purposes. It will be presented to the professional public or published anonymously in the professional press.

Your participation will significantly contribute to expanding knowledge in the research area and writing a scientific article needed for the author's dissertation thesis. If you feel a question is too personal, you do not have to answer it.

Thank you.

South American camelids - Questionnaire

Information about the farm and respondent

Date:

Location:

Farm:

Respondent name & gender:

1. What is the purpose of your llama breeding?

	Primary	Minor	Unimportant
Meat			
Fibre			
Skin			
Transport			
Ceremonies			
Grazing			
Tourism			
Other:			

2. How long do you breed llama?

____

3. How many llamas do you breed?

	Llamas	Alpacas	Others
Males			
Females			
Crias (until weaning)			

4. How many people are involved in your llama breeding?

Owner himself only
All family members
All adult family members
Owner and paid workers
Only paid (hired) workers
Others ____________________________

5. What is your type of grazing?

Free extensive pasture
Pasture with shepherd
Mixed grazing with other livestock
Grazing and supplementary feeding
Others ____

6. If you apply mixed grazing, what are the others animal species?

Cattle
Sheep
Horses
Donkeys
Others ____

7. What is your herd organization?

Males and females separately
Males and females together

One female per flock of females
Cria separated after weaning
The cria remain with mother even after weaning
Variable by season
Others ____

8. **What are the months of births?**
January
February
March
April
May
June
July
August
September
October
November
December

9. **What breeding management methods do you use?**
None – all animals in one herd all year around
Controlled admission - selected males with females on mating season
Males and females are selected for mating
Controlled weaning – all crias leave the herd at the age of …….
Cria males leave the herd at age …….. females remain in the herd
Note

10. **At what age are animals included in breeding?**
Males ________ months
Females ________ months

11. **What are you selection criteria for the males?**

Males	Priority	Secondary	Not important
Size			
Conformation			
Colour			
Temperament			
Growth rate			
Skin quality			
Libido			
Long distance walking capacity			
Pedigree			
Others			

12. **What are you selection criteria for the females?**

Females	Priority	Secondary	Not important
Size			
Conformation			

Colour			
Temperament			
Growth rate			
Skin quality			
Libido			
Long distance walking capacity			
Pedigree			
Others			

13. **How many males do you use for breeding?**

____

14. **At what age are the young ones weaned?**

____

15. **What are the main problems in your llama breeding?**

	Serious problem	Slight problem	Non problematic
Lack of pastures			
Congenital malformations of crias			
Internal parasitic diseases			
External parasitic diseases			
Infectious diseases			
Fertility problems			
Technical problems or handling problems			
Administrative problems			
Economic problems			

Appendix 2: Allonursing behaviour questionnaire

Nursing Behaviour in Alpacas: Parallels in the Andes and Central Europe, and a Rare Allonursing Occurrence

Jana Marešová [1], Tersia Kokošková [1], Eliška Tichá [1], Tamara Fedorova [1*]

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Questionnaire Sample – Allonursing behaviour

Participants were informed as follows:
The questionnaire is anonymous, so your personal data will not be published anywhere.
The information obtained through the questionnaire will be used exclusively for scientific purposes. It will be presented to the professional public or published anonymously in the professional press.
Your participation will significantly contribute to expanding knowledge in the research area and writing a scientific article needed for the author's dissertation thesis. If you feel a question is too personal, you do not have to answer it.

Information about the farm and respondent

Date:

Location:

Farm:

Have you noticed an occurrence of allonursing in your herd? (nursing of non-filial cria)

YES

NO

Appendix 3: Reproductive parameters of female dromedary camels within different climatic zones

Table 10a. Summary of the reproductive performance indicators reported for dromedary camels from the reviewed studies[1] conducted within different climatic zones, as classified according to the Köppen-Geiger classification – arid regions.

Climate	Arid			
	BSh	BWh	BSh & BWh	Other arid
Number of studies	3	61	28	4
Mean length of pregnancy (months)	12.3-12.7	12.0-12.8	12.0-13.0	12.0-12.8
Mean male age of puberty (months)	42.0	48.0-67.5	48.0-66.0	48.0
Mean female age of puberty (months)	36.0	31.1-57.0	37.4-53.0	39.6-40.2
Abortion rate (%)	N/A	5.1-11.1	6.1-50.0	60.0
Calf mortality (%)	N/A	5.4-66.7	3.0-61.5	11.0
Average lifespan (years)	N/A	20.0-23.5	18.4-29.8	32.8

[1]the review methodology is detailed in methodology; BSh = hot semi-arid (steppe) climate; BWh = hot deserts climate; N/A = data were not found by literature review based on the selected criteria.

Appendix 4: Reproductive parameters of female dromedary camels in different climatic zones

Table 10b. Summary of the reproductive performance indicators reported for dromedary camels from the reviewed studies[1] conducted within different climatic zones, as classified according to the Köppen-Geiger classification - regions other than arid.

Climate	**Equatorial**	**Warm**	**Arid & Equatorial**	**Arid & Warm**	**Warm & Equatorial**	**Arid, Warm & Equatorial**
	As & Aw	**Csa & Cwa**	**mix**	**mix**	**mix**	**mix**
Number of studies	5	4	2	6	4	4
Mean length of pregnancy (months)	12.4	12.2-12.3	13.0	12.4-12.8	12.0	12.6
Mean male age of puberty (months)	N/A	36.0-54.0	N/A	N/A	23.4	N/A
Mean female age of puberty (months)	N/A	24.0-36.0	N/A	51.0-55.2	22.3	N/A
Abortion rate (%)	8.4-21.0	N/A	N/A	11.6	8.6	6.8
Calf mortality (%)	27.0-27.8	N/A	N/A	14.0-16.4	7.0-66.7	30.6
Average lifespan (years)	16.5	N/A	20.0	20.0-22.5	N/A	N/A

[1]the review methodology is detailed in methodology; As = tropical dry savanna climate; Aw = tropical savanna, wet climate; Csa = hot-summer Mediterranean climate; Cwa = monsoon-influenced humid subtropical climate; mix = combination of more climatic zones; N/A = data were not found by literature review based on the selected criteria.

Appendix 5: Reproductive parameters of female dromedary camels in different husbandry systems

Table 11. Summary of the reproductive performance indicators reported for dromedary camels[1] conducted according to different husbandry systems across the tropical regions of Africa and Asia – intensive and semi-intensive systems.

Husbandry system	Intensive			Semi-intensive			
Region	**Northern Africa**	**Western Asia**	**Southern Asia**	**Northern Africa**	**Eastern Africa**	**Western Asia**	**Southern Asia**
Number of studies	11	7	4	5	1	1	4
Typical herd composition (male:female)	1:40	N/A	1:50	1:25-1:50	N/A	1:13	1:30-1:35
Female age at first mating (months)	31.8-92.2	39.8-42.3	57.0	54.0	N/A	N/A	36.0-54.0
Calving interval (months)	17.5-20.8	19.7-22.6	22.2-27.0	18.5-25.0	25.3	36.0	22.0-24.3
Calving rate (%)	33.3-80.0	80.5-82.6	N/A	N/A	N/A	N/A	19.6
Abortion rate (%)	N/A	5.1-6.8	N/A	N/A	5.6	N/A	N/A
Calf mortality (%)	32.0	N/A	N/A	N/A	4.0	27.0	11.0
Weaning Age (months)	12.0	N/A	10.0	1.0	N/A	N/A	12.6
Average lifespan (years)	N/A	N/A	N/A	21.0	N/A	N/A	N/A

[1]the review methodology for selection of studies is detailed in methodology; N/A = data were not found by literature review based on the selected criteria.

Appendix 6: Academic CV of the author

Personal data

Name: Jana Marešová

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Education:

10/2018-3/2025 PhD studies, Czech University of Life Sciences Prague, Department of Animal Science and Food Processing, Faculty of Tropical AgriSciencesTitleof PhD thesis - Breeding Management Practices, Maternal Behaviour and Reproductive Performance in Camelids.

9/2015-5/2017 MSc studies, Czech University of Life Sciences Prague, Faculty of Agrobiology. Food and Natural Resources. Title of master thesis - Reparative potential of mesenchymal stem cells in bisphenol S-stressed hepatocyte culture.

9/2012-5/2015 BSc studies, Czech University of Life Sciences Prague, Institute of Tropics and Subtropics. Title of BSc thesis - Comparison of guinea pig farmingin Latin America and Europe.

9/2008-5/2012 General grammar school “Nad Alejí”, Prague, general studies ended by Leaving exam.

Work experiences:

9/2021- present Teacher at primary school “Fakultní ZŠ Pedagogické fakulty Trávníčkova”

8/2022 - present Figure skating lector

9/2017-9/2019 Teacher at “Anglicky za rok”

Other skills:

Languages: Czech – native, English – active, Spanish – active, German – passive

Computer: MS Office, Statistica CZ, EndNote, Adobe Photoshop

Sports: Figure skating

Teaching:

Participation on selected lectures of courses during the PhD studies:

Chov zvířat v tropech (Animal Breeding in Tropics)

Úvod do tropického zemědělství (Introduction to Tropical Agriculture)

Základy výživy zvířat v tropech (Elements of Animal Feeding in Tropics)

Published articles:

Marešová, J.; Kokošková,T.; Tichá, E.; Fedorova, T. Nursing Behaviour in Alpacas: Parallels in the Andes and Central Europe, and a Rare Allonursing Occurrence. *Animals,* 2025, *15*, 916. https://doi.org/10.3390/ ani15070916

Articles under review:

Marešová, J., Kokošková, T., Fedorova, T. Husbandry and breeding practices of South American camelids in Ecuador and Peru, and the impact of country, gender, and farming experience thereon. *Tropical Animal Health and Production*.

Internships:

4/2022-5/2022 Escuela Superior Politécnica de Chimborazo (ESPOCH). Riobamba. Ecuador

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Conferences:

2nd World Congress on Veterinary Medicine, May 26-27, 2021 (Webinar) - presentation
48. Ethological Conference ČSEtS, November 5-6, 2021 (online) - poster
2nd International Multidisciplinary Conference for Young Researchers, Sustainable development trends and challenges under Covid-19, November 29-30, 2021, Sumy, Ukraine (Webinar) - presentation