WORKING PAPER

# A review of goat reproduction in East and Horn of Africa

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# Abbreviation list

| | |
|---|---|
| AI | Artificial Insemination |
| ART | Assisted Reproductive Technologies |
| AV | Artificial Vagina |
| BCS | Body Condition Score |
| CBBP | Community Based Breeding Programmes |
| CL | Corpus Luteum |
| eCG | Equine Chorionic Gonadotrophin |
| ET | Embryo Transfer |
| FGA | Fluorogestone Acetate |
| FSH | Follicle Stimulating Hormone |
| GnRH | Gonadotrophic Releasing Hormone |
| IVF | In Vitro Fertilization |
| KISS1 | Kisspeptin |
| MAP | Medroxyprogesterone Acetate |
| MOET | Multiple Ovulation and Embryo Transfer |
| $PGF_{2}\alpha$ | Prostaglandin |
| PP | Postpartum |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| SC | Scrotal Circumference |
| SEA | Small East African |
| SNP | Single nucleotide polymorphism |

# Glossary

**Anestrus**: applies to nonhuman mammals: a state or interval of sexual inactivity between two periods of estrus. (Agrovoc)

**Artificial Insemination (AI)**: placement of fresh or thawed frozen semen into the female mechanically without normal sexual contact. (Agrovoc)

**Assisted Reproductive Technologies (ARTs)**: ART includes all fertility treatments in which either eggs or embryos are handled. In general, ART procedures involve surgically removing eggs from a woman's ovaries, combining them with sperm in the laboratory, and returning them to the woman's body or donating them to another woman. (Centers for Disease Control and Prevention CDC)

**Blastocyst**: a ball of cells that forms early in a pregnancy, about five to six days after a sperm fertilizes an egg. (Cleveland Clinic)

**Brucellosis**: a disease caused by an infection with the gram-negative bacteria Brucella. This disease is characterised by fever, muscular pain, or sweating. Transmission is by ingestion of unpasteurized milk and soft cheeses made from infected animals. (Agrovoc)

**Buck effect**: exposure to males after a period of isolation – at least three weeks and one mile away – can be used for induction and synchronization of estrus during the breeding and non-breeding season without additional treatments in goats. The physiological basis for this response is due in part to smell and sight, with neither stimulus completely accounting for the response. (Extension Foundation)

**Conception rate**: the percentage of matings that result in the successful fusion of egg and sperm to produce a zygote. Term can be used to describe individuals as well as groups or populations that share a common characteristic. (USDA NAL Agricultural Thesaurus)

**Corpus Luteum**: the corpus luteum (Latin for "yellow body"; plural corpora lutea) is a temporary endocrine structure in female ovaries and is involved in the production of relatively high levels of progesterone and moderate levels of estradiol and inhibin A. It is the remains of the ovarian follicle that has released a mature ovum during a previous ovulation. (DBpedia)

**Cotyledonary placenta**: a placental unit of trophoblastic origin consisting of abundant blood vessels and connective tissue. (Wikivet)

**Crossbreeding**: involves the mating of animals from two breeds. Normally, breeds are chosen that have complementary traits that will enhance the offsprings' economic value. (The Britannica Dictionary)

**Embryo transfer**: Embryo transfer refers to a step in the process of assisted reproduction in which embryos are placed into the uterus of a female with the intent to establish a pregnancy. This technique (which is often used in connection with in vitro fertilization (IVF), may be used in humans or in animals, in which situations the goals may vary. (DBpedia)

**Estrus**: the period in the sexual cycle of female mammals, except the higher primates, during which they are in heat. (The Britannica Dictionary)

**Estrus synchronization**: involves manipulating the females' estrus cycle so they can be bred at about the same time. (University of Georgia Extension)

**Fertility**: The capacity to conceive or to induce conception. It may refer to either the male or female. (Agrovoc)

**Follicle**: or Ovarian Follicle, is a fluid-filled sac in the ovary that contains an egg that has not yet matured for sperm fertilization. During the menstrual cycle, an egg matures, and the follicle opens and releases the egg, preparing it for fertilization. (Medical News Today)

**Follicular phase**: The follicular phase of the estrus cycle refers to the narrow period of time right before estrus (heat) and ovulation (release of the egg for possible fertilization). During this phase, there is rapid growth of a dominant ovarian follicle and increased estrogen production. (U.S Food and Drug Administration)

**Follicle Stimulating Hormone**: a hormone produced by the anterior lobe of the pituitary gland that stimulates the growth of the ovum-containing follicles in the ovary and activates sperm-forming cells. (Merriam-Webster Dictionary)

**Gonadotropin**: any of several hormones occurring in vertebrates that are secreted from the anterior pituitary gland and that act on the gonads. (The Britannica Dictionary)

**Growth hormone**: also called somatotropin, is a peptide hormone secreted by the anterior lobe of the pituitary gland. It promotes growth of bone and other body tissues by stimulating protein synthesis and fat breakdown (for energy). (The Britannica Dictionary)

**Heritability**: the degree to which a given trait is controlled by inheritance, as opposed to being controlled by non-genetic factors. (Agrovoc)

**Hypothalamus**: a part of the brain that contains a number of small nuclei with a variety of functions. One of the most important functions is to link the nervous system to the endocrine system via the pituitary gland. (DBpedia)

**Implantation**: in reproduction physiology, it refers to the adherence of a fertilized egg to a surface in the reproductive tract, usually to the uterine wall, so that the egg may have a suitable environment for growth and development into a new offspring. (The Britannica Dictionary)

**In vitro fertilization (IVF)**: fertilization by mixing sperm with eggs surgically removed from an ovary followed by uterine implantation of one or more of the resulting fertilized eggs. (Merriam-Webster Dictionary)

**Luteal phase**: a stage of the ovarian cycle which lasts until the corpus luteum degenerates (luteolysis) and estradiol and progesterone production decreases. (The Britannica Dictionary)

**Luteinizing hormone (LH)**: a hormone secreted by the anterior lobe of the pituitary gland that in the female stimulates ovulation and the development of corpora lutea and in the male the development of interstitial tissue in the testis. (Merriam-Webster Dictionary)

**Luteolysis**: also known as luteal regression, is the structural and functional degradation of the corpus luteum, which occurs at the end of the luteal phase of both the estrous and menstrual cycles in the absence of pregnancy. (DBpedia)

**Leydig cells**: a cell of interstitial tissue of the testis that is usually considered the chief source of testicular androgens and especially testosterone. (Merriam-Webster Dictionary)

**Libido**: is a person's overall sexual drive or desire for sexual activity. Libido is influenced by biological, psychological, and social factors. (DBpedia)

**Mass motility (of sperm)**: is the ability of sperm to move efficiently. (Medical News Today)

**Melatonin**: is primarily known in animals as a hormone released by the pineal gland in the brain at night, and has long been associated with control of the sleep–wake cycle. (DBpedia)

**Met-estrus**: is the period in the estrus cycle following estrus, characterized by lack of sexual activity. (Collins Dictionary)

**Metabolism**: the chemical reactions that occur within the cells, tissues, or an organism. These processes include both the biosynthesis (anabolism) and the breakdown (catabolism) of organic materials utilized by the living organism. (Agrovoc)

**Neuroendocrine**: of, relating to, or denoting the dual control of certain body functions by both nervous and hormonal stimulation. (Collins Dictionary)

**Neuter**: usually refers to the action of removing the sex organs from a male animal. (The Britannica Dictionary)

**Oestradiol**: is the most potent of the estrogens. Functioning similarly to androgens, the estrogens promote the development of the primary and secondary female sex characteristics. (The Britannica Dictionary)

**Oocytes**: also called egg cell, or ovum (plural ova), is the female reproductive cell, or gamete, in most anisogamous organisms. (DBpedia)

**Ovulation**: the release of mammalian egg(s) from the ovary. (Agrovoc)

**Osmosis**: Osmosis is the spontaneous net movement or diffusion of solvent molecules through a selectively-permeable membrane from a region of high water potential (region of lower solute concentration) to a region of low water potential (region of higher solute concentration), in the direction that tends to equalize the solute concentrations on the two sides. (DBpedia)

**Pedigree**: The record of descent or ancestry, particularly of a particular condition or trait, indicating individual family members, their relationships, and their status with respect to the trait or condition. (Agrovoc)

**Pheromones**: a chemical substance that is usually produced by an animal and serves especially as a stimulus to other individuals of the same species for one or more behavioural responses. (Merriam-Webster Dictionary)

**Pituitary gland**: or hypophysis, is an endocrine gland, about the size of a chickpea and weighing, on average, 0.5 grams (0.018 oz) in humans. It is a protrusion off the bottom of the hypothalamus at the base of the brain. (DBpedia)

**Placental lactogen**: a hormone secreted by the syncytiotrophoblast that inhibits production of maternal insulin during pregnancy. (Merriam-Webster Dictionary)

**Placentome**: the whole group of fetal and maternal tissues that are involved in placentation. (Merriam-Webster Dictionary)

**Prolactin**: also known as lactotropin, is a protein best known for its role in enabling mammals to produce milk. (DBpedia)

**Progesterone (P4)**: is an endogenous steroid and progestogen sex hormone involved in the menstrual cycle, pregnancy, and embryogenesis of humans and other species. (DBpedia)

**Progestagens**: Compounds that interact with progesterone receptors in target tissues to bring about the effects similar to those of progesterone. (Agrovoc)

**Proceptivity**: the period during mating behaviour when females actively solicit males for copulation. (American Psychological Association)

**Prostaglandin ($PGF_{2\alpha}$)**: a naturally occurring prostaglandin that has oxytocic, luteolytic, and abortifacient activities. Due to its vasocontractile properties, the compound has a variety of other biological actions. (Agrovoc)

**Pyometra**: accumulation of pus in the uterus, normally caused by severe bacterial infection. (Agrovoc)

**Spermiogram**: A record of examining and classifying sperm in a semen sample. (Medical Dictionary Farlex)

**Spermatozoa**: is a motile sperm cell, or moving form of the haploid cell that is the male gamete. (Agrovoc)

**Sire**: the male parent of an animal and especially of a domestic animal. (Merriam-Webster Dictionary)

**Laparoscopy**: is an operation performed in the abdomen or pelvis using small incisions with the aid of a camera. The laparoscope aids diagnosis or therapeutic interventions with a few small cuts in the abdomen. (DBpedia)

**Testosterone**: is the primary sex hormone and anabolic steroid in males. In humans, testosterone plays a key role in the development of male reproductive tissues such as testes and prostate, as well as promoting secondary sexual characteristics such as increased muscle and bone mass, and the growth of body hair. (DBpedia)

**Toxoplasmosis**: a disease caused by an infection with the protozoan parasite *Toxoplasma gondii*. (Agrovoc)

**Zoonotic disease**: any disease or infection which is naturally transmissible from animals to humans. (Agrovoc)

# I. Introduction

The livestock sector creates livelihoods for 1 billion of the worlds' poor (World Bank, 2007). In the East and Horn of Africa, Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania and Uganda together have approximatively 735 million heads (excluding Tanzania) of cattle, sheep, goats, chickens, rabbits/hares, pigs, turkeys, asses, camels, horses, mules and hinnies, ducks and geese (FAOSTAT, 2020). In these 11 countries, cattle, sheep and goats represent 20.5, 17.4 and 24.7% of the total livestock population, with approximatively 150, 127 and 181 million heads, respectively (FAOSTAT, 2020)[1]. Ethiopia, Kenya and Sudan have the largest number of goats, with approximatively 52, 36 and 32 million heads, respectively (Figure 1). They are followed by Uganda, Tanzania, Somalia and Malawi (15, 15, 11 and 10 million heads, respectively). Djibouti has the lowest number with 517,153 heads of goats.

Goats were the first animal domesticated by humans and by 2020 the world's goat population was estimated to be 1.261 billion (FAOSTAT, 2020). The vast majority of the world's goats (95%) are found in developing countries, with 35% found in Africa (Skapetas and Bampidis, 2016). East African countries contribute 14.4% to the global population (FAOSTAT, 2020) and, in these countries, goat rearing represents one of the largest agricultural sectors, with most goats found in arid and semi-arid areas where they are kept in large flocks by pastoralists (Farm Africa, 1996).

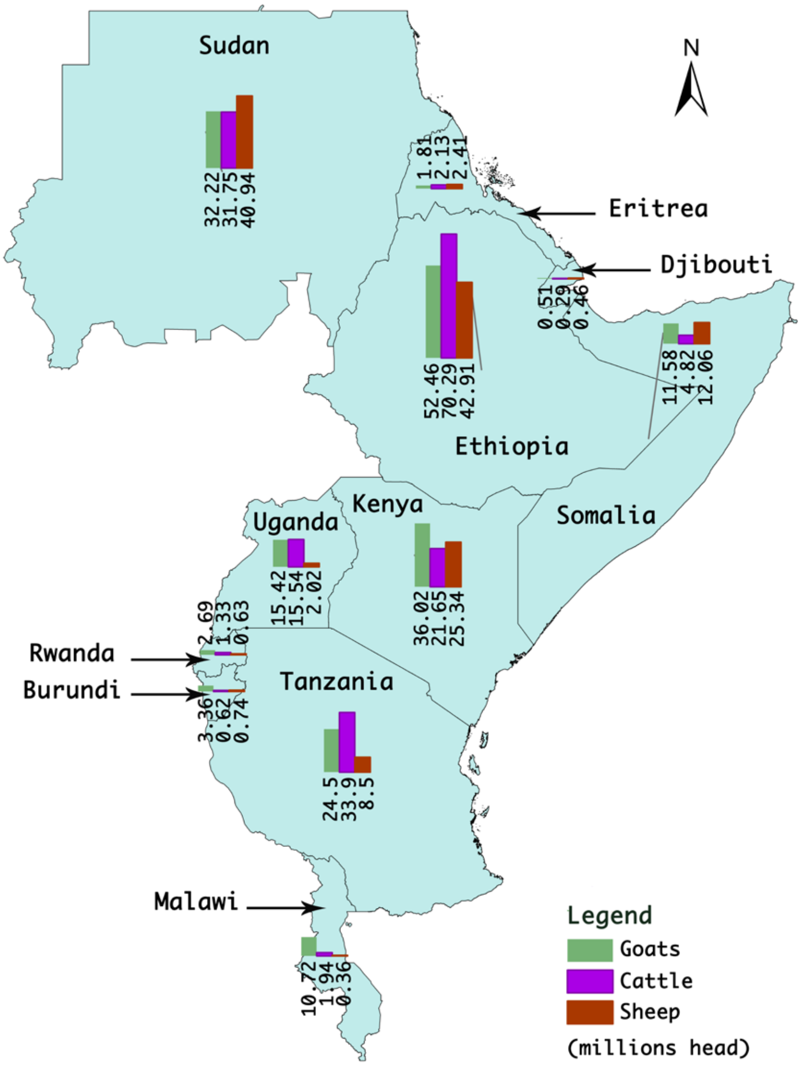



**FIGURE 1: Map representing cattle, sheep and goat populations in 11 countries in East and Horn of Africa (Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania and Uganda)**

1 The data was extracted from FAOSTAT (2020) except for Tanzania where records were those for the year 2017.

Goats are the most prolific of all domesticated ruminants under tropical and subtropical conditions; they are able to breed year-round and are characterized by a higher litter size than sheep, thriving in similar environments. In fact, under small-scale farming systems, poor farmers develop a preference for this activity due to low initial and maintenance costs, ease of management by any member of the family, even children (Mahmoud, 2010), production versatility (goats can produce meat, milk, skins and hides) that is appealing for women and a short generation interval. Goats can feed on a wide range of forages (Peacock, 2005) and have a higher digestion efficiency of bulky feed than cattle and sheep. They are easier to rear and to sell than cattle and require little land and minimal veterinary care (Amin and Silsmore, 1993). Generally, a high dependence on goats by pastoralists is a result of their adaptive capacity in arid environments (tolerant to heat stress, can walk long distances, genuine grazing behavior and valorization of low-quality feed resources).

With an increasing human population, sheep and goat production is becoming a means of survival particularly for the landless youth and female headed households in the rural areas and the demand for their products is increasing (Kosgay et al., 2008). They can even be owned by the landless (Kosgey and Okeyo, 2007).

Goats are socio-culturally important, providing traditional keepers and poor farmers in rural areas with a cash income, insurance against unforeseen events, and meat for home consumption. They also serve as an investment to be drawn upon when needed, and are used for the payment of dowries, traditional/cultural ceremonies, and the provision of skins, milk, and manure.

While indigenous goat breeds are more resilient to climate change, droughts, and extreme weather events than other ruminant species (Pragna et al., 2018), adapt well to local environmental conditions and endemic diseases, and show a low level of reproductive seasonality (Ndeke et al., 2015), they have relatively poor productivity indices (Mbuza, 1998). In tropical areas, native goat production in smallholder systems continue to face many challenges, resulting in low productivity in terms of growth rates, production, and reproduction performance. This could be attributed to overcrowding, poor nutrition and associated stress, causing many health problems and production losses (Lemma, 2002). Feed shortages in quality and quantity, poor access to quality veterinary services, and low management standards aggravate the situation. It is also important to note the lack and weakness of breeding and development programs targeting local goat breeds in the East and Horn of Africa. There have been attempts to establish breeding programs in some of these countries, but no significant impact is documented and very often, these initiatives are limited in time and geographically space.

In Uganda, for example, poor goat health and productivity has been attributed to predators, long kidding intervals as a result of anestrus and the occurrence of diseases such as contagious ecthyma, helminthiasis, trypanosomiasis and brucellosis (Katongole and Gombe, 1985; Siefert and Opuda-Asibo, 1994; Katunguka-Rwakishaya, 1996; Nakavuma et al., 1999). In Mali, 40% of kid mortality is attributed to predators, injuries, and malnutrition (Ba et al., 1996). In Tanzania, diseases account for 40-60% of losses in small ruminant production (Mtenga et al., 1986).

The lack of information about production systems, and the fact that policymakers are often more interested in developing enhanced breeding of large ruminants (Mueller et al., 2015), has resulted in the marginalization of the goat sector. This has resulted in the extensive management of goats with low productivity levels (Devendra, 2010). Marginalization of the goat sector is responsible of the reality today that indigenous tropical goats have a low genetic potential for meat and milk production (Haile et al., 2019).

In East and Horn of Africa, goats are mainly kept for meat production. In some countries, such as Uganda, people generally prefer goat meat to other meats due to its higher supply, lower price, and lower cholesterol content. In contrast, breeds for producing milk have not been of much importance to Africans, since there has not been a tradition of cheese or butter-making. Nevertheless, the change in consumers' preferences, and a new and growing interest in goat milk and goat milk products over the past 20 years globally, has led to a change in goat breeding plans, to seek better productivity and reproductive performances. This has resulted in the strategy of either replacing indigenous breeds with foreign breeds, or crossing indigenous breeds with foreign strains (Kosgey, 2004). The implementation of these strategies over time has, however, been unsystematic, resulting in a mosaic of genotypes (Haile et al., 2019).

In addition to low levels of productivity, indigenous goat breeds – which are often non-seasonal breeders – can exhibit prolonged periods of anovulation or anestrus, reduced ovulation rates, as well as high embryonic and perinatal losses, especially under harsh environmental factors and poor nutrition (Delgadillo and Malpaux, 1996; Walkden-Brown and Restall, 1996). Restricting mating to certain periods of the year has been argued as being an important step to improve the productivity of pastoral goat herds in tropical regions, avoiding does giving birth during unsuitable environmental conditions (Carles, 1983; Bradford and Berger, 1988, pp. 95-109; Delgadillo and Malpaux, 1996). Reproductive efficiency is one of the most important factors affecting the profitability of small ruminant breeding, which needs to be improved to lead to more efficient lamb and kid production (Hanford et al., 2003). We assume that the improvement of the reproductive outcome for goats has a greater economic impact for livestock owners, than the improvement of goats' growth rate.

While goats are an important pillar of livestock and agriculture sectors in East and Horn of Africa, little research is being published and access to unpublished data is very difficult. This working paper attempts to review the male and female reproductive characteristics of goats in 11 countries of East and Horn of Africa (Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania and Uganda), and to summarize studies that have looked at the improvement of reproductive performance of goats, and applications of reproductive biotechnologies, such as artificial insemination and embryo transfer. A section of this paper is dedicated to reviewing the main diseases affecting the reproduction of goats, and analyzing prevalence and main risk factors. This working paper is a first step to fill a gap in knowledge related to reproduction in goats. The volume and quality of information between countries varied considerably, so there are some disproportions in reporting findings and results for certain traits.

# II. Main goat breeds and production systems

In East and Horn of Africa there is a mosaic of breeds, comprising indigenous, cross, and exotic breeds (Table 1). In most countries, goats are raised primarily for meat production, with milk being a secondary product. In recent decades, exotic breeds have been imported, with crossbreeding aiming to upgrade indigenous breeds and be more productive. Uncontrolled crossbreeding, however, has resulted in mixed results across production systems.

In Tanzania, for example, 97% of the goat population are indigenous, belonging to the Small East African (SEA) breed (URT, 2012). This breed includes several ecotypes, namely Ujiji, Sukuma, Maasai, Gogo, Pare, Sonjo and Newala goats (Msanga et al., 2001), and these are characterized by their hardiness and their adaptability under harsh environmental conditions and in marginal areas. They have high reproductive capacity and growth rates, which make them suitable for poor smallholders (Devendra, 1999; Tibbo, 2006). SEA goats are not well characterized from a genotype and phenotype point of view. All strains of indigenous goats are named after either geographic locations where they are predominantly kept or ethnic groups keeping them.

In East and Horn of Africa, goats are raised under a variety of production systems (Figure 2). These include smallholder mixed crop-livestock systems, smallholder intensive systems, extensive pastoral and transhumance systems, and large-scale ranching systems. In Ethiopia, for example, 58% of the goat population are found in the lowlands and are raised in large flocks by pastoralists, while 42% are found in the highlands where there is a strong complementary relationship between small ruminant keeping and cropping (ESGPIP, 2008; Tibbo, 2006).

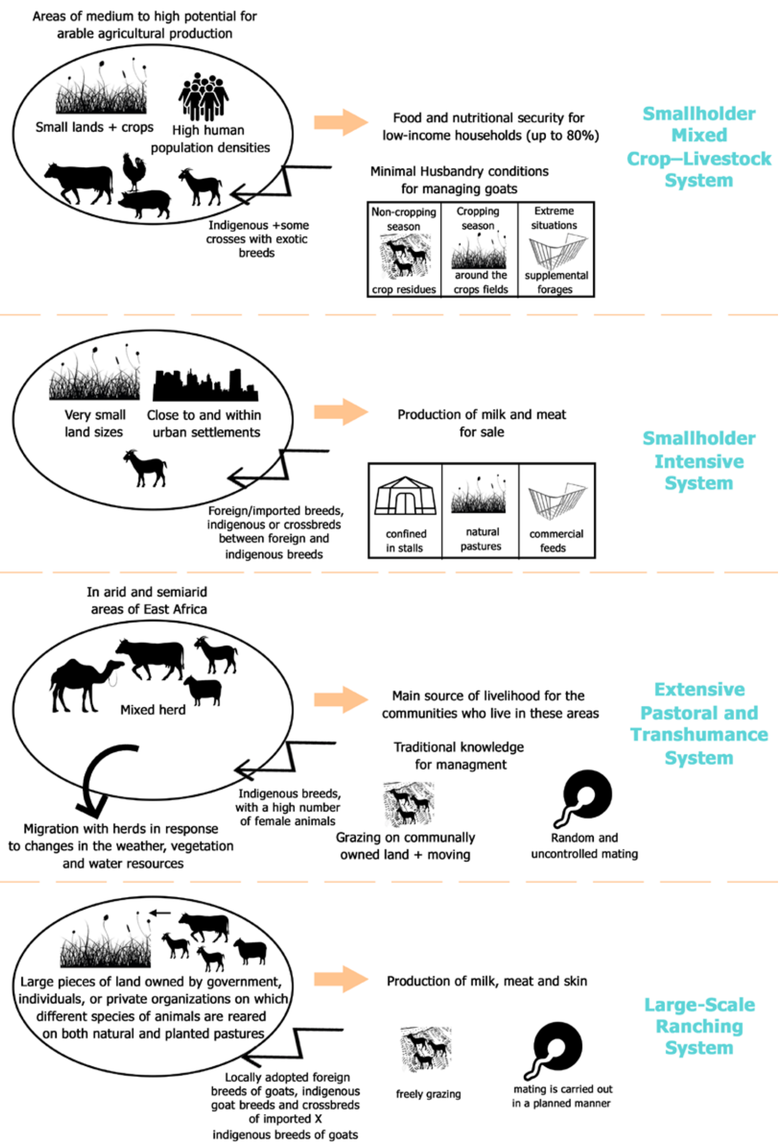



FIGURE 2: Main production systems in East and Horn of Africa

TABLE 1: Main breeds in 11 countries in East Africa, Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania and Uganda and their characteristics

| Breed | Geographic distribution | Physical features | Uses |
|---|---|---|---|
| **Small East African (SEA)** | Kenya<br>Uganda<br>Tanzania | Small-horned goat with short fine hair with variable coat color.<br>Found in a wide range of arid and semiarid environments. | Meat<br>Skins |
| **Western Highland** | Ethiopia<br>Sudan | This breed is small in size, and has a straight-to-concave facial profile. Some have wattles while most adult males have beards but no ruffs.<br>White, brown, and black in color with shiny short hair.<br>Both males and females are horned, that are straight or curved. | Meat<br>Milk<br>Skin/hides |
| **Western Lowland (Gumez)** | Ethiopia (locally called Western Lowland) | Short and straight face.<br>Fawn or white patchy color.<br>Most males have straight horns, orientated backwards. | Meat<br>Milk<br>Skin/hides |
| **Central highland (Brown goat)** | Eritrea (in southern Eritrea: Akale Guzay and Seraye)<br>Ethiopia | A tall bearded red-brown goat with a straight facial profile, backward-pointing horns and a short and smooth coat. | Milk<br>Skins |
| **Keffa** | Ethiopia (highlands and lowlands of Keffa and South Shewa zones of the Southern region) | This breed has been characterized as relatively short and it has a straight facial profile. Males have beards and ruffs, and waffles have been observed in some goats.<br>Black or brown are the dominant colors.<br>Most males have straight and backward-oriented horns.<br>A short bearded brown or black goat with a straight profile, straight backward facing horns, short pricked ears, and coarse or hairy coat. Mainly used for milk, meat, blood and skins. | Meat<br>Skin/hides<br>Milk<br>Blood |
| **Sudanese hill goat (Yei)** | Sudan (locally known as Baria, Latuka-Baria, and Latuka located in western Equatoria) | A small goat with a straight or concave profile, a small head, twisted horns, medium length pendulous ears, and a slender body. | Poor milking animals<br>Meat |
| **Mubende** | Uganda | A black-bearded goat with short fine hair, short horns and short to medium pricked ears. | Meat |

| Breed | Geographic distribution | Physical features | Uses |
|---|---|---|---|
| **Short-eared Somali** | Ethiopia (distributed in Hararghe Highland, Ogaden, Dire Dawa, and lowlands of Bale, lowlands of Borana Zone in Oromia, and in some parts of Sidama Zone in Southern Region)<br>Somali<br>Eritrea<br>Sudan | Males have beards but only the long-eared Somali bucks have ruffs. Short-eared Somali goats have shorter and slightly forward-pointed ears while the long-eared Somali goats have horizontally oriented and semi-pendulous ears. The animals mainly have a straight facial profile and short, smooth hair.<br>Mainly white coat.<br>Horns are present in both males and females and the horns are curved and oriented backwards. | Meat<br>Milk<br>Skin/hides |
| **Long-eared Somali (Boran)** | Somalia<br>Ethiopia<br>Kenya<br>Eritrea | A large bearded white goat with a straight facial profile and curved backward-pointing horns and horizontal semi-pendulous ears | Milk<br>Meat<br>Skins |
| **Somali Arab Goat** (originated from Arab Peninsula) | Djibouti<br>Kenya (known locally as Degeun, Deghier, Dighi yer, Modugh, Mudugh, and Galla, located in north-eastern Kenya)<br>Somalia (located along the coast of Somalia, and in northern Somalia where the goat is locally known as Degeun, Deghier, Dighi yer, Modugh, Mudugh, Galla and Ogaden) | Well adapted to semi-desert climate.<br>In Djibouti, the average weight is 40 and 30 kg respectively in males and females.<br>Animals are multi-colored: various but predominantly white, and horns in males are generally more pronounced than in females.<br>Uni-colored: brown in Somalia.<br>In Kenya, animals have short hair and ears, and are uni-colored: white, occasionally with spots or patches, and only males are horned.<br>Short ears, long hair.<br>In Kenya, the goats have an average lactation of 174 days, milk yield per lactation of 77 kg, and an average prolificacy of 1.06.<br>In Somalia, the goats have short hair and ears, and are uni colored: white, occasionally with spots or patches). Average prolificacy is 1.06. | Milk<br>Meat<br>Skins |

| Breed | Geographic distribution | Physical features | Uses |
|---|---|---|---|
| **Arsi-Bale** | Ethiopia (Arsi, Bale and Western Hararghe zones in Oromia Region, and high altitude areas of Sidama Zone in Southern Region, and in the Rift Valley from lake Abaya to South Shewa Zone)<br><br>Eretria<br><br>Djibouti | The breed has been characterized as medium to large size, with a straight facial profile. The animals have ruffs, most with beards, and males and females have wattles.<br><br>The dominant coat color varies considerably, with white as the most common color in males, and brown in females.<br><br>Goats at higher altitudes have longer hair.<br><br>Males have curved and backward-pointed horns while females mostly have shorter horns. | Fertilizer<br><br>Meat<br><br>Milk<br><br>Skin/hides |
| **Afar** | Djibouti (northern and western regions)<br><br>Ethiopia (Afar Region, and northern and western Hararghe Zones in Oromia Region)<br><br>Eritrea | Multi-colored: various colors, but predominantly black and brown, with an average weight 30 kg and 25 kg, for males and females respectively in Djibouti.<br><br>Absence of horns in both male and female in Eritrea and Djibouti.<br><br>Adapted to arid areas and environments where they are watered every three or four days (in Ethiopia).<br><br>In Ethiopia, they are characterized by having a concave facial profile, narrow face and forward-pointed ears, and are characterized as being leggy. Most males have beards, while wattles could appear in both males and females. Both males and females are horned, though females have smaller horns and have a patchy coat color with variable colors (white, light brown, black). | Milk<br><br>Meat<br><br>Medical<br><br>In Ethiopia the breed provides milk, delicate meat (bekel), and blood used as medicine. Afar goats are milked for domestic use or sale and maintained for meat, milk, and skin production. Socially, they are commonly given away as dowry |
| **Woyto-Guji** | Ethiopia (these goats inhabit a wide area extending from South Omo to southern Sidama and Wolayita, and are found in trypanosomiasis-affected areas in and along the Gelo valley to the south of Lake Abaya and other adjacent areas) | They are medium-sized, having a small head with mostly straight-to-concave facial profiles and wattles; males have beards and ruffs.<br><br>They are characterized as being covered with shiny and smooth hair of various colors – predominantly reddish-brown – and appearing in a patchy pattern with black or brown stripes running along the back.<br><br>Both males and females are mostly horned, which are oriented backward or upward, and sometimes laterally, but some are polled. | Fertilizer<br><br>Meat<br><br>Milk<br><br>Skin/hides |

| Breed | Geographic distribution | Physical features | Uses |
|---|---|---|---|
| **Abergelle** | Ethiopia (predominantly found in Abergelle and distributed along Tekeze River and through some parts of Alamata in the Tigray Region, and Wag-Himra (Sekota) as well as East Gondar zones in Amhara Region) | This breed has been characterized as having a stocky, compact and well-built body conformation with a straight to concave facial profile. The hair is short and smooth in both sexes, while males have beards and ruffs. The coat color of most goats is plain and patchy; spotted coat colors are common.<br>Both males and females have horns and in most cases the horns in males are much bigger and spiral shaped. | Meat<br>Milk<br>Skin/hides<br>In Ethiopia, this breed is used to produce milk for domestic consumption and their skin is also used to make aprons, containers, etc. |
| **Worre (Tseada)** | Eritrea (where they are also called Worre/Milege; found mainly in eastern lowlands and mid-altitudes around Keren and Nakfa)<br>Ethiopia | Small goats with short legs, a concave facial profile, straight or curved backward-pointing horns and beards in males. The coat has short smooth hair that is pied or white and brown in color | Milk<br>Skins |
| **Nubian** | Eritrea (called Hassan in this country and found in western Eritrea)<br>Sudan (Sudanese Nubian, Baladi, located along the Nile)<br>Ethiopia (northwestern Ethiopia) | In Eritrea, and like those also found in Sudan, they are large sized animals (average weight 34 kg and 30 kg, respectively for males and females).<br>In Eritrea, they could be uni colored: brown, occasionally white or multi-colored: black with red patches with the presence of horns.<br>Milk yield per lactation is 74 kg in Eritrea.<br>Very prolific species (2.1 in Eritrea).<br>In Sudan, the Nubian type has long hair, lop ears, and is uni colored: black. | Milk<br>Skins<br>This breed is reported to be the best milk producer in Sudan |
| **Barka** | Eritrea (in the western lowlands) | A bearded and horned white goat with a straight facial profile, and long pendulous ears. | Milk<br>Skins |
| **Benadir (Tuni)** | Somalia (locally known as Digwain/ Deguen, located in Webi Shibeli, southern Somalia)<br>Ethiopia | A white goat with short smooth hair, a large head with a straight profile and small, and backward-pointing horns. They have long legs | Milk<br>Meat |

| Breed | Geographic distribution | Physical features | Uses |
|---|---|---|---|
| **Bimal** (originated from the small coastal variety of Benadir) | Somalia (southern Somalia) | Multi-colored: white with small dark spots.<br>Males and females are armed. | Milk |
| **Ingessana** | Sudan (The main breed in the Ingessana area in the Blue Nile State) | Medium sized, short ears curved upwards. Uni colored: mainly black, also other colors.<br>Males and females are horned. | These goats are poor milkers<br>Meat |
| **Malawian** | Malawi (also called Malawi, more common in southern than in northern Malawi) | Average weight of 45 and 32.4 kg, respectively in males and females.<br>Ears pricked, with short fine hair.<br>Uni colored: black, brown, white.<br>Both males and females are horned. Horns are light, and short.<br>Average prolificacy is 1.4. | The main value of the local Malawi goat lies in their meat,<br>Milk production is quite low, so they have never been selected for milk production. |
| **Sudanese Desert** | Sudan (northern Sudan) | A large gray horned and bearded goat with a straight head profile, long drooping ears and a black stripe extending down the back. The neck and back are short, withers prominent, coat short and fine, and legs are long and bony. Males have manes that extend down the back. | Milk<br>Skins |

Source: Muigai et al. (2018); FAO DAD-IS (2019)

# III. Female reproductive biology and characteristics

# III.1. PUBERTY

Puberty in does is an important event. It affects the duration of the reproductive carrier of a female, since the age at first kidding, which is the age at which does give birth for the first time, is largely influenced by the advent of puberty (Ashebir and Asha, 2018). Puberty can be defined in different ways (Figure 3).

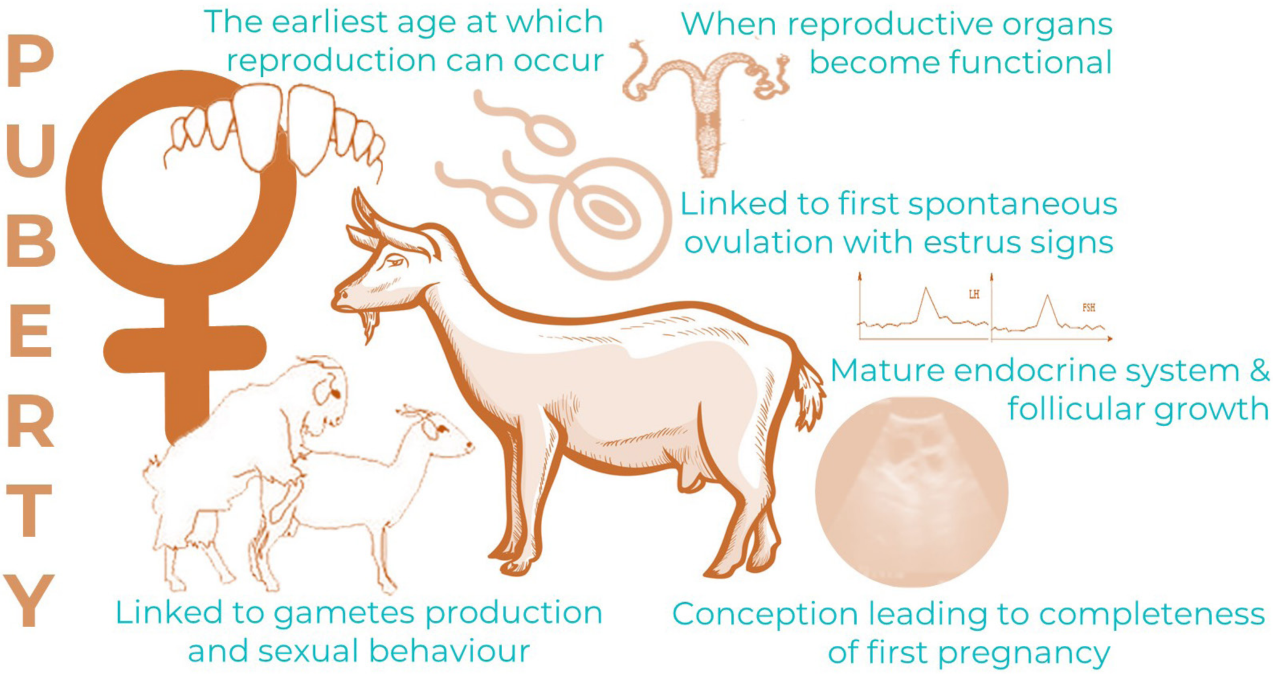



**FIGURE 3: Definitions of puberty in females**

The occurrence of puberty in goats follows the model of Foster and Ryan (1981) that was developed for young female sheep. At puberty, basal secretions of luteinizing hormone (LH) increase because of an acceleration in the rate of LH pulses, resulting in the development of one or more follicles. This is the first follicular phase, which is associated with an increase in the concentration of oestradiol, which eventually elicits the first pre-ovulatory LH surge (Figure 4).

Puberty is different from sexual maturity and, at puberty, the animal is not fully sexually competent (Atta et al., 2011). In goats, puberty is reached before animals are grown enough to physically support reproduction (Kunbhar et al., 2016).

The onset of puberty is influenced by many internal and external factors (Arthur et al., 1998; Alexander et al., 1999; Awemu et al., 1999; Getahun, 2008; Girma, 2008) (Figure 5). It is also closely related to live weight which depends on many other factors (Shelton, 1978; Smith, 1978; Bearden and Fuquay, 1997; Hafez and Hafez, 2000) (Figure 4). Animals which are well fed, and have a good growth rate, reach puberty before poorly fed ones with a slow growth rate (Arthur et al., 1998; Walkden-Brown, 2001).

Generally, and in most sheep and goat breeds, an achievement of 40 to 70% of the mature body weight is satisfactory for the onset of puberty. The large existing variations between and within breeds are especially related to genotype and post-weaning nutrition (Abera, 2017). While puberty is more closely related to mature weight than to age, it is still common for tropical goats to reach puberty at approximately 97 days old, and sexual maturity at 132 days (Payne and Wilson, 1999; Moaeen-ud Din et al., 2008). Tropical breeds reach puberty at an earlier age than those thriving under temperate conditions. However, and under tropical conditions, the attainment of puberty may be delayed by both low growth rates of animals and unfavorable management conditions in the tropics (Rekik et al., 2012).

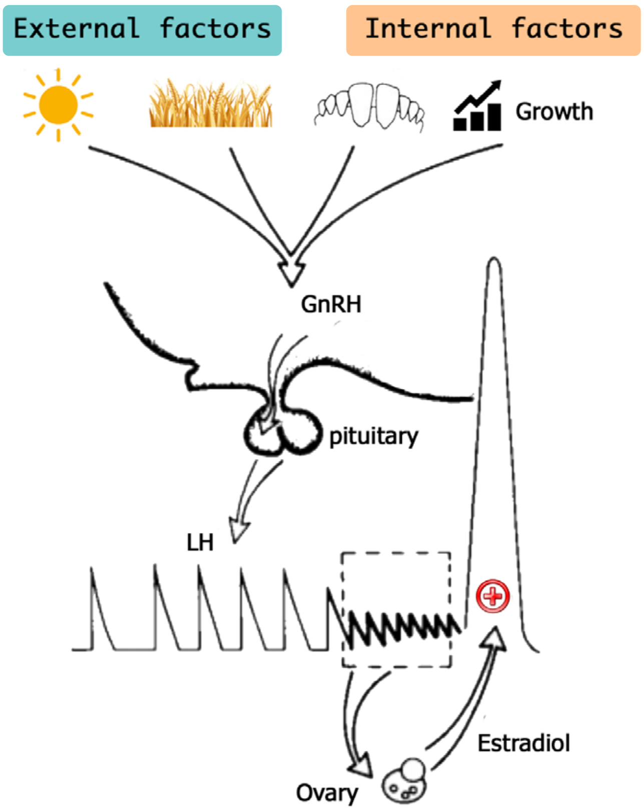



FIGURE 4: Internal and external factors responsible for the initiation of the pubertal follicular phase

Source: Redrawn from Foster et al., 1986

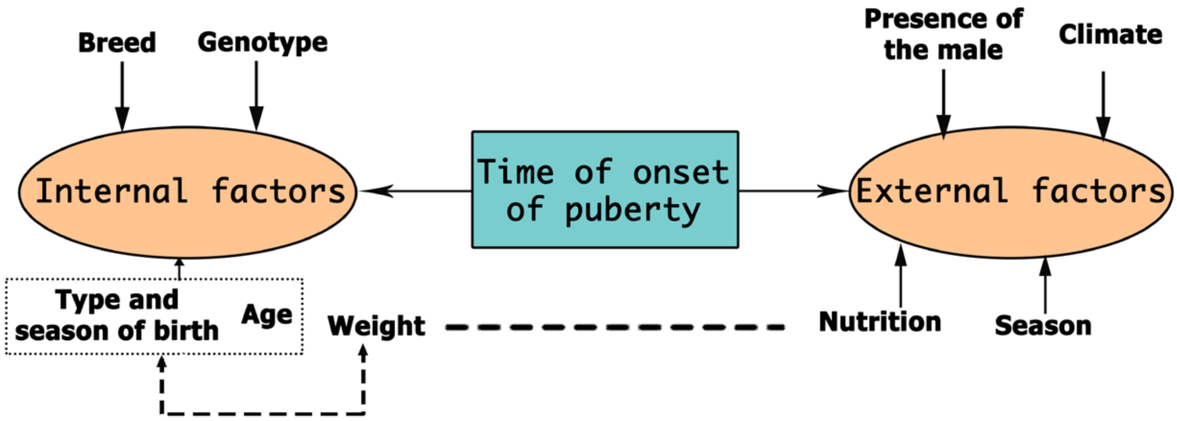



FIGURE 5: Factors affecting puberty and examples of studies taking place in the African context

The onset of puberty can also be influenced by the season of birth, especially in seasonal breeds, and by climate (Bearden and Fuquay, 1997; Arthur et al., 1998; Hafez and Hafez, 2000) (Figure 5).

Many studies have highlighted that the high presence of males of the same species than females is associated with rapid and highly synchronous onset of puberty in most female kids (Amoah and Bryant 1984; Bearden and Fuquay, 1997; Arthur and Ahunu, 1998; Hafez and Hafez, 2000; Walkden-Brown, 2001). In addition, puberty occurs earlier in animals bred in groups than those bred alone (Hafez and Hafez, 2000) (Figure 4).

Table 2 lists the age puberty onset has been reported for several breeds. For example, a study conducted by Tadesse et al. (2014), comparing three Ethiopian goat types kept under different production systems, showed that Bati and Hararghe Highland goats attained puberty at an

TABLE 2: Different ages and weights at puberty in different goat breeds

| Country | Goat breed | Age of onset of puberty (days) | Mean body weight at puberty (kg) | References |
|---|---|---|---|---|
| Ethiopia | Ethiopian indigenous goats in Bale Zone, Oromia | 240 | NA | Asefa et al., 2015 |
| | Begait Doeling goats in Western Zone of Tigray | 183 | NA | Hagos et al., 2016 |
| | Desert goats | 168.97 | NA | |
| | Taggari goats | 245.22 | NA | |
| Sudan | Nubian goats | 264.93±16.47 | 16.8 | Yagoub et al., 2013 |
| | Sudan Desert goats | 153.50±4.23 | 12.65±0.74 | Elzagafi Alli, 2000 |
| | Desert goats in North Kordofan State | 162.26 | NA | Mohamed Ali and Eldaw, 2015 |
| | Tagger goats in Gezira State | 238.51 | NA | Ombabi Mohammed, 2015 |
| | Sudanese Nubian Goat | 279.07 | 12.74±1.37 | El-Abid and Abu Nikhaila, 2009a |
| | Sudan Desert goats (under conventional feeding systems) | 189.95±23.00 | NA | Bushara et al., 2010 |
| | Taggar goats in the Dalanj area in Southern Kordofan State (Dalanj University) | 175.68±12.86 (single)<br>195.31±9.94 (twin)<br>206.61±8.19 (triplet) | 14.16±0.34<br>13.55±0.29<br>11.62±0.43 | Bushara et al., 2013a |
| | Desert goats (under natural grazing during the rainy season) | 242.57±4.97 | 23.09±0.44 | Bushara et al., 2017 |
| | Taggar goats (under natural grazing during the rainy season) | 211.33±5.48 | 18.59±0.34 | Bushara et al., 2017 |
| | Desert kids (under an extensive system in South Kordofan State for single and twin birth type) | 239.50±7.26 (single)<br>246.67±4.97 (twin) | 23.15±0.42<br>23.00±1.01 | Bushara et al., 2018 |
| | Taggari kids (under an extensive system in South Kordofan State for single and twin birth type) | 202.50±7. 50 (single)<br>215.75±2.14 (twin) | 18.59±0.34<br>18.55±0.44 | Bushara et al., 2018 |

*Note: NA: Not available*

earlier age, and first gave birth at a younger age than the Short Eared Somali goat (Tadesse et al., 2014).

## To conclude...

Differences in ages and weights at the onset of puberty, reported between and within countries, are due to different management conditions, care of female kids, and their growth rate resulting from feeding levels.

A delayed age at puberty may have negative consequences, especially for seasonal breeds. Information about age and body weight at the onset of puberty and attainment of sexual maturity are prerequisites for improving reproductive performance, by reducing the period between birth and initiation of reproduction.

# III.2. SEASONALITY OF REPRODUCTION

In both sheep and goats, seasonality of reproduction is governed by photoperiod, giving an onset of estrus activity with the beginning of the period of short and decreasing day length (Hafez and Hafez, 2000). This seasonal influence depends on the latitude and the breed of the animal. In extreme northern and southern latitudes, the impact of season is very prominent (Zeleke, 2003). In tropical conditions, local breeds of sheep and goats are often non-seasonal breeders or exhibit a weak seasonality of reproduction (Mukasa-Mugrewa et al., 2002; Girma, 2008). In fact, African small ruminants are different from temperate breeds and do not experience intense seasonal anestrus. This is explained by the fact that under tropical and subtropical latitudes, there is little variation in the amount of daylight so reproductive activity is not often affected.daylight shows a low variation to affect reproductive activity . It is therefore concluded that a doe's estrus activity is greater in the tropics than in temperate climates, and in the tropics females are characterized by a low or even the absence of reproductive seasonality (Ndeke et al., 2015).

Even in the absence of a seasonality of reproduction, several studies have highlighted that reproductive activity decreases at some points during the year, especially in very harsh environments. This reduced activity could be due to nutrition (Gallego-Calvo et al., 2014), sociosexual interactions (Delgadillo et al., 2015) or climatic (Silva et al., 1998; Morales et al., 2016).

In Uganda, for example, SEA goats are known as regular breeders with an ovarian cyclicity that occurs throughout the year (Sacker and Trail, 1966; Devendrá and Burns, 1970), yet several Ugandan studies have showed that seasonality in reproductive activity does occur in this breed of goats (Katongole and Gombe, 1985). In fact, plasma progesterone and estradiol levels are low in January and February, rise in March, reaching a peak in April and May when most of the goats become pregnant, and drop to low levels again between August and December (Mutayoba et al., 1988).

In Burundi, local ewe and goats which are descendants of the East African Small sheep and goat, are described as continuous polyoestrous, with non-seasonally reproductive activity (Branckaert and Habonimana, 1985). Nevertheless, as nutrition of small ruminants in the tropics is based on pasture and its quality varies a lot with the season, the interval between parturition and the resumption of estrous cycles are extended during the dry season and affect flock productivity (Berbigier, 1988).

In Sudan, Nubian goats are prolific and have no pattern of seasonal breeding (Kurohmaru and Nishida, 1987; Ritar, 1991). In the same way, in central Kenya, goats are non-seasonal breeders and kidding can occur all year round, although there is a peak in August (Mbai et al., 2001).

In Ethiopia, under prolonged drought in the arid and semiarid lowlands of the country and the resulting nutritional constraints aggravated by the seasonal availability of forages (Yami, 2008), several studies have reported conception peaks of does, which correspond to feed flushes and the availability of crop residues (Mukasa-Mugerwa et al., 2002; Tatek et al., 2004). Differences also exist between breeds and districts. For example, studies have shown that the Abergelle goat breed is almost a seasonal breeder. However, Abergelle does in Lay Armachiho District can give birth almost evenly throughout the year. This difference may be due to feed unavailability in Ziquala and Tanqua Abergelle districts during the dry season from December to June (Alemu, 2015).

### To conclude...

It is true that goat breeds from the tropics and subtropics are year-round breeders when placed under suitable conditions, such as adequate feed availability. Nevertheless, the proportion of small ruminant females producing offspring more than once a year is low because of a long postpartum (PP) anestrus. Concentrating reproductive activity in a single short breeding period, when the external environmental factors are favorable, could be a possible management intervention to improve the productivity of pastoral goat herds in tropical regions.

TABLE 3: Examples of seasonality of sexual activity of some goat breeds in some countries in East Africa

| Country | Region of the country | Breed | Conception period | Birth period | Reference |
|---|---|---|---|---|---|
| **Ethiopia** | Metema and Abergelle districts of Amhara National Regional State | Western Lowland and Abergelle goat breeds | June and July (the beginning of the major rainy season) | November and December | Abegaz, 2014 |
| | West Shoa Zone of Oromia Regional State | Indigenous goat breeds in Ada Barga and Ejere | Most goats are conceived during December, when there is sufficient forage in natural pasture, and crop residues and feed are available, resulting in good flushing of females | Throughout the year with apparent peaks of intensive kidding in April. The lowest kidding levels were recorded during February, August and November. | Bergaga, 2016 |
| | Sekota and Workadivno and Bilaqu Community Based Breeding Programmes (CBBP) villages | Abergelle goat | Mid June to mid July | From October up to January | Wondim, 2019 |
| | Ziquala and Tanqua Abergelle | Abergelle goat | From May to August, more specifically June | October to January with a peak birth rate in November | Alemu, 2015 |
| | Lay Armachiho District | Abergelle goat | Throughout the year | Throughout the year | Alemu, 2015 |
| | South-western Ethiopia | Woyto-Guji goats | NA | End of September to early October | Pastoral Community Development Project, 2008 |
| | Erob District in Eastern Zone of Tigray | Maefur goat | The major breeding season: between May and July<br>The second breeding season: between November and December | Major kidding season: in the dry season of October, November, and December | Gebreyowhens and Kumar, 2018 |
| | Alaba (southern Ethiopia) | Arsi-Bale breeds | The major breeding seasons are between November and January<br>The minor breeding season are April and June | NA | Hagos et al., 2016 |

| Country | Region of the country | Breed | Conception period | Birth period | Reference |
|---|---|---|---|---|---|
| **Ethiopia** | Western Zone of Tigray | Begait Goat | NA | At any time of the year<br>The highest births in both districts occurred during the rainy season | Belete, 2009 |
| | Goma District of the Jima administrative zone in Oromia Regional State | Indigenous goat | NA | Increase in kidding starting from April to October (rainy season)<br>Decrease in kidding starting from October to February | Urgessa et al., 2013 |
| | Bacho, Mettu and Darimu districts of the Ilu Abba Bora Zone in Oromia Regional State, South Western | Indigenous goat in Ilu Abba Bora Zone in Oromia | NA | Year-round<br>Most kidding: September to October and late April to June (small rainy seasons with adequate feed)<br>Lowest kidding: in January to early April (dry period) | Urgessa et al., 2013 |
| **Sudan** | Khartoum State | Saanen goats | Wet summer (July to October) | Cool winter season | Abdalla et al., 2015 |
| **Kenya** | Chiromo | SEA female goats | May to August | NA | Mutayoba et al., 1989 |
| | Nzeluni Division, Mwingi District, Kitui County | Galla and Toggenburg goats | NA | All year round with a peak in August | Ndeke et al., 2015 |
| **Tanzania** | Mgeta, Morogoro | Norwegian dairy goats | March and April | August and September | Sonola, 2015 |

# III.3. OVARIAN CYCLE

Female goats are seasonal polyestrus, with spontaneous ovulation during the natural breeding season. Unless interrupted by pregnancy or disease, goats display a succession of estrous cycles, defined as the interval between two behavioral estrus (lasting 21 days on average but can vary from 18-22 days according to the breed), stage of breeding season and environmental stress (Jainudeen et al., 2000).

In most goat breeds, ovulation occurs between 24-48 hours after onset of estrus with a spontaneous ovulation occurring, on average 24 hours after the onset of estrus (Rahman et al., 2008, Tsuma et al., 2015). This timing is different for some breeds, such as the Nubian goat, where ovulation is delayed, and this could be possibly due to a longer estrus cycle (Jainudeen et al., 2000). Average ovulation in does is 1-3 oocytes, but can vary from 1-5, depending on the different breeds and management conditions (Pineda, 2003).

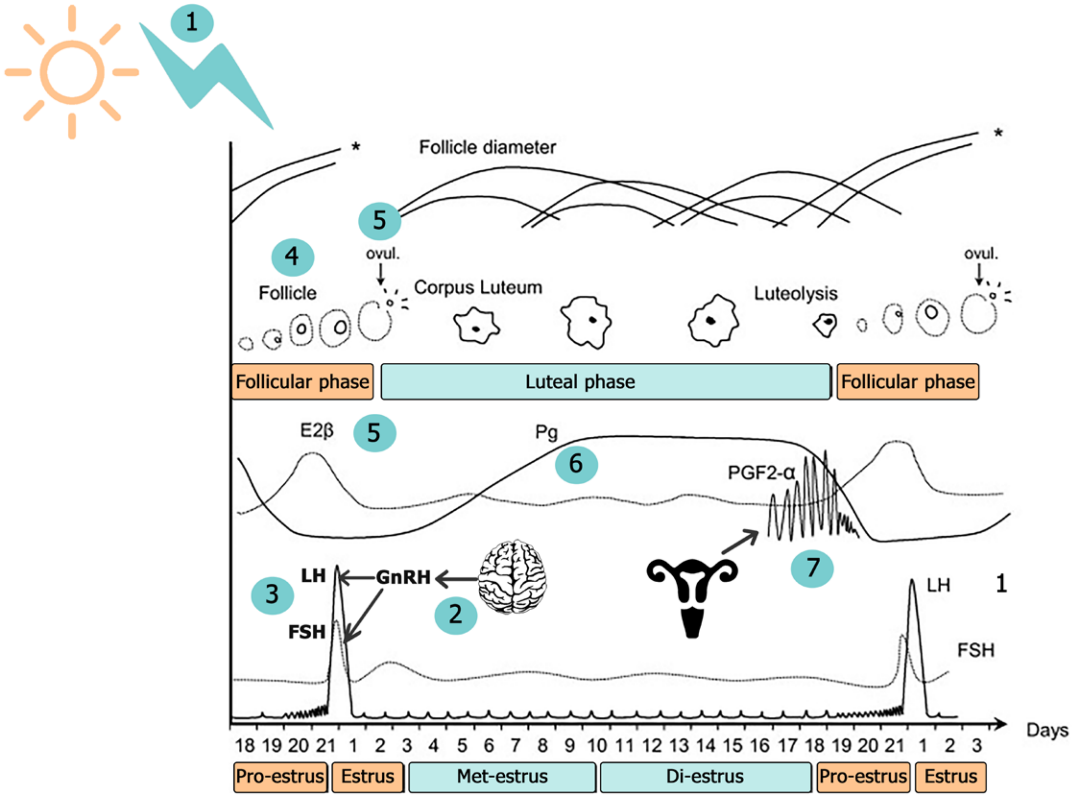
The cyclic reproductive patterns of the ewe or doe is maintained by the ovary producing ova and hormones. Ova is produced in the ovary by follicles, present in the ovaries from birth, under the influence of hormones from the pituitary gland (Edquist and Stabenfeldt, 1993). After puberty, and at each estrus cycle, small numbers of follicles are recruited from the large pool and begin to mature or ripen (Zeleke, 2003).

In the doe, events of the estrus cycle are maintained by the activities of four main organs: (i) the hypothalamus, (ii) the pituitary gland, (iii) ovaries, (iv) the uterus, and (v) a complex arrangement of stimulatory and inhibitory signals passing between them (Figure 6). During the estrus cycle, several endocrine events take place (detailed in Figure 6). The estrus cycle is divided into a luteal phase, where, the Graafian follicle transforms into the corpus luteum (CL, the luteinization process), following ovulation. The CL is active in secreting progesterone during the luteal phase, which lasts 16 days. If a doe does not conceive, the CL regresses (luteolysis), and a new phase of the estrus cycle starts, which is the follicular phase (Figure 6). During this phase, the growth of ovarian follicles in the ovary of does is characterized by the presence of four or more waves of follicle growth in the same cycle, and it is only in the final wave that the dominant follicle ovulates. An increase in follicle stimulating hormone (FSH) secretion occurs before each follicular wave (Medan et al., 2005). Even if the dominant follicle of the previous wave is still in its peak of development, the subsequent follicular wave could begin; this is different from other farm animals (Rahman et al., 2008) and is due to a weaker follicular dominance in the ovary of the doe (Ginther and Kot, 1994).

The seasonality of the ovarian cycle is maintained by two seasonal hormones. The first is prolactin which has its highest concentrations in the blood during long daylight length (Buys et al., 1990). Some studies have showed that a low prolactin concentration corresponds to the onset of ovarian activity (Thimonier et al, 1978; Kennaway et al., 1983), however others found that ovarian activity still occurs in the presence of high prolactin levels (Worthy et al., 1985). The second hormone is melatonin which is secreted by the pineal and controls reproductive activity via neuroendocrine pathways (Kennaway et al., 1984; Bassett, 1992). The concentration of melatonin in the blood is higher during dark periods and lower during light phases (Kennaway et al., 1987).

Ovarian activity is affected by environmental factors. Namely, heat stress, which may alter ovarian function directly or indirectly through the imbalance of hormones of the hypothalamo-pituitary-ovarian system (Ndeke et al., 2015). In contrast, rainfall is an important stimulator of ovarian activity during the transition to the breeding season, and some studies state that this is due to the strong growth of native pasture (Galina et al., 1995).

Nutrient supply is also an important factor stimulating reproductive processes, such as the onset of ovarian cyclicity. Requirements for reproduction depend on the phase of the reproductive cycle, and dairy goats often display reproductive problems that are associated with nutritional deficiencies (Orkov, 1999).




*Note: *Ovulatory follicle(s); 1. The pineal gland (epiphysis) produces melatonin. The hormonal activity of the pineal gland is influenced by both the dark-light cycle and the seasonal cycle, causing it to play an important role in the neuro-endocrine control of reproduction. The melatonin levels are high during the dark periods and low during light periods of the day. 2. The hypothalamus receives messages from the body, the environment, the ovaries, the pituitary and pineal gland in order to initiate reproduction. Messages are sent to the pituitary gland in the form of neuro-hormones: releasing factors or gonadotrophin releasing hormones (GnRH); 3. In response to signals from both hypothalamus and the ovary, the pituitary gland produces and stores the two main hormones (gonadotrophins) that directly control the function of the ovary (the follicle stimulating hormone: FSH and luteinizing hormone: LH); 4. Ova are produced in the ovary by follicles under the influence of hormones from the pituitary gland. Several thousands of these follicles are present in the ovaries from birth. After puberty, small numbers of follicles are recruited from the large pool at each oestrous cycle and these begin to mature or ripen; 5. The cells lining the hallow cavity of these follicles, the granulosa, are the sources of one of the ovary's hormone, oestrogen (E2ß). It is the predominant hormone during the follicular phase of the oestrous cycle that stimulates the production of luteinizing hormone (LH), which in turn signals the ovary to ovulate; 6. After ovulation (rapture of the mature follicle), the cells lining the cavity of the collapsed follicle eventually form luteal cells, and these produce progesterone (Pg) which inhibits GnRH secretion, and prevents the LH peak discharge; 7. The prostaglandin ($PGF_{2}\alpha$) is produced in the uterus if the previous ovulation fails to result in a viable embryo. It causes luteolysis, (degeneration of the corpus luteum) so that no more progesterone will be produced by the corpus luteum. The reduction of serum progesterone concentration will remove the blocking effect on the hypothalamus and pituitary gland, allowing another oestrous cycle to occur.*

**FIGURE 6: Schematic representation of the different physiological events occurring during estrus cycle in goat: pattern of follicle development, ovarian cycle and endocrine regulations**

Source: Adapted from Baril et al. (1993) and Evans (2003)

## To conclude…

Female goats thriving under tropical and equatorial regions show specificities about their ovarian and estrous cycles. A precise characterization of such specificities ensures that appropriate protocols are designed to improve reproductive performance and to apply reproductive biotechnologies.

# III.4. ESTRUS EXPRESSION, OVULATION AND OVULATION RATE

From puberty, and unless interrupted by pregnancy or disease, a doe comes on estrus at regular intervals of 21 days on average (Wondim, 2019). Estrus period is associated with the desire to be bred through displaying behavioral sexual activity and is the only time that the female will accept the male (Evans and Maxwell, 1987; Arthur et al., 1998). It is the period of sexual receptivity of the female, expressed in a short period of time lasting on average 36 hours, with a range from 19 to 48 hours (Abecia et al., 2011).

Audra (2014) defines estrus as the period during which the female will stand to be bred by the male. In addition, creamy vulval discharge may be observed (Melican and Gavin, 2008; Abera, 2017).

The complete estrus cycle in does is divided into four well marked phases, namely pro-estrus, estrus, met-estrus and di-estrus (Rahman et al., 2008). During the first phase of pro-estrus, known also as the phase of ‘proceptivity’, the female seeks partners for stimulation through intermittent approaches. The next phase of estrus is the phase of ‘receptivity’, and the female is then in heat. During this period, females undergo behavioral changes indicating sexual excitement and receptivity to the buck such as:

- Deviation of the tail.
- Flehmen gesture.
- Mounting behavior.
- Bleating.
- Urine emission.
- Clear mucous discharge from the vulva.
- Reddening and swelling of the vulva associated with mucus discharge.

The doe is known to be more expressive than other females of mammalian domestic species (Fabre-Nys, 2000).

In goats, estrus expression is primarily sustained by the increase of oestradiol, following regression of the CL at the end of the luteal phase, and to a much lesser extent the rapid fall in progesterone plasma concentrations. Progesterone plasma concentrations are very low on the day of oestrus. In the tropics, mean duration of estrus periods ranges between 17-48 hours (Devendra and Burns, 1970) (Table 4), and this duration is influenced by breed, age, season, and the presence of the buck (Jainudeen et al., 2000). Elmansoury et al. (2013) studied the effect of different levels of energy and protein supplementation in Sudanese Nubian goats and found that animals receiving low levels of energy presented a delay in appearance of estrus signs following synchronization.

Estrus expression and ovulation can be either induced using the strategic exposure of anestrous does to bucks (“the buck effect”) or using different hormones, such as progestagens (Westhuysen, 1976), prostaglandin ($PGF_{2}\alpha$) (Perera et al., 1978; Bretzlaff et al., 1981; Alacam et al., 1985) or a combination of $PGF_{2}\alpha$ and progestagens (Corteel, 1975; Wani et al., 1985). These last techniques will be covered in Chapter Five. The response to the “buck effect” depends on the level of sexual aggressiveness of the male, the intensity of the stimulation and the body condition of the doe (Véliz et al., 2006).

Observation of heat is an important technique that could influence the fertility of the flock. Various methods are used to detect heat, such as the use of a teaser buck or the observation of behavioral changes. In a study conducted in Sudan on female Nubian goats, estrus was detected using bucks with an excellent libido and fertility. Signs of estrus were detected by trained personnel three times a day for 30 minutes (7:00, 13:00, and 19:00) (Yagoub et al., 2013). The doe or the doeling was considered

TABLE 4: Duration of estrus in some countries in East Africa

| Country | Breed | Treatment | Estrus duration (hours) | Reference |
|---|---|---|---|---|
| **Tanzania** | East African short-horned goat | Yes (double injection of 125/µg cloprostenol IM) | 32.4±3.6 | Mgongo, 1987 |
| **Sudan** | Sudanese Nubian goats | No | 12-48 | Kudouda, 1985 |
| **Uganda** | Native Ugandan Does | Yes (fluorogestone intravaginal sponges + PMSG) | 30+4.6 | Bigirwa et al., 2015 |
| **Ethiopia** | Abergelle Goat | PMSG + Enzaprost<br>$PGF_{2\alpha}$ (single)<br>$PGF_{2\alpha}$ (double) | 39.0±1.39<br>41.6±1.39<br>42.1±1.56 | Wondim, 2019 |
| | Ethiopian local goat | Yes (two injections of $PGF_{2\alpha}$)<br>No<br>Double $PGF_{2\alpha}$<br>GnRH-$PGF_{2\alpha}$-GnRH<br>GnRH-$PGF_{2\alpha}$ | 34.97+3.74<br>34.97+3.74<br>36.57+2.78<br>48.90+1.61 | Gidena, 2017 |

in estrus when waggling the tail, bleating, mounting others and/or allowed the bucks or other goats to mount her were observed, based on the observations of Mackenzie (1967). These observations were enhanced by measurements of progesterone concentrations in milk. If the animal did not show oestrous signs, ovulation was assumed to have taken place four days before the first time the serum progesterone values were equal or greater than 0.5 ng/ml (Mavrogenis, 1987).

Even if the estrus period coincides with ovulation time, sometimes animals may show estrus which is not associated with ovulation (Gidey, 2017). For example, in some cases, and at puberty, the first ovulation is silent, resulting in an ovulation without estrus occurring before the first observed estrus.

Ovulation rate is a very important parameter, modulating the prolificacy of the doe. In fact, it has an impact on litter size and refers to a high number of kids born per doe. Ovulation rate is influenced by several factors such as the stage of breeding season, genotype, parity, and nutrition (Rekik et al., 2012).

Under African pastoral systems, despite the ability of many local goat breeds such as the SEA to be non-seasonal, does may display reproductive inefficiencies such as reduced ovulation rates due to poor and fluctuating nutritional levels (Delgadillo and Malpaux, 1996; Walkden-Brown and Restall, 1996). In fact, Henniawati and Fletcher (1986) showed that improved nutrition increases ovulation rate and the frequency of multiple births in goats. Therefore, to prepare females for the breeding season, flushing is used in different species, and namely in goats. This practice consists of providing extra energy and/or protein to breeding females prior to the breeding season and for the first several weeks of the breeding season. In goats, this energetic supplementation is done prior to the introduction of the buck and lasts approximately 21 days (Luginbuhl et al., 1998). In fact, pre- and post-mating nutrition affects the ovulation rate directly by acting on the gonadotrophic axis or on the ovary (Landau and Molle, 1979).

## To conclude...

Body weight and body condition score (BCS) at mating, which depend on nutrition levels, affect ovulation rate. For an optimal ovulation rate, goats should have a BCS of 2.5-3 (on a scale of 5); goats should not be too thin nor too fat.

# III.5. GESTATION AND POSTPARTUM ANESTRUS

When mating and conception occur, and for a successful pregnancy, communication between conceptus and the mother should take place. After maternal recognition, the implantation of the conceptus occurs on the uterine wall through a succession of common critical steps which differ considerably according to animal species. In ruminants, implantation occurs at the blastocyst stage, but the timing of implantation differs among species and is not particularly related to the length of gestation (Guillomot et al., 1993). In goats, implantation begins around days 14-17 of pregnancy when the embryo starts placentation (Bazer et al., 1997).

Ruminants have a cotyledonary placenta. The placentome, which is the combination of maternal caruncle and fetal cotyledons, serves as an immunological barrier and it is the organ through which respiratory gases, nutrients and wastes are transported (Kumar et al., 2015). Normal placentome growth and development is essential for fetal growth and development (Laven and Peters, 2001). The placenta secretes steroid hormones (oestradiol and progesterone) and placental lactogen which are essential for maintaining pregnancy and for mammary gland growth (Hayden et al., 1979).

Gestation length or pregnancy period is the period separating fertile mating or conception and parturition (Roberts, 1971; Arthur et al., 1998). Generally, the gestation length is around 150 days (Hafez and Hafez 2000). Gestation length is genetically determined (Roberts, 1971), therefore, maternal, fetal genetic and environmental factors can modify the duration of this period (Table 5).

For example, type of birth and the sex of the offspring could affect gestation length. Akusu and Ajala, (2000), found that the mean gestation length of West African Dwarf goats was shorter in multiple than single birth, and female kids were carried 1.13 days longer than male kids.

Nutrition is another important factor influencing gestation length, directly or indirectly, by affecting weights at mating (Amoah et al., 1996). In addition, the quality of the feed, such as the level of energy in the diet, affects the occurrence of abortions in goats. In fact, poor feed quality, combined with low energy, increased the incidence of abortion in goats (Hussain et al., 1996). In addition, and after parturition, metabolic requirements of the suckling does increase in relation to the lactation process, and this may induce a decrease in body weight if the nutritional level is not accurately balanced (Mbayahaga et al., 1998).

The reduction in the size of the genital tract after parturition is called involution and the greatest change, especially rapid shrinkage and contraction of the uterus, occurs during the first few days after parturition (during day 3-10 PP) (Noakes et al., 2009). Under normal non-pathological conditions, involution is completed by 20-25 days, according to measurements on Balady goats (Degefa el al., 2006).

The period from parturition of ovarian activity is called the PP anestrus period. The PP anoestrous length is considered as the interval between parturition and the first estrus, and it influences the kidding interval. Therefore, early diagnosis of uterine involution will help in early rebreeding, reducing kidding interval, and then increasing the number of kiddings per year.

During the PP period, a series of integrated anatomic and physiologic re-adjustments of both the uterus and endocrine system take place, to ensure the success of the resumption of reproductive capacity and regular cycling of a breeding goat (Bushara, 2010).

Physiologically, the endocrine mechanisms underlying PP anoestrous in goats are illustrated by an increased oestradiol feedback at the hypothalamo-pituitary axis leading to inadequate pulsatility of LH to promote follicular growth at the ovarian level (Rekik et al., 2012).

During PP anestrous, progesterone concentrations remain at basal levels (between 0.1 and 0.9 ng/mL) and the increase occurs with the resumption of the PP cyclicity period in Dwarf goats (Khanum et al., 2007). In indigenous Ugandan goats, the PP progesterone levels could remain low for up to eight months in some cases, suggesting a lack of ovulation and CL formation (Katongole and Gombe, 1985).

**TABLE 5: Gestation and postpartum anestrus length of breeds of goats in some countries in East Africa**

| Country | Breed | Location and experimental treatment (if available) | Gestation length (days) | PP anestrous length (days) | Reference |
|---|---|---|---|---|---|
| **Burundi** | Burundian goats | Imbo plain at the Maramvya Zootechnical Station | 148±4 | NA | Mbayahaga et al., 1996 |
| | Local Burundian goats | Sub-arid region of Burundi, at the Maramvya Zootechnical Station | NA | Simple 112±41<br>Twin 160±58 | Mbayahaga et al., 1996 |
| **Rwanda** | Common African and Alpine goat breeds | East of Kigali | 149.8±1.9 | NA | Mourad, 1996 |
| **Sudan** | Nilotic does | Animals transferred from the Upper Nile State in southern Sudan | 149.5 | 121.3 | Atta et al., 2012 |
| | Nubian goats | Managed intensively and fed molasses and sorghum-based diets | 149.5 | NA | Gubartalla, 1998 |
| | Nubian goats | Under an extensive management system | 148.6±3.6 | 148.3±62.4 | El-Abid and Abu Nikhaila, 2009b |
| | Nubian goats | NA | 147.3 | NA | Mohammed, 2003 |
| | Baggara goats | Resulting from crossing of Desert and Nilotic breeds | 147 | NA | Ageeb, 1992 |
| | Nubian goats | High energy, high protein (HEHP) ration<br>Low energy, low protein (LELP) ration<br>High energy, low protein (HELP) ration<br>Low energy, high protein (LEHP) ration<br>(Synchronized and hand mated by the buck) | 157.00±5.24<br>141.25±2.22<br>144.33±4.04<br>153.25±14.66 | 44.60±18.08<br>121.0±53.74<br>83.50±81.30<br>47.33±42.19<br>(P4 rise PP) | Elmansoury et al., 2013 |
| | Desert does | No hormonal treatment + natural mating<br>Internal drugs release device + AI<br>Internal drugs release device + PMSG + AI<br>Prostaglandin analogue (two doses) + AI<br>(Brought from Belal village and reared in Western Darfur) | 149.64±3.47<br>148.67±3.08<br>148.4±2.28<br>149.4±3.2 | 67.00±7.56<br>[56 and 82] | Elzagafi Alli, 2000 |
| | Nubian goats | Kuku goat improvement farm in Khartoum North | 147.1±0.8 | 51.0±4.5 | Yagoub et al., 2013 |

| Country | Breed | Location and experimental treatment (if available) | Gestation length (days) | PP anestrous length (days) | Reference |
|---|---|---|---|---|---|
| **Sudan** | Woyto-Guji goats | No concentrate | 135±0.0 | | Berhanu et al., 2013 |
| | | 200 g per goat daily | 138±2.3 | | |
| | | 400 g per goat daily | 136±1.8 | | |
| | | In JARC, located in the SNNPR | | | |
| **Ethiopia** | East African goats | Mated to Toggenburg and Anglo-nubian bucks | 148 | 68 | Bradford et al., 1989 |
| **Kenya** | Galla goats | Mated to Toggenburg and Anglo-nubian bucks | 149 | 77 | Bradford et al., 1989 |

*Note: AI: artificial insemination; JARC: Jinka Agricultural Research Center; NA: not available; PP: postpartum; SNNPR: South Omo zone of the Southern Nations, Nationalities, and People's Region*

For goat breeds thriving near the equator, the PP anestrous period is relatively short. In contrast, when the latitude increases (such as areas at latitude 30°), the kidding interval becomes longer, due to a longer period of PP anestrous. This difference may be explained by an interaction between seasonal anestrus and PP anestrus which delays resumption of reproductive activity following kidding (Rekik et al., 2012).

In a study conducted by Mbayahaga et al. (1998), the PP length was longer in local Burundian goats than in the ewes. Differently from sheep, the PP ovarian activity in goat is affected by various abnormalities such as short and long luteal phases.

Variations in the length of the PP period could be because of several factors, such as nutritional level, breed, season of the year, suckling intensity, prolificacy, and parity of the does (Abebe, 1996; Walkden-Brown, 2001) (Table 5).

In the tropics, goats are generally pasture-fed, and the quality of their nutrition varies a lot with the season. That is why nutrition level has a major role extending the resumption of estrus cycles when there is a decrease in feed quality and quantity during the dry season, and therefore affects flock productivity (Berbigier, 1988). In fact, in a study conducted by Berhane and Eik (2006) in northern Ethiopia, the authors showed that PP body weight of goats observed in concentrate supplemented groups enhanced the survival of kids and the performance of the Begait and Abergelle goats later in the PP period.

Furthermore, when tested with different energy and protein feeding regimens, a low energy/low protein Nubian goat group showed the longest period from delivery to the first serum P4 rise compared to the high energy/high protein, and low energy/high protein group. In addition, after parturition, all kidded does of the high energy/high protein group showed regular cycles of progesterone and all resumed their ovarian activity in a short time, which was not the case with the two other groups (Elmansoury et al., 2013).

PP length could also be affected by the prolificacy of a doe. For example, a significant correlation between the PP length and the type of the birth was highlighted in Desert goats in Sudan resulting in a longer PP length in does which delivered twins compared to the ones that had single births (Elzagafi Alli, 2000). Contradictorily, other authors (Mbayahaga et al., 1998) studying local Burundian goats, did not find that litter size significantly affected PP length.

## Notice that...

The start of estrus activity during the PP period is an important factor modulating kidding interval. The nutrition of a doe is an important factor that should be taken into consideration to speed up the return to estrus activity after the partum, pre- and PP.

# III.6. REPRODUCTIVE PERFORMANCE

Reproductive parameters are very important for a successful animal production program, as they directly affect productivity and hence economic traits (Getahun, 2008). In fact, all forms of output including milk, meat, and skins depend on these factors. Decreased productivity in livestock is the first consequence of a reproductive failure (Mukasa-Mugerwa et al., 2002).

Growth traits are also important factors influencing profitability, especially in meat producing. Measures of reproduction and growth that are commonly used (and we choose to adopt in this working paper) are (Table 6):

- **Conception rate**: Number of does conceived/number of does joined.
- **Age at first kidding**: Age at which does give birth for the first time.
- **Kidding interval**: Number of days between successive parturitions.
- **Kidding rate**: Number of does kidded/number of does joined.
- **Fertility**: Percentage of does kidded of the total mated.
- **Litter size at birth**: (Prolificacy) numbers of kids born per doe, per parturition.
- **Birth weight**: Weight of kids born per doe, per parturition.
- **Weaning weight**: Weight of kids reaching weaning per doe, per parturition.
- **Abortion rate**: Numbers of does aborted/number of does joined.

According to Alemu and Merkel (2008) several factors cause reproductive failure in sheep and goats which can be classified into:

- Failure to mate.
- Failure of fertilization in mated animals.
- Loss during any stage of gestation (embryonic, fetal losses).
- Neonatal mortality and subsequent loss occurring until the time of weaning.

### To conclude...

Under tropical conditions, although traditional free-ranging management system combined with the seasonality of goats allow breeding all over the year, uncontrolled breeding is complicated by disease transmission and inbreeding when the number of bucks is limited. In addition, goats in East and Horn of Africa are reared under poor management conditions, severely limited resources, and seasonal fluctuations in feed resources. Controlled breeding may be used as an approach to improve overall reproductive performance, and would allow better synchrony between the supply and the demand for nutrients by reproductive events.

**TABLE 6: Reproductive traits of goats in some East African countries**

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Burundi** | Indigenous goats (smallholder system) | NA | NA | NA | NA | NA | NA | 2.1±0.5 | 9.85±0.29 | NA | Manirakiza et al., 2020 |
| | Local Burundian goats | NA | NA | NA | NA | NA | NA | 1.54±0.29 | 5.75±1.4 | NA | Mbayahaga et al., 1994 |
| | On station local Burundian goats | NA | 599±158 | 254±74 | | 91.9 | 1.75 | S: 2.10<br>T: 1.82 | NA | NA | Mbayahaga et al., 1996 |
| | On farm local Burundian goats | NA | 663±209 | 284±78 | | 87.8 | 1.54 | S: 3.19<br>T: 2.72 | NA | NA | Mbayahaga et al., 1996 |
| | | NA | NA | NA | NA | NA | NA | 1.6±0.3 | 6.3±1.2 | NA | Mbayahaga et al., 1998 |
| **Ethiopia** | Abergelle | 65.4 | NA | NA | 89.4 | NA | 1.23±0.04 | 2.27±0.03 | NA | NA | Wondim, 2019 |
| | Arsi-Bale (traditional management) | NA | 369.05 | 246.13 | NA | NA | 1.21 | 2.28 | 8.39 | NA | Tatek et al., 2004 |
| | Indigenous goats in Alaba | NA | 362.95 | 376.02 | NA | 81.1 | 1.47±0.04 | 2.34±0.03 | 9.85±0.29 | 4.1% | Deribe, 2009 |
| | Arsi-Bale goats | NA | 868.03 | 293.18 | NA | NA | 1.64±0.58 | NA | NA | NA | Dadi et al., 2008 |
| | Begait goats in western Tigray | 90 | NA | 242.86 | NA | NA | 1.63 | NA | NA | NA | Abraham et al., 2018 |
| | Indigenous dairy goats in north-western Amhara | NA | 376.37 | 207.09 | NA | NA | | NA | NA | NA | Alemayehu and Kebede, 2017 |
| | Mid Rift Valley goats | 79 | NA | NA | NA | NA | NA | 1.00 ± 0 | 6.32±2.77 | NA | Tucho et al., 2000 |
| | Boran Somali goats | 74 | NA | NA | NA | NA | 1.00 | 2.36±0.51 | 6.89±1.20 | NA | Tucho et al., 2000 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ethiopia** | Abergelle goats | NA | NA | 332.45 | NA | NA | 1.07±0.019 | 2.82±0.091 | 15.1±0.385 | NA | Belay et al., 2014 |
| | Begait goats (first kidding season) | NA | NA | NA | NA | NA | NA | 3.37±0.09 | 9.05±0.81 | NA | Berhane and Eik, 2006 |
| | Abergelle goats (first kidding season) | NA | NA | NA | NA | NA | NA | 2.74±0.06 | 4.92±0.58 | NA | Berhane and Eik ,2006 |
| | Primiparous Woyto-Guji goats:<br>- No concentrate<br>- 200 g of concentrate<br>- 400 g of concentrate | 66.6<br>77.7<br>85.7 | | | 50<br>85.7<br>91.6 | | 1.0<br>1.0<br>1.0 | 1.5±0.01<br>1.8±0.07<br>2.1±0.08 | | 50<br>14.3<br>8.3 | Berhanu et al., 2013 |
| | Goats in agro-ecological *woredas* of Gedio Zone (Wenago, Kochra and Dilla) | NA | 394.67 | 253.15 | 63.5 | NA | 1.7±0.63 | NA | NA | NA | Debele and Habta, 2015 |
| | Boer-Arsi Bale cross kids (Dilla University) | NA | NA | NA | NA | NA | NA | 2.41±0.12 | 18.74±0.61 | NA | Debele and Habta, 2015 |
| | Abergelle goats (raised under traditional management systems) in Sekota District | NA | 448±29.4 | 290±17.0 | NA | NA | 1.04±0.02 | NA | NA | NA | Deribe and Taye, 2014 |
| | Arsi-Bale (Alaba) | NA | 369.05 | 210.45 | NA | NA | 1.75 | NA | NA | NA | Tsedeke, 2007 |
| | Arsi-Bale | NA | 396.5 | 350.75 | NA | NA | NA | NA | NA | NA | Samuel, 2005 |
| | Arsi-Bale (Loka Abaya) (traditional management) | NA | 451.4 | 183 | NA | NA | 2.07 | 2.52 | 9.56 | NA | Assefa, 2007 |
| | Keffa (traditional management) | NA | 380.03 | 240.03 | NA | NA | 1.7 | 2.78 | 9.1±0.6 | NA | Belete, 2009 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ethiopia** | Arsi-Bale (intensive management) | NA | NA | NA | NA | NA | NA | 2.45 | 9.2 | NA | Mehlet, 2008 |
| | Somali (on-station management) | NA | NA | NA | NA | NA | NA | 3.19 | 11.67 | NA | Zeleke, 2007 |
| | Toggenberg X Arsi-Bale (on-station management) | NA | NA | NA | NA | NA | NA | 2.57 | 9.43 | NA | Girma, 2002 |
| | Goats around Dire Dawa | NA | 606.95 | 186.05 | NA | NA | NA | NA | NA | NA | Gebreyesus et al., 2013 |
| | Maefur goats in Erob District in Eastern Zone of Tigray, northern Ethiopia | NA | 646.6 | 219.6 | NA | NA | NA | NA | NA | NA | Gebreyowhens and Kumar, 2018 |
| | Indigenous Arsi-Bale goats | NA | 574.9±8.3 | 280.3±13 | NA | NA | 1.60±0.03 | 3.7±0.08 | 9.11±0.38 | NA | Kebede et al., 2012 |
| | Indigenous goats in eastern and southern Ethiopia | NA | 638.06 | 205.57 | NA | NA | NA | NA | NA | NA | Nugissie, 2010 |
| | Crossbred goats in eastern and southern Ethiopia | NA | 566.385 | 248.88 | NA | NA | NA | NA | NA | NA | Nugissie, 2010 |
| | Boer x Central Highland goat crossbreeding program carried out at Ataye Research site, Debre Birhan Agricultural Research Center | 48.85 | NA | NA | 37.56 | NA | 1.40±0.03 | 3.63±0.07 | 10.68±0.28 | 9.99 | Mustefa et al., 2019 |
| | Indigenous goats in Ada Barga and Ejere of West Shoa Zone in Oromia Regional State | NA | 422.425 | 251.625 | NA | NA | 1.28±0.33 | NA | NA | NA | Bergaga, 2016 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ethiopia** | Western Lowland goats in Metema District, Amhara National Regional State | NA | 378.2 | 192.15 | NA | NA | NA | NA | NA | NA | Abegaz, 2014 |
| | Abergelle goats in Abergelle District, Amhara National Regional State | NA | 472.75 | 253.15 | NA | NA | NA | NA | NA | NA | Abegaz, 2014 |
| | Woyto-guji goat breeds (traditional management system) | NA | NA | 166.835 | NA | NA | NA | 2.03±0.04 | 9.04±0.18 | NA | Zergaw et al., 2016 |
| | Central Highland goat breeds (traditional management system) | NA | NA | 201.3 | NA | NA | NA | 2.68±0.04 | 9.42 ±0.19 | NA | Zergaw et al., 2016 |
| **Kenya** | Toggenburg dairy goats in the Eastern Highlands (smallholder production system) | NA | 759±82 | 287±42 | NA | NA | 1.67±0.66 | 3.27±0.66 | NA | NA | Ahuya et al., 2009 |
| | Kenya Dual Purpose goats (low-potential, owned by smallholders) | NA | 610 | 305 | 78.00 | NA | NA | 2.90 | 12.68 | NA | Bett et al., 2007 |
| | Kenya Dual Purpose goats (medium-potential, owned by smallholders) | NA | 549 | 244 | 83.00 | NA | NA | 2.40 | 10.90 | NA | Bett et al., 2007 |
| | Galla | NA | NA | NA | NA | 75 | 1.1 | 2.6 | NA | NA | Bradford et al., 1989 |
| | Crossbreeds | NA | NA | NA | NA | NA | NA | 2.5 | NA | NA | Bradford et al., 1989 |
| | Pastoral goat herds in northern Kenya | NA | NA | NA | 80.1 | NA | 1.41 | NA | NA | 5.9 | Hary et al., 2003 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kenya** | Crosses Galla x Toggenburg in Mwingi Sub-county | NA | 1066±37 | 439±40 | NA | NA | 1.291±0.03 | NA | NA | NA | Ndeke et al., 2015 |
| | Kenya Dual Purpose goats (high-potential, owned by smallholder) | NA | 579.5 | 274.5 | 80.50 | NA | NA | 2.00 | 9.00 | NA | Bett et al., 2007 |
| | East African | NA | NA | NA | NA | 90 | 1.3 | 2 | NA | NA | Bradford et al., 1989 |
| | Galla in Mwingi Sub-county | NA | NA | 464±30 | NA | NA | 1.255±0.02 | NA | NA | NA | Ndeke et al., 2015 |
| | Toggenburg in Mwingi Sub-county | NA | 976.04±79 | 371±29 | NA | NA | 1.000±0.00 | NA | NA | NA | Ndeke et al., 2015 |
| | Gabra goats in north-east and south-west Marsabit District in northern Kenya | NA | 366-1098 | 338.5 | NA | NA | 1.02 | NA | NA | 7 | Warui et al., 2007 |
| | Rendille goats in north-east and south-west Marsabit District in northern Kenya | NA | 366-1098 | 307.13 | NA | NA | 1.02 | NA | NA | 6 | Warui et al., 2007 |
| **Rwanda** | African Common goats in Kigali region (artificially inseminated with semen of selected Alpine bucks imported from France) | NA | NA | NA | NA | 56 | 2.17 | NA | NA | 5 | Mourad, 1994 |
| | Indigenous Rwanda goats | NA | 640±27.8 | 343±13.8 | NA | NA | 1.86 | NA | NA | NA | Wilson et al., 1989 |
| | SEA | NA | 598 | 323 | NA | NA | 1.78 | 2.35 | NA | NA | Wilson and Muray, 1988 |
| | Anglo-Nubian x SEA | NA | 766 | 384 | NA | NA | 1.82 | 2.68 | NA | NA | Wilson and Muray, 1988 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rwanda** | Alpine × SEA | NA | 557 | 323 | NA | NA | 1.66 | 2.89 | NA | NA | Wilson and Muray, 1988 |
| **Tanzania** | Malya goats in Maswa District | NA | NA | NA | NA | NA | NA | 2.37±0.03 | 11.08±0.19 | NA | Chavala, 2019 |
| | Sukuma goats in Maswa District | NA | NA | NA | NA | NA | NA | 1.66±0.06 | 5.13±0.34 | NA | Chavala, 2019 |
| | Crossbred goats in Maswa District | NA | NA | NA | NA | NA | NA | 2.18±0.05 | 7.22±0.2 | NA | Chavala, 2019 |
| | Goats in Mgeta Division located on the western slopes of the Uluguru Mountains in Morogoro | NA | NA | NA | NA | NA | NA | 2.6 | 11.1±0.15 | NA | Eik et al., 2008 |
| | SEA x Norwegian does (dietary treatment of 200 g of concentrate at Magadu research farm of Sokoine University of Agriculture, Morogoro) | 100 | NA | NA | NA | NA | 1.5 | 2.5 | 10.6 | NA | Massawe, 2010 |
| | SEA x Norwegian does (dietary treatment of 400 g of concentrate at Magadu research farm of Sokoine University of Agriculture, Morogoro) | 100 | NA | NA | NA | NA | 1.9 | 2.7 | 11.4 | NA | Massawe, 2010 |
| | SEA x Norwegian does (dietary treatment of 600 g of concentrate at Magadu research farm of Sokoine University of Agriculture, Morogoro) | 100 | NA | NA | NA | NA | 2.3 | 2.9 | 12.2 | NA | Massawe, 2010 |
| | Dairy Toggenburg goats in Mufindi | NA | 387.35 | 265.35 | NA | NA | NA | NA | NA | NA | Mtama, 2016 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tanzania** | Dairy Saanen goats in Mufindi | NA | 405.65 | 265.35 | NA | NA | NA | NA | NA | NA | Mtama, 2016 |
| | Dairy goats in Mgeta | NA | 526.125 | 310.185 | NA | NA | NA | 3.27±0.04 | 12.79±0.09 | NA | Sonola, 2015 |
| | | NA | NA | 353.8 | NA | NA | 1.3 | 2.1 | 12.9 | NA | Warner et al., 1985 |
| **Uganda** | Native Ugandan does at Buyana Stock Farm, Makerere University | 56.7 | NA | NA | NA | 52.9 | NA | NA | NA | 47.1 | Bigirwa et al., 2015 |
| **Sudan** | Crossbred (peri-urban areas, Khartoum) | NA | 401.99 | NA | NA | NA | NA | NA | 2.91±0.14 | NA | Abdalla et al., 2012 |
| | Nubian (peri-urban areas, Khartoum) | NA | 400.16 | NA | NA | NA | NA | NA | 2.46±0.15 | NA | Abdalla et al., 2012 |
| | Saanen (peri-urban areas, Khartoum) | NA | 381.25 | NA | NA | NA | NA | NA | 2.38±0.28 | NA | Abdalla et al., 2012 |
| | Saanen goats (raised under Sudan conditions for five years) | 96.87-90.09 | 458.1±11.8 | 315±14 | 151.6-162 | NA | NA | 3.25±0.06 | NA | 0-21.5 | Abdalla et al., 2015 |
| | Sudan Nilotic does (fed pelleted molasses-based diets) | 93.75 | NA | 261.7 | 93.33 | NA | 1.3 | NA | NA | 6.25 | Atta et al., 2012 |
| | Sudan Nilotic does (fed mash sorghum-based diets) | 86.67 | NA | 307.9 | 100 | NA | 1.3 | NA | NA | 0 | Atta et al., 2012 |
| | Taggar goats in western Sudan (dry land farming system, feed with two rations) | NA | NA | 247.8±8.38<br>242.60±7.88 | 100<br>100 | NA | 1.5±0.13<br>1.33±0.12 | NA | NA | 0<br>0 | Bushara et al., 2010 |
| | Sudan Desert goats (conventional feeding systems) | NA | NA | 238.60±25.1 | NA | NA | 1.00±0.00 | 1.55±0.23 | 8.58±1.07 | | Bushara, 2010 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sudan** | Sudan Desert goats (three supplemented feeding systems) | NA | NA | 210.2±11<br>231.5±29<br>230.7±23 | NA | NA | 1.10 ± 0.31<br>1.03 ± 0.18<br>1.00 ± 0.10 | 2.20±0.40<br>1.95±0.36<br>1.63±0.14 | 12.95±1.55<br>11.03±0.99<br>10.08±1.62 | | Bushara, 2010 |
| | Taggar goats (dryland farming in western Sudan with different parities)<br>1<br>2<br>3<br>4 | NA | NA | 337±13.9<br>319±15.7<br>310±15.0<br>294±16.1 | 85.7<br>100<br>100<br>100 | NA | 1.1±0.12<br>1.3±0.14<br>1.5±0.14<br>1.8±0.15 | 1.9±0.14<br>2.0±0.15<br>2.2±0.15<br>2.5±0.16 | NA | 14.3<br>0<br>0<br>0 | Bushara et al., 2011 |
| | Taggar goats in the Dalanj area of Southern Kordofan State (Dalanj University) | NA | 358.1±15.0<br>384.8±9.56<br>387.8±11.6 for S, T, TR | NA | NA | NA | NA | 1.92±0.05 | 7.12±0.26 | NA | Bushara et al., 2013b |
| | Taggar goats (in rainy and dry season) | NA | NA | 257±3.3<br>262±7.9 | 100<br>94.4 | NA | 1.45±0.09<br>1.18±0.09 | NA | NA | NA | Bushara et al., 2016 |
| | Desert goats (natural grazing during rainy season) | NA | 397.7±12.1 | NA | NA | NA | 1.50±0.19 | 2.15±0.07 | 10.84±0.34 | NA | Bushara et al., 2017 |
| | Taggar Goats (natural grazing during rainy season) | NA | 384.3±6.51 | NA | NA | NA | 1.42±0.15 | 1.95±0.04 | 8.41±0.19 | NA | Bushara et al., 2017 |
| | Desert kids (extensive system) in South Kordofan State for single and twin births | NA | 383.0±26.6<br>408.7±8.07 | NA | NA | NA | NA | 2.30±0.05<br>2.06±0.10 | 10.71±0.84<br>10.70±0. 34 | NA | Bushara et al., 2018 |

| Country | Breed | Conception rate | Age at first kidding (days) | Kidding interval (days) | Kidding rate | Fertility (%) | Litter size at birth | Birth weight (kg) | Weaning weight (kg) | Abortions (%) | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Taggar kids (extensive system) in South Kordofan State for single and twin births | NA | 377.5±22.5<br>387.7±3.17 | NA | NA | NA | NA | 1.96±0.08<br>1.94±0.04 | 8.41±0.19<br>8.21±0.23 | NA | Bushara et al., 2018 |

*Note: AI: artificial insemination; IDRD: internal drugs release device; NA: not available; NM: natural mating; PP: postpartum; S: single, T: twin; TR: triplet.*

# III. Male reproductive biology and characteristics

# IV.1. PUBERTY

In livestock, puberty and sexual maturity are very important and considered as economic traits since they affect the economic viability of livestock. In fact, attaining sexual maturity at a precocious age means more offspring produced during an animal's life (Becker-Silva et al., 2000).

Male animals reach puberty when at least some of the morphological traits (testes size, appearance of seminiferous tubules and beginning of spermatogenesis) are present (Chakraborty et al., 1989; Delgadillo and Malpaux 1996; Bielli et al., 2001). Puberty attainment can also be defined in various other ways (Figure 7).

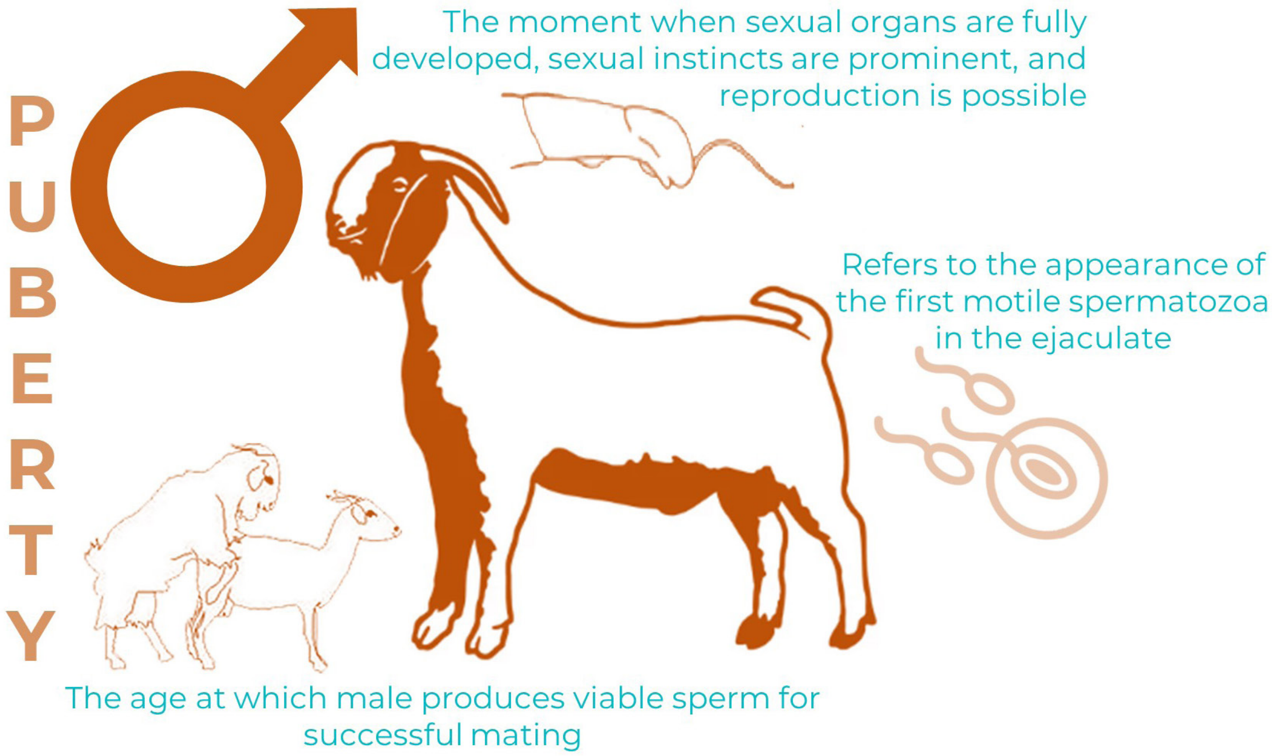



**FIGURE 7: Definitions of puberty in males**

The association between the increase of plasma testosterone concentrations and growth hormone discharges may precede the onset of puberty (Thompson et al., 1972). In goats, some traits and events such as weaning weight, growth rate, age at complete separation of prepuce from the penis, scrotal circumference (SC) at puberty, weight and age at puberty, volume of ejaculate, individual and mass motility percent of semen, abnormal morphology spermatozoa, and the concentration of spermatozoa are important puberty indicators (De La Vega et al., 2001; Bezerra et al., 2009).

However, puberty may often be reached before animals have grown enough to physically support reproduction and therefore animals may not be fully sexually competent at puberty (Gebre, 2007). Therefore, it is important to differentiate puberty from sexual maturity. Attainment of sexual maturity can be confirmed by the examination of semen characteristics. Animals are sexually mature when the characteristics of their semen becomes similar to that of their parents (Atta et al., 2011).

Depending on nutritional status and breed, most tropical male goats attain puberty at approximately eight months of age (Delgadillo et al., 1997; Madani and Rahal, 1988). It has also been reported that tropical male goats reach puberty at approximately 97 days and sexual maturity at 132 days of age (Payne and Wilson, 1999). Age at puberty is highly variable and is dependent on several factors such as the genetic type of the animal, nutritional management, season, and other environmental factors (Abi-Saab et al., 1997) (Table 7). Age at puberty depends also on live

**TABLE 7: Age at puberty, sexual maturity, first service and weight at puberty of male goats in some countries in East Africa**

| Country | Breed | Age at puberty (months) | Age at sexual maturity (months) | Age at first service (months) | Weight at puberty (kg) | Reference |
|---|---|---|---|---|---|---|
| **Ethiopia** | Northwestern Amhara indigenous dairy goats | NA | 9.52±0.60 | NA | NA | Alemayehu and Kebede, 2017 |
| | Indigenous goats in Bale Zone, Oromia | 7.6±0.14 | NA | NA | NA | Asefa et al., 2015 |
| | Abergelle cross Boer goat F1 kids | 7.62±0.183 | NA | NA | NA | Belay et al., 2014 |
| | Bati (Central Highland ecotype) indigenous goat | NA | 8.21±0.28 | NA | NA | Gatew, 2014 |
| | Borena (Long Eared Somali ecotype) indigenous goat | NA | 9.49±0.27 | NA | NA | Gatew, 2014 |
| | Short-Eared Somali indigenous goat | NA | 13.43±0.45 | NA | NA | Gatew, 2014 |
| | Goats in Dire Dawa | NA | | NA | 14.6+7.4 | Gebreyesus et al., 2013 |
| | Maefur goats in Erob District, Eastern Zone of Tigray | 11.1±1.5 | | NA | NA | Gebreyowhens and Kumar, 2018 |
| | Indigenous goats in eastern and southern Ethiopia | NA | 16.31±0.72 | NA | NA | Nigussie, 2010 |
| | Crossbred goats in eastern and southern Ethiopia | NA | 15.28±0.49 | NA | NA | Nigussie, 2010 |
| | Goats in Ada Barga and Ejere, West Shoa Zone in Oromia Regional State | NA | 8.39±0.06 | NA | NA | Bergaga, 2016 |
| | Male Arab goats | NA | NA | 7.0±1.0 | NA | Sheriff et al., 2019 |
| | Male Oromo goats | NA | NA | 7.6±0.9 | NA | Sheriff et al., 2019 |
| | Western Lowland goats | NA | NA | 7.4±2.01 | NA | Abegaz, 2014 |
| | Abergelle goats | NA | NA | 12.3±4.48 | NA | Abegaz, 2014 |
| | Indigenous goats in Horro Guduru Wollega Zone | NA | 9.80±0.03 | NA | NA | Seid et al., 2013 |
| **Sudan** | Crossbred goats in peri-urban areas of Khartoum State | NA | 7.32±0.28 | NA | NA | Abdalla et al., 2012 |
| | Nubian goats in peri-urban areas of Khartoum State | NA | 7.05±0.35 | NA | NA | Abdalla et al., 2012 |
| | Saanen goats in peri-urban areas of Khartoum State | NA | 6.88±0.61 | NA | NA | Abdalla et al., 2012 |
| | Nubian bucks | 5.04 | NA | NA | 11.5 | Abdelrahman et al., 2019 |
| | Sudan Nilotic male kids | 5.7 | 7.34 | NA | 10.90±1.11 | Atta et al., 2011 |

| Country | Breed | Age at puberty (months) | Age at sexual maturity (months) | Age at first service (months) | Weight at puberty (kg) | Reference |
|---|---|---|---|---|---|---|
| **Sudan** | Desert goats | 5.87 | NA | NA | NA | Bushara, 2010 |
| | Taggari goats | 7.43 | NA | NA | NA | Bushara, 2010 |
| | Crossbred male kids | 6.8 | NA | NA | 22.40±0.9 | Elhammali et al., 2013 |
| | Sudanese Desert goats in North Kordofan State | 5.84 | NA | 6.46 | NA | Mohamed Ali and Eldaw, 2015 |
| | Tagger goats in Gezira State | 8.04±0.20 | NA | 9.03±0.21 | NA | Ombabi Mohammed, 2015 |
| | Tagger goats in Eldalang area, South Kurdofan State | 7.4 | NA | 8.0 | NA | Mudawi, 2002 |

*Note: NA: Not available*

weight. In fact, males with a body weight ranging between 10-30 kg reach puberty between three and five months of age (Bearden and Fuquay, 1997). However, age at puberty ranges between five and seven months for bucks reaching approximately 50% of their mature weight (Walkden-Brown, 2001; Bushara, 2010). Sexual maturity may also be affected by weaning season and post weaning nutrition. In fact, good management could reduce the age at which first sexual maturity is reached (Bergaga, 2016).

Under field conditions, attempts are used to induce puberty in bucks. For example, the use of melatonin, a hormone produced by the pineal gland, is effective in inducing early puberty in bucks of temperate breeds. This hormone influences the activity of the testes, semen production, and puberty (Chemineau, 1992; Asher et al., 1993; Mukasa-Mugerwa and Lahlou-Kassi, 1995). West African Dwarf buck-kids administered with exogenous melatonin displayed an onset of spermatozoa release in the ejaculate when five months old (Daramola et al., 2007).

### To conclude...

Literature on age at puberty and the associated internal and external changes in goats is generally scarce. An attention should be paid to management practices and availability of feed input which are factors modulating age at puberty in male goats.

## IV.2. SEASONALITY OF REPRODUCTION

In bucks, spermatogenesis (all the processes that result in the production of spermatozoa) starts at puberty under the control of LH and FSH. In fact, these two pituitary hormones enable the differentiation and multiplication of germinal cells, and the synthesis and secretion of testosterone by Leydig cells. The produced testosterone maintains spermatogenesis, triggers male sexual behavior, and exerts feedback control on gonadotropins (Rekik et al., 2012).

In seasonal breeds, reproductive activity of the bucks is low during spring when the photoperiod increases and is intense during autumn and winter under a decreasing photoperiod. This is due to variations in gonadotropic activity. This could be confirmed by a close relationship between changes in gonadotropin plasma levels, the weight of the testes (as an indicator of spermatogenesis), and sexual behavior. Photoperiod acts by modulating the sensitivity of the hypothalamic-pituitary axis to feedback by steroids through the secretion of melatonin from the pineal gland (Rekik et al., 2012).

Generally, semen characteristics – such as mass motility, progressive motility, percentage of abnormal sperm, and volume of ejaculate – are affected by the season (Rekik et al., 2012). In a study conducted to assess semen quality of mature crossbred male goats during different seasons in Sudan, authors found that the traits of semen collected during autumn were superior to those of semen collected in summer and winter. The semen volume and concentration of sperm were high in autumn (the reproductive season) and lower in summer. In addition, the highest dead sperm percentage and abnormal sperms were recorded in summer compared to autumn (Elsheikh and Elhammali, 2015).

Unlike temperate goat breeds, local breeds under tropical conditions are non-seasonal or exhibit only a weak seasonality of reproduction (Mukasa-Mugrewa et al., 2002; Girma, 2008). This seasonality is rather related to a seasonality of rainfall distribution and therefore a marked seasonal variation in the quantity and quality of feed supply. During the dry season, there is an acute shortage of feed supply, and the available feeds are of a very poor quality. Therefore, animal productivity is determined by the fluctuation of feed resources.

### To conclude...

In tropical environments, as goats breed year-round, uncontrolled natural mating is often used since there is no tradition of using improved breeding techniques in extensive production systems. Such traditional practices affect flock fertility since infertile male and female goats are kept together. In addition, given the diversity of goat breeds, the risk of crossbreeding, and losses of pure-bred genotypes is increased.

# IV.3. SEMEN TRAITS

Semen is defined as the liquid or semi gelatinous cellular suspension containing the male gametes or spermatozoa, and secretions from the accessory organs of the male reproductive tract (Koray and Ali, 2016). Production of spermatozoa is possible after a series of complex changes which determine their number and properties.

The fertility of males, including the ability to produce normal spermatozoa and to mate, has a great influence on herd performance and livestock productivity (Gebre, 2007). Therefore, evaluating the fertility of a breeding male is very important and could be done directly by evaluating its ability to produce offspring or indirectly by evaluating its semen characteristics (Hafez, 1993). Evaluation of the spermiogram includes semen volume, sperm motility, sperm concentration and sperm morphology (Gebre, 2007) (Table 8). Evaluating semen is also useful, providing an important indicator of the breeding potential of males, which can then be used to eliminate infertile males from breeding programs (Gebre, 2007).

Semen is generally collected using two methods. The first is an artificial vagina (AV) which is the most common and the easiest technique. This procedure is painless, quick, and not stressful for the animal. The AV should be clean, dried and sterilized (Wondim, 2019). The inner rubber of the AV should be filled with water at 42-50°C through the tap at the side. Then, pressure is adjusted by inflating air through the valve on the tap. The open end of AV should be lubricated with Vaseline up to a depth of 3 cm. The collection tube, fitted at the other end, should be maintained at a temperature of 30-37°C to avoid cold shock to the collected spermatozoa (Elzagafi Alli, 2000). The second method is an electro ejaculator. The electrical stimulation increases the amount of seminal fluids, and therefore causes a damaging osmotic influence on the spermatozoa (Axner et al., 1998). Many authors confirm that the semen is of a better quality if collected by an AV (Rathore, 1970).

After semen collection, an evaluation should be done to verify that the semen meets the required standards. Semen diluents could be used to increase the volume and obtain many breeding doses that will be used for artificial insemination (AI). In addition, these diluents or extenders nourish the spermatozoa and provide a good environment for their survival (Koray and Ali, 2016).

Several factors, such as age, maturity, nutritional status, general health, endocrine balance, and normality of sex organs, influence male fertility and semen quality (Peters, 2002).

**TABLE 8: Parameters of the spermiogram**

| Parameter | Technique | Unit |
|---|---|---|
| Volume | Read directly from the graduated tube. | Recorded in ml |
| Color and consistency | Assessed by direct visual examination. The consistency was described as creamy, milky opaque and watery, depending on the contents of spermatozoa and seminal plasma. | NA |
| Motility of spermatozoa | A small drop of diluted semen, placed on a clean warm (37°C) glass slide, is examined under a high power (100x) of the microscope. | Estimated according to a grading system described by Evans and Maxwell (1987), scored from 0 to 5 |
| Mass motility | A small drop of undiluted semen, placed on a clean warm (37°C) glass slide, is examined under a low power (40x) of the microscope. | Estimated a according to a grading system described by Evans and Maxwell (1987), scored from 0 to 5 |
| Concentration of spermatozoa | A Burker-designed haemocytometer or a spectrophotometer. | 109 spermatozoa/ml |

*Note: NA: Not available*

**Nutrition**:

Nutrition is one of the main environmental influences on male genital function and therefore on the sperm quality, ensuring optimum spermatogenesis and a normal sperm maturation in the epididymis (Mekasha et al., 2008a).

In the tropics, where the influence of photoperiod is minimal, higher quality semen is reported during the rainy season, although this is due to the influence of nutrition rather than to the season (Carmenate and Gamcik, 1982). Nutrition improves sperm morphology by maintaining the secretion of gonadotropins and hence testicular function, and therefore the function of the male genital tract (Walkden-Brown et al., 1994). The amount of protein in the diet is important and is responsible for the production of morphologically normal spermatozoa (Brown, 1994). Higher protein intake increases sperm production and positively influences the neuro-endocrine system, resulting in improved semen characteristics (Abi-Saab et al., 1997).

In a study conducted on a smallholder livestock farming system in Ethiopia, the authors showed that supplementation with Khat leftovers induced an improvement not only in live body weight but also in testicular size, semen production and sperm motility in Ogaden bucks. In the same study, better nutrition also improved ejaculate volume, sperm numbers and sperm motility (Mekasha et al., 2007).

**Age and breed**:

Older bucks generally have a larger volume of ejaculate than younger bucks. A variation in abnormal spermatozoa between different breeds and different ages has also been reported (Karagiannidis et al., 2000).

**Seasonality**:

Even if tropical goats are not seasonal breeds, the season does affect semen characteristics in goats. In Sudan, high sperm motility of pubertal bucks was reported in the autumn, and low sperm motility in the summer, while the percentage of dead sperms was higher during the spring and summer compared to the autumn and winter (Elsheikh et al., 2013). In the same country, authors have reported that the percentages of dead and abnormal sperm increases in the summer and sperm motility decreases; while in the autumn the percentage of dead and abnormal sperm decreases and sperm concentration increases (Elsharif, 2003). In Nubian bucks and cross-bred bucks, it was reported that higher concentration of sperm was recorded in the autumn compared to the summer (Ahmed et al., 1997; Adam, 1996; Elsharif, 2003; Elsheikh and Elhammali, 2015).

**Male morphology**:

Sperm production closely linked with testicular size, and to predict sperm production and semen quality both direct testicular measurements and indirect measurements of testicular growth (by determining SC) are used (Elmore et al., 1976).

Larger SC is associated with greater ejaculate volume, higher sperm concentration, better seminal quality, and higher daily sperm production (Mukasa-Mugerwa and Ezaz, 1992; Coulter et al., 1997).

As for body weight or BCS, SC is influenced by various factors including genotype, age, season and nutrition (Bongso et al., 1982; Roca et al., 1992; Karagiannidis et al., 2000). Some nutritional regimes enhance testicular development and sexual maturity (Mukassa-Mugerewa and Ezaz, 1992). In a study conducted in Ogaden bucks, a higher growth rate (indicated by a higher body weight, BCS and larger SC) were observed when the animals consumed Khat leftovers ad libitum compared to two other nutritional treatments (Mekasha et al., 2007).

Large genotypes are usually heavier and have a larger SC than medium and small bucks of the same age (Al-Ghalban et al., 2004). For example, in Uganda, Boer bucks have a higher mean SC than indigenous bucks, and this is because Boer goats are larger in size (up to 130 kg) compared to indigenous goats (20-35 kg). Therefore, the ejaculate volume of Boer bucks was also higher than that of indigenous bucks (Bigirwa et al., 2015). In the same study, the authors found that sperm count and ejaculate volume were higher in Boer bucks, and determined that this was due to a higher testicular volume compared with indigenous bucks (Bigirwa et al., 2015).

Authors have also showed that there is a strong and linear positive association between body weight, SC and testicular weight, suggesting that the growth of the genital organ occurs in parallel to an increase in body mass (Coulter and Foote 1977; Bongso et al., 1982; Ahmad and Noakes 1996; Mekasha et al., 2007, 2008a).

When predicting sperm production, SC and the shape of the testes should be taken into consideration (Brito et al., 2002). In fact, scrotum shape affects thermoregulatory ability, sperm production and semen quality in domestic animals. In a study conducted in Ethiopia by Mekasha et al. (2008b), authors found that higher proportions of Afar and Woito-Guji, followed by Boran bucks, had long-ovoid shaped testes, and explained this finding by a physiological adaptation mechanism that dissipates high ambient heat load prevalent in the arid and semi-arid agro-ecology where these breeds prevail. However Central Highlands and Arsi-Bale bucks have a higher proportion of ovoid shaped scrotums as a form of adaptation to the low ambient temperature in the highland agro-ecological setup (Mekasha et al., 2008b).

### To conclude...

Sperm evaluation is considered as a prerequisite for selecting breeding males and is generally used to predict the breeding value of a sire used in natural service or AI and their certification. The collection of ejaculates in the tropics is not simple under an extensive husbandry system where multiple sires are present in the flock; this enhances male dominance and ejaculation frequency becomes uncontrollable. In addition to this, the lack of adequate infrastructure complicates this evaluation.

Evaluation of sperm morphology should be done together with clinical evaluations for different breeds at different ages and in different environments.

## IV.4. SEXUAL BEHAVIOR

As for other male species, the level of sexual behavior fluctuates during the year in relation to the concentration of testosterone. In a buck, this dependence is less accentuated and could be modulated by the social environment, such as the presence of other males and regular exposure to receptive females (Rekik et al., 2012). In fact, the socio-sexual environment in which males are reared strongly influences their future sexual behavior when adults. This phenomenon differs according to species. For example, contact with females during their prepubertal period has no effect on bulls (Lane et al., 1983; Price and Wallach, 1990; Borg et al., 1993). For a buck, brief and acute exposure to goats of yearling males in estrus does not modify their sexual performance when adults (Price et al., 1998), while permanent contact with adult does during their pre-pubertal development has a short-lasting positive effect on reproductive traits (Lacuesta et al., 2015). Bucks reared in isolation from females recognize other males as sexual partners and are therefore more predisposed to display homosexual behaviors than other bucks reared with females (Ungerfeld et al., 2013).

Sexual behavior of bucks has been extensively reviewed (Fabre-Nys, 2000), and is divided into several sequences:

- During the first, the buck adopts a posture where the head is stretched to the front with the ears, in a down position. Then, the anogenital area of the female is sniffled by the buck who urinates directly after and displays the characteristic 'flehmen' reaction. If the doe shows signs of receptivity, the buck starts courtship behavior by rotating its head in the direction of the female, emitting brief sounds at a low frequency and striking the doe with his foreleg.

- The second sequence of steps starts by copulation attempts and ends with erection, mounting, intromission and ejaculation. In the buck, ejaculation usually lasts a few seconds and follows the first intromission. Directly after ejaculation, the buck usually turns to feeding if available.

Several factors affect sexual behavior in a buck. The season is among the main factors affecting sexual behavior, especially in temperate zones. In fact, in temperate zones, the bucks express sexual behavior seasonally, during the autumn and winter. The expression of sexual behavior follows an increase in the testosterone rate (from 3 to 20 ng/ml) six weeks before sexual behaviour begins (Rouger, 1974; Ahmad and Noakes, 1995).

Other factors also affect a buck's sexual behavior. The effect of age and previous experience are difficult to dissociate in a young buck, but the social environment in which male goats were reared greatly impacts sexual behavior (Lacuesta et al., 2018).

Generally, libido is measured as the reaction time from presenting the buck to a female, generally with an induced estrus, until ejaculation. It is also called latency time (Atta et al., 2011). The number of courtship and mounting (mount attempts, mounts without and with ejaculation) behaviors can also be recorded.

### To conclude...

Male sexual behavior has direct consequences on reproductive success and is an important factor for flock breeding efficiency and productivity in goat farming. In fact, under field conditions, numerous does are generally mated to a single buck, therefore male fertility is a vital issue. On the other hand, male sexual behavior is important for heat detection and for libido, modulating the buck's desire to mate does and therefore the success of mating.

In addition to natural mating, sexual behavior is important for the success of some reproductive biotechnologies. For example, if sexual behaviors are expressed and semen is collected at earlier ages, breeding programs will be successful. Therefore, evaluation of male fertility using a serving capacity test prior to mating is good practice to reach breeding success.

## IV.5. ABILITY TO MATE IN THE FIELD

As the buck influences the overall pregnancy rate of the flock, and contributes 50% of the genetic make-up of the kid, it is considered an important animal in the flock. Therefore, the choice of breeding buck based on its conformation, growth rate, coat color, libido, maternal history, genital organs, and semen quality is a very important management decision (Gatew, 2014). When choosing a buck, a first step could be screening just based on physical traits. At a later stage, further selection could be done based on production and reproduction characteristics (Gatew, 2014). Together with semen evaluation, body size and testicular traits of domestic animals allow breeding soundness evaluations.

In small flocks, generally one breeding buck is kept in the flock but sometimes more than one buck is kept as a replacement. Some farmers do not have breeding bucks and prefer to borrow a neighbor's (Gatew, 2014). When more than one buck exists in the flock, other bucks will be castrated and kept for other purposes, including fattening and sale. Only the breeding buck is left uncastrated and will serve 2-3 years (Getachew et al., 2020), and could remain up to 5.5 years of mean age but this practice would increase consanguinity problems in the flock (Abegaz, 2014). The number of bucks selected for breeding depends on the number of does available for mating, with a ratio of 1:25 recommended for tropical traditional production systems (Wilson and Durkin, 1988). Other ratios have been reported in East Africa depending on management conditions and the resources of farmers (Table 9).

In East and Horn of Africa, keeping males and females together is a common practice, allowing year-round breeding. Nevertheless, uncontrolled mating, practiced in small flock sizes, and combined with poor or even no record keeping on pedigree, leads to inbreeding problems and therefore poor growth rates (Saico and Abul, 2007).

Controlled natural mating (using breeding bucks individually) is less frequent and is practiced in regions where the sector is organized, for example with the implementation of community-based breeding programs. Such a program minimizes inbreeding problems among the flocks, and selection of breeding bucks takes place within the community flocks to increase selection intensity and effectiveness (Sheriff et al., 2019). Several months prior to its initiation, some actions are required for the success of the breeding season (Figure 8).

TABLE 9: Mating ratios in flocks of goats in some localities in Ethiopia

| Country | Location | Ratio | Reference |
|---|---|---|---|
| Ethiopia | Ziquala District | 1:4 | Alemu, 2015 |
| | Tanqua Abergelle District | 1:5 | |
| | Lay Armachiho District | 1:4 | |
| | Mid Rift Valley | 1:17 | Tucho et al., 2000 |
| | Boran Somali | 1:15 | |
| | Indigenous goat types in Bale Zone, Oromia | 1:8.4 | Asefa et al., 2015 |
| | Indigenous goats in Horro Guduru Wollega Zone | 1:12 | Seid et al., 2013 |
| | Abergelle Agricultural Research Station | 1:50 | Belay et al., 2014 |
| | Bati | 1:5.3 | Gatew, 2014 |
| | Borena | 1.8.6 | |
| | Siti | 1:9.4 | |
| | Pastoral production system | 1:11.23 | Gebre et al., 2019 |
| | Agropastoral system | 1:9.74 | |
| | Konso | 1:10 | Getachew et al., 2020 |
| | Goats kept by Arab and Oromo keepers, north-western Ethiopia | 1:5 | Sheriff et al., 2019 |
| | Local goats in western Ethiopia | 1:5 | Belete, 2009 |
| | Western Lowland goats | 1:7 | Abegaz, 2014 |
| | Abergelle goats | 1:12 | |


FIGURE 8: Actions required for the success of the mating season

Flushing is an important practice, to provide extra energy and/or protein to breeding bucks prior to the breeding season and for the first several weeks of the breeding season. This practice allows increased weight gain and has a positive effect on spermatogenesis. For example, buck owners in the Bati area in Ethiopia give additional supplements such as homemade grain, kitchen and food residues and sometimes purchased concentrates (Gatew, 2014).

## To conclude...

The number and availability of breeding males in the flock is responsible for the improvement in genetic. In traditional production systems in the tropics, few breeding males are maintained in the flocks for breeding purposes throughout the year. The bucks are generally used for breeding at the age of one year and will serve for two to three years. Some reproductive biotechnologies, such as AI, could be advantageous in offering more economic mating schemes particularly when associated to genetic improvement programs and a screening of males for diseases.

# IV.6. FACTORS AFFECTING REPRODUCTION

Reproduction in goats is affected by serval factors such as nutrition, breed, age, season and health status (Roca et al., 1992; Bielli, 1999; Karagiannidis et al., 2000).

Nutrition affects reproduction through growth and sperm, especially in tropical environments where nutritional resources fluctuate according to the season. Nutrition exerts long-, medium- and short-term effects on the reproductive function of small ruminants. Nutrients are first essential for maintenance of body metabolism, followed by growth, then production and reproduction. Abi-Saab et al. (1997) reported that improving protein content in feed enhanced body weight, testicular size, semen characteristics and fertility. Energy intake is also important and favorably influences testicular growth and sperm production (Braden et al., 1974; Murray et al., 1990). In addition, improved nutrition increases the secretion of gonadotrophins and enhances the production of morphologically normal spermatozoa (Walkden-Brown et al., 1994).

Breed is another factor affecting reproduction through body size, and testicular and seminal traits. In fact, as large-sized breeds are heavier, they have larger testicular measurements and continue to grow until late in their maturation (Al-Ghalban et al., 2004). Seminal characteristics were also different between Alpine, Saanen and Damascus goat breeds (Karagiannidis et al., 2000).

In addition to body size, the presence of horns has a significant effect on sperm concentration, total sperm per ejaculate and viable sperm concentration for all breeds. In a study conducted by Hasan and Shaker (1990), authors found that fertility is improved when using horned rather than polled Damascus bucks during the breeding season. Some authors attribute this to the genetic link between the locus for the presence of horns and the fertility characteristics of bucks (Devendra and Burns, 1970). Therefore, it is better to select replacement sires that are horned, and all bucks from two polled parents should be excluded from the breeding flock.

In addition to nutrition and breed, age of the buck also affects reproduction. In fact, differences in physiological stages at various ages influence body size and testicular growth in domestic animals (Karagiannidis et al., 2000). Animals grow faster when they are young, and then they grow more slowly when reaching maturity. In goat kids, the development of testes is rapid at an early age, followed then by a period of slow growth (Nsoso et al., 2004). In addition, the increase in SC is also related to age (Bongso et al., 1982). When compared with their younger counterparts, mature Damascus bucks had higher body weight, greater SC, total number of sperm per ejaculate, and sperm concentration. Those same animals presented a lower percentage of abnormal spermatozoa (Al-Ghalban et al., 2004).

### To conclude...

Unfortunately, information regarding male goats - compared to that available for females - is scarce.

Use of breeding bucks should be done at an optimal age when semen characteristics and growth performance are at their optimum.

When comparing bucks' performance, factors such as age, management practices, and breed should be taken into consideration.

# V. Improvement of reproductive performance and reproductive biotechnologies

Goats significantly contribute to livestock GDP and the livelihoods of the poor and small-scale farmers in many low and middle-income countries, but their productivity remains low, especially in low-input systems. This is also due to the genetic potential of indigenous stock. Reproduction is an important pillar of the overall herds' productivity and, therefore, reproductive traits are economically important which could be improved through various interventions, namely:

i. induction of puberty;

ii. feeding strategies;

iii. out-of-season breeding;

iv. hormonal manipulations;

v. improvement of litter size;

vi. selection for reproductive performance; and

vii. reproductive biotechnologies which are essentially AI and embryo transfer (ET).

All of these techniques and their application in East and Horn of Africa will be discussed in this section.

# V.1. IMPROVEMENT OF REPRODUCTIVE PERFORMANCE

## V.1.1. Induction of puberty

In farm animals, the onset of puberty is related to body weight. Therefore, it is related to nutrition, age, type of birth and season of birth (Devendra and Bums, 1970; Gill and Dev, 1972; Shelton, 1978; Smith, 1978). In goats, authors have related puberty essentially to body mass and age of the doe at first estrus (Shelton, 1978; Smith, 1978; Prasad and Bhattacharyya, 1979a, b).

Generally, and in most sheep and goat breeds, breeding is delayed until animals attain 60-75% of their mature body mass (Shelton, 1978; Smith, 1980). Inducing an early puberty in young female goats could offer a good solution for intensive production.

Social interactions are among techniques used to induce puberty in goats. In fact, those stimulations are involved in modifying the expression of some reproductive traits in both sexes, and many have studied the effect of the presence of the male on the puberty of females (Bearden and Fuquay, 1997; Arthur and Ahunu, 1998; Hafez and Hafez, 2000; Walkden-Brown, 2001). They reported that exposure of females to males of the same species will advance the timing of the onset of puberty, and this is called the male effect. The presence of the male may modify the age of puberty and estrus behavior (Shelton, 1977; Ott et al., 1980). In a study conducted in different groups of female Boer goat kids exposed to three male stimulation treatment groups – (i) permanent male group (permanent presence of a male), (ii) a teaser male group (limited daily exposure to a male), and (iii) a control group (isolated from males) in December and April weaning seasons – the authors found that contact with male goats did have a beneficial effect on synchronization and timing of puberty, while nutrition played a minor role (Greyling and van Niekerk, 1990). Therefore, the authors concluded that, in both seasons, the permanent presence of a male did have a marked beneficial effect on the number of animals exhibiting estrus (Greyling and van Niekerk, 1990). Some authors reported that the male effect is probably mediated by pheromones and other sensory cues influencing hypothalamic-GnRH secretion (Arthur et al., 1998).

Feed supplementation is also used as a technique to induce puberty. In fact, nutritional levels modulate age at puberty (Bearden and Fuquay, 1997; Hafez and Hafez, 2000) and many authors have showed that well fed animals with a good growth rate reach puberty before those which are poorly fed have a slow growth rate (Arthur et al., 1998; Walkden-Brown, 2001). Wilson (1957) cited by Kiango (1996), observed that under good nutrition which enhances faster growth rates, East African goats can reach sexual maturity before four months of age, if they attain a weight of 14-16 kg.

In a study conducted by Bushara (2010), authors evaluated the reproductive performance of Sudanese Desert goats under traditional management systems, with supplemented feed containing different energy levels with iso-nitrogenous protein. They found that the age at puberty was significantly affected by feed supplementation. In fact, female kids belonging to the supplemented feed group were sexually mature at an earlier age when compared to their counterparts in the unsupplemented feed group. Therefore, the authors confirmed that feed supplementation accelerates age of sexual maturity age.

Hormones could also be used to induce puberty, namely exogenously-administered melatonin which advances the onset of the breeding season in sheep and goats by mimicking the stimulatory effect of short days.

### To conclude...

Inducing early puberty in young goats is one way to intensify production and could ameliorate reproductive performance. Initiation of early reproduction has been studied extensively in sheep, but little information is available in goats.

### V.1.2. Feeding strategies

In many countries of East and Horn of Africa, animals suffer from nutritional constraints, especially when they are raised under a traditional system. This nutritional stress affects growth rate and reproductive performance (Tolera et al., 2000; Ohiokpehai, 2003). In addition, reproduction increases an animal's requirement for nutrients. While reproductive performance depends on the interaction of genetic and environmental factors, it is deeply subject to nutrient requirements (El Mansoury et al., 2013).

Nutrient supply to animals can influence their reproductive processes, such as the onset of ovarian cyclicity, length of breeding season, ovulation rate, fertilization rate, PP anestrus period, growth and viability of the offspring (Kudouda, 1985; Jubartalla, 1998).

The common practice used to prepare animals for the breeding season is 'flushing', consisting of providing extra energy and/or protein to breeding does prior to the breeding season and for the first few weeks of the breeding season (Massawe, 2010). In fact, ovulation rate is directly affected by pre- and post-mating nutrition, acting on the gonadotrophic axis or on the ovary (Landau and Molle, 1979). Some authors have noted that a restricted energy intake is involved in the alteration of adrenal cortex production, which directly or indirectly influences ovarian activity and the concentration of peripheral plasma progesterone (Wagner et al., 1972; First, 1979).

In Jahid et al. (2010), the total number of ovulatory follicles, ovulation rate, and plasma concentrations of glucose and insulin, were increased after short-term intermittent nutritional stimulus from the luteal phase in goats.

Other authors have showed that ovulation and fetal implantation in the uterus are improved with flushing in small ruminants (Kusina et al., 2001; Acero et al., 2008). This could be related to the increased weight gain of does which should be moderate. Although thin does respond best to flushing (Schoenian, 2009), does that are too thin will express low weaning and low growth rates, and overly fat does can suffer from pregnancy toxemia.

Nutrition also has an effect on the different stages of intra-uterine growth and other associated tissues. The need for placental growth is very limited before day 60 of gestation, and will increase at the final stage of pregnancy to enable the adequate nourishment of the fetus and will ameliorate kids' birth weight (Abd El Gadir et al., 2005). During the final six weeks of pregnancy, fetal growth is rapid, and this imposes a metabolic challenge to the doe, leading to a mobilization of maternal body tissue (Akusu and Ajala, 2000).

Flushing could also ameliorate reproduction in males since many studies showed that feed availability had a positive effect on testicular mass and sperm production (Walkden-Brown et al., 1994; Mekasha et al., 2007). Nistane and Honmode (1982) found that increased availability of amino acids to bucks resulted in improved sperm viability. In fact, raised total proteins increase cell proliferation in the seminiferous tubules (Abi-Saab et al., 1997). Similarly, Abi-Saab et al. (1997) reported that Baladi goats had improved body weight, testicular size, and fertility when they were under high-protein diets. Nutrition also improves sperm morphology by maintaining the secretion of gonadotropins, and hence testicular function and the function of the male genital tract (Walkden-Brown et al., 1994).

In East Africa, 2 studies were conducted to evaluate the effect of feed supplementation on male reproductive performances (Figure 9).

### To conclude...

Reproductive performance could be ameliorated through different levels of feed supplementation (protein, energy, etc.). In East and Horn of Africa countries, many feeding resources could be valorized, such as industrial or agricultural sub-products. Overfeeding during pregnancy may cause wastage through dystocia due to absolute fetal oversize, therefore this technique should be applied reasonably.

## V.1.3. Out of season breeding

African small ruminants do not normally experience deep seasonal anestrus as most temperate breeds, but many studies showed that reproductive activity often diminishes at some points of the year, especially in very harsh environments. In addition, improved breeds are less adapted to local conditions in many East African countries, exhibit reproductive inefficiency, and do not reach the desired performance (Oluka, 2006). Out-of-season breeding could therefore be induced using natural methods – buck affect, manipulating photoperiod or a combination of photoperiod and exposure to intact males – to intensify the rhythms of kidding and improve the productivity of indigenous goats.

Unfortunately, according to some authors, the male effect is only an effective mean of inducing ovulation and estrus in seasonally anovulatory does and is therefore a technique restricted to seasonal breeders (Shelton, 1960; Chemineau, 1983). Therefore, the male effect may only have a limited effect on non-seasonal breeds, which is the case for intertropical breeds.

After a period of total separation, the introduction of a male has been shown to induce a rapid increase in LH pulse frequency, leading to a pre-ovulatory LH surge (Oldman et al., 1980; Ungerfeld and Rubianes, 1999; Romano et al., 2000; Lucidi et al., 2001; Knights et al., 2002). It has also been shown that buck teasing enhances luteolysis and early ovulation in cycling females (Chemineau, 1983; Martin et al., 1986). In addition, females will exhibit stronger behavioral estrous in the presence of males (Smith, 1980). Nevertheless, this technique is not effective when used during the breeding season (Godfrey et al., 1997).

In some studies, authors have tried to combine the male effect with hormonal treatments (Mgongo, 1988). In Tanzania, a study was conducted on East African short-horned female goats to test the combination of buck teasing and low doses of a $PGF_{2}\alpha$ analogue, cloprostenol, given intravulvo-submucoselly. Authors found that all goats exhibited estrus within 68 hours, but the number of goats receiving low doses of $PGF_{2}\alpha$-cloprostenol observed that in estrus increased with exposure to bucks. The exposure of females to males prior to AI was also an advantage because copious mucus eased penetration (Mgongo, 1988).

Manipulating photoperiod is another technique used to induce out-of-season breeding and consists of modifying the photoperiod using melatonin implants. When reproducing long days for a period of two months or more, animals will interpret the prevailing photoperiod as short days. This is because the natural photoperiod is of shorter duration than that imposed by the photoperiod treatment, and this will result in an increase in melatonin secretion during the night at the end of the winter and beginning of spring, which will initiate sexual activity in females. As reproduction in temperate breeds is not affected by photoperiod, this technique is not very adaptable to East and Horn of Africa. The cost of the technique is also very high and may prohibit its use in low-input extensive systems.

### To conclude...

Natural methods used to induce breeding are cheaper than hormonal methods. In addition, they satisfy consumers' exigence for hormone-free animal product. Nevertheless, the variability of the response of animals may require the use of hormones, which are more efficient, especially when AI at a fixed time is applied.

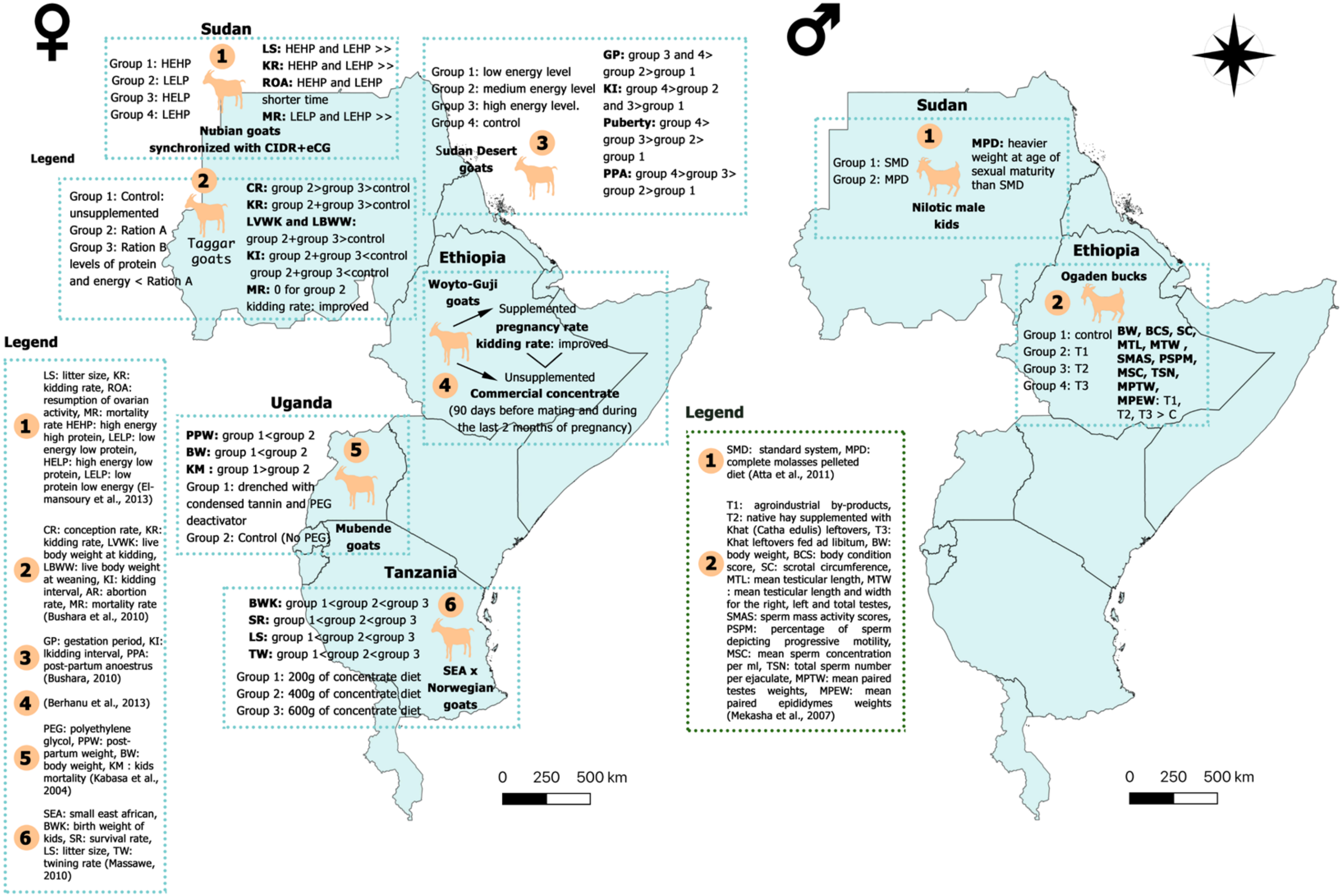



**FIGURE 9: Trials conducted in some East African countries presenting the effect of feeding strategies on some reproductive traits**

Source: Kabasa et al. (2004); Mekasha et al. (2007); Bushara (2010); Bushara et al. (2010); Massawe (2010); Atta et al. (2011); Berhanu et al. (2013); Elmansoury et al. (2013)

### V.1.4. Hormonal manipulations

Under temperate climatic conditions, goats, as well as ewes, spontaneously ovulate and are commonly considered as seasonally polyestrous animals (Fatet et al., 2011). However, under tropical and intertropical conditions, anestrus periods are generally the result of nutrition rather than photoperiod (Abera, 2017). Induction and synchronization of estrus and ovulation are therefore necessary in these regions, allowing producers to ameliorate production and to reach better economic goals than natural conditions allow. When associated with AI or natural mating, estrus induction/synchronization provides a better level of fertility. When applying this technique, the reproductive cycle of an animal is manipulated using hormones or their analogues. The luteal or the follicular phases of the estrus cycle could be manipulated. Nevertheless, in does and ewes, control during the luteal phase, which is longer and more responsive to manipulation, is easier.

The objective of the main strategies used is to extend luteal or the follicular phases of the estrus cycle by using exogenous progesterone, or to shorten it by regressing artificially and prematurely the existing corpora lutea (Abera, 2017). Several hormones can be used to control the estrous cycle and are summarized in Table 10 and Figure 10. Estrus synchronization and induction also has the advantage of helping mature animals, that do not visually show intrinsic reproductive rhythms, to be used (Hunter, 1980).

This reproductive technique facilitates and becomes the basis of many Assisted Reproductive Technologies (ARTs) such as AI, multiple ovulation and embryo transfer (MOET), and in vitro fertilization (IVF) programs, which are all use to accelerate genetic gain and enhance the reproductive performance of various livestock species.

In East Africa, different techniques of estrus synchronization are used and are summarized in Table 11. In tropical and sub-tropical regions, when animals are maintained under optimal environments, animals do not show real seasonal anestrus. Therefore, simple methods such as synchronization using prostaglandins could be used and showed good results (Table 11).

When using hormonal manipulations, ovulation and estrus occur at a precise point in time, enabling reproduction in a chosen period of time, and ensuring kidding at an optimum time of the year, corresponding to a better climate and market demand, especially in regions where demand is seasonal or characterized by peaks periods (for example Christmas or any other religious event). The optimum time of year will also correspond with good availability and quality of forage, which will improve milk production and will therefore ensure higher kid survival and growth rates (Baril and Saumande, 2000). In addition, estrus synchronization and induction minimize the time and the difficulty of estrus detection, and allows uniform kidding distribution throughout the year, facilitating animal management.

As induction and synchronization are used to ameliorate productivity, and for the success of those techniques, attention should be paid to other factors such as feed quality (Hussain et al., 1996), age of the dam (England et al., 1997), type of birth (litter size) (Galina et al., 1996 ), birth weight, season of the year, stress factors, and the physiological status of the animals (Figure 11).

### To conclude...

There are several methods of estrus synchronization and induction, and the choice between them depends on the specific farming conditions and the environment where the animals live. There is no rule to recommend a specific synchronization technique and the results are variable according to breed, season, location, farming condition and even individual differences between animals.

The most important recommendation is that the chosen technique should be effective in regulating ovarian activity, so that most of the treated animals will experience estrus approximately at the same time. Fertility should not be depressed at the induced oestrous period, and the technique should be easy to use for the operator and animals and the products should be locally available at an accessible cost.

| TABLE 10: Different hormones used for estrus synchronization and induction, and their commercial name | | | | |
|---|---|---|---|---|
| **Hormones** | **Normal function** | **Artificial function** | **Protocol of use** | **Commercial name** |
| **Prostaglandins ($PGF_{2}\alpha$)** | Hormone occurring during the normal estrous cycle of a non-pregnant animal.<br>Released from the uterus 16 to 18 days after the animal was in heat (non-pregnant animal) to destroy the CL. | Synchronizing hormone.<br>Only used in cyclic females and in a responsive phase of the estrous cycle (from day 3 of the estrus cycle) and luteal regression can only be induced between day 5 to 16 of the estrus cycle in goats.<br>Synthetic $PGF_{2}\alpha$ will imitate the natural PGF release and cause CL regression, synchronizing a decline in progesterone and resulting in the final growth of the dominant follicle to produce estradiol and behavioral heat.<br>Administered by an intramuscular injection, and has low hormonal residues, since it is rapidly and almost completely metabolized in the lungs.<br>In normal cyclic females: estrus occurs within 2 to 6 days after intramuscular injections of $PGF_{2}\alpha$ or one of its analogues.<br>Can be used throughout the entire year in tropical breeds.<br>At any trimester of pregnancy, the injection of $PGF_{2}\alpha$ causes abortion in goats. | One shot $PGF_{2}\alpha$<br>Single injection of $PGF_{2}\alpha$ is given to cyclic females, one-third of the females will not respond to the injection.<br>This technique had a lower cost compared to other protocols and females are only handled once.<br>Two shot $PGF_{2}\alpha$<br>Two injections of $PGF_{2}\alpha$, 7 or 11 days apart. Non-cycling animals will not generally respond to $PGF_{2}\alpha$ products. With this protocol more animals should come into estrus, but administering two injections of $PGF_{2}\alpha$ to all animals increases financial costs and labor requirements. | Lutalyse®<br>Carboprost®<br>Fenprostenol®<br>Estrumate®<br>estroPlan®<br>Enzaprost®<br>Cloprostenol® |

| Hormones | Normal function | Artificial function | Protocol of use | Commercial name |
|---|---|---|---|---|
| **Gonadotropin-Releasing Hormone (GnRH)** | The primary hypothalamic signal peptide, governing reproductive function by regulating the synthesis, glycosylation, and secretion of LH and FSH.<br><br>It controls the estrus cycle and is released by the hypothalamus. | When artificially administrated, it affects follicle development on the ovary and causes ovulation.<br><br>When GnRH is given with $PGF_{2\alpha}$ to estrous cyclic and non-cyclic females, the patterns of follicular development are altered, inducing ovulation.<br><br>This treatment may induce estrus in 10-30% of anestrous females. | Used together with progestogen P4, at the end of the protocol: GnRH-$PGF_{2\alpha}$ based synchronization.<br><br>An initial GnRH injection (day 1): follicle growth in cyclic females and induces ovulation (to provide progestin pre-exposure) in anestrous females.<br><br>$PGF_{2\alpha}$ (day 7): deterioration of CL that are present causes a decline in progesterone.<br><br>Second GnRH (day 9-10): encourages ovulation of dominant follicles that have been pre-programmed by the first GnRH treatment.<br><br>After treatment with P4 and gonadotropin, the animals tend to manifest estrus in approximately 48 hours and ovulation occurs in approximately 60 hours. | Cystorelin®<br><br>Fentanyl®<br><br>Factrel®<br><br>Ova Cyst® |

| Hormones | Normal function | Artificial function | Protocol of use | Commercial name |
|---|---|---|---|---|
| Progesterone | Hormone produced by the CL after ovulation maintaining pregnancy, by controlling LH secretion from the pituitary, and blocking estrus and ovulation during the diestrum phase of the estrous cycle. | Steroid hormone.<br><br>Inducing during the non-breeding season and synchronizing during the breeding season.<br><br>Used in cycling does, as well as in seasonally anestrus does.<br><br>Affects the luteal phase of the cycle.<br><br>Used with or without accompanying treatments such as gonadatropins or $PGF_{2\alpha}$ analogs.<br><br>Given with $PGF_{2\alpha}$ to estrous cyclic and non-cyclic females, the patterns of follicular development are altered, inducing ovulation. | Exogenous progestogens are used to extend the luteal phase of the oestrous cycle, so that the natural CL regresses naturally during the period when progestogen is administered.<br><br>- Exogenous progestogen continues to exert negative feedback on FSH and LH secretion, even after CL regression has occurred in the animals.<br><br>- When progestogen is later withdrawn, follicular growth starts simultaneously in all treated females, and estrus and ovulation occur within 2-8 days.<br><br>- The traditional method for synchronizing estrus is the use of intra-vaginal sponges with equine chorionic gonadotrophin (eCG) injected at the time of sponge removal, or 48 hours prior to sponge removal.<br><br>- Females usually show estrus 24 to 48 hours after removal.<br><br>- ECG stimulates ovulation. | <u>Oral administration</u>:<br><br>Medroxyprogesterone acetate (MAP)<br><br>Zeranol<br><br>PG-600®<br><br><u>Intravaginal administration</u>:<br><br>Progestagen-impregnated intravaginal sponge with:<br><br>* fluorogestone acetate (FGA) (45 mg), marketed as Chronogest® or Cronolone®, widely used with eCG (PMSG), FSH or $PGF_{2\alpha}$ for synchronization and/or induction of a superovulatory response.<br><br>* 6-methyl-17-MAP-treated intravaginal sponge 01erarnix®, Repromap®, containing 60 mg of this progesterone analogue, used in conjunction with PMSG or prostaglandin.<br><br>Sponges impregnated with natural progesterone in higher doses (400-500 mg).<br><br>Intravaginal progesterone impregnated device: Controlled Internal Drug Releasing (CIDR) developed in New Zealand (CIDR-G is used for sheep and goats).<br><br><u>Progestogen implant treatments</u>:<br><br>A silicone rubber progesterone-impregnated device.<br><br>Ear implant impregnated with the potent progestogen, norgestmet. |

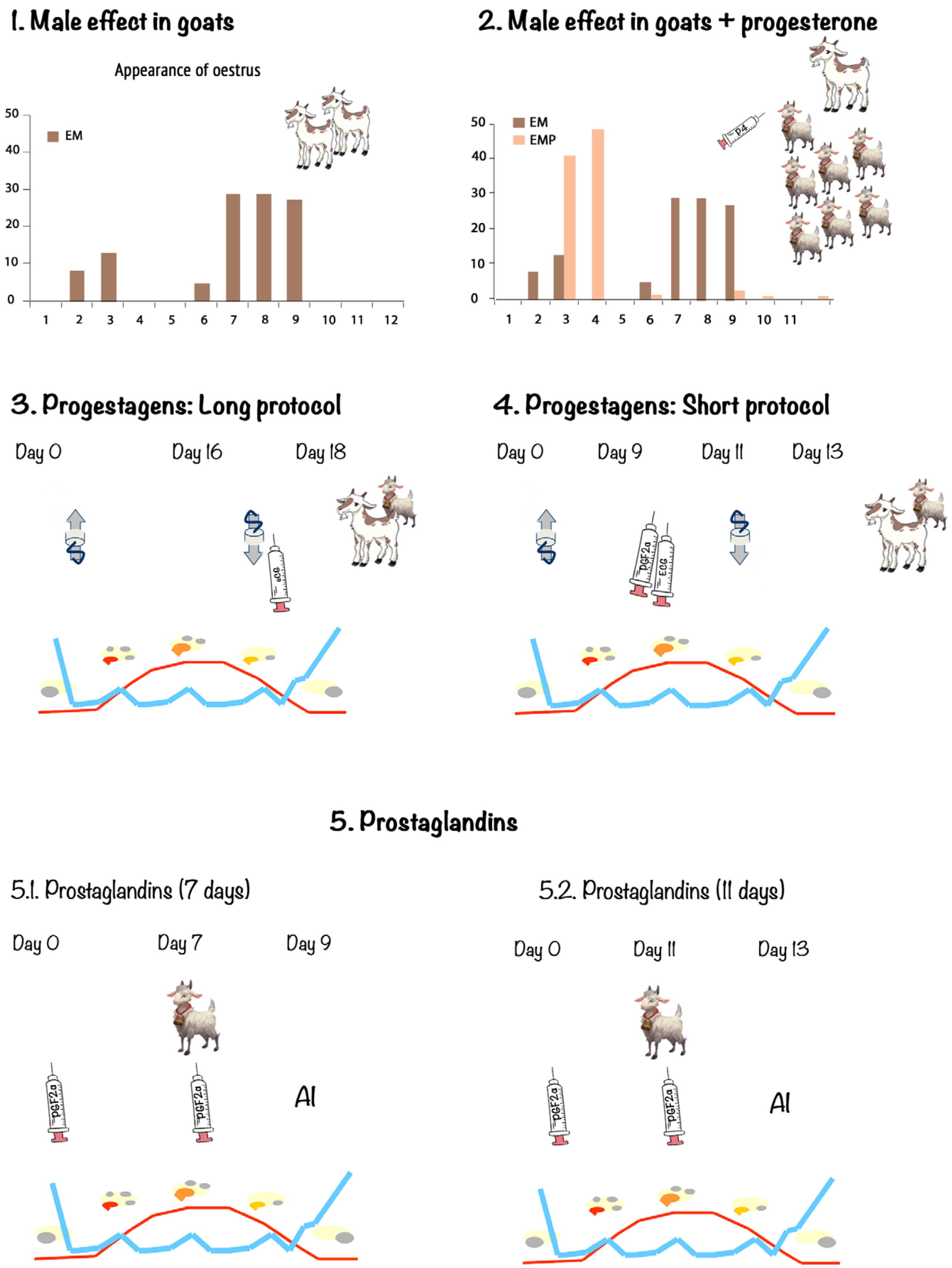



FIGURE 10: Different techniques for estrus induction and synchronization in goats

**TABLE 11: Different trials dealing with hormonal treatments in some East African countries and the obtained results**

| Country | Animals | Experimental procedures | Results | References |
|---|---|---|---|---|
| **Rwanda** | 605 does of a local breed | Impregned FGA sponge (11 days) + PMSG (48 hours before sponge removal/at sponge removal) at a dose of 300IU or 200IU + Cloprostenol | Fertility rate: 61.2% (higher for PMSG 48 hours before sponge removal)<br>Abortion rate: 6.4%<br>Prolificity rate: 2.14 (higher for 300IU dose of PMSG)<br>Mortality rate: 13.3% (higher for 300IU dose of PMSG) | Leboeuf et al., 1994 |
| **Tanzania** | 66 Norwegian Dairy goats | A synthetic form of progesterone for 13 days (Chronogest® for goats) (FGA) + intramuscularly injection of Prosolvin® (synthetic $PGF_{2}\alpha$ analogue, Intervet) at day 10 + 400 IU Folligon® (Intervet) (eCG) at sponge removal | First round:<br>- Conception rate: 54%<br>- Abortion rate: 20%<br>- % twins: 18.5%<br>- % of triplets: 3.7%<br>Second round:<br>- Conception rate: 55%<br>- Mortality rate: 23% | Kifaro 2008 |
| **Ethiopia** | Aberegelle goats | Three estrus synchronization protocols:<br>- the standard protocol using progestogens, gonadotropins and prostaglandins;<br>- single injection of prostaglandin; and<br>- double injection of $PGF_{2}\alpha$ (11 days apart). | Estrus response: 67.6% (higher for the standard protocol than the single and double injection of $PGF_{2}\alpha$ groups)<br>Onset of estrus: 14.4±0.47 hours (earlier in the double injection of $PGF_{2}\alpha$ group, followed by the standard group, and finally the double injection of $PGF_{2}\alpha$ group)<br>Estrus duration: 45.5±0.45 hours | Wondim et al., 2022 |

| Country | Animals | Experimental procedures | Results | References |
|---|---|---|---|---|
| **Ethiopia** | 120 local Somali female goats | MAP 60mg/fluorogesterone acetate (pGA; 40mg) intravaginal sponges for 9, 12, 15 or 18 days + 3 PMSG treatments:<br>1. 300IU PMSG 24 hours prior to sponge withdrawal<br>2. 300IU PMSG at sponge withdrawal<br>3. no PMSG | Overall mean estrus response: 97.4% (not significantly affected by the type or the duration of intravaginal progestogen sponge treatment and the time of PMSG administration relative to intravaginal progestogen sponge withdrawal)<br>The overall mean time interval from intravaginal progestogen sponge withdrawal to the onset of oestrus: 33.3±2.7 hours<br>The duration of induced estrus: 35.5±4.2 hours<br>The time to onset and the duration of induced estrus were not significantly affected by the type of progestogen and time of PMSG administration but they were affected by the duration of the intravaginal progestogen sponge priming (earlier in does primed for 9 days, compared to those primed for 12, 15 and 18 days) | Zeleke, 2003 |
| | 64 non-descripte puluriparous local does | Four groups:<br>1. control<br>2. double $PGF_{2\alpha}$ 14 days apart with the same amount<br>3. GnRH (7 days) + $PGF_{2\alpha}$ (9 days) + GnRH (Ovsynch protocol)<br>4. GnRH (7 days) + $PGF_{2\alpha}$ | Overall estrus expression rate: 71.88%<br>Mean estrus response according to treatment groups:<br>1. 50%<br>2. 81.25%<br>3. 81.25%<br>4. 75.00%<br>Significantly higher in GnRH-$PGF_{2\alpha}$-GnRH than the three other groups<br>*Average heat estrus response time according to treatment groups:*<br>1. 10.89±2.91 hours<br>2. 13.92±3.10 hours<br>3. 27.35±5.14 hours<br>4. 13.87±1.72 hours<br>*Average duration of estrus time according to treatment groups:*<br>1.199.23±49.85 hours<br>2. 34.97±3.74 hours<br>3. 36.57±2.78 hours<br>4. 48.90±1.61 hours | Abera, 2017 |

| Country | Animals | Experimental procedures | Results | | References |
|---|---|---|---|---|---|
| Ethiopia | 104 non-pregnant and non-suckling adult females of Woyito-Guji local goats | Group 1: singular IM 5 mg injection of the $PGF_{2\alpha}$ analogue dinoprost (1 ml Enzaprost®; CEVA Laboratories, Libourne, France).<br>Group 2: 2 i.m. injections of $PGF_{2\alpha}$ administered 7 days apart.<br>Group 3: 2 i.m. injections of $PGF_{2\alpha}$ administered<br>11 days apart. | *Estrus response (%) (NS):*<br>Group 1: 91.67±4.61<br>Group 2: 97.06±2.90<br>Group 3: 88.24±5.53<br>*Onset of estrus (hours) (NS):*<br>Group 1: 54.00±23.09<br>Group 2: 51.33±24.08<br>Group 3: 49.06±22.96<br>*Estrus duration (hours) (NS):*<br>Group 1: 12.80±2.53<br>Group 2: 12.44±2.33<br>Group 3: 12.94±2.66 | *Conception rate (%) (NS):*<br>Group 1: 66.67±8.21<br>Group 2: 63.64±8.37<br>Group 3: 63.33±8.80<br>*Kidding rate (%) (NS):*<br>Group 1: 63.64±8.37<br>Group 2: 45.45±8.67<br>Group 3: 50.00±9.13<br>*Litter size (NS):*<br>Group 1: 1.05±0,22<br>Group 2: 1.00±0.0<br>Group 3: 1.00±0.0 | |

*Note: NS: non significant*

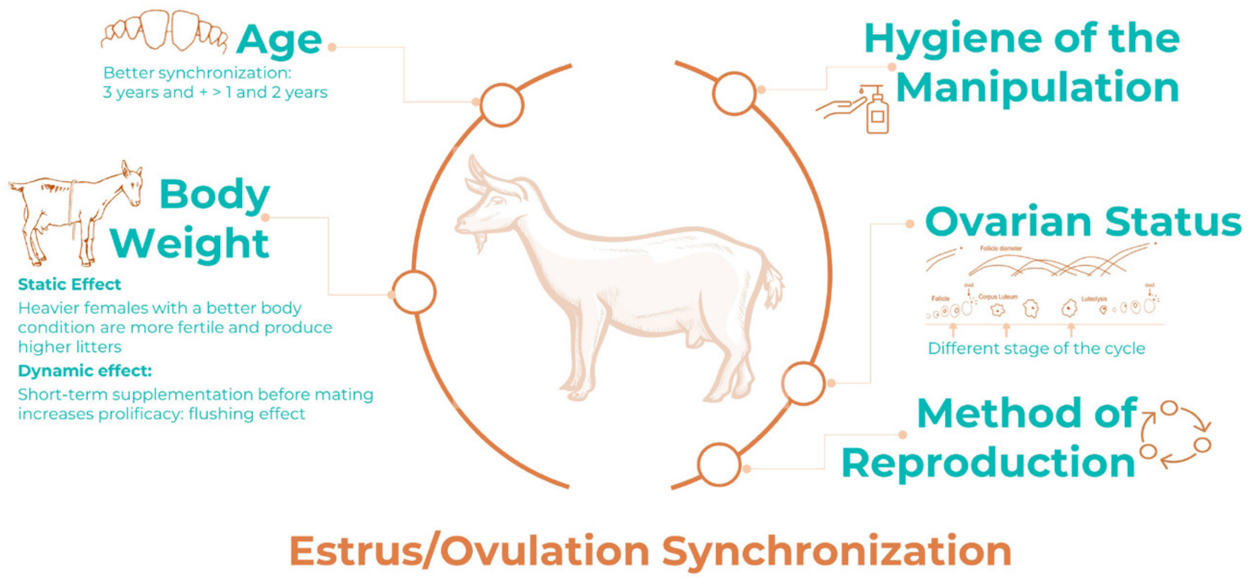



**FIGURE 11: Factors affecting the success of hormonal treatments**

### V.1.5. Improvement of litter size

Litter size, which is the number of kids born per parturition, is the combination of ovulation rate and embryo survival. It is known that litter size is correlated to the ewe body weight at mating and is significantly affected by year of lambing and parity (Abegaz et al., 2002; Gemeda et al., 2002; Belay and Haile, 2009). Some authors found that an increase of body weight by 1 kg prior to mating increased litter size by 3.8% (Getahun, 2008; Girma, 2008). For tropical breeds, litter size varies between 1.08 and 1.75 (Devendra and Burns, 1970; Girma, 2008).

Reproductive rates can be improved by an increase in litter size through ovulation rate improvement. This could be done using several techniques:

i. improvement of nutrient intake before mating;

ii. through genetics, by crossbreeding prolific with nonprolific breeds;

iii. immunization of ewes against sex steroids; and

iv. exogenous hormones, especially gonadotropins.

In Sudan, when supplemented with protein and energy, Taggar goat does secured a higher litter size, compared with a control group. In addition, kidding rate was high, body weight was heavier at time of kidding, and time at weaning in supplemented does compared with control does. In addition, the service period, and abortion and mortality rates were reduced (Bushara et al., 2013a).

In Rwanda, 605 does of a local breed were inseminated after estrus synchronization with an impregned FGA sponge (11 days), Cloprostenol and PMSG at different doses. The mean prolificity was 2.14 and was significantly higher in does that received a higher dose of PMSG (2.23 when a dose of 300UI PMSG was injected, vs 2.05 when a dose of 300UI PMSG is injected). Nevertheless, mortality rates of kids were higher in does that received a higher dose of PMSG (Lebeouf et al., 1994).

### To conclude…

Improvement of litter size should be carefully considered. Since animals are generally managed under harsh environmental conditions, management of large litter sizes will be difficult and will lead to high mortality rates.

### V.1.6. Selection for reproductive performance

Reproduction traits are very important economically in any livestock farming, and their expression is very variable according to management practices and the genetic make-up of the population (Kebede et al., 2012). For improvement of reproductive performance, reproductive traits of interest include conception rate, kidding rate, ability to breed out of season, prolificacy (defined as the number of kids born per doe), and age at first kidding.

Reproduction traits could be improved by selection of local breeds, or crossbreeding between exotic and common African goats, which can be used to produce desired combinations of traits that are not present in an existing local breed (Mourad, 1994). Estimates of phenotypic and genetic parameters in relation with reproduction are very useful for selection and for maximizing progress. Heritability values for reproductive traits are unfortunately low in magnitude, but remain positive (Table 12).

In Africa many attempts to improve reproductive traits of local indigenous goat populations genetically by selection and crossbreeding have been employed. These techniques have a valuable role in goat production, but they must be carefully planned, properly organized and operated to effectively achieve genetic advantages (Mourad, 1996).

Litter size is considered one of the most important components of reproductive performance. However, as for other reproductive traits, the heritability value is low and, in addition, litter size is a sex-limited characteristic. For African common goats in Rwanda, heritability and repeatability estimates are 0.025 and 0.061, respectively, for the number of kids born, indicating that using selection to improve these reproductive traits would take a long time (Mourad, 1994, 1996). However, the genetic correlation between the number of kids born and the number of kids alive was positive, which means that selection for one character could improve the other.

Genetic parameters for Arsi-Bale goats in Ethiopia were estimates for age at first kidding, kidding interval, litter size at birth, litter size at weaning, litter weight at birth, litter weight at weaning, and the result showed a low to moderate direct heritability and repeatability estimates. Authors suggest that direct selection for these reproduction traits would lead to small annual genetic progress (Kebede et al., 2012). In this same study, authors found that, among investigated traits, age at first kidding and litter weight at birth had better estimates of direct heritability in all calculation models, suggesting that selection for these traits will result in desirable genetic gains (Kebede et al., 2012).

Goats from tropical regions are non-seasonal breeders and kid all year round and incorporating this trait of non-seasonality would also be advantageous for selection.

To ameliorate livestock reproductive performance, and for genetic improvement, crossbreeding with exotic animals is a technique that has been widely used. Unfortunately, it has been unsuccessful in most cases in traditional low input production systems in the tropics (Kosgey et al., 2006). In fact, such programs need accurate information on pedigree and performance. Because of the constraints on small-scale farming systems, such as high illiteracy rates among smallholders, lack of animal identification and pedigree recording systems, and the non-existence of institutional frameworks, such information is often not available (FAO, 2016; Ibeagha-awemu et al., 2019). Therefore, community breeding organizations were set up in many developing countries and have an important role to play supporting programs to improve the performance of small ruminants (Mirkena et al., 2012; Gizaw et al., 2014).

In a genetic study conducted by Mourad (1996), repeatability estimates obtained from Common African and Alpine goat breeds were low, indicating that selection for number of kids born would take a long time. Sire breed and parity affected the number of kids born, so crossing females of local breed by a sire of an exotic breed, characterized by high litter size, is important to improve the number of kids born in the next generation.

Selection for reproductive performance could also be done through genomics, representing a faster way than selection and crossbreeding. In fact, the increasing availability of whole-genome sequencing data facilitates the detection of traces of introgression in the genome. In Ethiopia, polymorphism analysis of the Kisspeptin (KISS1) gene, and its association with litter size, were conducted in two (Gondar and Woyto Guji) Ethiopian indigenous goat populations. In the studied

**TABLE 12: Estimates of heritabilities and repeatabilities for some reproductive traits of East African goat**

| Country | Animals | Trait | Heritability | Repeatability | References |
|---|---|---|---|---|---|
| **Ethiopia** | Arsi-Bale goats | Age at first kidding | 0.245±0.19 | - | Kebede et al., 2012 |
| | | Kidding interval | 0.060±0.08 | 0.13 | |
| | | Litter size at birth | 0.074±0.05 | 0.15 | |
| | | Litter size at weaning | 0.006±0.05 | 0.18 | |
| | | Litter weight at birth | 0.125±0.05 | 0.16 | |
| | | Litter weight at weaning | 0.053±0.07 | 0.12 | |
| **Rwanda** | African Common goats | Number of kids alive | 0.017 | - | Mourad, 1994 |
| | | Number of kids born | 0.025 | - | |
| | | Number of kids dead | 0.018 | - | |
| | | Index of fertility | 0.061 | - | |
| | Common African and Alpine goat breeds | Number of kids born | | 0.061±+ 0.003 | Mourad, 1996 |
| **Kenya** | Kenya Dual Purpose goat | Birth weight | 0.13±0.03 | | Mugambi et al., 2007 |
| | | Weaning weight | 0.16±0.01 | | |
| | | Yearling weight | 0.16±0.04 | | |
| | | Pre-weaning average daily gains | 0.24±0.01 | | |
| | | Post-weaning average daily gains | 0.10±0.02 | | |
| **Sudan** | Tagger goats | Body weight at birth | 0.46±0.66 | | Ombabi Mohammed, 2015 |
| | | Body weight at 8 weeks | 0.73±0.64 | | |
| | | Body weight at 12 weeks | 0.82±0.63 | | |
| **Burundi** | Indigenous goats under smallholders | Kid survival | 0.02 | | Josiane et al., 2020 |

target regions of the gene, the Single nucleotide polymorphism (SNP ) confirmed the contribution of the KISS1 gene for fecundity trait, suggesting the importance of the gene for marker assisted selection in goat breeding programs (Mekiriaw et al., 2017).

## To conclude...

Genetic knowledge about reproductive traits is essential to optimize breeding programs . Direct selection could take a long time and are non-profitable compared to new biotechnologies such as genome sequencing. Those techniques offer a huge potential for mutation detection and their later introgression.

# V.2. APPLICATION OF REPRODUCTIVE BIOTECHNOLOGIES

To accelerate genetic gain, and ameliorate the reproductive performance of many live species, including goats, several ARTs are now used. Biotechnology in animal breeding includes AI and ET in practical breeding. AI was initially developed to reduce the incidence of reproductive disease in animals, but now allows the use of superior male animals and remains the most used reproductive technique (Tsuma et al., 2015). ET is more complicated, expensive, and has strict quarantine requirements.

## V.2.1. Artificial insemination

AI is generally used in cattle but has also been used with other species, such as sheep and goats. This technology allows genetic improvement, through better dissemination over limited or wide geographical areas, and offers animal keepers easier breeding management.

Compared to natural breeding, AI is economically advantageous when combined with estrus synchronization (Kupferschmied and Muther, 1977; Wani et al., 1985). In fact, the success of AI depends on the artificial control of the reproductive cycle of the female. Therefore, this technique is generally combined with the synchronization or the artificial induction of estrus.

This reproductive biotechnology reduces the risk of disease transmission and offers the opportunity to increase the number of offspring from a genetically superior sire in limited or wide geographical areas without the need of importing bucks, and enables the use of semen from males that are no longer alive.

Unfortunately, in many East African countries, such as Tanzania, AI in goats has rarely been performed (Kifaro et al., 2008). In Ethiopia, AI is neither well developed nor organized at a national level and there is only one national AI center, mainly providing services for cattle. Some AI activities have also been undertaken by some governmental and non-governmental organizations (Gebre, 2007).

AI in goats could be done using fresh, refrigerated, and frozen/thawed semen. Fresh semen is generally collected from bucks on the farm during the breeding season. Refrigeration, when semen is stored at 4°C, can be used for up to 24 hours after collection, allowing for the transport of semen in restricted areas. Finally, frozen semen allows for a long preservation period, which facilitates the genetic spread over wide areas.

Semen is usually collected from bucks trained to serve an AV, and once they are trained to the vagina collection can be done two to three times daily on alternate days. Then, semen is evaluated for macroscopic and microscopic quality. It is then conserved in a medium to provide an insemination dose of 20 million (frozen, laparoscopic intrauterine) to 300 million (fresh, cervical) spermatozoa (Rekik et al., 2012). Quality of the semen is among the factors modulating the success of the insemination.

Two techniques of insemination are used worldwide in goats: cervical and intrauterine (Evans and Maxwell, 1987; Chemineau and Cognié, 1991; Amoah and Gelaye, 1997; Leboeuf et al., 2000). However, intrauterine AI in goats is rarely practiced since semen is often deposited inside the uterus when using cervical insemination. The place of semen deposition in the female genital tract affects the conception and kidding rate.

Evans and Maxwell (1987) and Moore et al. (1988) have reported low conception rates in goats inseminated cervically with frozen-thawed semen after progestogen-PMSG treatment. Moore et al. (1989) reported a kidding rate of below 30% using this method. However, Bowen (1988) reported a kidding rate of 56% following cervical insemination after progestagen treatment.

In general, and unlike ewes, doe's cervix enables deposition of semen deeper into the cervical canal or the uterus through the cervix (Lindsay, 1991). As a result of such anatomical difference, fertility following cervical AI with frozen-thawed semen is usually higher in goats compared to sheep.

Intra-uterine inseminations are generally more successful (Moore et al., 1989) and acceptable conception rates with frozen-thawed semen are obtained when using this technique in both sheep and goats (Evans and Maxwell, 1987).

Nevertheless, laparoscopic insemination involves the use of a laparoscope and depositing fresh or frozen-thawed semen directly into the uterine horns. Laparoscopic insemination procedures are described for sheep and goats (Ritar and Ball, 1991), and higher conception rates, exceeding 80%, are obtained using this route. However, this technique remains expensive and requires a skilled operator.

AI can be performed at a fixed time after hormonal treatment, or after the detection of estrus. Some authors recommend insemination at a fixed time for practical purposes and for simplicity (Moses et al., 1997). The success of the AI depends largely on the knowledge of the length of the oestrous period and the time of ovulation (Evans and Maxwell, 1987; Ritar et al., 1989; McKelvey, 1990; Baril et al., 1993).

Within the same estrus period, fertility can also be increased when the number of inseminations is increased. However, this is not true for all insemination techniques. In fact, when fresh (diluted or undiluted) semen is used, double insemination has no effect on fertility (Evans and Maxwell, 1987; Amoah and Gelaye, 1990). However, two inseminations are recommended when frozen-thawed semen is used for cervical inseminations. At the same time, and in addition to time and labor, handling animals twice will be stressful and could reduce the fertility rate (Evans and Maxwell, 1987).

Reproductive performance following estrus synchronization and AI can also be affected by age, body weight and the BCS of does.

In a study conducted in Ethiopia, the pregnancy rate was higher in six year-old Ethiopian Somali does compared to one and nine year-old does when synchronized and artificially inseminated. The pregnancy rate was also significantly higher in does weighing between 21 and 30 kg at AI, compared to those weighing between 15 and 20 kg.

Furthermore, a higher pregnancy rate after AI was achieved in does with a BCS of between 2.6 and 3.0 compared to does below or above this BCS. The non-return rate was significantly higher in does weighing between 41 and 50 kg, compared to does weighing between 15 and 20 kg, 21 and 30 kg, or 31 and 40 kg. The non-return rate was significantly higher in does with a BCS of between 3.1 to 3.5, compared to does with another BCS.

Trials resorting to AI in goats in East Africa are summarized in Table 13.

### To conclude...

Reproductive biotechnologies, such as AI, are widely used to increase production, reproductive efficiency, and rates of genetic improvement. Therefore, AI is the recommended mating technique when coupled with breeding programs and cannot be a substitute to natural mating. The constraints of using this technique in low and middle-income countries are the lack of infrastructure and technical skills which handicap adoption and wide use.

### V.2.2. Embryo transfer

Even if crossbreeding East African breeds with highly productive exotic animals increases genetic progress, a faster gain could be achieved when using another ET.

ET is a method of assisted reproduction, consisting of producing multiple embryos in a female donor (genetically superior mother). These embryos are then transferred to various female recipients which should be hormonally synchronized with the donor female. Estrus synchronization is generally done with gonadotropins (FSH and eCG). ET increases the reproductive potential of high genetic value females, shortens the generational interval, and improves flocks and herds through introducing desired characteristics (Gibbons and Cueto, 2011). However, ET is not very important in developing countries and even its importance in developed countries is questionable.

In small ruminants, this technique is limited due to commercial and market factors. In addition, in sheep and goats, and other animals such as pig this biotechnology requires surgical or laparoscopic methods for embryo collection and transfer (Pinto, 2022).

TABLE 13: Different protocols of artificial insemination used in East Africa

| Country | Animals | Method of synchronization | AI | Results | References |
|---|---|---|---|---|---|
| **Tanzania** | First trial: 46 dairy goats<br>Second trial: 20 does | Estrus, sponges with a synthetic form of progesterone for 13 days (Chronogest® for goats, Fluorogestone acetate, progestagen) + intramuscularly injection of Prosolvin® (synthetic PGF₂α analogue, Intervet) at day 10 + 400 IU Folligon® (Intervet) at sponge removal. | With frozen semen | First trial:<br>25 goats conceived (54%)<br>Only 20 goats completed the gestation period (43%)<br>27 kids were born alive, of which 10 were twins and three were triplets.<br>Only one kid died during first four months of life.<br>Second trial:<br>11 does conceived (55%)<br>13 kids were born, out of which three died shortly after birth | Kebede et al., 2012 |
| **Rwanda** | 605 does of a local breed | Estrus synchronized with impregnated FGA sponge (11 days) + and Cloprostenol and 1 or 2+<br>1- PMSG injected 48 hours before sponge removal<br>2- PMSG injected at sponge removal | Insemination with frozen semen (100 million spermatozoa):<br>- 41 hours after sponge removal<br>- 45 hours sponge removal | Overall conception rate: 61.2%<br>- 66.9% when PMSG is injected 48 hours before sponge removal<br>- 54.5% when PMSG is injected at sponge removal<br>Abortion rate: 6.4%<br>Mean prolificity: 2.14<br>- 2.23 when a dose of 300UI PMSG is injected<br>- 2.05 when a dose of 200UI PMSG is injected<br>Mortality rate during the first 15 days after kidding: 13.3%<br>- 17.1% when a dose of 300UI PMSG is injected<br>- 9% when a dose of 200UI PMSG is injected | Leboeuf et al., 1994 |

| Country | Animals | Method of synchronization | AI | Results | References |
|---|---|---|---|---|---|
| **Ethiopia** | 335 Abergelle does | Three estrus synchronization protocols and a control group:<br>- Standard protocol: progestagens + gonadotropins + prostaglandins<br>- Single injection of prostaglandin<br>- Double injection of $PGF_{2\alpha}$ (11 days apart) | Semen from five proven Abergelle bucks | Overall conception rate: 65.4%<br>- 57.6% with the standard protocol<br>- 64.7% with the single injection of prostaglandin<br>- 78.8% with double injection of prostaglandin<br>Overall kidding rate: 89.4%<br>- 91.8% with the standard protocol<br>- 90.9% with the single injection of prostaglandin<br>- 85.3% with double injection of prostaglandin<br>Litter size: 1.23<br>- 1.65 with the standard protocol<br>- 1.0 with the single injection of $PGF_{2\alpha}$ and the double injection of prostaglandin | Wondim et al., 2022 |
| | 120 local Somali female goats | Estrus synchronized using two types of intravaginal progestagen sponges for 9, 12, 15 or 18 days:<br>- MAP; 60 mg<br>- Fluorogesterone acetate (pGA; 40mg)<br>Does were randomly allocated to three PMSG treatments<br>- 300IU PMSG 24 hours prior to sponge withdrawal<br>- 300IU PMSG at sponge withdrawal<br>- no PMSG | Semen from five healthy and fertile Anglo-Nubian bucks | Overall conception rate: 31.5%<br>Non-return rate: 62.4%<br>Kidding rate: 35.2%<br>Fecundity: 112%<br>Litter size: 1.1<br>Gestation length: 149.4<br>Kid birth weight: 2.7<br>Total litter weight: 3.2<br>Perinatal mortality: 29% | Zeleke, 2003 |

Few studies dealing with ET were conducted in East Africa. In one from Kenya, six Togsenburg dairy goats that ha kidded previously were used as donors, and 15 mature East African Dwarf goats were used as recipients. Eestrus was synchronized in both groups with progesterone ear implants (Synchromate-B, Ceva Laboratories, USA) left for 17 days. Each donor was injected subcutaneously with 1,000 IU of PMSG (Fohigon, Intervet International BV, Boxmeer, The Netherlands) one day before implant removal. After estrus detection, donor does were mated to a buck of known fertility. Collection of embryos was done by flushing both the uterine horns and the oviducts of each donor using a mid-ventral laparotomy under general anesthesia. The transferred embryos were deposited into the anterior third of the ipsilateral uterine horn through a puncture made in the uterine wall. Four donors and 10 recipients showed estrus 36 to 48 hours after implant removal, with a slightly earlier occurrence in the donors. Thirty-two five-day-old embryos were collected from five donors, since one of the donors did not ovulate and 30 of these embryos were transferred in pairs to 15 estrus-synchronized recipients. Only seven recipients conceived, producing eight kids. The donors were subsequently mated during their second natural estrus and produced eight kids. Even if conception rates following these transfers is low, 16 pure Toggenburg kids were born from six donors in seven months, which is an improvement compared to the natural (Mutiga, 1991).

## To conclude...

Even if ET can increase the number of offspring from a genetically superior female, enabling it to contribute to genetic improvement programs by furthering the distribution of goat genes with high productive value, further studies are needed to reduce costs and increase the number of offspring per donor. Application of this technique remains very limited due to its cost and required technicity.

# VI. Reproductive diseases in East and Horn of Africa

# VI.1. CONTEXT AND JUSTIFICATION

After West Africa, East Africa has the largest numbers of goats in Africa. According to the Food and Agriculture Organization of the United Nations (FAO), East Africa has about 183,591,469 heads of goats, which represents more than 37% of the goat herds in Africa (FAOSTAT, 2020). Goats are among the most important livestock species in developing countries and they are of significant socioeconomic, nutritional, and cultural importance in smallholder farming systems. Goats can play an important role for home consumption and they are an important source of cash income for farmers, through products such as meat, milk, hides, and manure (Lie et al., 2012).

One of the most important constraints of small ruminants production is animal diseases (Armson et al., 2020; Kaboré et al., 2011). Among some of the health issues are abortions, which are a major problem for pregnant sheep and cause significant financial losses for small breeders. This is a limiting factor to production as it reduces the potential number of replacement stock for the herd, decreases dairy production, and increases the number of unproductive females kept in the herd for long periods of time (Hassen and Tesfaye, 2014; Alemayehu et al., 2021; Esmaeili et al., 2022).

The aetiology of abortions generally reveals two categories of causes: infectious and non-infectious diseases. The most common infectious causes of abortion in sheep and goats are *Coxiella burnetii* (*C. burnetii*), *Chlamydia abortus* (*C. abortus*), *Brucella* spp., *Leptospira* spp., *Campylobacter fetus*, *Listeria* spp., and *Toxoplasma gondii* (*T.gondii*) (Lacasta et al., 2015; Gebretensay et al., 2019; Thomas et al., 2022). These pathogens are also zoonotic and can therefore pose serious risks of infection for farming communities and represent a real public health problem (Ganter, 2015; LeJeune and Kersting, 2010).

To have a better view on the aetiology of abortive pathologies in East and Horn of Africa, and the risk factors associated with these pathologies, a systematic review of the various studies carried out on the subject was made.

# VI.2. METHODOLOGY

- The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed in this systematic review.
- PRISMA is a minimum set of elements for evidence-based reporting in systematic reviews and meta-analyses.
- The PRISMA guidelines aim to provide writers with standards for formatting PRISMA.

# VI.3. SEARCH STRATEGY

- The keywords and boolean operators used were the following: goat or small ruminant, and reproduction and diseases, or failure and pathology, abortion, pathogens, risk factors, and (East and Horn of Africa) Burundi, or Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Somalia, Sudan, Tanzania or Uganda.
- Keywords were introduced in Google.

# VI.4. SELECTION OF ARTICLES

### VI.4.1. Inclusion criteria

- Original articles written in English.
- Studies related to reproductive failure of goats in East and Horn of Africa countries.
- Studies on the risk factors of reproductive failure of goats in East and Horn of Africa countries.
- No temporal restriction.

### VI.4.2. Exclusion criteria

- All studies that did not address pathologic etiology of reproduction failure.
- Studies that do not clear stated pathogens or disease names.
- Studies on genetic resistance of pathogens or parasites.
- Studies on economic losses of reproductive diseases.
- Experimental studies on reproductive diseases.

# VI.5. RESULTS

After screening, according to the various (inclusion and exclusion) criteria, 17 studies were selected among the 38 articles identified by the keywords.

### VI.5.1. Temporal distribution of studies on reproductive diseases in East and Horn of Africa

The temporal distribution of articles shows that the interest of scientists on the topic has been constant since 2013. Studies were sporadic from 1972 to 2013. We have at least one publication per year on reproductive diseases since 2013 (Figure 12). It should be noted that several studies have been carried out on the reproductive problems of goats, but most have not specified the causes of these problems.

### VI.5.2. Spatial distribution of studies on reproductive diseases in East and Horn of Africa

The spatial distribution of the studies shows that research on reproductive diseases in goats has been carried out in six different countries in East and Horn of Africa. These are Ethiopia, Kenya, Rwanda, Somalia, Sudan, and Uganda. Most were implemented in Ethiopia and Sudan (Figure 13). Ethiopia has the largest goat population in the East African region.

Among the seven pathogens most often involved in reproductive diseases of goats, only two were clearly identified in the studies conducted. These were Brucella and Toxoplasma. This suggests that they are the ones most responsible for reproductive health issues in the region.

### VI.5.3. Prevalence of reproductive diseases in East and Horn of Africa

The prevalence of seven pathologies were recorded in this review. Among these pathologies, some are infectious (Brucellosis, Mastitis, Toxoplasmosis) and others are non-infectious (Hydrometra). According to selected papers, Toxoplasmosis is the most prevalent reproduction disease, with an average prevalence of 44.63% in the region, followed by Mastitis (Table 14).

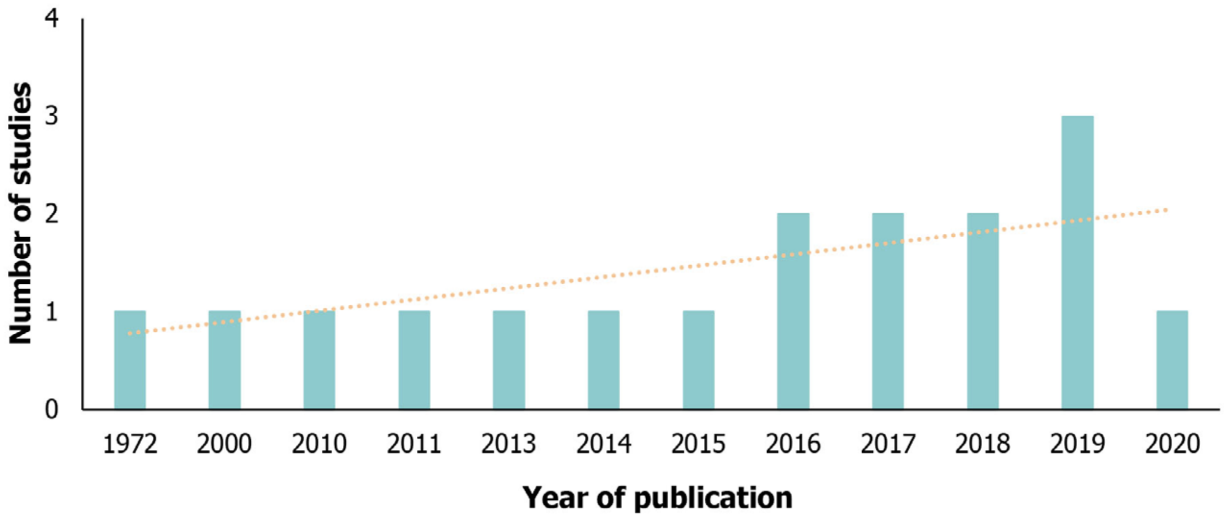



FIGURE 12: Temporal distribution of the studies

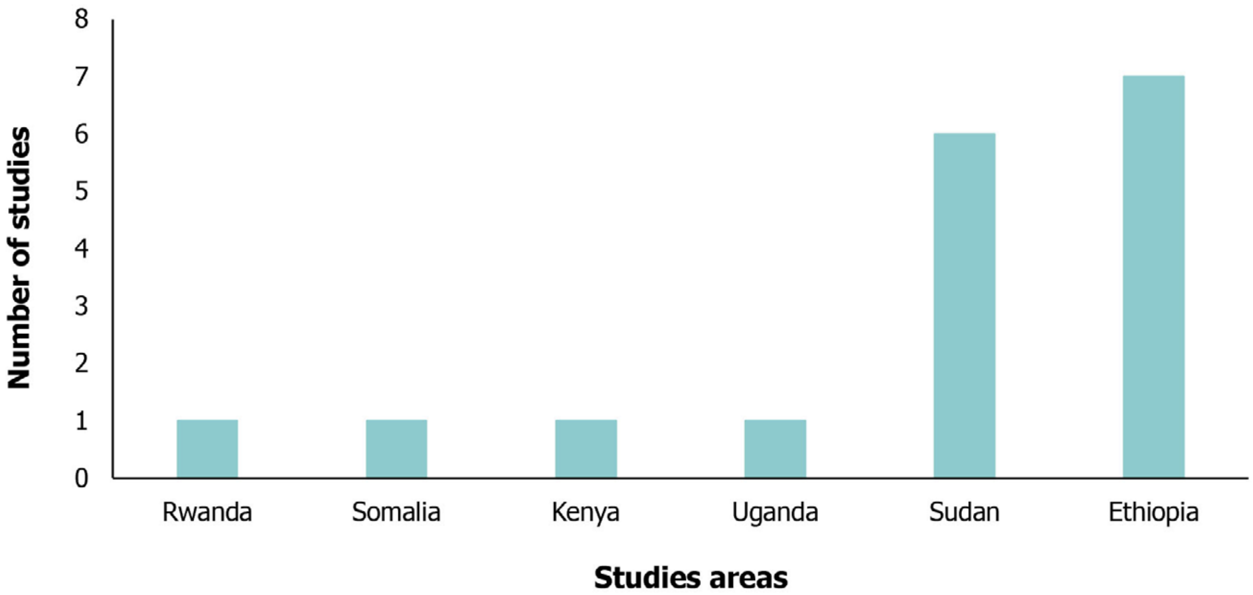



FIGURE 13: Spatial distribution of studies

TABLE 14: Causes of identified diseases and their average prevalence

| Diseases | Causes of the pathology | Prevalence average (%) |
|---|---|---|
| **Brucellosis** | *Brucella melitensis* | 10.975 |
| **Fetal Death in goats** | Not specified | 8.2 |
| **Hydrometra** | Not specified | 9.87 |
| **Mastitis** | *Staphylococcus aureus, S. hyicus, S. epidermidis, S. chromogenes, Streptococcus dysagalactiae, Str. Ubris, Str. pneumoniae, Enerococcus faecalis, Corynebacterium bovis, Actinomyces* | 15.5 |
| **Organ abnormalities** | Not specified | 7.8 |
| **Pyometra** | Not specified | 0.42 |
| **Toxoplasmosis** | *Toxoplasma gondii* | 44.63 |

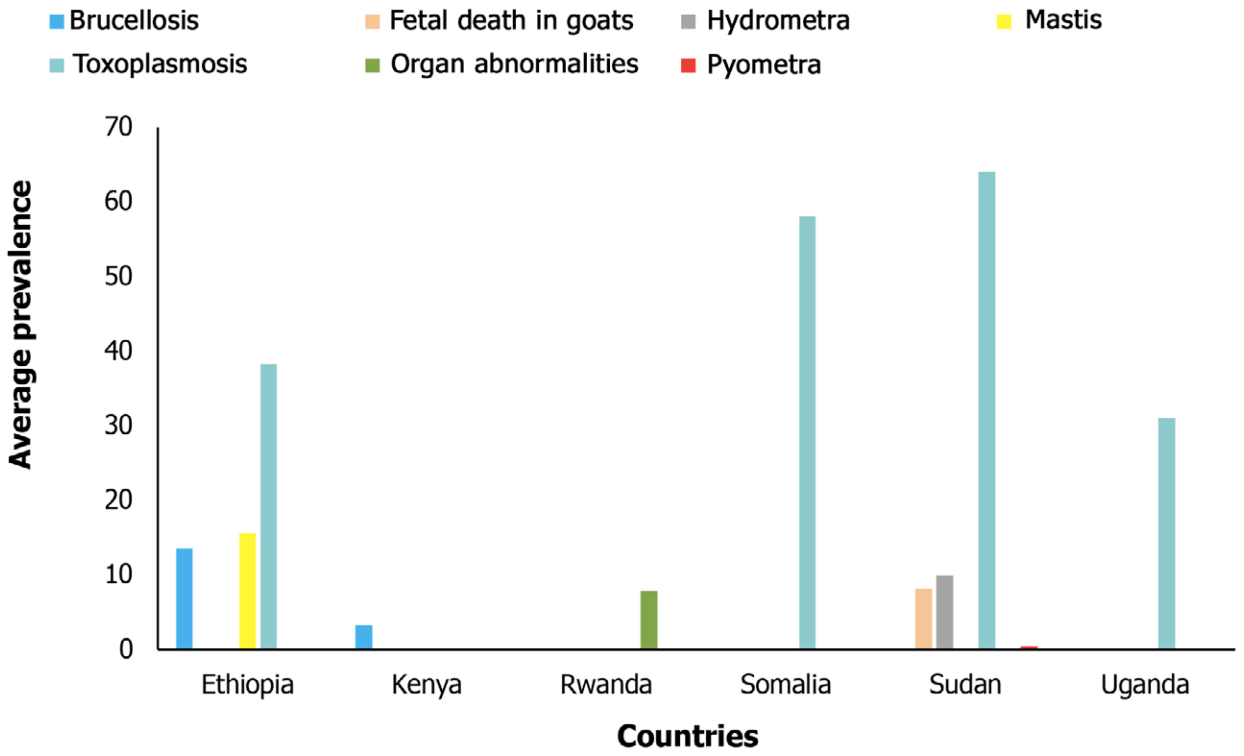



FIGURE 14: Spatial distribution of the prevalence of reproductive diseases

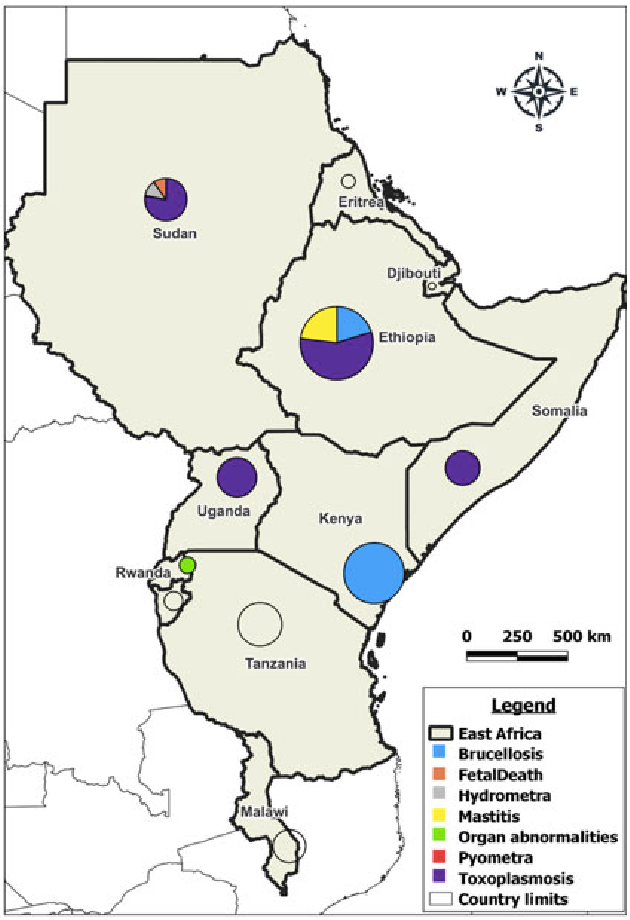



FIGURE 15: Mapping the distribution of the prevalence of reproductive diseases in East and Horn of Africa

Sudan has the highest prevalence of Toxoplasmosis (64%), followed by Somalia (58%), while Ethiopia has the highest prevalence of Brucellosis (13.5%) (Figure 14 and 15). There is a variety of reproductive diseases in Ethiopia and Sudan unlike the other four countries. Mastitis, the second most prevalent disease was recorded only in Ethiopia (Figure 14 and 15).

### VI.5.4. Risk factors associated with reproductive diseases in East and Horn of Africa

As mentioned previously, flocks of small ruminants, goats in particular, are important to local economy, gastronomy and culture in the East and Horn of Africa (Lie et al., 2021). However, one of the main limiting factors to small ruminants' production development in this area is animal health issues (Armson et al., 2020; Kaboré et al., 2011), including reproductive diseases (Hassen and Tesfaye, 2014; Alemayehu et al., 2021; Esmaeili et al., 2022), namely Toxoplasmosis (*Toxoplasma gondii*) and Brucellosis (*Brucella melitensis*). An effective management of these diseases requires a thorough knowledge of their risk factors in order to control them.

For Toxoplasmosis, a higher prevalence was seen in goats than in sheep (Gebremedhin et al., 2013), in females than in males (Tegegne et al., 2016; Tilahun et al., 2018) and in adults than in young animals (Tegegne et al., 2016; Tilahun et al., 2018; Bisson et al., 2000). In addition to that, goats found in urban areas or in highlands have higher risks of infection than goats in rural areas or in lowlands (Bisson et al., 2000; Tegegne et al., 2016). Farm environments are also an important risk factor to mention, as some of them are suitable for oocysts survival and transmission. This is due to failure to isolate aborting animals and to dispose, hygienically, of abortion products (Bisson et al., 2000). Consequently, a higher prevalence is observed in large flocks as the hygienic management becomes more challenging than in small flocks (Gebremedhin et al., 2013). Toxoplasmosis prevalence in goats can also vary depending on agricultural production systems and water sources. In fact, goats that are raised in a pastoral or agropastoral farming system, grazing in plain lands and drinking from pipe and/or river water have higher risks to get the infection as their feed and water sources are accessible to cats and can be contaminated with their faeces (Gebremedhin et al., 2013; Tilahun et al., 2018).

For Brucellosis, a variation of prevalence was observed depending on age and geographic origins of goats (Wolde, 2017). Furthermore, deliveries in goats are increased in wet seasons. As a consequence, the excretion of Brucella organisms will possibly be increased. That being so, goats are predisposed to higher risk of getting the infection in wet seasons than in dry seasons (Megersa et al., 2011). In addition, goats which are pregnant or which have history of retained fetal membrane are most likely to contract brucellosis (Wedajo et al., 2015).

Table 15 summarizes the risk factors associated to reproduction diseases.

**TABLE 15: Risk factors associated with reproductive diseases**

| Diseases | Pathogens | Risk factors | References |
|---|---|---|---|
| **Toxoplasmosis** | *Toxoplasma gondii* | Urban areas, age, farm environment | Bisson et al., 2000 |
| **Toxoplasmosis** | *Toxoplasma gondii* | Species, flock size, farming production systems, water sources | Gebremedhin et al., 2013 |
| **Toxoplasmosis** | *Toxoplasma gondii* | Age | Afrah et al., 2020 |
| **Brucellosis** | *Brucella spp.* | Wet season | Megersa et al., 2011 |
| **Brucellosis** | *Brucella melitensis* | Pregnancy, retained fetal membrane | Wedajo et al., 2015 |
| **Toxoplasmosis** | *Toxoplasma gondii* | Age, gender<br>Highlands | Tegegne et al., 2016 |
| **Toxoplasmosis** | *Toxoplasma gondii* | District, species, gender, age, and water source | Tilahun et al., 2018 |
| **Brucellosis** | *Brucella melitensis* | Age, geographic origin | (Wolde, 2017) |

## To conclude...

This review has revealed that Toxoplasmosis, Mastitis and Brucellosis are among the main reproductive diseases in East and Horn of Africa. Season, species, sex, age, environment, and farming method are the main risk factors identified in various studies. Greater systematic review is needed to gain a better understanding of the causes and risk factors associated with diseases of goat reproduction in East and Horn of Africa.

# VII. Concluding remarks

This working paper, which reviews the reproduction of goats in the East and Horn of Africa, is unique in having considered an important species in the livestock sector in this part of the world, and in having attempted to fill an important gap by reviewing existing literature about reproduction of this species. We selected this topic because improvements in reproductive performance lead to quick wins in productivity and farmers' incomes; a priority area for livestock development projects and initiatives in low and middle-income countries, particularly in Africa.

Here we highlight a few concluding remarks and suggestions to better approach research and field improvements of goat reproduction in the East and Horn of Africa.

- Our review inventoried a huge diversity of goat breeds and populations that are indigenous to the East and Horn of Africa. In addition to their adaptation to the production environments, these breeds have also developed several specific reproductive features that further enhance their acclimatization to the prevailing environments where they thrive.
- The precocious age puberty starts, short kidding intervals and high litter sizes are examples of traits that are often desired by farmers.
- The most important characteristic common to most of the studied breeds is the non-seasonality of reproduction. Seasonality of reproduction is a major physiological constraint to intensifying reproduction rhythms and, therefore, farmers in the East and Horn of Africa can breed goats anytime of the year and set flexible management rhythms that match changes and fluctuations in market demand.
- If seasonal changes driven by the photoperiod are not a constraint, other factors such as poor feeding, stress resulting from walking long distances in pastoral systems, or the chronic burden of parasites and other diseases such as abortive diseases result in the occurrence of "management anoestrus";
- The function of reproduction has a physiological determinism. It relies on fine and precise endocrine balances and feedbacks, is very sensitive to changes in quantitative and qualitative inputs of nutrients, and is affected when the animals are not healthy. At the same time, reproduction is a behavioral function and depends on social cues and a large array of interactions between animals in the same herd and beyond. This is to stress that interventions to improve reproductive performance need to be inclusive of all factors of variation. Isolated actions may only yield short-lived improvements.
- We did not aim to assess the existing human and infrastructure capacity in goat reproduction in the East and Horn of Africa, but from our experience working in some of these countries we can state that such capacity is weak and research and development projects addressing goats in these countries should dedicate specific and significant funds to improve capacity in this area.
- Women and children often take the lead in goat production, therefore research and development projects can only be successful if gender is mainstreamed so that women's concerns and perceptions are prioritized.
- There is limited scope to increase the use of reproductive techniques and biotechnologies. There are several reasons for this: a lack of capacity and deficient infrastructure (proper buildings, electricity, cooling chain); poor access to hormones; and an absence of large breeding programs to justify the use of technologies such as AI for the dissemination of improved genetics. Innovations in this area do exist and there are attempts to develop and design low-cost, low-infrastructure AI itineraries in East Africa to support existing goat breeding programs.

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INITIATIVE ON
Sustainable Animal Productivity

## About CGIAR Initiative on Sustainable Animal Productivity

CGIAR's Sustainable Animal Productivity for Livelihoods, Nutrition and Gender inclusion (SAPLING) is working in seven countries focusing on livestock value chains to package and scale out tried-and-tested, as well as new, innovations in livestock health, genetics, feed and market systems. SAPLING aims to demonstrate that improvements in livestock productivity can offer a triple win: generating improved livelihoods and nutritional outcomes; contributing to women's empowerment; and, reducing impacts on climate and the environment. Its seven focus countries are Ethiopia, Kenya, Mali, Nepal, Tanzania, Uganda and Vietnam.

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