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Specialty: Reproduction and Biotechnologies

Title

Epidemiological study of abortions associated with *Toxoplasma gondii* and *Neospora caninum* in camels in Algeria

Presented by
DJEDDOU BENABID Amira

The jury

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Doctorat en 3ème cycle en Sciences Vétérinaires
Spécialité : Reproduction et biotechnologies

Titre

Etude épidemiologique des avortements à *Toxoplasma gondii* et *Neospora caninum* chez les camelins en Algérie

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" الحمدُ للهِ الذي بنعمتِهِ تتمُّ الصالحات، وبشكره تدومُ النِّعم، الحمدُ للهِ الذي بتوفيقِهِ وتيسيرِهِ تصلحُ الأمورُ وتتمُّ كُبرى النِّعم "

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Dedication

To my dearest parents

Who have accompanied and supported me at every moment of my life,
and who instilled in me a sense of organization, a love of learning, and a spirit of perseverance. Through their love, sacrifices, and precious advice,
they have guided my path and given me the strength and determination needed to achieve my goals.
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Whom I consider as my second parents.

In memory of my grandparents

To all those who are dear to me, near or far

Abstract

Abortions represent one of the major challenges faced by dromedary breeders in Algeria due to their economic, health, and zoonotic implications. Among the causative agents, *Toxoplasma gondii* and *Neospora caninum*, two heteroxenous apicomplexan parasites, are recognized as major causes of reproductive disorders in numerous mammalian species. In this context, the present study aimed, through an integrated epidemiological approach, to assess the extent of reproductive losses using a breeder-based survey and to identify the associated risk factors; to determine the seroprevalence of *T. gondii* and *N. caninum* in dromedaries (*Camelus dromedarius*) as well as the risk factors associated with seropositivity; and to investigate the presence of these parasites through histopathological analysis in order to characterize the associated lesions. The epidemiological survey conducted in 75 herds revealed that 80% had a history of abortion, of which 60% also reported cases of stillbirth. Abortion rates ranged from 8.5% to 11.1% in primiparous females and from 9.3% to 10.3% in multiparous females. Most abortions (90%) occurred between mid and late gestation, with a marked seasonal concentration from August to November. Furthermore, fetal and placental lesions compatible with *T. gondii* and *N. caninum* infections were observed in 28% and 40% of abortion cases, respectively. Multiple correspondence analysis (MCA) identified three distinct herd classes characterized by different health and epidemiological profiles. Risk factor analysis for reproductive losses showed a significant association with the presence of domestic cats and dogs ($p < 0.05$). In parallel, a serological study carried out on 184 apparently healthy dromedaries revealed no seropositivity for *N. caninum*, providing the first available data for this species in Algeria. In contrast, an overall seroprevalence of 8.69% (95% CI: 5.1–13.7) was observed for *T. gondii*. Analysis of risk factors for seropositivity showed a significant association with age, the presence of cats, and a history of abortion ($p < 0.05$). Finally, histopathological analysis performed on 126 samples (63 hearts and 63 diaphragms) collected from 63 slaughtered dromedaries revealed structures compatible with *T. gondii* exclusively in the cardiac muscle of adult females. Tachyzoites were observed in one animal (1.6%), and tissue cysts in two animals (3.17%), whereas no structures compatible with *N. caninum* were detected. Cardiac lesions were characterized by mononuclear cell infiltration, focal hemorrhages, and areas of necrosis, indicating marked inflammatory and vascular responses. Overall, these findings suggest a potential involvement of *T. gondii* in reproductive losses in dromedaries in Algeria and highlight the need to implement appropriate surveillance and control strategies.

Keywords

Abortion, *Toxoplasma gondii, Neospora caninum*, risk factors, Algeria, *Camelus dromedarius*

Résumé

Les avortements constituent l’un des principaux défis auxquels sont confrontés les éleveurs de dromadaires en Algérie, en raison de leurs répercussions économiques, sanitaires et zoonotiques. Parmi les agents incriminés, *Toxoplasma gondii* et *Neospora caninum*, deux parasites apicomplexes hétéroxènes, sont reconnus comme des causes majeures de troubles de la reproduction chez de nombreuses espèces de mammifères. Dans ce contexte, la présente étude avait pour objectif, à travers une approche épidémiologique intégrée d’évaluer l’ampleur des pertes de reproduction à l’aide d’une enquête menée auprès des éleveurs et d’identifier les facteurs de risque associés, de déterminer la séroprévalence de *T. gondii* et *N. caninum* chez le dromadaire *(Camelus dromedarius)* ainsi que les facteurs de risque de la séropositivité, et de rechercher la présence de ces parasites par analyse histopathologique afin de caractériser les lésions associées. L’enquête épidémiologique menée auprès de 75 troupeaux a révélé que 80 % d’entre eux présentaient des antécédents d’avortement, dont 60 % étaient également concernés par des cas de mortinatalité. Les taux d’avortement variaient de 8,5 % à 11,1 % chez les femelles primipares et de 9,3 % à 10,3 % chez les femelles multipares. La majorité des avortements (90 %) survenaient entre le milieu et la fin de la gestation, avec une concentration saisonnière marquée entre août et novembre. Par ailleurs, des lésions fœtales et placentaires compatibles avec des infections à Toxoplasma gondii et Neospora caninum ont été observées respectivement dans 28 % et 40 % des cas d’avortement. L’analyse des correspondances multiples (ACM) a permis d’identifier trois classes distinctes de troupeaux, caractérisées par des profils sanitaires et épidémiologiques différenciés.L’analyse des facteurs de risque liés aux pertes de reproduction a mis en évidence une association significative avec la présence de chats et de chiens domestiques ($p < 0,05$). Parallèlement, une étude sérologique réalisée sur 184 dromadaires apparemment sains a montré l’absence de séropositivité vis-à-vis de *N. caninum*, constituant ainsi les premières données disponibles chez cette espèce en Algérie. En revanche, une séroprévalence globale de 8,69 % (IC 95 % : 5,1–13,7) a été observée pour *T. gondii*. L’analyse des facteurs de risque de la séropositivité a révélé une association significative avec l’âge, la présence de chats et les antécédents d’avortement ($p < 0,05$). Enfin, l’étude histopathologique réalisée sur 126 prélèvements (63 cœurs et 63 diaphragmes) issus de 63 dromadaires abattus a permis de mettre en évidence des formes compatibles avec *T. gondii* exclusivement au niveau du muscle cardiaque des femelles adultes. Des tachyzoïtes ont été observés chez un animal (1,6 %) et des kystes tissulaires chez deux animaux (3,17 %), tandis qu’aucune structure parasitaire compatible avec *N. caninum* n’a été détectée. Les lésions cardiaques étaient caractérisées par des infiltrats de cellules mononucléées, des hémorragies focales et des zones de nécrose, traduisant une réponse inflammatoire et vasculaire marquée. Dans l’ensemble, ces résultats suggèrent une implication potentielle de *T. gondii* dans les pertes de reproduction chez le dromadaire en Algérie et soulignent la nécessité de mettre en place des stratégies de surveillance et de contrôle adaptées.

Mots clé

Avortement, *Toxoplasma gondii*, *Neospora caninum*, facteurs de risque, Algérie, *Camelus dromedarius*

الملخــــــص

تُعد حالات الإجهاض من أبرز التحديات التي تواجه مربي الإبل في الجزائر، نظرًا لانعكاساتها الاقتصادية والصحية والوبائية المشتركة. ومن بين العوامل المسببة، يُعتبر كل من *Toxoplasma gondii* و *Neospora caninum*، وهما طفيليان من الأبيكومبلكسا ذات دورة حياة غير مباشرة، من الأسباب الرئيسية لاضطرابات التكاثر لدى العديد من أنواع الثدييات. في هذا السياق، هدفت هذه الدراسة، من خلال مقاربة وبائية متكاملة، إلى تقييم مدى خسائر التكاثر اعتمادًا على استبيان موجه للمربين وتحديد عوامل الخطر المرتبطة بها؛ وتحديد الانتشار المصلي لكل من *T. gondii* و *N. caninum* لدى الإبل (*Camelus dromedarius*)، بالإضافة إلى تحديد عوامل الخطر المرتبطة بالإيجابية المصلية؛ وكذلك البحث عن وجود هذه الطفيليات من خلال التحليل النسيجي المرضي بهدف توصيف الآفات المرتبطة بها. أظهرت الدراسة الوبائية التي شملت 75 قطيعًا أن 80٪ منها سجلت سوابق إجهاض، من بينها 60٪ سجلت أيضًا حالات ولادة جنين ميت. وتراوحت نسب الإجهاض بين 8.5٪ و11.1٪ لدى الإناث البِكر، وبين 9.3٪ و10.3٪ لدى الإناث متعددة الولادات. كما لوحظ أن معظم حالات الإجهاض (90٪) حدثت خلال منتصف ونهاية فترة الحمل، مع تركز موسمي واضح بين شهري أوت ونوفمبر. كما تم تسجيل آفات جنينية ومشيمية متوافقة مع الإصابة بـ *T. gondii* و *N. caninum* بنسبة 28٪ و40٪ على التوالي من حالات الإجهاض. وأظهر تحليل المراسلات المتعددة (ACM) وجود ثلاث فئات متميزة من القطعان، تتميز بخصائص صحية ووبائية مختلفة. كما أظهر تحليل عوامل الخطر المرتبطة بخسائر التكاثر وجود علاقة ذات دلالة إحصائية مع وجود القطط والكلاب المنزلية ($p < 0.05$). بالتوازي، كشفت الدراسة المصلية التي أُجريت على 184 رأسًا من الإبل السليمة ظاهريًا عن عدم وجود إيجابية مصلية لـ *N. caninum*، مما يمثل أول بيانات متاحة لهذه الفصيلة في الجزائر. في المقابل، تم تسجيل نسبة انتشار مصلي إجمالية قدرها 8.69٪ (95% CI: 5.1–13.7) بالنسبة لـ *T. gondii.* كما أظهر تحليل عوامل الخطر للإيجابية المصلية وجود علاقة معنوية مع العمر، ووجود القطط، وسوابق الإجهاض ($p < 0.05$). وأخيرًا، أظهرت الدراسة النسيجية المرضية، التي شملت 126 عينة (63 قلبًا و63 حجابًا حاجزًا) من 63 رأسًا من الإبل المذبوحة، وجود تراكيب متوافقة مع *T. gondii* على مستوى العضلة القلبية لدى الإناث البالغة فقط. حيث تم الكشف عن التاكيزويتات لدى حيوان واحد (1.6٪) والأكياس النسيجية لدى حيوانين (3.17٪)، في حين لم يتم تسجيل أي دليل على وجود *N. caninum.* وتميزت الآفات القلبية بوجود ارتشاحات خلوية أحادية النواة، ونزيف بؤري، ومناطق نخر، مما يدل على استجابة التهابية ووعائية ملحوظة. تشير هذه النتائج إلى احتمال تورط *T. gondii* في خسائر التكاثر لدى الإبل في الجزائر، وتؤكد ضرورة وضع استراتيجيات ملائمة للمراقبة والسيطرة على هذا الطفيلي.

الكلمات المفتاحية

الإجهاض، *Toxoplasma gondii*، *Neospora caninum*، عوامل الخطر، الجزائر، الإبل

SUMMARY

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List of abreviations

CI	Confidence Interval
CRBt	Biotechnology Research Center
DNA	Deoxyribonucleic Acid
ELISA	Enzyme Linked Immunosorbent Assay
FAO	Food and Agriculture Organization
H&E	Hematoxylin and Eosin
HA	Herds reporting abortions
IgG	Immunoglobulin G
N. caninum	*Neospora caninum*
NC	Negative control
OD	Optical density
OR	Odds Ratio
PC	Positive control
PCR	Polymerase Chain Reaction
rpm	revolutions per minute
SH	Surveyed herds
S/P %	Sample/Positive
T. gondii	*Toxoplasma gondii*
TMB	3,3′,5,5′-tetramethylbenzidine
($\chi 2$)	Pearson Chi-Square
µm	micromètre

General introduction

General introduction

Camelids, belonging to the order *Tylopoda*, which includes digitigrade ruminants, originated in North America approximately 40 million years ago. Although they possess a three-compartment stomach and exhibit rumination behavior, they are classified as special ruminants or sometimes pseudoruminants. The family is divided into two main groups: large and small camelids. The large camelids include the dromedary *(Camelus dromedarius)*, with a single hump and adapted to hot desert environments and the Bactrian camel *(Camelus bactrianus)*, with two humps suited to cold desert climates. A hybrid known as the *Turkoman* results from the crossbreeding of these two species, combining traits of both. Small camelids are native to the high plateaus of South America and include the llama, alpaca, guanaco and vicuña (Khan et al., 2003; Meyer, 2009).

Large camelids, such as the dromedary *(Camelus dromedarius)* and the Bactrian camel *(Camelus bactrianus)*, exhibit low reproductive performance with only 6 to 8 births per female over a reproductive lifespan of 20 to 30 years. This limited fertility is particularly exacerbated in arid and semi-arid regions, where scarce food resources increase neonatal vulnerability, mortality may reach 20% in extensive systems and deplete the dam's physiological reserves, especially those stored in the hump, due to the high demands of milk production. In contrast, semi-intensive and intensive systems, characterized by balanced nutrition and improved veterinary care, enhance neonatal survival and female fertility, thereby contributing to greater overall reproductive output within herds (Konuspayeva and Magnan, 2022).

The dromedary *(Camelus dromedarius)* is a highly versatile domestic species that plays a crucial role in many countries, including Algeria. Its distribution is largely confined to the desert and semi-arid belt extending from North Africa to Southwest Asia, where it has adapted remarkably well to extreme environmental conditions (Osman et al., 2016). Since 1961, the global population of large camelids has more than doubled, although growth patterns have varied significantly between countries. Algeria is among the countries experiencing rapid but relatively recent growth in camel populations (Type A) (Faye et al., 2013). According to FAOSTAT data (2022), the global population of large camelids was estimated at approximately 42 million head in 2020. Algeria ranks 14th worldwide, with around 90% of its camel population concentrated in Saharan regions, while the remainder is distributed across steppe areas. Algeria's camel population was estimated at 459.616 heads, with an average annual growth rate of 2.94% (Faye et al., 2025).

In Algeria, camel farming relies on Saharan rangelands with sparse vegetation adapted to arid conditions. In this resource-poor environment, the dromedary stands out for its adaptive capacities, enabling it to survive, reproduce, and produce within an extensive system. (Chehma and Faye, 2011). This species holds a strategic position in the national economy by providing essential products such as meat, milk and hides. Furthermore, the dromedary possesses multifaceted importance economic, ecological, social and cultural which reinforces its central role within local pastoral systems (Djeddou-Benabid et al., 2025).

In Algeria, the diagnostic rate in ruminants including the dromedary, remains particularly low and the scientific data available in this field are still limited. This situation highlights the need for in-depth investigations supported by specific diagnostic tests. Etiological identification is further complicated by the wide range of pathogens: bacteria, protozoa, viruses and fungi potentially involved in abortions (Guidoum, 2021).

The main aim of the present study was to conduct an in-depth investigation into the possible involvement and to assess the potential role of the protozoa *T. gondii* and *N. caninum* in the occurrence of abortions in dromedary camels *(Camelus dromedarius)* in southeastern Algeria, specifically in the El-Oued province. To this end and within the framework of a multidimensional approach, the work was structured into three distinct sections, each addressing a specific objective, clearly stated and closely related to the research question:

Study I: Epidemiological survey of abortions associated with *Toxoplasma gondii* and *Neospora caninum* in dromedaries *(Camelus dromedarius)* in the El-Oued province.

Study II: Seroprevalence of *Toxoplasma gondii* and *Neospora caninum* and identification of associated risk factors in dromedaries *(Camelus dromedarius)* in the El-Oued province.

Study III: Histopathological detection of *Toxoplasma gondii* and *Neospora caninum* in slaughtered dromedaries *(Camelus dromedarius)* in the El-Oued province.

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CHAPTER I

Dromedary farming and Reproduction management in Algeria

I.1. Camel population and its geographical distribution

According to Ben Aissa (1989), the Algerian camel population comprises several ecotypes distributed across different geographical regions:

- **Chaambi**: a robust and well-muscled dromedary, primarily used for riding and meat production. It is distributed between the Western and Eastern Erg regions.
- **Ouled Sidi-Cheikh**: a medium-sized riding camel, well adapted to rocky terrains. It inhabits the high plateaus bordering the Great Western Erg.
- **Sahraoui**: a hybrid resulting from the crossbreeding of Chaambi and Ouled Sidi-Cheikh camels. It is a highly valued méhari, known for its endurance and strength, with a range extending from the Great Western Erg to the central Sahara.
- **Aït Khebbach**: a powerful and muscular camel primarily used for pack transport and meat production. This breed is found in southwestern Algeria.
- **Steppe camel**: employed mainly for short-distance transhumance. It is found in transitional zones between the northern Sahara and steppe regions.
- **Tergui**: a prestigious riding camel (méhari) originating from the Hoggar and central Sahara. It is characterized by impressive height (>2 m) and a light-colored coat, typically white or pale yellow.
- **Ajjer**: a camel used for transport and tourism, mainly found in the Tassili n'Ajjer region.
- **Reguibi**: a saddle camel native to the southwestern regions (Béchar, Tindouf), particularly around Oum El-Assel. It is appreciated both for its riding qualities and the high milk yield of its females.
- **Aftouh**: A draught and pack camel primarily raised for meat. It is distributed across the Tindouf and Béchar regions.

In Algeria, camel herds are mainly distributed across 17 provinces, spanning both Saharan (9 provinces) and steppe (8 provinces) regions. According to Ben Aissa (1989), the national territory is classified into three major camel breeding zones:

- **Southeastern Region:** Includes El Oued, Biskra and adjacent steppe provinces (M'Sila, Tébessa, Batna, Khenchela, Laghouat, Djelfa, Ouargla and Ghardaïa).

- **Southwestern Region:** Comprises Béchar, Tindouf, northern Adrar, Naâma and El Bayadh.

- **Extreme Southern Region:** Encompasses Tamanrasset, Illizi and southern Adrar.

I.2. Camel husbandry systems and herd management

Camel husbandry in Algeria encompasses three main systems (Kiema et al., 2015; Mekhloufi, 2020):

- **Extensive system:** Practiced over vast rangelands, it relies on natural vegetation with minimal inputs. It includes:
    - ***Nomadism*:** Characterized by full mobility of herders and their families across large distances, dictated by water and forage availability.
    - ***Transhumance:*** Seasonal and cyclical movements of herds along established routes, adapted to climatic variability and resource distribution.
    - ***Sedentarization*:** A shift from mobile to settled lifestyles, often involving agriculture, which may lead to the socio-economic marginalization of former pastoralists.

- **Semi-intensive system:** Combines partial confinement with managed grazing. Lactating females are commonly kept near urban zones, receiving feed supplements during the dry season and relying on natural pastures during the rainy season.

- **Intensive system:** Involves camel fattening in feedlots for commercial slaughter. Animals are transported from production areas to specialized units. Intensification is also seen in racing camel breeding, characterized by high-input management and specialized training. This system responds to increasing urban demand for camel products.

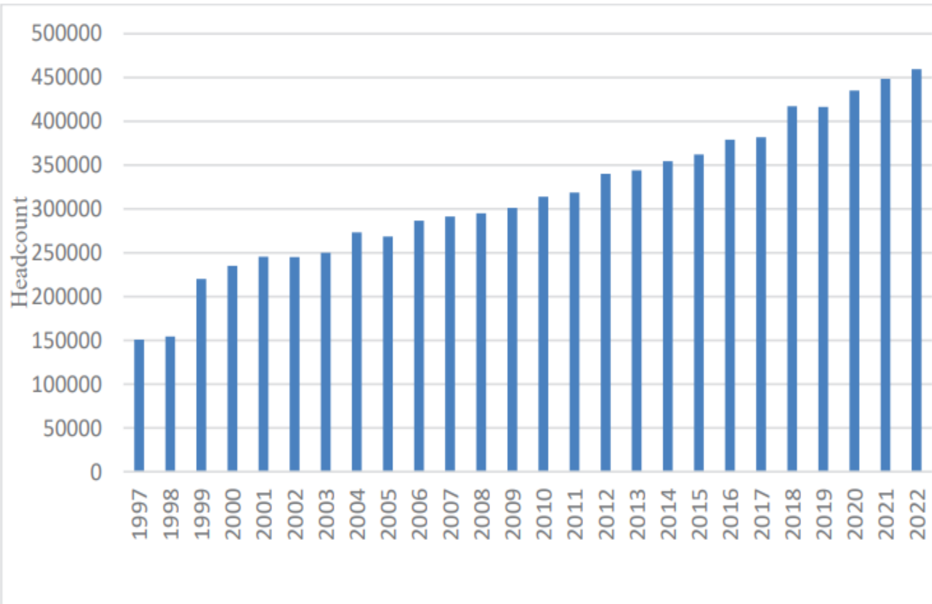


Figure 1: Evolution of camel populations in Algeria (1997–2022) (FAO 2022).

I.3. Biological parameters and reproductive life cycle of the dromedary

Based on available physiological data, particularly those reported by Faye et al. (2022), the reproductive life cycle of the dromedary can be described as follows (Table 1):

- **Birth:** the calf is born after a gestation period of approximately 13 months. Parturition typically occurs during the winter season (November to March), reflecting the seasonality of the male rut, which is expressed during this period.
- **Neonatal growth:** if the newborn survives, its growth is supported by maternal milk, particularly during the early months of life. In extensive systems, weaning is delayed and rarely occurs before the age of six months.
- **Puberty and sexual maturity:** puberty is generally reached between 3 and 4 years of age, although it varies depending on sex, genetics, health status and above all, nutritional management. Puberty typically coincides with the animal reaching 70–80% of its mature body weight. First calving usually occurs between 4 and 5 years of age.
- **Gestation:** the average gestation length is about 390 days. This duration may vary depending on the sex and weight of the fetus, as well as the season of calving.
- **Lactation:** lactation can last from 6 to 18 months, with an average duration of 12 months. However, milk production declines rapidly following conception, making concurrent gestation and lactation challenging. As a result, the average calving interval is around two years; one year dedicated to milk production and another to gestation.
- **Body growth:** the dromedary reaches its mature body weight at approximately 7 years of age.
- **Productive lifespan:** the reproductive lifespan of a female camel generally ranges from 10 to 16 years. Nevertheless, individuals can live up to 30 years under favorable nutritional and sanitary conditions.
- **Culling:** female camels are usually culled at an advanced age often beyond 20 years, depending on their reproductive performance and general health status.
- **Males:** males not selected for breeding are typically slaughtered at a young age. Those intended for reproduction reach sexual maturity around 4 to 5 years of age, although sexual behavior may be observed earlier. They are rarely used for breeding before the age of 5 or 6 and remain active as sires for a period ranging from 5 to 10 years depending on the breeder's replacement strategy.

Table 1. Selected reproductive parameters in large camelids (Faye et al., 2022).

Parameters	Range
Age at puberty	30–48 months
Age at first calving	42–72 months
Gestation length	370–390 days
Twinning rate	0.4%
Calving interval	15*–36 months**
Number of births per lifetime	3–8
Annual herd fertility rate	30–45%

* In female camels not used for milk production and calving early in the breeding season

** Particularly in cases of abortion

In male dromedaries, reproduction is seasonally limited to 50–100 days, with timing influenced by environmental factors. A single male can mate with 10–14 females per day and a 1 to 20–25 ratio is optimal. After conception, females reject further mating, signaling pregnancy. Behavioral cues such as tail cocking and urination are used for early detection. Ultrasonography confirms pregnancy from day 18 by visualizing the embryonic vesicle (Sayid, 2018).

1.4. Factors affecting reproductive performance

1.4.1. Biological limitations

Among the main biological constraints affecting reproduction in dromedaries are the delayed onset of puberty in both males and females (females reaching puberty at 3–4 years but typically not entering breeding programs until 5–6 years of age and males attain puberty around 3 years, though full reproductive capacity is only achieved by 6–7 years), a prolonged gestation period (approximately 13 months) and an extended postpartum anoestrus, often associated with 8–10 months of lactation under sub-optimal nutritional conditions. In addition, the species is characterized by a relatively short breeding season. The age at first calving varies widely, ranging from 36 to 71 months, while the inter-calving interval spans from 17.5 to 51 months. This marked variability in reproductive parameters suggests the involvement of multiple, yet insufficiently documented factors, including nutritional status, genetic differences among breeds, and the general health condition of the animals (Sayid, 2018; Tibary et al., 2005). In all likelihood, fertility in dromedary camels remains relatively low, with an estimated rate of approximately 50%, which is considerably lower than that observed in most other domestic animal species (Wilson, 1984).

In addition, In dromedary camels, the generation interval is considerably long. The age of the parents at the time of offspring birth generally ranges from 6 to 27 years in males and from 6 to over 30 years in females. This extended interval is mainly due to poor reproductive performance, delayed age at first calving and an unusually long reproductive lifespan. Such a prolonged generation interval represents a major constraint to the rate of annual genetic gain in this species. (Sayid, 2018)

1.4.2. Pathological factors

The reproductive performance of an animal is closely linked to the anatomical integrity and normal physiological function of its genital system. However, this complex process can be disrupted by a wide range of factors, including nutritional deficiencies, specific or non-specific infections, hormonal imbalances, immunological disorders and various forms of environmental stress. Genital tract infections can result in temporary or permanent infertility in both males and females. Also reproductive diseases are recognized as a major factor contributing to the decline in fertility potential in large farm animals. In dairy livestock, infertility is generally associated with reduced milk yield, increased veterinary and treatment costs, greater labor requirements and a higher culling rate (Mandefro, 2020; Tibary et al., 2006).

Metritis **and** ***endometritis*** are among the leading causes of infertility in female dromedaries. They are primarily associated with bacterial pathogens, notably *Escherichia coli* and *Streptococcus equi subsp. Zooepidemicus.* A study conducted in the central region of Saudi

Arabia identified metritis as a key factor limiting reproductive performance in this species (Tibary, 2004; Tibary et al., 2006). Several factors contribute to the development of these uterine disorders, notably excessive or poorly managed mating practices, which can cause repeated uterine trauma and impair the natural defense mechanisms of the endometrium (Tibary et al., 2006).

In addition, the structural integrity of the endometrium whether compromised by degenerative lesions or chronic infections caused by pathogenic microorganisms greatly diminishes the uterus's ability to eliminate infectious agents and to re-establish an environment conducive to embryonic implantation. Mandefro (2020) reported a higher prevalence of uterine lesions in female dromedary camels compared to cows. In this study, endometritis was identified as the most common uterine pathology observed in dromedaries. This finding may be partially explained by the reproductive status of the animals examined, as nearly all of them had been culled and brought to the abattoir due to one or more reproductive disorders rendering them non-productive. Other predisposing factors to endometritis include postpartum complications and gynecological manipulations performed under poor hygienic conditions. Clinically, these pathologies are most often manifested by repeat breeding behavior. However, some females may exhibit mating refusal or prolonged periods of anestrus (Mandefro, 2020; Tibary, 2004).

Among the main causes of reduced fertility in dromedary camels are ***early embryonic losses*** and ***abortions***, with prevalence rates reaching up to 40% depending on management, health status and environmental conditions (Tibary et al., 2005). These reproductive failures significantly compromise breeding success and represent a major obstacle to optimizing zootechnical performance in camel production systems.

Vaginal adhesions represent a significant yet often underestimated reproductive disorder contributing to infertility in female dromedaries. Their occurrence is commonly linked to chronic untreated vaginitis, excessive or forceful mating, traumatic copulation practices, injuries sustained during parturition, and a high number of previous pregnancies (multiparity). Clinically, affected females typically exhibit persistent refusal to mate, mechanical difficulties during copulation, or post-coital bleeding. These symptoms should prompt attention from breeders and veterinarians alike, as they not only hinder conception but also compromise the reproductive health and welfare of the animal. Such adhesions may result from repeated inflammatory insults or unresolved local trauma, highlighting the importance of appropriate breeding management and early diagnosis of gynecological disorders (Tibary et al., 2006a).

Neonatal mortality represents another major limiting factor in reproductive performance among dromedaries, with rates ranging from 10% to 90% of births depending on the farming context. Although this phenomenon has been partially investigated, further research is required to fully elucidate its underlying causes, particularly those related to environmental, health and management factors (Tibary et al., 2005).

The reproductive performance of female dromedaries can also be influenced by other interrelated factors, such as poor health status, the detrimental effects of heat stress and suboptimal husbandry practices. These constraints often act synergistically, compromising reproductive efficiency and negatively affecting the productivity and profitability of camel farming systems.

Among the infectious causes of infertility in male dromedaries, Tibary et al. (2006) emphasizes that it may result from severe infections, whether localized to the reproductive tract or of systemic origin. In dromedary camels, trypanosomiasis *(Trypanosoma evansi)* is frequently associated with significant testicular degeneration. Beyond its direct gonadal effects, the disease may impair pituitary function, thereby disrupting spermatogenesis and compromising semen quality. Although testicular function typically recovers within 75 to 90 days following clinical recovery, infertility may persist and in severe cases become irreversible. Orchitis and epididymitis have also been associated with brucellosis, particularly that caused by *Brucella abortus* and *Brucella melitensis*. Moreover, infestation with the filarial parasite *Dipetalonema evansi* has been identified as a contributing factor to testicular and epididymal lesions in dromedaries, especially in humid regions, where reported prevalence ranges from 2.3% to 10%.

1.4.3. Strategies for the enhancement of reproductive performance

Significant progress has been made in recent years in the diagnosis and management of infertility and reproductive losses in dromedaries, particularly through the use of ultrasonography, microbiological cultures, and endometrial biopsy. However, research on the causes of abortion and the methodological protocols for investigating gestational losses remains insufficient. Moreover, male infertility is still largely understudied, despite its critical role in overall reproductive performance. Genetic improvement through selective breeding, along with optimized nutritional management, represent key levers for enhancing reproductive performance. Moreover, early weaning has proven effective in significantly reducing the calving interval, thereby contributing to improved overall herd productivity (Tibary et al., 2005).

Khan et al. (2003) also emphasize that the implementation of appropriate feeding practices from the early stages of life plays a pivotal role in promoting rapid body growth and the early onset of puberty in female dromedaries. This nutritional strategy contributes to lowering the age at first calving and enhancing overall reproductive efficiency.

Indeed, nutrition plays a critical role in the physiological processes associated with puberty and reproductive performance. Rapid growth promotes the early onset of sexual maturity, whereas undernutrition delays this event in both males and females. In fact, in male dromedaries, inadequate nutritional management represents a major limiting factor for reproductive performance. Maintaining an optimal body condition throughout the year is essential to ensure effective sexual activity during the breeding season. A body condition score of 3 is considered ideal for reproduction, whereas extreme conditions, either obesity or emaciation, are associated with reduced libido. From a physiological perspective, severe nutritional deficiencies, although insufficiently studied in camelids, are known to be associated with delayed puberty, testicular atrophy, and a marked reduction in sperm production. In particular, vitamin A deficiency leads to decreased testicular weight and impaired spermatogenesis. When nutritional restriction is severe, it may even lead to regressive changes in the reproductive organs after they have fully developed (Sayid, 2018; Tibary and Anouassi, 1997).

Furthermore, early weaning of calves, combined with targeted nutritional support for the dam during lactation, has been shown to shorten the inter-calving interval and improve reproductive performance. Concurrently, strict management of nutrition and health can extend the productive lifespan of breeding animals. The application of these integrated practices increases the number of offspring produced per female over her reproductive career, thereby reducing the need to maintain a large breeding herd. Optimizing zootechnical performance represents a strategic lever for simultaneously improving the productivity and economic profitability of camel farming systems. It not only reduces herd management constraints but also helps to minimize pressure on pastoral resources and the fragile ecosystems in which this form of livestock production typically operates (Khan et al., 2003).

CHAPTER II

Abortion in the Dromedary Camel *(Camelus dromedarius)*

Abortion is defined as the expulsion of an immature fetus, either alive or dead, before the completion of the normal gestation period and prior to the expected time of parturition. It typically results from the disruption of physiological mechanisms responsible for the maintenance of pregnancy. When pregnancy loss occurs before organogenesis, it is referred to as early embryonic death. In contrast, a stillbirth corresponds to the delivery of a fully developed fetus that dies in utero and is born dead. Neonatal mortality refers to the death of newborns, primarily occurring within the first seven days of life (Shaapan, 2016).

In pregnant females, infectious agents are also capable of inducing abortion, as well as contributing to prenatal and neonatal losses. Indeed in camels, parturition rates seldom exceed 40% in extensively managed nomadic herds and rarely surpass 70% under more intensive husbandry systems. Beyond these inherently low reproductive outputs, camel herds are also affected by high neonatal mortality, which can in certain circumstances reach epizootic proportions (Tibary et al., 2006).

According to Tibary (2021), pregnancy loss is a frequent concern in camelid reproductive practice. While the diagnostic approach largely parallels that employed in other domestic species, certain unique anatomical and physiological features of camelid reproduction must be considered. Notably, in nearly all pregnancies, embryo implantation occurs exclusively in the left uterine horn, regardless of the ovary of origin. Additionally, the camelid placenta is epitheliochorial and diffuse with microcotyledonary structures, resembling the placentation pattern found in equines. A distinct characteristic lies in the adherence of the allantochorion to the amniotic sac, a configuration that may influence feto-maternal exchanges and contribute to the specific vulnerability of camelids to gestational losses.

According to Tibary et al., (2005) ,the pregnancy or birth rate in breeding females shows wide variability, ranging from 12% to 85%. This disparity reflects a frequently compromised reproductive efficiency, primarily due to early pregnancy losses and abortions, which can reach up to 40%. The incidence and etiology of abortion in camelids remain insufficiently documented particularly in dromedaries. While abortion is considered rare in South American small camelids (llamas and alpacas), available data indicate a wide variability in abortion rates in dromedaries ranging from 2% to 25% (Tibary et al., 2006).

A wide range of causes has been reported in the literature, including infectious agents (bacteria, parasites, viruses), trauma as well as toxic and environmental factors. Although significant advances have been made in recent years in diagnostic methodologies particularly ultrasonography, microbial culture and biopsy as well as in the treatment of infertility causes, a comprehensive understanding of reproductive losses remains limited. Notably, the etiologies of abortion are still insufficiently investigated and the methodological approaches required to elucidate their underlying mechanisms are lacking, thereby hindering improvements in reproductive performance in this species. This limitation is primarily attributed to the absence of standardized laboratory diagnostic protocols applied consistently to abortion cases in camel herds. This methodological gap constitutes a major obstacle to the understanding of pathological reproductive mechanisms in camelids and underscores the urgent need to implement species-specific reproductive monitoring strategies (Tibary et al., 2005; Tibary et al., 2006).

Furthermore, the diagnosis of abortion remains a significant challenge for both livestock producers and veterinarians, particularly during the early stages when clinical signs are often subtle or absent. Observable indicators may include the presence of placental tissues protruding from the vulva, the discovery of a dead fetus within the pen or paddock, or unexpected signs of estrus behavior suggestive of a return to receptivity (Fowler, 2011).

Abortion in dromedaries leads to significant economic losses. Beyond the direct loss of the fetus, it is often associated with complications such as uterine infections, reduced reproductive performance, prolonged calving intervals, infertility, decreased milk production, and the culling or death of affected animals. In addition, public health is also at risk, as several abortive agents are zoonotic in nature (Hassani, 2021).

II.1. Non-infectious causes

- *Fetal and Placental Abnormalities* (twinning, umbilical cord torsion, severe deformities, chromosomal abnormalities and placental insufficiency, uterine torsion).
- *Luteal insufficiency* (hypoluteidism) occasionally linked to obesity or presumed hypothyroidism.
- Environmental and Physiological Stress Factors (severe systemic disease, prolonged transport and handling stress, Acute heat stress).
- *Iatrogenic Causes* (inappropriate administration of prostaglandin F2α, corticosteroids, 8-way combination vaccines).
- *Nutritional Deficiencies* (Selenium, vitamin A, Iodine).
- *Toxicoses* (Copper, Iodine).
- *Physiological and Management-related Factors* (lactating females, young nulliparous females).

II.2. Infectious causes

Reproductive losses in camelids are due to infertility, pregnancy loss, udder diseases and neonatal mortality caused by a variety of infectious diseases. Uterine infections and abortion represent the main clinical concerns in camelid veterinary practice. Abortion rates linked to infectious diseases range from 10% to over 70% in certain regions (Tibary et al., 2006).

In dromedary camels, although adult mortality rates remain relatively low (3–5% per year), reproductive losses, particularly those associated with abortion and early embryonic mortality, represent a major limiting factor for herd productivity. These losses may be exacerbated by unfavorable environmental conditions, such as prolonged drought periods, which indirectly affect reproductive performance. Furthermore, dromedaries are exposed to a wide range of infectious and parasitic pathogens, some of which are involved in reproductive disorders, particularly abortion (Khan et al., 2003).

In east-central Niger, Saley (1990) reported a calving rate of approximately 45%, along with postnatal mortality rates ranging from 10% to 25% in dromedary calves aged between birth and six months. Similarly, in Tunisia, Djellouli and Saint-Martin (1992) documented an overall calving rate of around 40% across 30 herds, as well as a mortality rate of 17% between birth and one year of age. In Libya, El-Azab et al., (1997) also estimated the average calving rate in dromedary camels at only 39.1%. Furthermore, Al-Dahash and Sassi (2009) reported an abortion rate of approximately 5% and a neonatal mortality rate of about 5% during the first two weeks postpartum. Based on a survey conducted in the Mourtcha district of Chad, Touka et al. (2025) also estimated a calving rate of 21.3% and an average abortion rate of 6.8% in female dromedaries.

Several studies conducted across different countries have focused on identifying the major abortive pathologies in dromedary camels. A few of them are presented below:

- According to Tibary et al. (2006), brucellosis and trypanosomosis are the predominant infectious causes of abortion in dromedaries raised in the Middle East and Africa. In contrast, in South American small camelids particularly llamas and alpacas the main reported etiological agents include leptospirosis, toxoplasmosis and chlamydiosis.

- In Algeria, according to a serological study conducted by Benaissa (2015) in southeastern Algeria on a sample of 865 dromedary camels targeting four abortion-associated pathogens, the reported seroprevalence rates were 4.7% for *Brucella spp.*, 49.5% for *Trypanosoma evansi*, 2.5% for *Chlamydia abortus* and 3.7% for Bovine Herpesvirus type 1 (BoHV-1).

- In Egypt, Osman et al. (2016) identified *Toxoplasma gondii, Theileria spp., Anaplasma spp.* and *Chlamydia psittaci* as potential etiological agents involved in cases of abortion, stillbirths and mortality of camel calves within six months of birth, reported in Maghribian dromedaries during the year 2013 in a farm in Mersa Matrouh governorate.

- In Saudi Arabia, Khalafalla et al. (2017) reported that the analysis of infected uterine samples collected from female dromedaries identified five major pathogens potentially associated with abortion cases: *Coxiella burnetii* (36%), *Campylobacter spp.* (27%), *Brucella spp.* (17%), *Salmonella spp.* (13%) and *Chlamydia spp.* (7%). Additionally, the seroprevalence of *Brucella spp.* and bovine viral diarrhea virus (BVDV) was estimated at 8.2% and 29.1%, respectively across all analyzed serum samples.

- Furthermore in Saudi Arabia, Khalifa et al. (2018) reported the presence of several abortive agents in 378 female dromedary camels. Serological analysis revealed prevalence rates of

16.67% for brucellosis, 49.18% for toxoplasmosis, 13.32% for neosporosis, 10.05% for chlamydiosis and 42.36% for coxiellosis.

- In Iran, Hassani (2021) estimated that the main causes of fetal losses in dromedary camels include brucellosis, trypanosomosis, leptospirosis, salmonellosis, bovine viral diarrhea (BVD), infectious bovine rhinotracheitis (IBR) and aspergillosis.

- According to Shaapan (2016), toxoplasmosis, neosporosis, sarcocystosis and trypanosomosis are among the main zoonotic protozoan diseases associated with abortion in dromedary camels. These conditions are caused by unicellular protozoan parasites, namely *Toxoplasma gondii, Neospora caninum, Sarcocystis spp.* and *Trypanosoma evansi* respectively.

II. 3. Major abortive diseases of protozoan origin

II.3.1. Toxoplasmosis

II.3.1.1. Etiology

Toxoplasmosis is a widespread zoonosis caused by the apicomplexan protozoan *Toxoplasma gondii*, which is capable of infecting all warm-blooded animals, including birds, humans, livestock and marine mammals. This parasite belongs to the phylum Apicomplexa, class Sporozoasida, subclass Coccidiasina, order Eimeriorina, and family Toxoplasmatidae (Hill et al., 2005). The name *Toxoplasma gondii* is derived from the Greek words toxón (arc) and plásma (form), referring to the characteristic crescent shape of the tachyzoite, the proliferative stage of the parasite, which measures approximately (2×6 µm) similar in size to an erythrocyte. The species name *" gondii "* refers to *Ctenodactylus gundi*, a North African rodent from which the parasite was first isolated in 1908 by Nicolle and Manceaux (Dubey, 2010).

In 1941, *T. gondii* was classified into types I, II, III, and atypical based on infection in mice. Infections caused by types I and III have been identified in the brains of dogs with neurological disorders. Types II and III are frequently involved in animal infections. The genome of *T. gondii* was mapped in 2005 (Dubey, 2008).

II.3.1.2. Structure and biological cycle of *T. gondii*

There are three infectious stages of *T. gondii* for all hosts: tachyzoites (individual or in groups), bradyzoites (within tissue cysts), and sporozoites (contained within sporocysts inside sporulated oocysts) (Fig. 2).

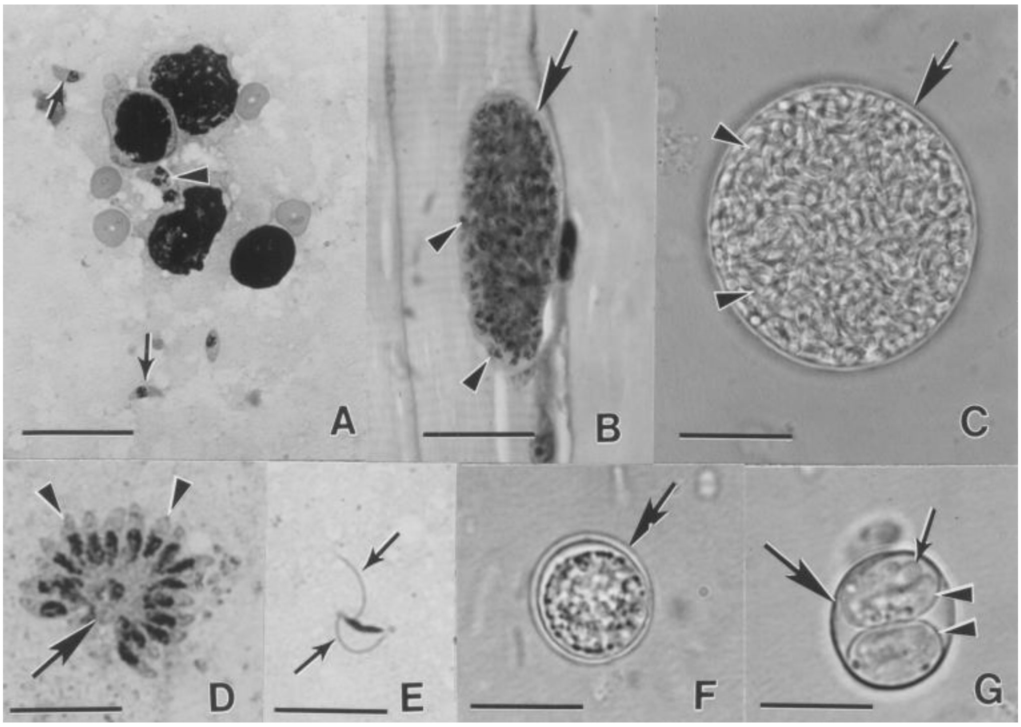


Figure 2. Stages of *T. gondii* (Hill et al., 2005). Scale bar in (A)–(D) = 20 mm, in (E)–(G) = 10 mm. **A.** Tachyzoites: crescent-shaped forms, rapidly multiplying in tissues. **B.** Tissue cyst (muscle): thin-walled structure containing numerous bradyzoites. **C.** Isolated tissue cyst (brain): contains hundreds of bradyzoites. **D.** Schizont: produces several merozoites in the intestine of the cat. **E.** Male gamete: flagellated cell involved in reproduction. **F.** Unsporulated oocyst: immature form excreted in feces. **G.** Sporulated oocyst: infective form containing sporocysts with sporozoites.

Oocysts of *Toxoplasma gondii* are produced exclusively in felids, whether domestic or wild. Domestic cats may shed oocysts after ingesting tachyzoites, bradyzoites, or sporozoites. However, less than 50% of cats shed oocysts after ingesting tachyzoites or oocysts, whereas oocyst shedding occurs in nearly all cats following ingestion of tissue cysts (Dubey et al., 1998; Dubey and Lindsay, 2006). Oocysts excreted in freshly passed feces are initially unsporulated and therefore non-infective. They are spherical to subspherical in shape, measuring approximately 10 to 12 µm in diameter. Sporulation occurs in the external environment within 1 to 5 days, depending on environmental conditions such as humidity, oxygen availability, and temperature. Sporulated oocysts contain two ellipsoidal sporocysts, each enclosing four sporozoites. These sporozoites measure approximately 6 to 8 µm in length and 2 µm in width (Lindsay and Dubey, 2020).

The tachyzoite and bradyzoite stages of *T. gondii* show close morphological and biological similarities to those of *Neospora caninum* (Dubey et al., 1998, 2017). Tachyzoites, the proliferative forms of the parasite, are metabolically active and sensitive to therapeutic agents used against coccidia. In contrast, bradyzoites, characterized by slow growth and located within tissue cysts, exhibit reduced metabolic activity and generally escape the action of these treatments. Tissue cysts develop and persist within host cells. Their size typically ranges from

5 to 70 µm, and they contain a variable number of bradyzoites, from a few dozen to several hundred. Although these cysts can form in various visceral organs such as the lungs, liver, and kidneys, they are preferentially located in muscular and nervous tissues, particularly the brain, eye, skeletal muscles, and cardiac muscle. Intact tissue cysts are generally considered to be of low pathogenicity and may persist throughout the host's lifetime (Dubey, 2010; Dubey et al., 1998; Lindsay and Dubey, 2020).

Felids, particularly domestic cats and wild relatives, act as the definitive hosts, where sexual replication takes place in the intestinal epithelium. The parasite follows an indirect life cycle, with asexual replication occurring in intermediate hosts namely all warm-blooded species (Elmore et al., 2010) (Fig. 3).

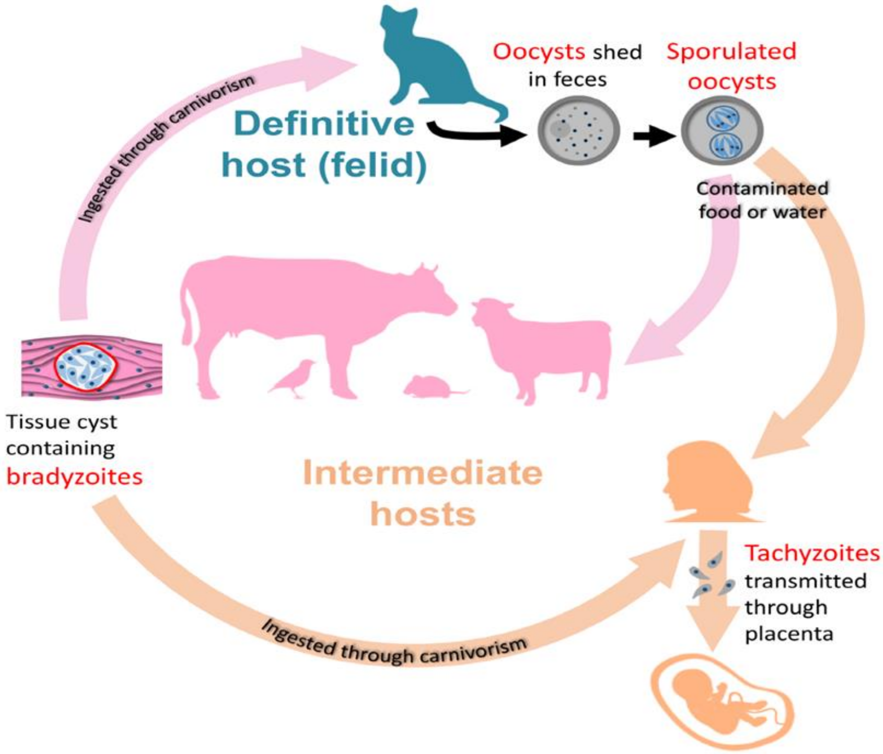


Figure 3. Life cycle of *Toxoplasma gondii* (Cerutti et al., 2020).

II.3.1.3. Epidemiology

Domestic felids are the main source of dissemination of *T. gondii* oocysts in the environment due to their abundance and their high level of shedding. These oocysts are highly resistant, can persist for long periods, and spread easily through soil and certain invertebrates. Once sporulated, they exhibit strong resistance and can survive for extended periods under favorable environmental conditions. Their dispersion is facilitated by various factors, including soil erosion as well as mechanical transport by arthropods and invertebrates such as flies, cockroaches, dung beetles, and earthworms (Dubey, 2004, 2010).

A global analysis of 337 studies (1970–2020) highlights the major epidemiological role of felids, the definitive hosts of *Toxoplasma gondii*. Seroprevalence reaches 37.5% in domestic cats and 64% in wild felids, reflecting widespread circulation of the parasite, closely linked to infection levels in local prey populations (birds and rodents). Serological assessment appears more relevant than coprological examination, as it indicates prior exposure and past oocyst shedding, thus reflecting the level of environmental contamination. Although oocyst shedding is relatively low (about 2.6% in domestic cats and 2.4% in wild felids), it plays a key role in parasite dissemination. The detection of oocysts in 16.2% of soil samples further highlights the importance of the environment as a reservoir of contamination. Overall, these findings point to a significant risk for both animal and public health, supporting the need for appropriate prevention and control strategies (Hatam-Nahavandi et al., 2021; Lindsay and Dubey, 2020).

In camelids, infection typically occurs through ingestion of sporulated oocysts excreted by felids contaminating feed, water or pasture. According to Djeddou-Benabid et al. (2025), a review of 81 studies conducted between 2004 and 2024 on 22,040 camelids from 23 countries reported an overall seroprevalence of *T. gondii* infection of 28.76%. The highest rates were recorded in Europe (73.01%), followed by Africa (39.26%), Asia (22.16%) and America (22.05%). Egypt, Sudan and Ethiopia exhibit the highest prevalence rates in Africa. These findings underscore the potential role of camelids in the transmission of this zoonotic parasite. These findings highlight the significant involvement of *T. gondii* in reproductive disorders in camelids particularly its potential role as an etiological agent of abortion.

II.3.1.4. Clinical Toxoplasmosis

La distribution de *T. gondii* varie considérablement selon les espèces, les élevages et les pays.
In the definitive host, represented by cats, infection may remain asymptomatic or progress to a systemic disease, with rare cases of transplacental or lactogenic transmission (Farhab et al., 2025). In intermediate hosts of *T. gondii*, infections are most often asymptomatic; however, they may occasionally result in severe or even fatal disease in certain species, including humans. From a reproductive standpoint, infection can lead to embryonic resorption, fetal mummification, abortion, neonatal mortality, and the birth of weak and non-viable offspring (Dubey, 2010).

Sheep, goats, and pigs are the most susceptible species to *Toxoplasma gondii* infection, exhibiting the highest seroprevalence rates. In small ruminants, this parasite can cause severe disease and is responsible for significant economic losses in the livestock industry (Tenter et al., 2000a). In contrast, most other livestock species, such as cattle and water buffaloes, are more resistant to acute clinical toxoplasmosis, and no confirmed cases of clinical disease have been reported in these animals. They generally resist infection or act as asymptomatic reservoirs (Lindsay and Dubey, 2020).

In dromedary camels, most infections remain subclinical; when clinical signs occur, they are usually non-specific and may include respiratory disorders, fever, anorexia, and episodes of diarrhea (Hagemoser et al., 1990; Hanon, 2018). As in other livestock species, *T. gondii* infection in camels has been associated with reproductive disorders, including abortion, stillbirth and infertility, leading to substantial economic losses in affected herds (Hamidinejat et al., 2013).

II.3.1.5. Diagnosis

The diagnosis of toxoplasmosis can be established using biological, serological, molecular, or histological methods, either alone or in combination (Dubey, 2010). Although traditional serological tests such as indirect hemagglutination assay (IHA), indirect fluorescent antibody test (IFAT), and latex agglutination test (LAT) have historically been widely used, some of these methods are now considered outdated. Nevertheless, serology remains a cornerstone for the diagnosis of *T. gondii* in veterinary medicine, both for clinical and epidemiological purposes. Despite the emergence of newer molecular techniques, well-established serological assays continue to provide reliable and reproducible results. In this context, the enzyme-linked immunosorbent assay (ELISA) remains widely used due to its reliability, sensitivity, and potential for automation (Ceylan et al., 2024).

From an immunological perspective, increased IgM titers (>1:256) are indicative of recent infection. IgG titers should be evaluated using paired serum samples collected during the acute and convalescent phases (3–4 weeks apart), with at least a fourfold change in antibody titer required to confirm active infection. However, high antibody titers may persist for several months following infection (Lindsay and Dubey, 2020; Schaefer et al., 2013).

Histological examination may reveal forms of *T. gondii* (tachyzoites or bradyzoites), but it remains insufficient due to morphological similarities with other coccidia. Therefore, for a reliable diagnosis—especially in food animals—it is necessary to combine several approaches. Immunohistochemistry allows the specific detection of parasite antigens, while PCR identifies its DNA from tissue samples. These molecular and immunological methods, together with serology, provide complementary tools that improve diagnostic accuracy (Dubey et al., 2013; Lindsay and Dubey, 2020).

Table 2. Summary of serological methods for detection of *T. gondii* infection (Liu et al., 2015).

Serological methods	Antigens or antibodies used	Antibody/antigen type tested
DT	Live tachyzoite	IgG, IgM, IgA
MAT	Formalin-fixed tachyzoite	IgG
IFAT	Killed whole tachyzoite	IgG, IgM
IHA	Tanned red blood cells sensitized with soluble antigens	IgG
ELISA	Tachyzoite lysate antigen, recombinant antigens, specific antibodies	IgG, IgM, IgA, antigens
ISAGA	anti-human IgM antibodies	IgM
LAT	Soluble antigen coated latex particles	IgG, IgM
PIA	Antigen coated gold nanoparticles	IgG
WB	Tachyzoite lysate antigen, recombinant antigens	IgG, IgM
ICT	Antigens or antibodies labeled with colloidal gold	IgG, ESA
Avidity test	tachyzoite lysate antigen, recombinant antigens	IgG, IgA, IgE

The ELISA test is generally based on the use of an antigen or antibody immobilized on a solid phase, combined with an enzyme-conjugated antigen or antibody, along with a specific substrate that allows visualization of the enzymatic reaction. This principle can be adapted for the detection of both antibodies and antigens. ELISA offers the advantage of being easily automated, allowing the simultaneous analysis of a large number of samples with good reproducibility. Several variants have been developed for the diagnosis of *T. gondii*, including indirect ELISA and sandwich ELISA, which are widely used for the detection of antibodies or antigens (Fig. 4).

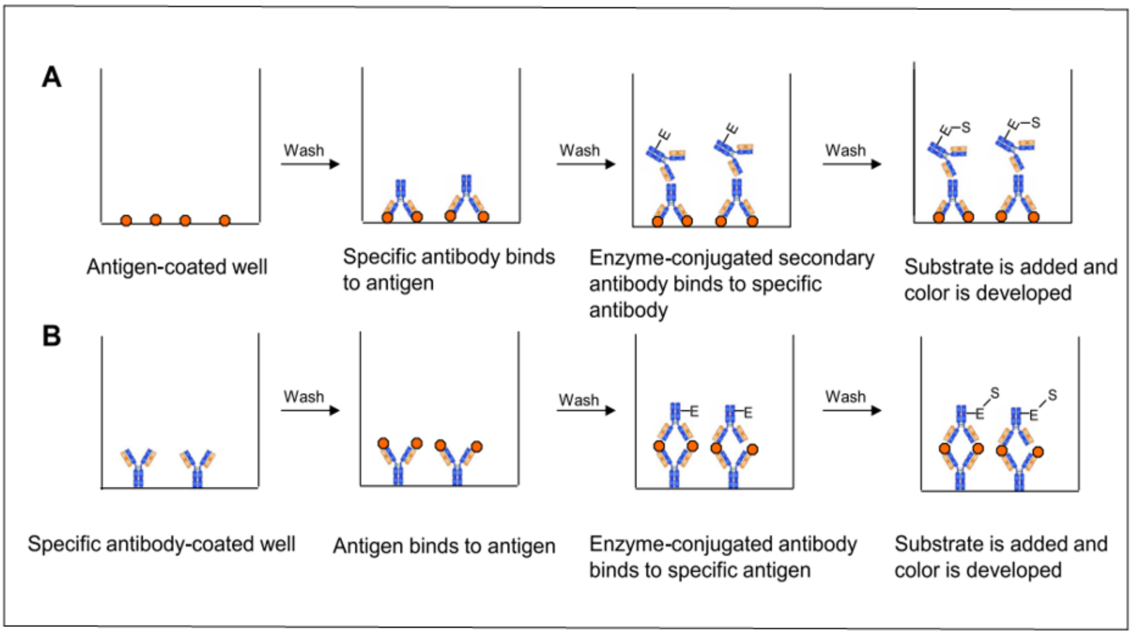


Figure 4. Schematic diagram of the ELISA test (Liu et al., 2015). **(A)** Indirect ELISA, used for the detection of anti-*Toxoplasma gondii* antibodies, based on antigens coated onto a solid phase and an enzyme-conjugated secondary antibody. **(B)** Sandwich ELISA, used for antigen detection, based on an antibody coated onto the solid phase and an enzyme-conjugated antibody.

II.3.1.6. Prevention and Control

Effective sanitary planning in animal production is essential to reduce *T. gondii* infection in livestock. To achieve this, farms should implement strict biosecurity measures aimed at limiting exposure to sources of contamination. These measures include rodent and wild bird control to reduce the presence of potentially infected prey, as well as proper feed storage to prevent contamination with cat feces. In addition, access of cats to livestock areas and feed storage facilities should be strictly restricted (Lindsay and Dubey, 2020; Stelzer et al., 2019).

Furthermore, vaccination of sheep, where available, represents an effective control strategy. A live vaccine based on the S48 strain of *T. gondii*, which does not persist in tissues, is used in Europe and New Zealand to reduce fetal losses associated with toxoplasmosis. Finally, proper management of biological waste, particularly the disposal of placental and fetal tissues from abortion cases, is crucial to prevent environmental contamination with *T. gondii* oocysts (Kurth et al., 2021; Kuruca et al., 2023).

II.3.2. Neosporosis

II.3.2.1. Etiology

Neospora caninum is an obligate intracellular protozoan belonging to the phylum *Apicomplexa*, responsible for infections in a wide range of animal species, both domestic and wild. Until 1988, this parasite was frequently misidentified as *T. gondii* due to morphological and antigenic similarities. It was first identified in 1984 in a dog in Norway and subsequently Dubey et al. (1988) formally described the genus and species *N. caninum*, thereby establishing neosporosis as a distinct pathological entity. Since its identification, *N. caninum* has been recognized as a prominent emerging pathogen, primarily affecting cattle and canids. It is considered a major cause of abortion and stillbirth in cattle, and is also implicated in the development of neuromuscular disorders in dogs (Khan et al., 2020).

II.3.2.2. Structure and biological cycle of *N. Caninum*

The life cycle includes three infectious stages: tachyzoites, tissue cysts (bradyzoites), and oocysts (Fig. 5). Tachyzoites are the active and proliferative form. They move between host cells or through the bloodstream, allowing dissemination of the infection. They are intracellular, located within vacuoles derived from the host cell membrane, and measure approximately 6 × 2 µm.

They multiply rapidly by endodyogeny (asexual division producing two daughter cells), causing tissue damage and can be transmitted to the fetus via the transplacental route. In response to host signals, tachyzoites differentiate into bradyzoites, which are slow-growing, dormant forms contained within thick-walled tissue cysts, responsible for the chronic phase of infection (Dubey, 2003; Lindsay and Dubey, 2020).

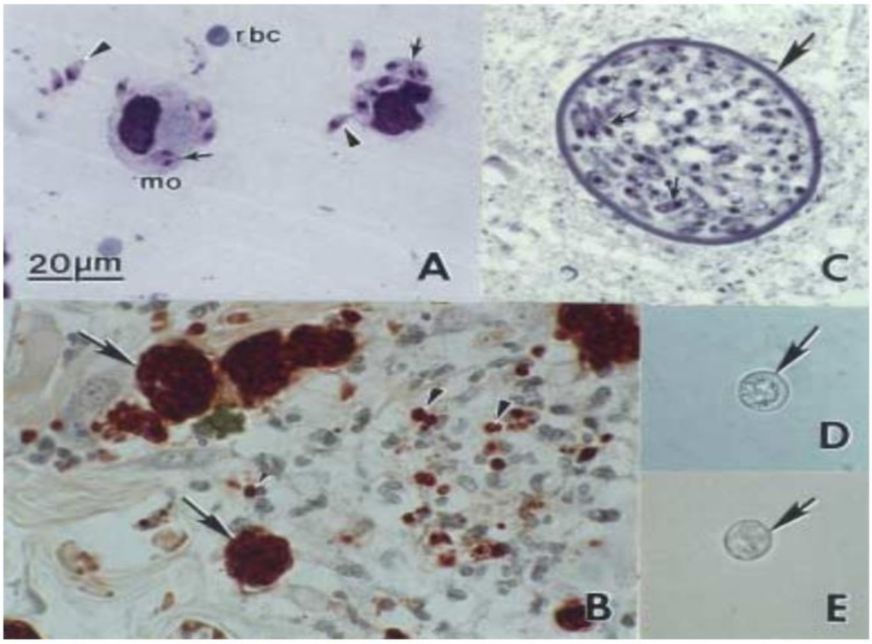


Figure 5. *Neospora caninum* stages in dogs (Bar = 20 µm and applies to all figures) (Dubey, 2003). **A**. Tachyzoites in the lung, observed individually or undergoing division (Giemsa stain). **B**. Tachyzoites in the skin, present in groups or individually (immunohistochemistry). **C**. Tissue cyst in the brain, containing bradyzoites surrounded by a thick wall. **D**. Unsporulated oocyst (immature form). **E**. Sporulated oocyst (infective form).

In 1998, the domestic dog was identified as a definitive host capable of excreting oocysts. Coyotes, wolves, and dingoes are also definitive hosts and contribute to maintaining the parasite in a sylvatic cycle (Dubey and Lindsay, 2006). Viable forms of *N. caninum* have been isolated from several animal species, including dogs, cattle, white-tailed deer, water buffaloes, sheep and camels (Guarino et al., 2000; Hässig et al., 2003; Karimi et al., 2023; Robbe et al., 2016) (Fig. 6). No natural infection has been reported in primates or humans.

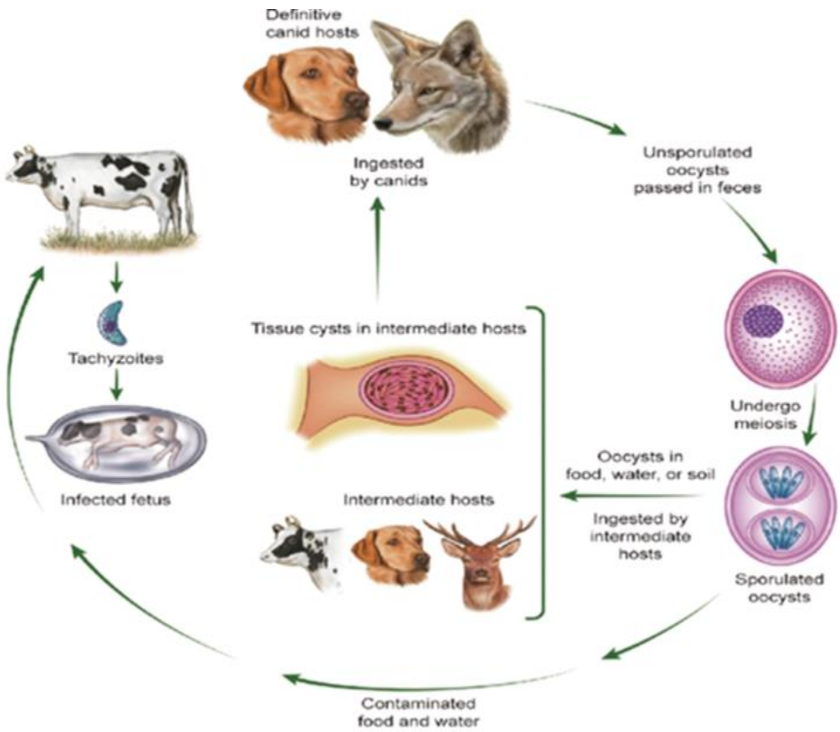


Figure 6. Life cycle of *Neospora caninum* (Khan et al., 2020).

II.3.2.3. Epidemiology

Oocysts play a central role in the epidemiology of neosporosis, although their biology remains poorly understood. In dogs, oocyst shedding generally begins at least 5 days after ingestion of infected tissues and occurs over a short and variable period. The intensity and duration of shedding are highly heterogeneous and influenced by factors that are still poorly understood. However, higher shedding levels are observed following ingestion of bovine tissues, in young animals, and under immunosuppressed conditions.

Carnivores are primarily infected through the ingestion of tissues containing bradyzoites. In contrast, in herbivores, infection mainly occurs via the ingestion of food or water contaminated with sporulated oocysts of *N. caninum*, shed into the environment by definitive hosts. Moreover, vertical transmission represents a major epidemiological mechanism in the persistence of the infection. It occurs when tachyzoites cross the placental barrier and infect the fetus during gestation (Dubey et al., 2007; Lindsay et al., 2001). Tissue cysts and bradyzoites remain viable for up to two weeks at refrigeration temperature (4 °C) but are inactivated by freezing. Oocysts are orally infective to cattle, goats, and sheep, as well as to various rodents, including mice, gerbils (*Meriones unguiculatus*), and guinea pigs (*Cavia porcellus*) (McAllister, 2016; Schares et al., 2001).

Apart from cattle, *N. caninum* seropositivity has been widely documented worldwide, particularly in dogs, goats and other ruminants. The presence of specific antibodies against this parasite has also been reported in a broad range of wild and domestic animal species, including raccoons, camels, pigs, horses, cats, foxes and coyotes. In addition, sporadic cases of clinical neosporosis have been reported in a wide range of animal species, including adult horses, a 16-day-old rhinoceros (*Ceratotherium simum*), a juvenile raccoon (*Procyon lotor*), a 2-month-old black-tailed deer (*Odocoileus hemionus columbianus*), as well as neonatal alpacas (*Vicugna pacos*) and llamas (*Lama glama*). Cases have also been documented in goats, sheep, Eld's deer (*Cervus eldi siamensis*), fallow deer (*Dama dama*), and antelopes (*Tragelaphus imberbis*). However, viable parasites have been successfully isolated from definitive hosts, particularly dogs, as well as from various intermediate hosts such as cattle, sheep, white-tailed deer, water buffaloes and dromedary camel (Dubey et al., 2006; Karimi et al., 2023; A. Khan et al., 2020; Lindsay and Dubey, 2020).

II.3.2.4. Clinical Manifestations

In cattle, it is now considered one of the leading infectious causes of abortion worldwide, with significant economic consequences, especially in intensive livestock production systems (Dubey et al., 2007). In both dairy and beef cattle, seropositivity to *N. caninum* is recognized as a major risk factor, being significantly associated with a higher incidence of abortion compared to seronegative animals. this protozoan can cause gestational losses at any stage, including embryonic resorption, mummification, autolysis, or abortion. Fetuses that die in utero between the third and eighth month of gestation are typically expelled with moderate signs of autolysis. In contrast, those dying before five months of gestation may become mummified and remain in the uterus for several months, whereas early embryonic deaths may result in resorption, often leading to repeat breeding in the dam (Dubey et al., 2006).

However, a significant proportion of live-born calves from infected dams (up to 95%) are congenitally infected, although they typically show no clinical signs at birth (Dubey and Schares, 2006; Khan et al., 2020).

II.3.2.5. Diagnosis

Serological examination of an aborting cow only indicates exposure to *N. caninum*; a definitive diagnosis of neosporosis-related abortion relies on histopathological examination of the fetus. The preferred samples include the brain, heart, liver, placenta, as well as body fluids or serum, with higher diagnostic sensitivity achieved when multiple tissues are analyzed. Among these, the fetal brain is the most consistently affected organ (Dubey et al., 2006; Maley et al., 2003).

Due to the frequent autolysis of aborted fetuses, even degraded brain tissue should be fixed in 10% neutral buffered formalin for histological examination using hematoxylin and eosin staining. However, the low parasite burden in autolyzed tissues often necessitates the use of immunohistochemistry to confirm the presence of the parasite. The characteristic lesion of neosporosis is focal encephalitis associated with necrosis and nonsuppurative inflammation. Lesions may also be observed in other organs, particularly the liver—more commonly in epizootic abortions—as well as in the placenta, although protozoa are difficult to detect in this tissue (Baszler et al., 1999; Dubey et al., 2006).

Furthermore, PCR represents a complementary diagnostic tool whose performance depends on sample quality and the degree of autolysis, with fresh or frozen tissues providing greater sensitivity than formalin-fixed samples. Serological methods (ELISA, indirect immunofluorescence, agglutination tests) are used to detect antibodies, including variants such as avidity ELISA to assess the recency of infection and antigen capture assays (Álvarez-García et al., 2003; Lindsay and Dubey, 2020; Schares et al., 1999)

II.3.2.6. Control Measures

Prevention of neosporosis relies on controlling both horizontal and vertical transmission, along with the implementation of strict biosecurity measures. Horizontal transmission can be reduced by preventing contamination of feed and water with oocysts, particularly by restricting the access of dogs and other canids to feeding areas, farm buildings, and pastures, although this measure can be difficult to implement in practice. Reducing vertical transmission involves management strategies such as culling seropositive females and/or their offspring, as well as the use of embryo transfer from seropositive donors to seronegative recipients (Lindsay and Dubey, 2020). Furthermore, no effective treatment is currently available against bradyzoites within tissue cysts, and the only commercial vaccine (NeoGuard) has been withdrawn from the market due to insufficient evidence of its efficacy (Barling et al., 2003).

At the farm level, biosecurity plays a crucial role and includes quarantine and testing of introduced animals, rodent control, limiting contact with potential definitive hosts, and managing factors that may promote recrudescence of infection in congenitally infected animals. Appropriate reproductive management also contributes to reducing the spread of infection within the herd (Dubey et al., 2007).

EXPERIMENTAL SECTION

EXPERIMENT I

Epidemiological profile of abortions potentially associated with *Toxoplasma gondii* and *Neospora caninum* in dromedaries (Camelus dromedarius) in El-Oued province

I.1. Introduction

In Algeria, the population of camels (*Camelus dromedarius*) plays a central role in livestock production systems (Faye, 2022). The dromedary is perfectly adapted to desert climates and extreme living conditions, thanks to its ability to efficiently utilize limited nutritional resources and convert them into edible products. It plays a key role in the national economy by providing essential products such as meat, milk and hides (Djeddou-Benabid et al. 2025; Djeddi et al. 2024). These animals play a crucial role in food security, providing a major source of animal protein, particularly for the populations of the arid regions of Algeria (Djeddou-Benabid et al. 2025).

Abortions constitute one of the most commonly observed problems in veterinary practice in camelids. Indeed, the birth rate generally does not exceed 40% in nomadic herds and 70% in intensive herds (Tibary et al. 2006). In addition to these low birth rates, camel herds experience significant neonatal losses, sometimes reaching epidemic proportions. The understanding of the incidence and etiology of abortions in camelids remains limited. Among the contributing factors, infectious, traumatic, and toxic agents appear to play a predominant role (Tibary et al. 2006; 2005). Nevertheless, reproductive losses, such as pregnancy loss and neonatal mortality, are often associated with various infections (Houssou et al., 2025).

The dromedary plays a critical role in the transmission of diseases to other livestock and its involvement in zoonotic diseases (Sazmand et al., 2019). Parasitic agents responsible for abortive diseases, such as *Toxoplasma* and *Neospora* pose a major risk to both animal and public health (Shaapan 2016).

Toxoplasmosis is a globally distributed zoonosis caused by *Toxoplasma gondii*, an intracellular parasite with a facultative heteroxenous life cycle. Felids, especially domesticated cats, serve as definitive hosts, excreting environmentally resistant oocysts through their feces (Dubey, 2010).

Neosporosis is primarily a disease of cattle and dogs and is not considered zoonotic. It is caused by a cosmopolitan coccidian parasite, *Neospora caninum*, which is morphologically similar to T. gondii, but the two parasite species are biologically distinct (Dubey et Schares, 2011). N. caninum is one of the most frequent causes of abortion in livestock, particularly in cattle, water buffaloes and camels (Dubey, 2003).

A highly characteristic clinical sign of abortions induced by these two protozoa is the presence of multiple white necrotic foci scattered on the surface of the placental cotyledons, which may be accompanied by hemorrhages observed in the fetus (Arranz-Solís et al. 2015; Henker et al. 2022).

The lack of an overview of reproductive failures in dromedaries, especially cases of abortion and stillbirth have never been reported. Therefore, the present study aims to:

(i) Estimate the incidence of abortions and stillbirths within the herds studied in the Algerian Sahara.

(ii) Describe and identify potential factors associated with abortions in dromedary camels.

(iii) Examine a possible contribution of *T.gondii* and *N.caninum* (Fetal and placental appearance).

(iv) Provide a descriptive basis for future research including biological and serological tests to confirm the role of these infectious agents.

I.2. Materials and methods

I.2.1. Study area

Data were collected from camel farms located in the El-Oued province in southeastern Algeria (33°21′21″ N 6°51′47″ E) (Fig. 7). This province spans an area of 44,586.80 km², occupies a strategic position and is among the largest administrative divisions in the country. It is one of the main areas for sourcing dromedaries in Algeria. It is bordered to the north by Khenchela province, to the northeast by Tébessa, to the northwest by Biskra, to the west by Touggourt and M'ghair, to the south by Ouargla, and to the east by Tunisia (approximately 300 km of shared borders). The climate is Saharan and desert-like according to the Köppen climate classification, characterized by very hot summers and mild winters.

In El Oued, temperatures fluctuate significantly throughout the year, with an average maximum of 39°C (104°F) and an average minimum of 21.8°C (74.2°F). The relative humidity averages 24.3%. Rainfall is scarce, generally ranging between 80 and 100 mm annually, and occurs predominantly between November and February, mainly as moderate showers, although occasional sudden downpours can also be observed.

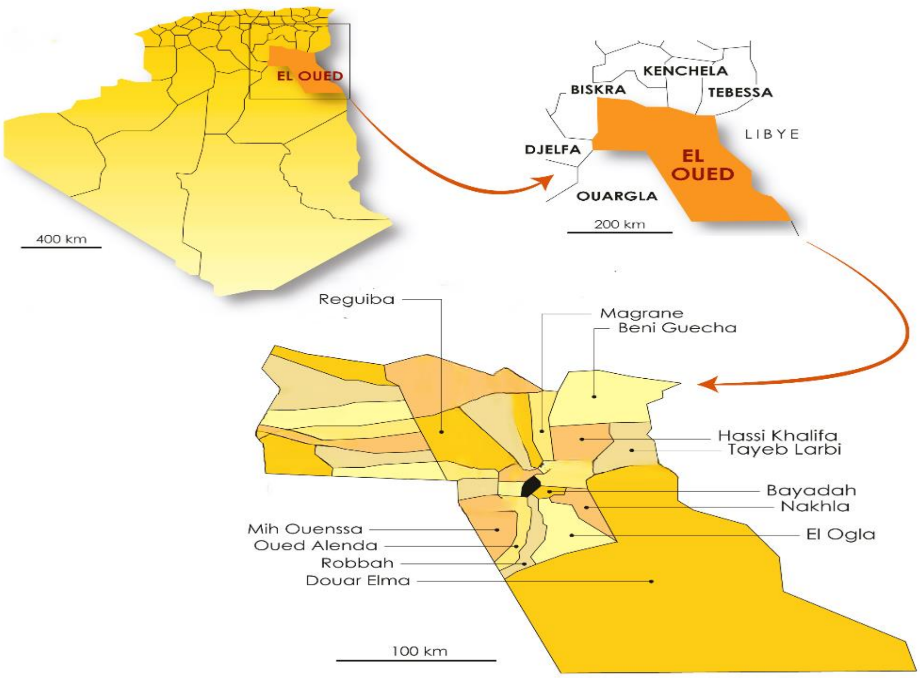


Figure 7. Geographic location of the communes in El Oued province where the questionnaire survey was conducted (Map of Algeria).

I.2.2. Study design and herd selection procedure

The sample size was defined considering the number of dromedary camel herds available during the study period, with the aim of obtaining an adequate representation of abortion occurrence in the investigated region. Herds were selected from different geographical areas of the Algerian Sahara to ensure representative spatial coverage. A random selection procedure was applied based on the available herd lists, thereby ensuring an objective selection of the study units. The surveyed animals were adult female dromedaries of reproductive age (5 to 18 years), selected based on their available reproductive history and their presence within the herds included in the study.

A questionnaire was developed to collect information on reproductive events and potential factors associated with the occurrence of abortions in dromedary camel herds. An epidemiological survey was conducted among 75 camel breeders from 13 municipalities in El Oued Province. These herds comprised a total of 5870 dromedary camels, including 4460 breeding females. The questionnaire was administered through direct interviews with herd owners during field visits. The information provided by the respondents was recorded and subsequently used for epidemiological analysis (Fig. 8).

Figure 8. Field survey and data collection among camel breeders in El Oued Province (Personal photograph).

I.2.3. Questionnaire survey

An epidemiological survey was conducted using a questionnaire among 75 camel breeders/owners from 13 communes in the El Oued province. The breeders were randomly selected. The questionnaire is semi-structured in order to obtain precise, rich and detailed information, allowing for a clarified and in-depth analysis of all elements that can be identified as potential risk factors. The questionnaire includes two sections:

- *The first section concerning data related to livestock:* the size of the camel herd (female camels, male dromedaries and young camels), the size of other animal species (cattle, sheep, goats and others), presence of cats (no/yes/number), presence of dogs (no/yes/number), breeding method (extensive, intensive, semi-intensive) and herd renewal method (purchase, self-replacement, mixed).

- *The second section concerns data related to reproductive losses:*

  - **History of abortions** (yes/no), month of abortion, abortion cases recorded during the 2022-2025 period (number of births "primiparous and multiparous"/year, number of abortions "primiparous and multiparous"/year), stage of gestation (1st trimester, 2nd trimester, 3rd trimester and 4th trimester), appearance of the fetus (normal, mummified, hemorrhagic, malformation), delivery (complete, incomplete), appearance of the placenta (normal, hemorrhagic, necrotic), course of action following an abortion (none, isolation, veterinary consultation) (Fig. 9).

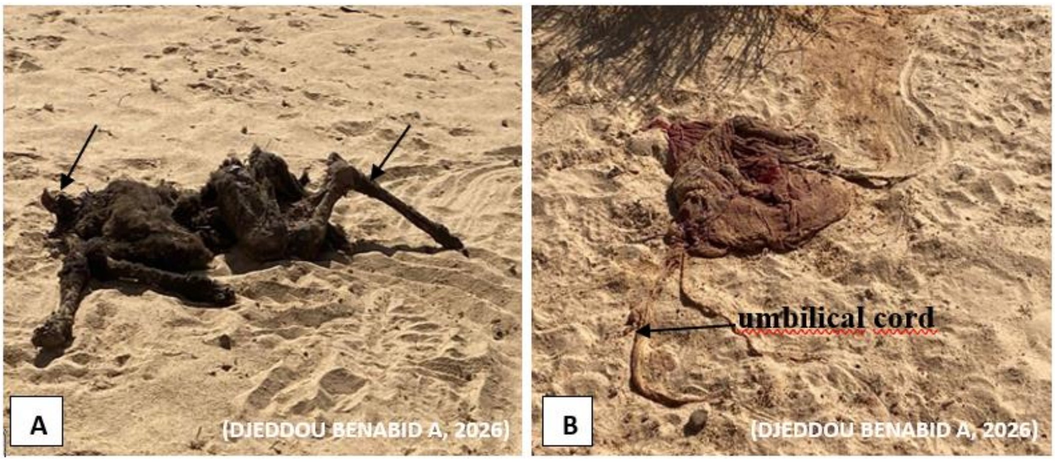


Figure 9. Case of late-term abortion (11 months) observed during our survey in the Saharan region of El Oued province. **A.** Aborted fetus in an advanced state of desiccation with absence of the head and exposed bones of the hind limbs (arrows), suggesting scavenging by wild animals. **B.** Placenta from the she-camel that aborted (Personal photograph).

  - **History of stillbirth** (yes/no), their frequency (rare, frequent, very frequent) and their number.

In addition, open-ended questions were designed to collect information regarding: symptoms observed in the aborting animal, the fate of the placenta and the fetus, possible causes of abortions according to the breeder, symptoms observed in cases of stillbirth and general observations.

I.2.4. Statistical analysis

The questionnaire survey data were recorded and coded in a Microsoft Excel spreadsheet (Microsoft Corporation) and then analyzed using the SPSS software (version 27). A descriptive analysis was performed to summarize and interpret the key characteristics of the studied variables. Qualitative variables were analyzed using multiple correspondence analysis (MCA) to establish a typology, allowing the identification of homogeneous groups of observations (farms), each distinctly differentiated from the others.

Herd-level abortion prevalence was defined as the proportion of herds reporting at least one abortion during the reproduction period and was calculated by dividing the number of positive herds by the total number of herds surveyed. Associations between this prevalence and potential risk factors were assessed using Chi-square and Fisher's exact tests. A 95 % confidence level was adopted, and $p < 0.05$ was considered statistically significant.

I.3. Results

I.3.1. Descriptive Analysis

I.3.1.1. General information on livestock farming

The descriptive analysis was conducted among 75 breeders across 13 Municipalities, covering a total of 5870 dromedaries including 4460 females (Fig. 10).

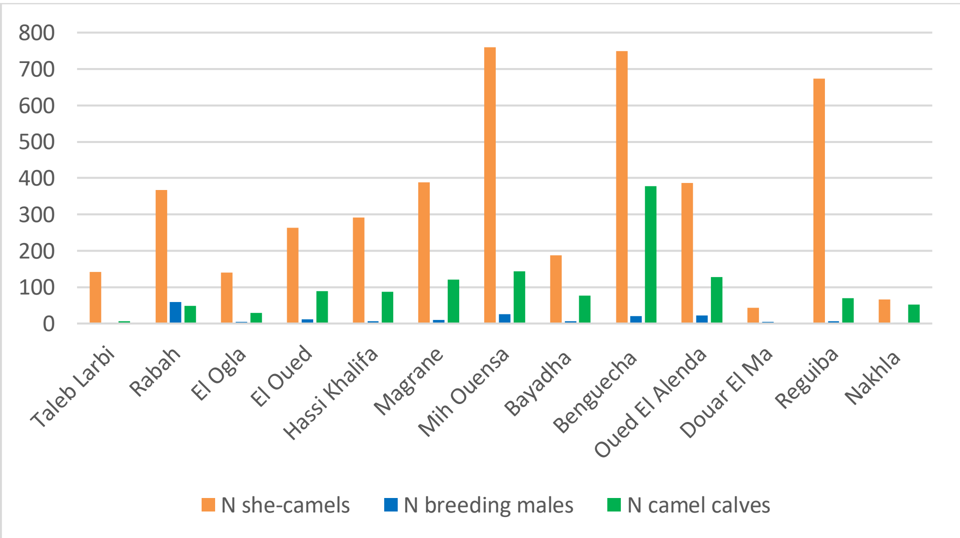


Figure 10. Camel herd size among breeders by municipality.

- **Camel breeding:** based on camel herd size, six categories were identified: [1-50[, [50-100[, [100-200[, [200-300[, [300-400[and [400-500[, with respective proportions of 44.0%, 33.3%, 16.0%, 1.3%, 4.0% and 1.3%.
- **Farming systems:** the three farming systems extensive, intensive and semi-intensive are represented by 62.7%, 9.3% and 28.0% respectively.
- **Herd renewal:** herd renewal based on purchasing accounts for 12%, self-replacement for 58.7% and a mixed renewal system for 29.3%.

I.3.1.2. Abortion Data in the Studied Farms

- **History of abortions:** among the 75 farmers surveyed, 60 (80%) reported a history of abortion. The study was conducted on a total of 5207 camels including 3936 females.
- **Frequency:** Among the 60 herds, 8.3% (5/60) experienced high abortion rates, 40% (24/60) experienced frequent abortions, and 51.7% (31/60) experienced rare abortions. Abortion frequency (%) was calculated by dividing the number of females that aborted by the total number of females in the herd. It was then classified according to the thresholds defined by (Givens and Marley, 2008) in cattle: high rate (>5 %), frequent (2–5 %), and rare (<2 %).
- **Parity:** Multiparous females consistently had a higher number of births than primiparous ones. Among primiparous animals, the number of abortions decreased in 2023 before rising significantly until 2025. Meanwhile, multiparous animals showed a slightly increasing trend in abortions throughout the period.

Overall, abortions remained more frequent among multiparous than primiparous animals. After a period of relative stability between 2022 and 2023, a progressive increase in abortion cases was observed from 2024 to 2025 (Fig. 11).

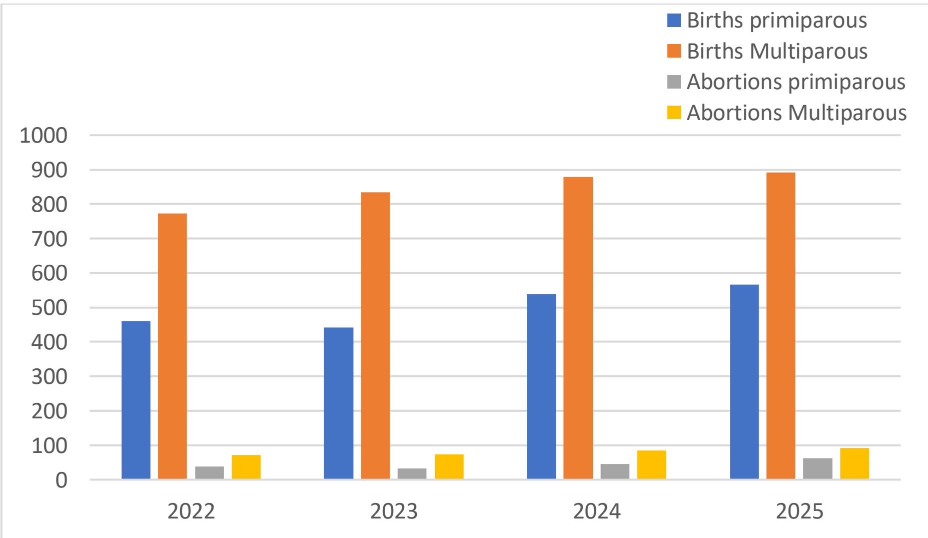


Figure 11. Evolution of births and abortions between 2022 and 2025.

The abortion rate (%) over the different periods is as follows:

- 2022: Primiparous (8.5%), Multiparous (9.3%)
- 2023: Primiparous (7.5%), Multiparous (8.9%)

- 2024: Primiparous (8.3%), Multiparous (9.6%)
- 2025: Primiparous (11.1%), Multiparous (10.3%)

A notable increase in the abortion rate is observed in 2025, particularly among primiparous animals.

The results related to reproductive events in female dromedaries, namely parturitions and abortions, are presented in Tables 1 and 2. **Table 3** details the distribution of parturitions across the studied municipalities, whereas **Table 4** illustrates the distribution of recorded abortions in the same localities. The analysis of these data highlights inter-municipality variations in both the frequency of parturitions and that of abortions.

Table 3. Distribution of parturitions in female dromedaries across the studied municipalities.

Municipality	2022		2023		2024		2025	
	P	M	P	M	P	M	P	M
Taleb Larbi	30	30	25	35	27	38	30	30
El Rabah	37	60	48	60	55	60	50	81
Mih Ouensa	80	141	56	145	93	176	94	186
El Ogla	20	35	12	34	15	24	28	25
Hassi Khalifa	44	78	57	84	55	83	58	91
El Oued	40	35	25	35	30	55	25	27
Magrane	34	40	24	58	27	55	56	55
Bayadha	15	35	22	37	20	33	18	36
Oued El Alenda	32	62	24	71	29	76	32	64
Reguiba	41	100	38	111	33	100	33	94
Benguecha	74	126	95	129	128	142	121	161
Douar El Ma	10	16	8	21	15	19	11	18
Nakhla	4	14	8	14	12	17	11	23
Total	**461**	**772**	**442**	**834**	**539**	**878**	**567**	**891**

P: Primiparous **M:** Multiparous

Table 4. Distribution of abortions in female dromedaries across the surveyed municipalities.

Municipality	2022		2023		2024		2025	
	P	M	P	M	P	M	P	M
Taleb Larbi	2	5	1	5	2	6	2	6
El Rabah	6	10	2	8	5	9	6	7
Mih Ouensa	14	19	7	5	9	25	10	12
El Ogla	4	5	3	8	5	0	6	9
Hassi Khalifa	2	2	3	5	2	4	5	5
El Oued	0	4	0	0	0	2	0	1
Magrane	0	0	4	5	2	5	6	5
Bayadha	1	0	0	3	1	3	2	2
Oued El Alenda	2	9	1	8	1	13	8	10
Reguiba	3	7	3	18	2	2	3	13
Benguecha	5	6	8	9	15	13	14	20
Douar El Ma	0	1	1	0	1	0	1	1
Nakhla	0	4	0	0	0	2	0	1
Total	**39**	**72**	**33**	**74**	**45**	**84**	**63**	**92**

P: Primiparous **M:** Multiparous

- **Abortion month:** Table 5 summarizes the monthly distribution of abortions in female dromedaries. The data reveal that abortion cases were not uniformly distributed throughout the year but tended to cluster in specific months. In particular, the period from August to November (August, September, October and November) revealed a markedly higher occurrence of abortions.

Table 5. Distribution of abortions in female dromedaries according to the month of occurrence.

Month	Frequency	Percentage (%)
January	4	6,7
February	2	3,3
March	3	5,0
April	3	5,0
May	4	6,7
June	3	5,0
July	10	16,7
August	15	25,0
September	32	53,3
October	29	48,3
November	17	28,3
December	5	8,3

- **Distribution of abortions according to gestational stage:** as shown in Table 6, abortions were rare in early pregnancy but predominantly occurred during the advanced stages (third and fourth trimesters)

Table 6. Occurrence of abortions according to gestational stage in female dromedaries.

Trimester	Frequency	Percentage (%)
1st trimester	2	3.3
2nd trimester	4	6.7
3rd trimester	39	65.0
4th trimester	15	25.0

- **Clinical manifestations associated with abortion cases:** the analysis of data collected from farmers indicated that female dromedaries experiencing abortion exhibited a variety of clinical signs (Table 7). However, it is noteworthy that a considerable proportion of animals showed no specific clinical symptoms associated with abortion.

Table 7. Clinical manifestations associated with abortion in female dromedaries.

Clinical sign	Frequency	Percentage (%)
None	26	43.3
Depression (lethargy)	9	15.0
Nervous signs	2	3.3
Stress	3	5.0
Fever	7	11.7
Anorexia	6	10.0
Agitation	2	3.3
Pulmonary inflammation	1	1.7
Weight loss	4	6.7
Weakness	2	3.3

- **Appearance of aborted fetuses:** the analysis (Table 8) revealed that most abortion cases involved fetuses with a normal appearance. Mummified and hemorrhagic fetuses were observed less frequently, whereas fetal malformations represented a rare occurrence.

Table 8. Morphological characteristics of aborted fetuses in female dromedaries.

Category	Frequency	Percentage (%)
Normal fetus	43	71.6
Mummified fetus	9	15.0
Hemorrhagic fetus	7	11.7
Malformed fetus	1	1.7

- **Placental expulsion status in aborted females:** the analysis revealed that, in most cases (93.3%), placental expulsion occurred normally and was complete while incomplete expulsion was only occasionally reported.
- **Placental appearance and pathological changes:** the evaluation of placental appearance revealed that most cases exhibited a normal aspect, while pathological changes such as hemorrhage or necrosis were also reported but with lower frequency (Table 9).

Table 9. Macroscopic characteristics of the placenta in female dromedaries.

Placental appearance	Frequency	Percentage (%)
Normal placenta	36	60.0
Hemorrhagic placenta	13	21.7
Necrotic placenta	11	18.3

- **Management of aborted material and post-abortion practices:** the analysis of farmers' responses revealed that in the vast majority of cases, the placenta and the aborted fetus were disposed of by burial (88.3%). In contrast, a smaller proportion of breeders reported abandoning them in the desert environment (10%), while a very limited minority resorted to incineration (1.7%). Regarding post-abortion measures, most breeders (75%) reported taking no particular action, whereas a quarter (25%) sought veterinary intervention.

These findings highlight the predominance of burial as the main disposal method of aborted material, a practice generally favorable to limiting the dissemination of infectious agents. However, the persistence of inappropriate behaviors, such as abandoning aborted material in the desert, combined with the limited recourse to veterinary services after abortion, reflects a lack of awareness regarding biosecurity and herd health management.

- **Farmer-reported factors associated with abortions:** farmers' responses revealed a diversity of factors potentially involved in abortions, including environmental conditions (drought, excessive heat), nutrition and hygiene, as well as pathological causes (diseases, fever, poisoning). This distribution suggests that abortions in dromedaries may result from a combination of climatic, nutritional and health-related factors (Table 10).

Table 10. Suspected causes of abortion reported by camel herders.

Suspected causes	Frequency	Percentage (%)
Drought	33	55.0
Excessive heat	8	13.3
Consumption of wastewater	14	23.3
Insect infestation	17	28.3
Malnutrition	10	16.7
Fever	4	6.7
Diseases	14	23.3
Poor maintenance	2	3.3
Anorexia	1	1.7
Poisoning (toxic plants)	1	1.7

- **Other animal species present on camel farms:** in the sixty camel farms reporting a history of abortion, the presence of other animal species was notable. Small ruminants, particularly sheep and goats, were frequently kept alongside camels, while companion animals, such as dogs and cats were also commonly present. The potential contact with stray dogs and cats suggests an additional route for interspecies transmission of pathogens, which may contribute to reproductive disorders in camels (Table 11).

Table 11. Coexisting animal species in camel farms.

Species	Yes (N)	No (N)
Cattle	3	57
Sheep	35	25
Goats	36	24
Dogs	43	17
Cats	48	12

I.3.1.3. Stillbirth Data in the Studied Farms

- **History of stillbirths in dromedary herds:** among the 60 farmers reporting abortion cases, the majority also documented stillbirth events over the period 2022–2025. Thirty-six farmers (60 %) reported approximately 169 stillbirths and three farmers (5 %) observed mortality occurring between the 2nd and 6th day after parturition. In contrast, 21 farmers (35 %) did not report any cases.
  Some farmers reported that pregnant she-camels reaching full term without apparent signs of parturition or exhibiting absent fetal vitality (fetal death) are directly sent to the slaughterhouse. In the vast majority of farms, no veterinary intervention is performed, even when obstetrical assistance, such as a cesarean section, could be considered. This practice highlights a lack of veterinary supervision and management of complicated parturitions, potentially contributing to the prevalence of stillbirths in the herds.

- **Clinical manifestations associated with stillbirth cases:** Most stillbirth cases occurred without apparent clinical signs. Observed manifestations were sporadic and infrequent, indicating that early detection is challenging and highlighting the importance of regular veterinary monitoring to improve reproductive health in dromedary herds (Table 12).

Table 12. Clinical manifestations associated with stillbirth in female dromedaries.

Clinical manifestations	Frequency (N)	Percentage (%)
None	27	75.0
Swelling of the fetus	2	5.5
Stress during the last 3 days before parturition	1	2.8
Fever	3	8.3
Anemia/cachexia	2	5.5
Lethargy	1	2.8

I.3.2. Multiple Correspondence Analysis (MCA)

This dataset comprises 60 camel farms and 12 categorical variables related to camel husbandry. It includes information on farm type, herd replacement strategy, municipalities, as well as the frequency and circumstances of abortions (season, gestational stage). Additionally, it records the presence of other animal species (dogs, cats, cattle, sheep, and goats) and describes the appearance of aborted fetuses and placentas, enabling the identification of potential associations that may influence the reproductive health of female dromedaries.

I.3.2.1. Variable Analysis

The inertia of the factorial axes provides insights into both the underlying structure of the variables and the determination of the optimal number of principal components for analysis. In the present study, the first two axes accounted for 54.3% of the total inertia, indicating that they capture over half of the overall variability in the dataset. This substantial proportion demonstrates that the first factorial plane effectively represents the main patterns of variation among the individuals or variables under consideration.

The internal consistency of the variables was assessed using Cronbach's alpha, yielding a value of 0.776, which reflects a satisfactory level of reliability. This result indicates that the variables consistently measure coherent and homogeneous aspects of the underlying construct (Table 13).

The analysis, based on a total of 5207 camels including 3936 females from 60 farms showed that Axis 1 and Axis 2 explained 30.2% and 24.1% of the total inertia respectively, summing to 54.3% (Fig. 12). These findings underscore the adequacy of the first factorial plane in capturing the primary dimensions of variability in the dataset.

Table 13. Internal Consistency (Cronbach's Alpha) and Variance Explained by the Extracted Dimensions.

Dimension	Cronbach's Alpha	Explained Variance		
		Total (Eigenvalue)	Inertia	% of Variance
1	0.807	3.924	0.302	30.186
2	0.738	3.137	0.241	24.127
Total		7.061	**0.543**	
Average	**0.776**	3.530	0.272	27.157

- **Axis 1** (30.2%) was primarily defined by variables including the municipality, presence of small ruminants, type of husbandry system, season, and morphological characteristics of the aborted fetus.

- **Axis 2** (24.1%) was mainly characterized by the presence of cattle, dogs, and cats, herd replacement strategy, abortion frequency, gestational stage at abortion, and placental appearance.

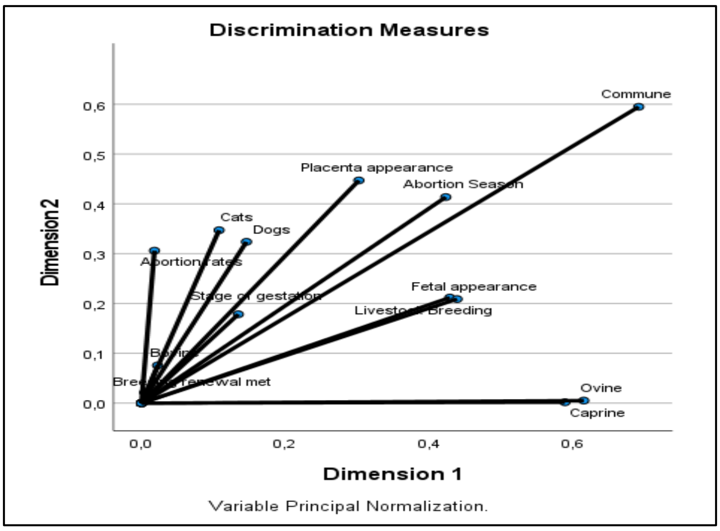


Figure 12. Graphical representation of variables using MCA.

I.3.2.2. Analysis of Individuals

Multiple correspondence analysis (MCA) combined with hierarchical ascending classification (HAC) identified three distinct clusters (Figs. 13-14), reflecting the main patterns of similarity and variation among the studied farms with respect to reproductive and management variables.

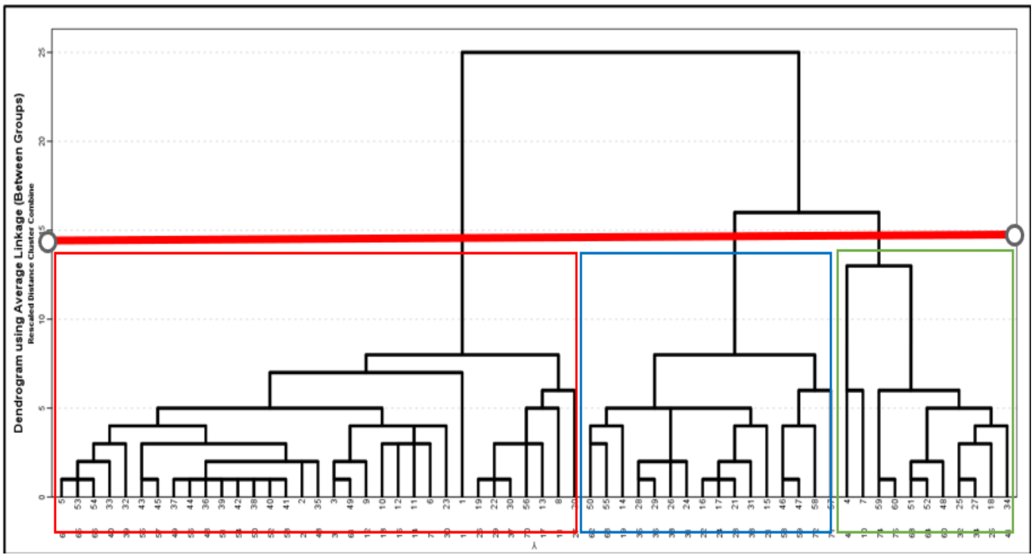


Figure 13. Hierarchical clustering of farms based on MCA analysis.

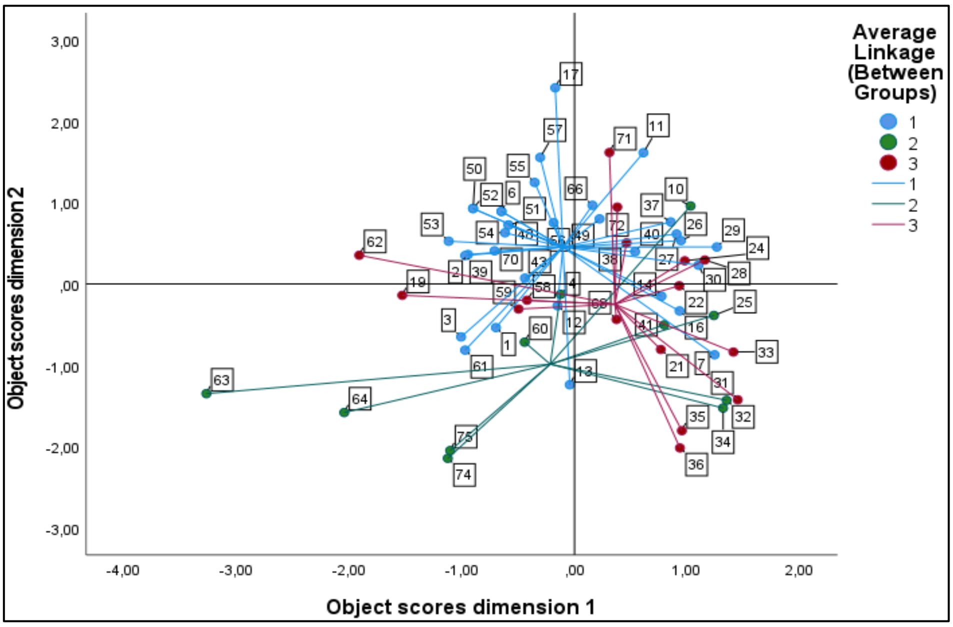


Figure 14. Presentation of farms using MCA analysis.

Table 14 presents a synthesis of the descriptive values of the ordinal qualitative variables examined across the three classes derived from the Multiple Correspondence Analysis (MCA).

Table 14. Distribution of camel herds according to the three classes identified by MCA-HAC.

		Classe 1 (33)	Classe 2 (11)	Classe 3 (16)
Municipality	**Taleb Larbi**	1 (3%)	0	0
	El Rabah	3 (9,1%)	0	0
	Mih Ouensa	15 (45,5%)	0	0
	El Ogla	2 (6,1%)	1 (9,1%)	0
	Hassi Khalifa	6 (18,2%)	0	0
	El Oued	1 (3%)	0	0
	Magrane	4 (12,1)	1 (9,1%)	0
	Bayadha	1 (3%)	0	0
	Oued El Alenda	0	3 (27,3%)	1 (6,3%)
	Reguiba	0	3 (27,3%)	2 (12,5%)
	Benguecha	0	3 (27,3%)	9 (56,3%)
	Douar El Ma	0	0	2 (12,5%)
	Nakhla	0	0	2 (12,5%)
Bovine	**Yes**	2 (6,1%)	1 (9,1%)	0
	No	31 (93,9%)	10 (90,9%)	16 (100%)
Ovine	**Yes**	16 (48,5%)	6 (54,5%)	14 (87,5%)
	No	17 (51,5%)	5 (45,5%)	2 (12,5%)
Caprine	**Yes**	17 (51,5%)	6 (54,5%)	13 (81,3%)
	No	16 (48,5%)	5 (45,5%)	3 (18,8%)
Dogs	**Yes**	26 (78,8%)	7 (63,6%)	10 (62,5%)
	No	7 (21,2%)	4 (36,4%)	6 (37,5%)
Cats	**Yes**	29 (87,9%)	6 (54,5%)	13 (81,3%)
	No	4 (12,1%)	5 (45,5%)	3 (18,8%)
Livestock Breeding	**Extensif**	24 (72,7%)	4 (36,4%)	9 (56,3%)
	Intensif	0	2 (18,2%)	1 (6,3%)
	Semi-intensif	9 (27,3%)	5 (45,5%)	6 (37,5)
Breeding renewal method	**Purchases**	1(3%)	1 (9,1%)	0
	Self-replacement	25 (75,8%)	5 (45,5%)	8 (50%)
	Mixed	7 (21,2%)	5 (45,5%)	8 (50%)
Abortion rates	**Very frequent**	3 (9,1%)	1 (9,1%)	1 (6,3%)
	Frequent	10 (30,3%)	8 (72,7%)	6 (37,5%)
	Rare	20 (60,6%)	2 (18,2%)	9 (56,3%)
Abortion Season	**Summer only**	6 (18,2%)	0	1 (6,3%)
	Autumn only	23 (69,7%)	0	9 (56,3%)
	Spring only	3 (9,1%)	0	1 (6,3%)
	Winter only	1 (3%)	0	3 (18,8%)
	Winter to spring	0	0	1 (6,3%)
	Autumn to winter	0	2 (18,2%)	1 (6,3%)
	Spring to summer	0	1 (9,1%)	0
	Summer to autumn	0	7 (63,6%)	0

	Spring, summer and autumn	0	1 (9,1%)	0
Stage of gestation	**1st trimester**	1 (3%)	0	2 (6,3%)
	2nd trimester	3 (9,1%)	1(9,1%)	0
	3rd trimester	21 (63,6%)	9 (81,8%)	9 (56,3%)
	4th trimester	8 (24,2%)	1(9,1%)	6 (37,5%)
Fetal appearance	**Normal**	27 (81,8%)	8 (72,7%)	8 (50%)
	Mummified	3 (9,1%)	2 (18,2%)	4 (25%)
	Hemorrhagic	2 (6,1%)	1 (9,1%)	4 (25%)
	Malformed	1 (3%)	0	0
Placenta appearance	**Normal**	22 (66,7%)	5 (45,5%)	9 (56,3%)
	Hemorrhagic	8 (24,2%)	2 (18,2%)	3 (18,8%)
	Necrotic	3 (9,1%)	4 (36,4%)	4 (25%)

The first cluster, comprising 33 herds distributed across eight communes (Taleb Larbi, El Rabah, El Ogla, Hassi Khalifa, Magrane, El Oued, Bayadha and Mih Ouensa with the latter accounting for the highest proportion, 45.5%), was characterized by a marginal presence of cattle (6.1%), whereas sheep and goats were predominant (48.5% and 51.5%, respectively). Dogs (78.8%) and cats (87.9%) were widely reported. Most herds followed an extensive system (72.7%), relying predominantly on self-replacement (75.8%). Abortions were mostly rare (60.6%), although 30.3% of herds reported frequent and 9.1% very frequent cases. These events occurred primarily in autumn (69.7%) and during the third trimester (63.6%). Abnormal fetal appearance (mummification, hemorrhage, malformation) was noted in 18.2% of cases while placental lesions (hemorrhagic or necrotic) were reported in 33.3% of herds.

The second cluster grouped 11 herds across five communes (El Ogla, Magrane, Oued El Alenda, Reguiba and Benguecha—the last three representing 27.3% each). Cattle were scarcely present (9.1%), while sheep and goats predominated (54.5% each). Dogs (63.6%) were slightly more frequent than cats (54.5%). Nearly half of the farms followed a semi-intensive system (45.5%) with a mixed herd renewal strategy (45.5%). Abortions were frequently reported in 72.7% of herds, mainly in summer–autumn (63.6%) and during the third trimester (81.8%). Abnormal fetuses were observed in 27.3% of cases and placental pathology in 54.6% of herds.

The third cluster, including 16 herds distributed over five communes (Oued El Alenda, Reguiba, Douar El Ma, Nakhla, and Benguecha—the latter accounting for 56.3%), was marked by the absence of cattle, with very high frequencies of sheep (87.5%) and goats (81.3%). Cats (81.3%) were more common than dogs (62.5%). Most herds adopted an extensive system (56.3%) with a mixed herd renewal strategy (50%). Abortions were mostly rare (56.3%), concentrated in autumn (56.3%) and during the third trimester (56.3%). Abnormal fetal appearance was observed in 50% of cases while pathological placental lesions were reported in 43.8% of herds.

I.3.2.3. Correlation analysis and risk factors: Chi-square test

Table 15 summarizes the analysis of potential risk factors associated with the prevalence of abortions in female dromedaries. Among the investigated variables, two factors demonstrated statistically significant associations with abortion occurrence: the presence of cats and the presence of dogs ($p < 0.05$).

In contrast, no significant associations were observed with other factors, including cohabitation with cattle or small ruminants (sheep and goats), geographical location and herd management practices.

Table 15. Analysis of potential risk factors associated with abortion in female dromedaries.

Variables	Categories	N. of SH	N. of HA	(χ^2)	*P*- value
Locality	Taleb Larbi	1	1	16,485	0.170
	El Rabah	6	3		
	Mih Ouensa	20	16		
	El Ogla	3	3		
	Hassi Khalifa	7	6		
	El Oued	3	1		
	Magrane	5	5		
	Bayadha	2	1		
	Oued El Alenda	6	4		
	Reguiba	5	5		
	Benguecha	13	11		
	Douar El Ma	2	2		
	Nakhla	2	2		
The presence of cattle	No	68	57	0.425	0.514
	Yes	7	3		
The presence of sheep	No	35	25	0.044	0.833
	Yes	40	35		
The presence of goats	No	31	24	0.044	0.833
	Yes	44	36		
The presence of dogs	No	26	17	7.520	**0.006***
	yes	49	43		
The presence of cats	No	23	12	4.271	**0.039***
	Yes	52	48		
Husbandry system	Extensive	45	35	2.394	0.302
	Intensive	7	3		
	Semi-intensive	23	22		

N: Number **(χ^2):** Pearson Chi-Square *: significant
SH: Surveyed herds **HA:** herds reporting abortions

I.4. Discussion

I.4.1 General information on livestock farming

The camel herd population in the study area showed significant variation and a notable difference in the number of animals. The vast majority of the herds studied (77.3%) contained between 1 and 100 animals and the average herd size was 78.2 animals. Female camels account for approximately 76% of the total herd size, while calves make up around 21% and adult males only 3%. This predominance of females and young camels in herd composition aligns with the findings of Megersa et al. (2008) and Al-Dahash and Sassi (2009). Regarding the three production systems identified: extensive (62.7%), semi-intensive (28%) and intensive (9.3%), these results fall within the range reported by Adamou (2008) and Mayouf et al. (2014). Herd renewal, which is primarily based on self-replacement for the majority of herders, largely explains why the growth and stability of herds are attributed to the higher proportion of females in the studied areas.

I.4.2. Abortion data from the studied farms

Generally, the gestation period in camels ranges from 370 to 390 days, with an average of 380 days. The interval between two calvings averages 24 months but can extend up to 36 months, particularly in cases of abortion (Faye et al., 2022). This low reproductive frequency is attributed to several biological and environmental factors, including marked seasonality in sexual activity, the relatively late age at first mating (around 4 years) and the long gestation period. Consequently, a female typically produces only one calf every two years or more (Monaco et al., 2015). Among camel herders, (80%) reported a history of abortion in their herds, while (20%) reported no previous cases. The majority of respondents (75%) do not seek veterinary assistance in case of abortion and about 10% do not dispose of the placenta and the aborted fetus. These findings are consistent with those reported by Khalafalla et al. (2017).

In our study, births were more frequent in multiparous than in primiparous females, which is expected given their reproductive experience. Moreover, abortions remained more common in multiparous than in primiparous females. This trend can be explained by several factors including age and parity, which can lead to a decrease in immune defenses and an increased risk of chronic infections. The number of abortions has been continuously increasing between 2024 and 2025 suggesting the influence of stress factors or pathologies affecting reproduction. Between 2022 and 2025, the abortion rate fluctuated between 8.5% and 11.1% in primiparous females and between 9.3% and 10.3% in multiparous ones. These values are higher than those reported by Al-Dahash and Sassi (2009) (5%) and Nagy et al. (2023) (5.1%). However, they are lower than the abortion rate observed by Gilles et al. (2006), which was 17.9%. According to the limited number of studies, abortion rates in female dromedaries range from 2% to 25% (Nagy et al., 2023).

According to the farmers' reports, abortion cases were mainly observed between late summer and late autumn (from August to November) with a marked peak in September and October. This peak does not coincide with the calving season. These findings are similar to those reported by Nagy et al. (2023), who noted a clear seasonal variation, with the highest incidence recorded in August. In contrast, they differ from the results of Gilles et al. (2006), where abortion peaks were observed in June and from January to March. The frequency of retained placenta was estimated at 6.6%. This value is close to the findings reported by Al-Dahash et Sassi (2009) who estimated it at approximately 8%.

I.4.2.1. State of gestation

In our survey, the majority of farmers reported abortions occurring in the third stage of gestation (65%), followed by those observed in the final third (25%), accounting for (90%) of abortions occurring between the middle and end of gestation. These results are in perfect agreement with those of Nagy et al. (2023), who reported that one-third of total pregnancy losses in dromedaries occurred during the mid to late stages of gestation.
In the absence of prior studies that have clearly identified the gestational stage at which abortions associated with *T. gondii* and/or *N. caninum* occur in female dromedaries, this issue remains poorly documented to date.

However, several studies have been conducted in other animal species, notably in small ruminants (*T. gondii*) and in cattle (*N. caninum*), providing useful points of comparison. In fact, previous research have reported *T. gondii*-related abortions in goats occurring between 10 and 13 weeks (Pereira et al., 2021), as well as between 16 and 20 weeks of gestation (Caldeira et al., 2011). In sheep, *T. gondii* infection typically results in early abortions accompanied by leukoencephalomalacia lesions. Furthermore, an experimental study demonstrated that ewes infected with *T. gondii* oocysts during the 12th week of gestation aborted at the 14th week (Gutiérrez-Expósito et al., 2020). Typically, abortions in both natural and experimental ovine toxoplasmosis occur about one month after infection (Castaño et al., 2014) .These findings suggest that *T. gondii* induced abortions in small ruminants can occur at various stages of gestation, with a predominance between the second and final third.

In cattle, *N. caninum*-associated abortion typically occurs between the third month of gestation and term, but most commonly in mid-gestation (5 to 6 months). However, up to 95% of congenitally infected calves born to seropositive dams may appear clinically normal. In rare cases, neurological disorders may occur, ranging from mild ataxia to tetraplegia and can be associated with increased mortality, hydrocephalus, exophthalmia and growth retardation (Toolan, 2003).

I.4.2.2. The appearance of aborted fetuses and placenta

The clinical signs of toxoplasmosis in both humans and animals are generally non-specific and do not allow for a definitive diagnosis. In animals, the most severe manifestations are observed in pregnant ewes and goats, and include abortions, stillbirths, or mummified fetuses. Characteristic lesions, particularly focal white areas of necrosis, are frequently found in the placental cotyledons (Dubey, 2010; Henker et al., 2022). Buxton et al. (1982) reported that in the case of ovine toxoplasmosis, placental lesions are considered the primary cause of fetal hypoxia which can lead to fetal death. The infection can also cause significant perinatal changes in lambs.

Similarly, in the case of neosporosis in cattle, following an experimental infection with *N. caninum* in pregnant cows at different stages of gestation (70 and 210 days), Gibney et al. (2008) observed generalized fetal tissue necrosis associated with the parasite. Additionally, extensive areas of the placenta were damaged, with evidence of the parasite's presence in these necrotic regions, which could lead to placental insufficiency and consequently fetal mortality. Other experimental studies have also proven a link between neosporosis and focal necrosis and placentitis (Maley et al., 2003; Macaldowie et al., 2004). An earlier study highlighted the close relationship between this disease and these specific lesions in cows naturally infected (Barr et al., 1991). Also, *N. caninum* has been recognized as an abortive agent in small ruminants and equines (Mohammed et al., 2023).

this pathological phenomenon can be explained by the pro-inflammatory maternal immune response activated in the placenta to limit the multiplication and spread of the parasite, which can lead to severe necrotic changes in both placental and fetal tissues, thus constituting a direct cause of fetal death and abortion (Williams et al., 2000). The involvement of these parasites in abortions was demonstrated by Basso et al. (Basso et al., 2022), who revealed a high prevalence of *T. gondii* infections and a lower prevalence of *N. caninum* infections in small ruminants in Switzerland.

Studies investigating the involvement of one or both parasites in abortion cases in dromedaries are extremely rare. However, an isolated case was reported in Greece, involving a Bactrian camel that aborted a mummified fetus. The animal exhibited several clinical signs, including severe dehydration, depression, anorexia, mild dyspnea and diarrhea. Laboratory analyses performed on the aborted fetus and its membranes confirmed *T. gondii* infection (Komnenou et al., 2022). Similar symptoms, such as depression, anorexia and signs of respiratory inflammation, were also reported by some farmers during our survey.

Obvious macroscopic lesions justify the use of histological and immunohistochemical examinations on biopsy or autopsy samples, particularly from lymph nodes, aborted fetal tissues and the placenta for the diagnosis of toxoplasmosis. Additionally, immunohistochemistry aids in detecting antigens in tissues labeled with conjugated antibodies (Ferguson et al., 2013). The same approach, combined with fetal histopathology, is commonly used to diagnose *Neospora* induced abortions (Wouda et al., 1997). These techniques allow for the detection of characteristic necrotic lesions, the identification of infected tissues and sometimes the infectious stages of both parasites.

I.4.2.3. Potential causes of abortions

The most frequently mentioned causes of abortion by farmers, in descending order were drought (55%), the presence of insects (28.3%), diseases (23.3%), wastewater (23.3%), and food shortage (16.7%). Significant variations in these factors were observed across different communes. Indeed, the prolonged drought observed in the study area has led to significant food shortages, notably a marked decline in forage vegetation. This situation has harmful effects on the animals, resulting in weight loss and weakened immunity (Adamou, 2008), which may compromise the reproductive performance of she-camels and lead to abortions and stillbirths. Other non-infectious factors were also reported by Nagy et al. (2023), including fetal and placental abnormalities (such as twinning, umbilical cord torsion, placental insufficiency and genetic defects), endocrine disorders, and various environmental factors, such as nutritional deficiencies, toxicosis, trauma and maternal diseases.

Infectious agents play a major role in the occurrence of abortions, with incidence rates showing significant regional disparities, ranging from 10% to over 70% depending on the geographic area. Brucellosis and trypanosomiasis (mainly transmitted through insect bites) are the main causes of infectious abortion in camels, particularly in the Middle East and Africa. In contrast, in llamas and alpacas, abortions are mainly attributed to leptospirosis, toxoplasmosis and chlamydiosis (Tibary et al., 2006). The distribution of both infectious and non-infectious causes of abortion varies across countries and breeding seasons. Nevertheless, a considerable proportion of cases (8% to 35%) remain of unknown etiology (Nagy et al., 2021).

I.4.3. Stillbirth data from the studied farms

In our survey, 33 breeders reported cases of stillbirths, while 3 others mentioned mortalities occurring between 2 and 6 days after parturition, with a total of approximately 169 cases. These results are comparable to those reported by Nagy et al. (2023), who observed the birth of well-developed but stillborn calves at term, as well as the death of newborns within 48 hours postpartum with a total of 148 cases. Tibary et al. (2005) reported that camel herds face high neonatal mortality, which can reach epizootic proportions. Additionally, approximately 5% of newborn calves die within the first two weeks after birth (Al-Dahash et Sassi, 2009).

I.4.4. MCA analysis and risk factors

The analysis of the three classes resulting from the multiple correspondence analysis (MCA) reveals that the third class, comprising 16 herds, is characterized by a high frequency of pathological fetal (50%) and placental (43.8%) lesions. It is also associated with a high presence of cats (81.3%) and a notable proportion of dogs (62.5%). In contrast, the first class, which includes 33 herds, shows the lowest frequencies of pathological fetal (18.2%) and placental (33.3%) lesions, despite a very high presence of cats (87.9%) and dogs (78.8%). The second class, consisting of 11 herds, is distinguished by a high frequency of placental lesions (54.6%) and to a lesser extent fetal lesions (27.3%). This class is also characterized by a comparatively lower presence of cats (54.5%) and dogs (63.6%) than in the other two classes.

The analysis of correlations between the various variables and the frequency of abortions in female dromedaries revealed statistically significant associations, particularly with the presence of cats and dogs. These factors, considered as potential risk factors, suggest a possible involvement of *T. gondii* and *N. caninum* infections in abortion cases. Indeed, these animals, considered the definitive hosts of *T. gondii* and *N. caninum* respectively, play a key role in the epidemiological cycle of these protozoa by shedding millions of oocysts capable of infecting a wide range of intermediate hosts. These findings are consistent with previous studies by Gebremedhin et al. (2014) and Gebremedhin et al. (2016), who reported a significantly higher prevalence of *T. gondii* infection in dromedaries living in areas where domestic cats are present. Furthermore, the role of dogs as reservoirs of *N. caninum* is supported by the findings of Selim and Abdelhady (2020), who observed a significant increase in seropositivity among females with a history of abortion and raised in the presence of dogs.

Following our investigations, pathological fetal lesions (such as mummified, hemorrhagic, or malformed fetuses) were observed in (28.4%) of abortion cases. Similarly, alterations in placental tissue particularly hemorrhagic or necrotic placentas were recorded in (40%) of cases. Considering the characteristic nature of these lesions, the predominant timing of abortion occurrences (from mid to late gestation) and the identification of the presence of cats and dogs as major risk factors, a possible involvement of *T. gondii* and/or *N. caninum* in these cases is strongly suspected.

The analysis of correlations between herd-level abortion prevalence and various variables revealed statistically significant associations, particularly with the presence of cats and dogs, suggesting that these domestic carnivores may play a key role in the transmission of infectious agents such as *T. gondii, N. caninum*, which can affect dromedary reproduction.

I.5. Conclusion

This study highlights a high frequency of abortions in dromedary camel herds, accompanied by a notable proportion of stillbirths. Most factors related to herd characteristics and management practices showed no significant association with abortion occurrence within the framework of this survey. These findings should be interpreted with caution due to the observational and declarative nature of the data. In this context, further investigations integrating epidemiological, clinical, pathological, and laboratory diagnostic approaches are required to better understand the underlying mechanisms of abortion in dromedaries and to guide appropriate preventive strategies.

EXPERIMENT II

Seroprevalence and Risk Factors of Toxoplasmosis and Neosporosis in Camels (*Camelus dromedarius*) in El Oued province

II. 1. Introduction

The dromedary camel *(Camelus dromedarius)* accounts for approximately 95% of the Old-World camel population and is distributed across 47 countries, primarily in Asia and Africa (FAO, 2022). In Algeria, these animals represent a crucial source of milk and meat and contribute significantly to both local and national economies (Djeddou-Benabid et al., 2025).

Abortions constitute a major issue in veterinary medicine and are among the leading causes of reproductive failure. In dromedaries, abortion rates range from 2% to 25%. Furthermore, camel herds exhibit high neonatal mortality, which may sometimes reach epizootic proportions (Tibary et al., 2006), underscoring their considerable health and economic impact. Reproductive losses, such as pregnancy loss and neonatal mortality, are often associated with various infections (Houssou et al., 2025). The dromedary camel plays a critical role in the transmission of diseases to other livestock and its involvement in zoonotic diseases (Sazmand et al., 2019). Parasitic agents responsible for abortive diseases, such as *Toxoplasma* and *Neospora* pose a major risk to both animal and public health (Shaapan, 2016).

Toxoplasma gondii and *Neospora caninum* (Apicomplexa, Sarcocystidae) are obligate intracellular protozoan parasites that can affect a wide variety of domestic and wild animals around the world (Dubey, 2003; Dubey, 2010). Both parasites have heteroxenous life cycles in their definitive hosts (i.e., *T. gondii* in domestic and wild felids, *N. caninum* in dogs, wolves, coyotes, and dingoes) (Dubey and Lindsay, 2006). Natural infections with *T. gondii* and/or *N. caninum* in livestock mainly occur through the ingestion of oocysts contaminating feed or water, as well as via transplacental transmission during gestation (Fereig et al., 2022).

They cause significant economic losses in livestock production by inducing various reproductive disorders, including embryonic resorption, fetal mummification, abortion, stillbirth, and neonatal mortality (Dubey, 2003; Dubey, 2010). Infections with with both parasites have been reported in numerous domestic and wild animal species, exhibiting highly variable clinical manifestations (Basso et al., 2020). In intermediate hosts of *T. gondii*, infections are most often asymptomatic, but they can occasionally cause severe or even fatal disease in some hosts, including humans. The most frequent clinical manifestations include abortion and neurological disorders. (Dubey, 2010). In dromedaries, most infections remain subclinical; when clinical signs do appear, they are generally non-specific and may present as respiratory disorders, fever, anorexia, and episodes of diarrhea (Hanon, 2018). In intermediate hosts of *N. caninum*, infections are frequently subclinical; however, they can result in abortion or the birth of congenitally infected offspring, particularly in cattle (McAllister, 2016). Due to their importance for animal health, numerous studies have been conducted to assess the presence of antibodies against *T. gondii* and *N. caninum* in camelids across multiple continents (Fereig et al., 2022).

In Algeria, current knowledge on the seroprevalence of *T. gondii* in dromedary camels remains limited, relying on a small number of recent studies. In contrast, no data are currently available regarding *N. caninum* infection in this species, leaving its epidemiological status largely unexplored. To our knowledge, the present study is the first to simultaneously assess the seroprevalence of *T. gondii* and *N. caninum* in dromedary camels in Southeastern Algeria (El Oued province), while also analyzing potential risk factors associated with seropositivity.

II. 2. Materials and methods

II. 2.1. Study area

El Oued is one of the 69 provinces of Algeria, located in the South-east of the country (33°21′21″ N, 6°51′47″ E). The province covers an area of 44,586.8 km², representing approximately 1.87 % of the national territory (Fig. 1). It comprises three main types of areas: urban (71.1%), peri-urban (18.2%), and rural (10.7%), with an average population density of 19 inhabitants per km², although this density is highly heterogeneous across the province. The climate of the study area is hyper-arid, characterized by very hot, dry summers and mild winters (Köppen-Geiger classification: BWh). Relative humidity is influenced by precipitation, wind, and temperature, with average monthly values around 30% in summer (July–August) and reaching up to 65% in winter (December–January). Temperatures can reach 45°C in summer and drop to freezing in winter, with an annual mean temperature of approximately 26°C. Precipitation is low, irregular, and highly variable, with annual averages generally not exceeding 70 mm and rarely reaching 100 mm, while evaporation is very high, exceeding 2200 mm per year. The main economic activities in the province are livestock farming and irrigated agriculture.

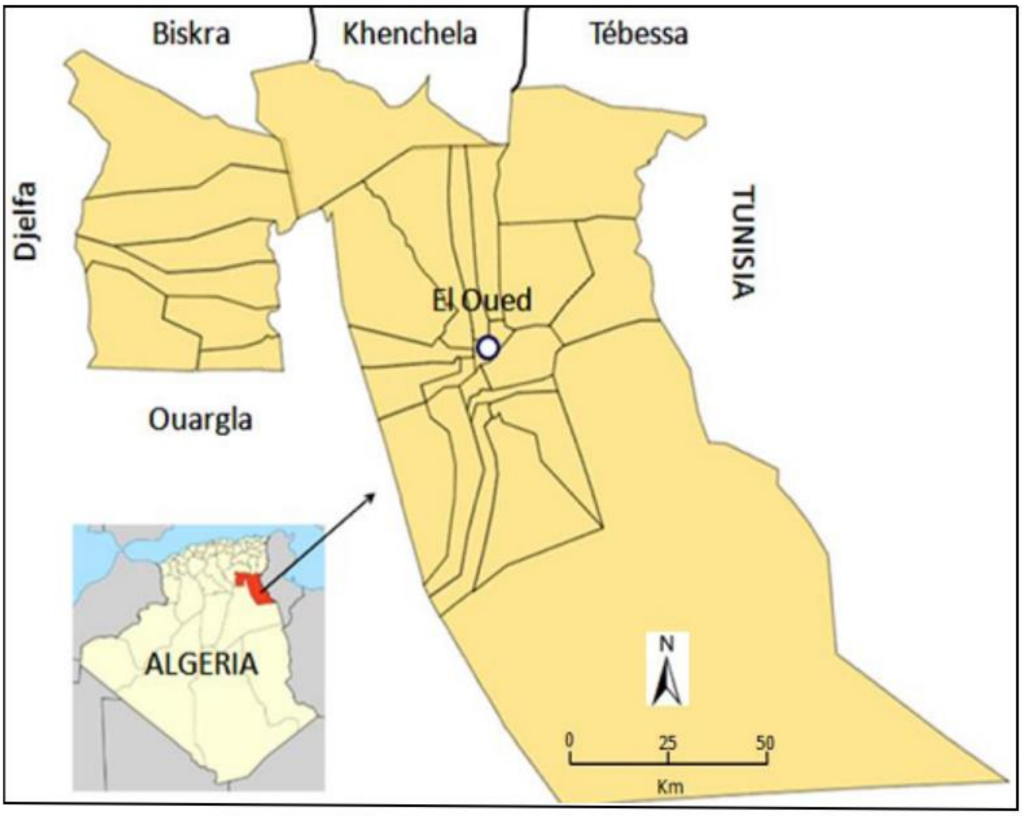


Figure 15. Geographical location of the sampling area (El Oued province) (Map of Algeria).

II.2.2. Animals and sample collection

A cross-sectional study was conducted from February 2024 to October 2025 in the El Oued province. Different age and sex groups of dromedaries were included in this study.

A total of 184 apparently healthy dromedary camels were included in this study for serum sample collection during the winter and autumn seasons. Among them, 100 were females and 84 males from El Oued province, with individuals randomly selected. Three age groups were defined: <4 years, 4–8 years, and >8 years. Animals aged less than 4 years were considered young**,** those aged between 4 and 8 years as adults, and animals over 8 years as old. Additional information regarding gender**,** breed**,** contact with cats, contact with other domestic animals**,** and history of abortion was recorded for all animals.

Blood samples were collected from the jugular vein using Vacutainer tubes without anticoagulant. The samples were labeled and left at room temperature for 30 minutes to allow serum separation, followed by centrifugation at 3000 rpm for 10 minutes. The serum was then transferred into 1.5 ml Eppendorf tubes and stored at −20 °C until serological analysis.

Figure 16. Blood samples collection from the jugular vein of dromedary camels in EL Oued (Personal photograph).

II.2.3. Serological testing

Camel serum samples were analyzed for the detection of anti-*T. gondii* and anti-*N. caninum* antibodies, respectively, using commercial Multispecies ELISA kits (ID Screen® Toxoplasmosis Indirect Multispecies and ID Screen® *Neospora caninum* Indirect Multispecies, both ID VET, Grabels, France). Positive and negative controls provided with the kit were included, and the tests were performed according to the manufacturer's instructions. Optical density (OD) was measured at 450 nm using EnSpire® multimode ELISA plate reader (PerkinElmer, Waltham, MA, USA).

The Toxoplasmosis kit detects specific immunoglobulin G (IgG) antibodies against the P30 *T. gondii* protein using a peroxidase-conjugated anti-multi-species secondary antibody. In the NC kit, the antigen is based on a purified *N. caninum* extract. An anti-ruminant conjugate is used as the secondary antibody, and 3,3′,5,5′-tetramethylbenzidine (TMB) serves as the substrate. The tests were performed according to the manufacturer’s instructions, where OD represents the optical density of the sample, the positive control (PC), or the negative control (NC) provided with the kit. According to the manufacturer, for the Toxoplasmosis kit, animals with an S/P % ≤ 40 % were considered negative, those with 40 % < S/P % < 50 % were considered doubtful, those with 50 % ≤ S/P % < 200 % were considered positive, and those with S/P % ≥ 200 % were considered to have an acute infection. For the *N. caninum* kit, animals with an S/P % ≤ 40 % were considered negative, those with 40 % < S/P % < 50 % were considered doubtful, and those with S/P % ≥ 50 % were considered positive.
For both assays, the sample-to-positive (S/P %) ratio was calculated for each serum sample using the following formula:

$$S/P\% = \frac{OD\ sample\ -\ OD\ negative\ control}{OD\ positive\ control\ -\ OD\ negative\ control} \times 100$$

II.2.4. Statistical analysis

Data analysis was performed using R software (version 4.3.2). Descriptive statistics were used to calculate overall and category-specific seroprevalence, expressed as percentages with 95% confidence intervals (CI) using the binomial exact method.
For univariate analysis, associations between seropositivity and risk factors were assessed using chi-square tests (or Fisher's exact test for small expected frequencies). Odds ratios (OR) with 95% CI were calculated for each category relative to a reference level (e.g., the lowest seroprevalence category). Significance was set at $p < 0.05$, with stars (*) indicating significant categories ($p < 0.05$ vs reference).

II.3. Results

In this study, specific antibodies against *T. gondii* were detected in 16 of the 184 animals examined, of which 6 had an acute infection (3.26%; 95 % CI: 1.2–6.9) and 10 had a non-acute infection (5.43%; 95 % CI: 2.6–9.7), corresponding to an overall prevalence of 8.69% (95 % CI: 5.1–13.7). In contrast, no animals tested positive for anti-*N. caninum* antibodies (Table 16).

Table 16. Seroprevalence of *T. gondii* and *N.caninum* in dromedaries *(Camelus dromedarius).*

Type of infection	No. of tested	No. of negative (%)	No. of doubtful (%)	No. of positive (%)	No. Acute infection	95% CI
T. gondii	184	165 (89.67)	3 (1.63)	10 (5.43)	6 (3.26)	
				16 (8.69)		5.1 - 13.7
N. caninum	184	184 (100)	0	0		/

Based on the available data, age, the presence of cats, and a history of abortion were significantly associated with the seroprevalence of *T. gondii* infection. In contrast, variables such as gender, breed, season, and the presence of sheep and goats showed no significant association with infection ($p > 0.05$) (Table 2).

The analysis in Table 17, showed a significant association between (1) *T. gondii* seropositivity and age ($p = 0.023$). A more pronounced seroprevalence was observed in adult animals (21.05%) and older animals (11.24%) compared to young individuals (2.74%), (2) *T. gondii* seropositivity and the presence of cats ($p < 0.001$; OR = 9.91; 95% CI: 2.92–33.69), and (3) *T. gondii* seropositivity and history of abortion ($p = 0.007$; OR = 6.39; 95% CI: 1.69–24.15). Seroprevalence was very similar between the Tergui (8.57%) and Sahraoui (8.90%) breeds. No significant variation was observed according to gender, with rates of 6.10% in males and 11.11% in females. Seasonal variation was not observed, with seroprevalence of 13.51% in winter and 7.64% in autumn. Furthermore, the presence of small ruminants was not associated with seroprevalence.

Table 17. Analysis of risk factors related to *T. gondii* seroprevalence in dromedary camels.

Risk factors	Category	No. Animals tested	No. Positive (%)	OR (95% CI)	p_value
Age (years)	<4	73	2 (2.74)	1 (ref.)	0.023*
	04_08	19	4 (21.05)	8.30 (1.61-42.83)	
	>8	89	10 (11.24)	3.78 (0.92-15.56)	
Gender	Female	99	11 (11.11)	1 (ref.)	> 0.05
	Male	82	5 (6.10)	0.55 (0.19-1.58)	
Breed	Sahraoui	146	13 (8.90)	1 (ref.)	> 0.05
	Tergui	35	3 (8.57)	1.06 (0.31-3.67)	
Season	Autumn	37	5 (13.51)	1 (ref.)	> 0.05
	Winter	144	11 (7.64)	0.51 (0.17-1.51)	
Presence of cats	No	122	3 (2.46)	1 (ref.)	<0.001*
	Yes	59	13 (22.03)	9.91 (2.92-33.69)*	
Presence of sheep and goats	No	134	12 (8.96)	1 (ref.)	> 0.05
	Yes	47	4 (8.51)	1.01 (0.33-3.14)	
History of abortion (females only)	No	67	3 (4.48)	1 (ref.)	0.007*
	Yes	32	8 (25.00)	6.39 (1.69-24.15)*	

CI: Confidence Interval; OR: odds ratio; *: significant

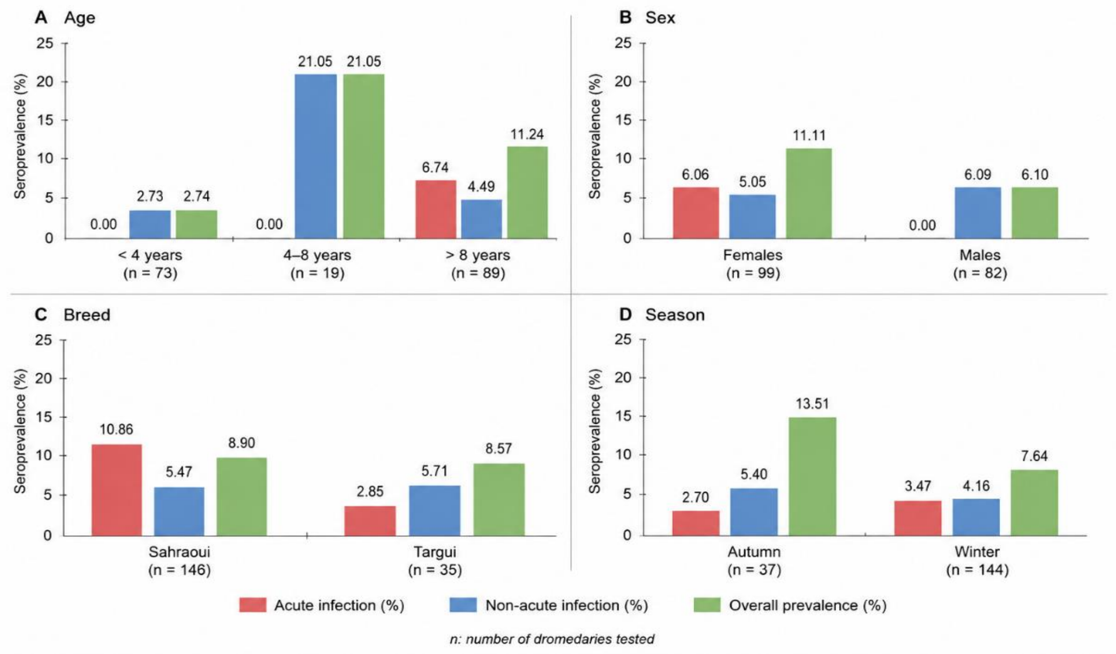


Figure 17. Seroprevalence of acute and non-acute *Toxoplasma* infection in dromedary camels.

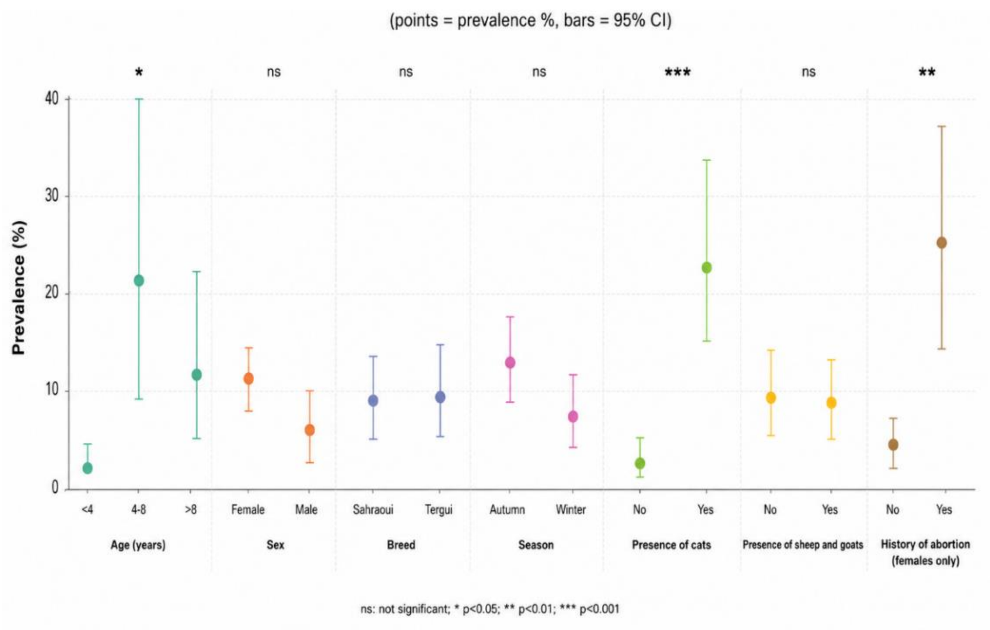


Figure 18. Dot plot showing *T. gondii* seroprevalence across studied variables with 95% confidence intervals.

Although the present study primarily focuses on abortion, cases of stillbirth were also observed in seropositive females. Notably, two seropositive females with a history of abortion also experienced stillbirth (Figure 19).

Figure 19. Stillbirth in a dromedary fetus from a female seropositive for *T. gondii* (Personal photograph).

II.4. Discussion

This study represents the first seroepidemiological investigation in Algeria assessing the concurrent prevalence of *T. gondii* and *N. caninum* in dromedaries, along with the associated risk factors. A seroprevalence of 8.69% for *T. gondii* was recorded, whereas no infection with *N. caninum* was detected, highlighting the predominance of *T. gondii* and distinct transmission dynamics between these two protozoan parasites in dromedaries from Southeastern Algeria. This pattern is further supported by recent data from the same study area (Djeddou-Benabid et al., 2026), where histological detection of *T. gondii* in adult females confirms its persistence within the camel population. In contrast, no tissue stages of *N. caninum* were identified, suggesting limited circulation of this protozoan. The relatively low seroprevalence of *T. gondii* reported in this study may reflect a limited infection pressure within the investigated area. Environmental conditions characteristic of the Saharan ecosystem particularly aridity, high temperatures, and the low density of definitive hosts, are unfavorable to the persistence and dissemination of *T. gondii* oocysts. However, despite this low prevalence, the detection of seropositive cases indicates a non-negligible circulation of the parasite within the camel population. This circulation may be associated with herd mobility toward more humid or subarid areas, animal trade between regions, as well as cumulative exposure with increasing age (Gebremedhin et al., 2014; Megersa, 2010).

In Algeria, data on *T. gondii* infection in dromedary camels remain limited and are mainly based on a few recent studies. In the wilaya of El Oued, a seroprevalence of 7.59% has been reported

(Abdallah et al., 2020), which is close to that observed in the present study, while a higher prevalence of 25% was described by Mekroud et al. (2026). At the national level, considerable regional variations have been observed. Moderate rates were recorded in Ghardaïa, Ouargla, and Biskra (9.78%, 10.33%, and 29.57%, respectively) (Abdallah et al., 2020), whereas particularly high levels have been reported in certain regions, notably in Biskra (90%), Tindouf (69.7%), and Laghouat (57.1%) (Mekroud et al., 2026). This spatial heterogeneity may be explained by differences in cat density, water sanitary quality, herd management practices, as well as climatic conditions (Mekroud et al., 2026). At the global scale, the seroprevalence of *T. gondii* observed in the present study (8.69%) is higher than those reported in Iran (4.16%) (Sadrebazzaz et al., 2006), Somalia (6.3%) (Kadle, 2014), and Saudi Arabia, where null (Derar et al., 2017) or low rates (6.5%) (Alanazi, 2011) have been described. Conversely, it is comparable to those reported in Saudi Arabia (8%) (Al-Mohammed, 2011), Ethiopia (8.33%) (E. Gebremedhin et al., 2016), Iran (9.93%) (Azma et al., 2015), and Pakistan (10%) (Chaudhry et al., 2014). Higher seroprevalence levels have been reported in several African countries, particularly in Sudan, where Ishag et al. (2014), Jiomaa et al. (2017), and Mohammed et al. (2021) reported prevalence rates of 56.5%, 49.7%, and 30%, respectively. In Ethiopia, rates of 40.49% and 14.38% were documented by Gebremedhin et al. (2014) and Tilahun et al. (2018). In Egypt, several recent studies have shown substantial variability, with seroprevalence ranging from 13.84% to 58.24% (Elmahallawy et al., 2025; Fereig et al., 2022; Mahmoud et al., 2024; Selim et al., 2023). Additionally, seroprevalence rates of 29.8% in Tunisia (Jeljli et al., 2024) have been reported. In Asian countries, variable but generally notable prevalence rates have also been documented. In Iraq, prevalence rates of 22.8% and 23.62% were reported by Al-Dhalimy and Mahmoud (2019) and Hanon (2018) , respectively. In Iran, rates of 26% and 15% were recorded by Tavakoli et al. (2018) and Yektaseresht et al. (2023). In Pakistan, higher seroprevalence levels reaching 40.1% and 38% have been reported (Fatima et al., 2019; Shehzad et al., 2022). Comparable levels have also been reported in Gulf countries. In Saudi Arabia, seroprevalence rates of 35.8%, 49.18%, and 34.3% were reported by Al-Afaleq et al. (2018), Khalifa et al. (2018) and Mohammed et al. (2020), respectively. In addition, a recent study conducted in Qatar by Boughattas et al. (2025) reported a rate of 32%, , while in the United Arab Emirates, a rate of 22.4% was reported by Abu-Zeid (2002). En Europe, reported seroprevalence rates also appear to be substantial. Markova et al. (2018) reported a seroprevalence of 30% in Italy, while Mentaberre et al. (2013) documented a comparable rate in Spain (36.5%). Furthermore, markedly higher levels of anti-*T. gondii* antibodies in dromedaries have been reported in other countries, reaching 90.9% in Turkey (Ütük et al., 2012) and 69% in the Czech Republic (Bártová et al., 2017).

No seropositivity for *N. caninum* was detected in dromedaries in the present study, a finding consistent with that reported in Italy by Markova et al. (2019), where the seroprevalence was also null (0%). In Algeria, the seroprevalence of *N. caninum* infection has been widely studied in sheep and cattle, whereas data on dromedaries are nonexistent, which limits national-level comparisons. However, at the global scale, other studies have demonstrated variability in seroprevalence rates. Relatively low levels have been reported in Egypt by Fereig et al. (2022) (3.9%) and Hilali et al. (1998) (3.7%), as well as in Iran by Hamidinejat et al. (2013), Hosseininezhad et al. (2009), and Sadrebazzaz et al. (2006), with respective prevalence rates of

3.94%, 3.22%, and 5.83%. Similar rates have also been observed in Saudi Arabia (5.6%) (Alanazi, 2011). In contrast, intermediate prevalence levels have been reported in Pakistan (11.10%) Nazir et al. (2017), in Egypt (11%) (Selim & Abdelhady, 2020b), as well as in Saudi Arabia (21.99% and 16.60%) (Aljumaah et al., 2018; Mohammed et al., 2020). Finally, an exceptionally high seroprevalence was reported in Spain, reaching 86% (Mentaberre et al., 2013).

The considerable variability in seroprevalence rates observed across these studies may be attributed to several factors, including sample size, breeding and management practices, soil type, as well as geographic and climatic conditions. Additional contributing factors may include stress, nutritional deficiencies, and concurrent infections. This variability may also be explained by differences related to animal characteristics, such as age, sex, season, and breed, as well as by the density of domestic cats and wild felids. Furthermore, variations in the sensitivity of diagnostic tools and the serological methods employed may also account for these discrepancies (Dubey and Lindsay, 2006; Dubey, 2010; Gebremedhin et al., 2014).

The analysis of the data from the present study shows that adult and older dromedaries (≥ 4 years and > 8 years, respectively) exhibit a higher seroprevalence of *T. gondii* compared to younger animals (< 4 years). This finding is consistent with several previous studies (Abdallah et al., 2020; Al-Dhalimy & Mahmoud, 2019; Boughattas et al., 2025; Elmahallawy et al., 2025; Gebremedhin et al., 2016; Mahmoud et al., 2024; Selim et al., 2023). However, it contrasts with the observations of Chaudhry et al. (2014) and Al-Malki (2022), who reported a lower seroprevalence in older animals compared to younger ones. Moreover, some studies have found no significant association between the age of dromedaries and *T. gondii* seroprevalence (Aljumaah et al., 2018; Hamidinejat et al., 2013; Karimi et al., 2023). The higher prevalence observed in adult dromedaries may be attributed to the cumulative effect of exposure to the parasite over time. Additionally, factors such as changes in management practices and the decline in immune status in older animals may also contribute to this trend (Djeddou-Benabid et al., 2025; Zarnke et al., 2000).

No significant difference in the seroprevalence of anti-*T. gondii* antibodies was observed between male and female dromedaries, which is consistent with findings reported in several previous studies (Abdallah et al., 2020; Al-Dhalimy & Mahmoud, 2019; Boughattas et al., 2025; Elmahallawy et al., 2025; Karimi et al., 2023; Mohammed et al., 2020). In contrast, these findings differ from those reported by Hanon (2018), Mahmoud et al., 2014, Mahmoud et al. (2024) and Selim et al. (2023), who observed a significantly higher seroprevalence in females. Conversely, Abu-Zeid (2002) and Shehzad et al. (2022) reported higher seroprevalence in males compared to females.

In the present study, no significant association was found between breed and *T. gondii* infection, in agreement with the findings of Abdallah et al. (2020) and Fatima et al. (2019). However, these results contrast with those of Mahmoud et al. (2024), who demonstrated a significant influence of breed on seroprevalence. Similarly, no significant seasonal effect on *T. gondii* prevalence was observed, which is consistent with the findings of Boughattas et al. (2025). In contrast, other studies have reported a seasonal influence, notably Fereig et al. (2022) and

Mahmoud et al. (2024). The presence of domestic cats was identified as a risk factor for *T. gondii* seropositivity, in line with several previous studies (E. Gebremedhin et al., 2014; Hadush & Gebremaryam, 2015; Jeljli et al., 2024). However, these findings differ from those reported by Gebremedhin et al. (2016). This association can be explained by the central role of felids in the epidemiology of *T. gondii*, as definitive hosts shedding millions of oocysts into the environment. These oocysts can contaminate a wide range of intermediate hosts, including dromedaries, which become infected primarily through ingestion of contaminated water or feed, or through contact with contaminated soil (Djeddou-Benabid et al., 2025).In contrast, no significant association was observed between *T. gondii* infection and the presence of sheep and goats, in agreement with Abdallah et al. (2020), but in contradiction with the findings of Selim et al. (2023).

Furthermore, the present study highlights a positive association between abortion history and *T. gondii* infection, in agreement with several previous studies (Chaudhry et al., 2014; Fatima et al., 2019; E. Gebremedhin et al., 2014; Selim et al., 2023; Shehzad et al., 2022; Yawoz, 2021). However, this relationship has not been reported in other studies (Abdallah et al., 2020; E. Gebremedhin et al., 2016; Hadush & Gebremaryam, 2015; Jeljli et al., 2024; Yektaseresht et al., 2023). This significant association is consistent with previous studies highlighting the abortifacient role of this parasite in camels. Indeed, in the dromedary camel (*Camelus dromedarius*), a case of acute toxoplasmosis associated with abortion and clinical signs has been reported (Hagemoser et al., 1990). Furthermore, an abortion attributed to *T. gondii*, associated with hemorrhagic colic and toxoplasmic peritonitis, has recently been reported in a Bactrian camel (Komnenou et al., 2022b).

The observed association between serological profiles and abortion history, combined with the epidemiological data from the present study, provides converging evidence supporting the involvement of *T. gondii* in reproductive disorders, particularly abortions, in dromedary camels from the study area.

II.5. Conclusion

The present study revealed a relatively low seroprevalence of T. gondii in dromedary camels in southeastern Algeria, while nevertheless confirming its circulation in this environment. In contrast, no seropositivity to N. caninum was detected, representing, to our knowledge, the first serological data available in dromedary camels in Algeria. Age, the presence of domestic cats and a history of abortion were identified as risk factors associated with infection. These findings support the hypothesis of a potential involvement of T. gondii in reproductive disorders, particularly abortions, although further investigations are required to confirm this association. Overall, this study highlights the need to implement targeted preventive measures aimed at reducing environmental contamination and raising awareness among camel breeders in order to effectively limit parasite transmission.

EXPERIMENT III

Histopathological investigation of Toxoplasmosis and Neosporosis in camels (*Camelus dromedarius*) from Southeastern Algeria

III.1. Inroduction

Toxoplasma gondii and *Neospora caninum* are cyst-forming coccidian protozoa with a worldwide distribution. These pathogens are major causes of embryonic death and fetal resorption, fetal death and mummification, abortion, stillbirth, and neonatal death in herbivorous livestock, thereby causing substantial economic losses in livestock production system (Djeddou-Benabid et al., 2025; Houssou et al., 2025). Their lifecycle is heteroxenous, involving a sexual phase with oocyst production in the intestines of definitive hosts (*T. gondii* in domestic and wild felids, *N. caninum* in dogs, wolves, coyotes, and dingoes) and an asexual phase occurring in the extraintestinal tissues (tissue cysts) of intermediate hosts (Dubey and Lindsay, 2006). There are three different infectious stages: sporozoites within oocysts, tachyzoites, and bradyzoites present in tissue cysts (de Moraes et al., 2011).

The transmission of these protozoan parasites in herbivorous livestock can occur via two main routes: horizontally or vertically. In addition, carnivorous and omnivorous species may become infected by ingesting tissues from intermediate hosts containing viable cyst stages (Basso et al., 2022). Due to their microscopic size, routine detection of *T. gondii* and *N. caninum* cysts during meat inspection is not feasible. Consequently, the diagnosis of *T. gondii* and *N. caninum* infection relies primarily on serological approaches. Indeed, according to Fereig et al. (2022), the global seroprevalence of *T. gondii* and *N. caninum* in the Camelidae family has been estimated at 28.16% and 14.3%, respectively.

Although no microscopic identification of tissue cysts was reported, molecular detection methods (PCR) have been applied to cardiac and diaphragmatic muscle samples in studies conducted in Egypt, where prevalence rates of 55.5% (2017) and 1.1% (2019) were reported, as well as in Iran, with prevalence rates of 65% (2016) and 13% (2018) (Fereig et al., 2022). Furthermore, Tonouhewa et al. (2017) estimated the overall seroprevalence of toxoplasmosis in dromedaries *(Camelus dromedarius)* in Africa to be 36% (18% to 56%). However, this serological evidence was not supported by direct detection or microscopic examination of *T. gondii* cysts in muscle tissues.

Abortions caused by *T. gondii* and *N. caninum* have been widely documented in small ruminants and cattle, respectively (Dubey and Lindsay, 2006). In contrast, abortions attributed to these two protozoa are rare in camelids. Nevertheless, a few clinical cases have been reported: abortions associated with *N. caninum* infection have been described in alpacas and llamas (Serrano-Martínez et al., 2007), while an abortion attributed to *T. gondii*, associated with hemorrhagic colic and toxoplasmic peritonitis, was recently reported in a Bactrian camel (Komnenou et al., 2022b). In dromedaries *(Camelus dromedarius)*, only a single case of acute toxoplasmosis has been reported, associated with abortion and clinical signs in the animal (Hagemoser et al., 1990).

To date, no study has reported the microscopic detection of *T. gondii* and *N. caninum* in dromedary camels in Algeria. Therefore, the present study aimed to perform a histopathological analysis to identify *T. gondii* and *N. caninum* in selected tissues from slaughtered dromedaries in Southeastern Algeria.

III.2. Materials and methods

III. 2.1. Study area

The study was conducted in El-Oued Province, located in Southeastern Algeria (33°21′21″ N, 6°51′47″ E). Covering an area of 44,586.80 km², El Oued is one of the largest administrative regions in the country, occupying a strategic position and serving as a major center for dromedary breeding and supply in Southeastern Algeria. The region is characterized by a hot desert climate (Köppen-Geiger classification BWh), with annual temperatures ranging from an average minimum of 21.8°C to a maximum of 39°C, a mean relative humidity of 24.3%, and scarce rainfall averaging between 80 and 100 mm per year.

III.2.2. Histopathological analysis

This study was conducted in February 2025 on 63 clinically healthy dromedaries, comprising 23 males and 40 females, with ages ranging from 12 months to 15 years. All animals were slaughtered at the municipal slaughterhouse (Royal), located near the capital city of El Oued province. The selection of apparently healthy animals at slaughter was intended to provide representative tissue samples under field-relevant conditions and to minimize bias related to overt clinical disease.

A total of 126 tissue samples were collected, including 63 cardiac muscle and 63 diaphragmatic muscle specimens. Immediately after evisceration, approximately 50 g of each tissue was aseptically excised to ensure adequate sampling for histopathological examination. All samples were promptly fixed in 10% neutral-buffered formalin for a minimum of 24 hours to preserve tissue architecture and prevent autolysis, which is essential for reliable microscopic evaluation.

Following fixation, tissues were processed using standard histological techniques. This included systematic trimming, dehydration through ascending grades of ethanol, clearing in xylene, and infiltration with molten paraffin wax before embedding. Paraffin blocks were then prepared for sectioning. Thin tissue sections of 4–5 µm were obtained using a rotary microtome, ensuring uniformity and optimal thickness for microscopic visualization of cellular and parasitic structures.

The sections were subsequently mounted on glass slides, deparaffinized, and rehydrated through graded alcohols. Routine hematoxylin and eosin (H&E) staining was applied to allow detailed visualization of both nuclear and cytoplasmic structures, as well as inflammatory and degenerative changes within tissues. This classical staining method remains widely used in parasitological histopathology due to its reliability in detecting morphological alterations associated with protozoan infections.

Microscopic examination was performed using a high-quality light microscope (OPTIKA B-293PLi, Italy) equipped with 10× and 40× objectives. The system included a motorized stage and a digital imaging camera connected to a computer workstation. This configuration enabled systematic scanning of entire tissue sections, minimizing the risk of missing focal lesions or low-density parasitic structures. Automated image acquisition further ensured precise documentation, archiving, and analysis of histopathological findings.

Figure 20. Study workflow: Tissue collection, histopathological processing, and microscopic examination (Personal photograph).

III.3. Results

Detection of *T. gondii* and *N. caninum* using histopathological analysis

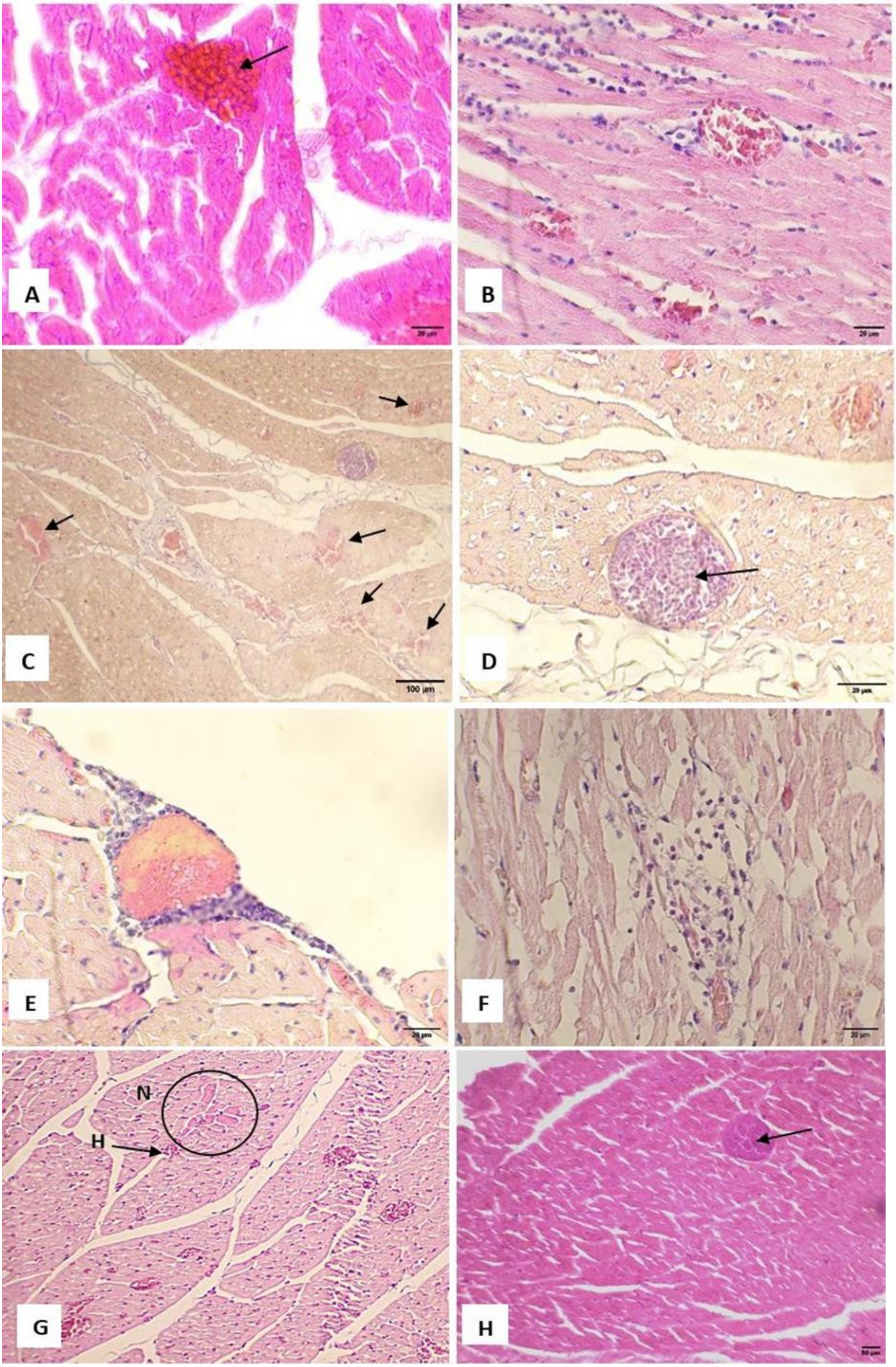
A total of 126 tissue samples, including 63 cardiac muscle and 63 diaphragmatic muscle samples, were examined histopathologically. Parasitic structures morphologically compatible with *T. gondii* were detected exclusively in the cardiac muscle of three female dromedaries (3/63; 4.8% of the examined animals). No cysts were observed in the diaphragmatic samples. The positive animals corresponded to samples No. 11, No. 12, and No. 60, aged 10, 12, and 11 years old, respectively.

Tachyzoites were observed in sample No. 11 (1/63; 1.6% of the examined animals) (Fig. 1A), whereas tissue cysts containing bradyzoites were identified in samples No. 12 and No. 60 (2/63; 3.17% of the examined animals) (Fig. 1H and Fig. 1D, respectively).

The identification of *T. gondii* cysts in HE-stained sections is challenging due to their morphological similarity to other protozoa such as *N. caninum* and *Sarcocystis* spp. The tissue cysts observed in the cardiac muscle (Fig. 21 D–H) exhibited a regular structure, measuring 72 and 100 µm, respectively. They were surrounded by a thin and uniform cyst wall (< 0.5 µm), morphological features consistent with *T. gondii*. In the differential diagnosis, cysts of *N. caninum* exhibit a thicker and more irregular wall (0.5-4 µm), whereas those of *Sarcocystis* spp. vary in size and shape and are characterized by a cyst wall with hair-like projections or radial striations (Dahmani et al., 2018; Dubey and Lindsay, 2006).

An inflammatory response was associated with parasite presence in two cases: sample No. 11 showed a cardiac inflammatory infiltrate composed of mononuclear cells (Fig. 1B), and sample No. 60 exhibited marked inflammatory lesions characterized by mononuclear cell infiltrates, focal hemorrhages, and areas of necrosis (Fig. 1C, E, F, G). In contrast, no inflammatory reaction was observed in sample No. 12 despite the presence of tissue cysts. No inflammatory lesions were detected in the diaphragmatic muscle of any of the examined animals.

Furthermore, no parasitic elements compatible with *N. caninum* were identified in either the cardiac or diaphragmatic muscle analyzed.


A
B
C
100 µm
D
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H
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H

Figure 21. Cardiac lesions and detection of *Toxoplasma gondii* in histological sections of the heart of naturally infected dromedaries (**A-I** hematoxylin and eosin H&E). **A.** Dense cluster of *T. gondii* tachyzoites within cardiac muscle fibers (arrow). **B.** Mononuclear interstitial inflammatory infiltrate consistent with focal active myocarditis. The massive infiltration of inflammatory cells within the muscle fibers is manifested by numerous nuclei stained dark purple. **C.** Tissue cyst of *T. gondii* with diffuse microvascular congestion of blood vessels (arrows). **D.** Detail of a toxoplasmic cyst ×400. Note the circular, well-defined outline of the cyst and the numerous *T. gondii* bradyzoites within (arrows). The cyst size is estimated at approximately 72 µm, cyst wall (<0.5 µm), scale bar=20µm. **E.** Marked interstitial and perivascular lymphoid infiltrate surrounding a congested venule within the cardiac tissue ×400, scale bar=20µm. **F.** Focal lymphohistiocytic infiltration in the tissue characterized by an aggregation of mononuclear inflammatory cells. **G.** Moderate necrosis (N) and hemorrhage (H) in cardiac tissue ×100, scale bar=50 µm. **H.** *T. gondii* cyst without inflammation or tissue lesions (arrow) ×100, scale bar=50 µm.

III.4. Discussion

Data on the presence of *T. gondii* and *N. caninum* in the tissues of naturally infected dromedaries in North Africa remain limited. To our knowledge, this study represents the first combined histopathological report of these two protozoa in dromedaries slaughtered in Algeria, documenting their presence in cardiac muscle and providing baseline data for future investigations on their potential role in reproductive health.

Histological examination of hematoxylin-eosin stained (H&E) sections of the organs studied (heart and diaphragm) revealed forms compatible with *T. gondii* exclusively in the heart. No forms of *N. caninum* were detected in either the heart or the diaphragm. It should be noted that *N. caninum* tissue cysts are rare, and compared with *T. gondii*, their numbers are very limited in naturally infected animals such as cattle and other intermediate hosts (Speer et al., 1999). The absence of histopathological detection of *N. caninum* in our study is consistent with the observations of Amdouni et al. (2022), who reported that microscopic examination of the brain, tongue, and masseter muscle of infected dromedaries was negative, despite a molecular prevalence of 34.3% (12/35). In contrast, Karimi et al. (2023) identified suspected *N. caninum* stages in the brain of a single dromedary, which also tested PCR-positive in the brain, blood, and lymph nodes.

To date, only two studies have reported the isolation of *T. gondii* from naturally infected dromedaries: in Saudi Arabia (Hilali et al., 1995) from the tongue and esophagus, and in Ethiopia (E. Gebremedhin et al., 2014) from the heart and tongue, with cysts isolated in 16.13% (5/31) of DAT-positive animals. In Algeria, no data are available regarding the presence of this parasite in dromedary tissues. However, a single histopathological study conducted in sheep detected *T. gondii* cysts in the heart and diaphragm, with a very low prevalence of 0.59% (2/335) (Dahmani et al., 2018).

The absence of *T. gondii* or *N. caninum* in one or both organs (heart, diaphragm) may be explained by the inherent difficulties in detecting these parasites in tissue sections from large animals. These challenges are related to the limited sample size, low parasite density, and the restricted sensitivity of microscopy, with the pathogen potentially residing in unexamined areas (Esteban-Redondo et al., 1999; E. Gebremedhin et al., 2014). Moreover, a negative histological result does not necessarily indicate that the entire tissue is free of the parasite (Nunes et al., 2015). It should also be emphasized that the low proportion of positive cases (3 out of 63 subjects examined) may represent a limitation of the study.

Parasitic involvement was strictly confined to the cardiac muscle, with tachyzoites detected in one animal (1.6% of the sampled subjects) and tissue cysts in two animals (3.17%). The identified cysts (Fig. 1 D-H) exhibited a regular and well-defined structure, with a thin cyst wall enclosing numerous bradyzoites, measuring 72 and 100 µm, respectively. According to Dubey et al. (1998), a mature tissue cyst of *T. gondii* is generally spherical in the brain and measures on average 50-70 µm in diameter, whereas in muscle tissues, cysts are typically more elongated and may reach up to 100 µm in length. More broadly, the size of tissue cysts varies depending on cyst age, the type of infected host cell, the *T. gondii* strain, and the cytological method used for measurement. Other authors have also reported toxoplasmic cysts measuring up to 100-200 µm (Desoubeaux et al., 2012).

The cardiac tropism observed in dromedaries may reflect a preference of the parasite for the heart, without excluding its ability to reach other tissues. It should be emphasized that the presence of tachyzoites and bradyzoites may reflect different stages of infection and is closely associated with the tissue tropism of *T. gondii* within each organ (Kılınç et al., 2023). During the acute phase of infection, the parasite can rapidly cross intestinal epithelial cells and reach various cell types in different tissues via the bloodstream and/or lymphatic circulation (Tenter et al., 2000b). In contrast, cystic forms predominate during chronic infection and are more frequently observed in nervous tissues (brain and retina) as well as in muscular tissues, notably skeletal and cardiac muscles (Dubey and Lindsay, 2006). Experimental studies have shown that at high infectious doses, *T. gondii* is more frequently and consistently detected in the brain and heart, suggesting that these organs represent preferential sites for tissue localization in animals (Esteban-Redondo et al., 1999; Kılınç et al., 2023).

Toxoplasmic cysts were detected in the heart of adult dromedaries in the study by Gebremedhin et al. (2014). Apart from this research, no published histopathological study has definitively confirmed the presence of cysts in the cardiac muscle or diaphragm of dromedaries, alpacas, or llamas. Nevertheless, several studies in ruminants and other species indicate that these tissues serve as preferential sites for cyst persistence. In domestic ruminants, *T. gondii* cysts have been detected in the cardiac muscle of seropositive buffaloes and sheep, whereas their presence in the diaphragm appears to be less frequent (Gareh et al., 2025; Tenter et al., 1992; Zghair, 2016). These observations are fully consistent with our results and indicate that *T. gondii* shows a marked predilection for the cardiac muscle over skeletal muscles, although cysts can also be detected in the latter, particularly under natural infection conditions (Hussein et al., 2023). Studies in birds of prey have also reported *T. gondii* cysts in the myocardium and skeletal muscles, confirming the parasite's ability to persist in these tissues (Elmore et al., 2010; Zanet et al., 2023). For *N. caninum*, thin-walled cysts have been described in the muscles of naturally infected cattle and dogs, although their detection in experimentally infected animals remains limited (Dubey and Lindsay, 2006; Peters et al., 2001). Therefore, the cardiac and skeletal muscles represent potential reservoirs for the persistence and transmission of both parasites.

In the present study, all dromedaries in which tissue forms of *T. gondii* were identified were female Sahraoui camels aged 10 years or older. These observations suggest that, in older females, chronic infection associated with the presence of tissue cysts may constitute a risk factor for parasite reactivation during gestation, thereby facilitating transplacental transmission to the fetus and increasing the risk of abortion. This association between advanced age, chronic infection, and adverse reproductive outcomes is supported by studies in other ruminants, where chronically infected females could transmit the parasite to the fetus, resulting in abortion or stillbirth (Dubey, 2009; Innes et al., 2007).

Significant histopathological lesions were observed exclusively in the heart. These lesions were characterized by a mononuclear cell infiltrate, associated or not with a perivascular inflammatory cuff. The alterations were also accompanied by venular congestion, focal hemorrhages, and areas of necrosis, indicating a marked inflammatory and vascular response in the cardiac tissue. According to Nunes et al. (2015), the intensity and nature of histological changes may vary between studies, particularly regarding the extent of the mononuclear infiltrate in tissues targeted by the parasite. These authors specifically reported that the main histopathological lesion observed in the heart consisted of a mononuclear cell infiltrate. Desoubeaux et al. (2012) also described that the influx of inflammatory cells within cardiac muscle fibers is manifested by the visualization of their nuclei stained dark purple within an interstitial and perivascular lymphoid infiltrate. Furthermore, Dubey et al. (1998) reported that intact tissue cysts likely cause no tissue damage and can persist without inducing a host inflammatory response, whereas severe inflammation accompanied by local necrosis occurs when cysts rupture and release the parasites. Consistent with our findings, Machado et al. (2016) also demonstrated that experimental *T. gondii* infection leads to cardiac alterations, histopathologically characterized by necrosis, hemorrhagic areas, and inflammatory infiltrates.

To date, no data have established a direct link between toxoplasmosis or neosporosis and abortions in dromedaries *(Camelus dromedarius)*, with the exception of a single case of acute toxoplasmosis reported by Hagemoser et al. (1990). It involved a 6-year-old female that had aborted a near-term fetus, presenting with anorexia and dyspnea, in which *T. gondii* tachyzoites were detected in pleural macrophages and anti-*T. gondii* antibodies were strongly positive, confirming the diagnosis.

It is important to note that infection with *T. gondii* or *N. caninum* has long been recognized as a potential cause of abortion in alpacas and llamas (Pearson et al., 2014). In these two camelid species, *N. caninum* DNA as well as various parasitic stages have been identified in the brain and heart of aborted fetuses using histology, immunohistochemistry, and PCR techniques (Serrano-Martínez et al., 2007). Furthermore, Dubey et al. (2014) reported the first confirmed case of abortion associated with toxoplasmosis in an alpaca. In this context, tissue cysts of *T. gondii* were detected in the kidneys and brain of the fetus, while mild inflammatory lesions were observed in the placenta, liver, lungs, and brain, including nonsuppurative meningoencephalitis, hydrocephalus, and hydromyelia. Given the limited sensitivity of histology, it is recommended to combine it with other techniques, particularly serological and molecular methods, in order to more reliably assess the contribution of these two protozoa to abortions, while also providing a better understanding of their tissue distribution and tropism.

III.5. Conclusion

The detection of *T. gondii* tissue forms in adult female dromedaries, together with the observed association between herd-level abortion history and the presence of domestic carnivores (cats and dogs) in the study area, suggests that *T. gondii* may be a contributing factor to reproductive losses in Algerian dromedaries. However, as no direct causal link was established between infected animals and previous abortion events, it is likely that other factors, such as environmental conditions, herd management practices, or exposure to other infectious agents, also play a significant role. These findings highlight the susceptibility of dromedaries to protozoan infections and underscore the need for integrated reproductive health management approaches, combining parasite control with improved husbandry practices.

General Conclusion and Recommendations

This study, based on a multidisciplinary approach integrating an epidemiological survey, serological analyses, and histopathological investigation, provides original and in-depth data on the involvement of *Toxoplasma gondii* and *Neospora caninum* in dromedaries (*Camelus dromedarius*) in Southeastern Algeria, particularly in the wilaya of El Oued. It represents one of the few investigations focused on abortive protozoal infections in camelids in this Saharan region, where scientific knowledge on reproductive diseases remains limited.

The epidemiological survey (Experiment I) revealed a high occurrence of abortions and stillbirths in the studied herds. Analysis of associated risk factors identified the major role of the presence of domestic carnivores, particularly cats and dogs, as key risk factors for reproductive disorders. This association suggests that infectious diseases transmitted by these carnivores may contribute to the occurrence of the observed abortions. However, the multifactorial nature of reproductive losses in dromedaries cannot be excluded, as environmental, nutritional, infectious, and management-related factors may act simultaneously. Extreme Saharan climatic conditions, heat stress, nutritional deficiencies, and insufficient veterinary monitoring are also likely to exacerbate reproductive losses in extensive production systems.

The serological investigation (Experiment II) demonstrated the presence of anti-*T. gondii* antibodies in the examined dromedaries, with an overall seroprevalence of 8.7%, indicating active circulation of the parasite in camel herds in southeastern Algeria. In contrast, no seropositivity for *N. caninum* was detected, suggesting a limited or absent role of this protozoan in the studied population. Risk factor analysis identified several variables associated with T. gondii infection, including age, history of abortion, and the presence of domestic carnivores, particularly cats. These findings confirm the central role of felids in the dissemination of *T. gondii* oocysts and highlight the importance of husbandry practices in parasite transmission dynamics. Inadequate disposal of abortion materials and the free access of cats to feed and water sources may further facilitate environmental contamination and the maintenance of the parasite's life cycle within camel herds.

The histopathological study (Experiment III) provided complementary and particularly important evidence by revealing tissue stages compatible with *T. gondii*, including tachyzoites and parasitic cysts, in several examined samples. The presence of these parasitic structures indicates active or chronic infection in the studied animals and confirms parasite circulation within camel herds in the region. Microscopic examination also revealed inflammatory lesions and various histopathological alterations, including inflammatory cell infiltration, tissue degeneration, and localized necrotic areas, suggesting an active pathological role of the parasite in the examined organs. In contrast, no tissue forms compatible with *N. caninum* were detected during histopathological examination.

This finding, together with the negative serological results, suggests a limited or absent involvement of this protozoan in the investigated cases within the camel population of the

El Oued region. However, the absence of histological detection alone cannot definitively rule out the presence of the parasite, particularly in low-grade or low-parasite-load infections.

The results of the three complementary approaches — epidemiological survey, serological analyses, and histopathological investigation — converge toward a consistent interpretation. Epidemiological data suggest the circulation of infectious agents involved in the observed reproductive disorders. Serologically, the detection of antibodies against *T. gondii* confirms exposure in dromedaries, whereas no seropositivity was observed for *N. caninum*. Histopathological findings further support these results by demonstrating tissue forms compatible with *T. gondii* and the absence of structures consistent with *N. caninum*.

Overall, the findings suggest a probable involvement of *T. gondii* in the reproductive disorders observed, while *N. caninum* does not appear to play a significant role in the studied population, although further investigations are still required to definitively exclude its involvement.

In light of these results, strengthening prevention and control strategies for protozoal infections in camel herds is essential. Priority measures should include improving farm hygiene, proper management of abortion materials, restricting cats' access to feed and water sources, and controlling stray animals around herds. Raising farmers' awareness of the health and zoonotic risks associated with toxoplasmosis is also crucial to reducing parasite circulation in traditional production systems.

Furthermore, this study highlights the need to develop targeted surveillance programs for reproductive diseases in dromedaries in Algeria. Enhanced diagnostic investigations, improved veterinary coverage in Saharan regions, and longitudinal studies would help better understand the epidemiology of abortive infections and their true impact on herd productivity. Additional molecular studies are also needed to identify circulating T. gondii genotypes and assess their potential virulence in camelids.

In conclusion, this study makes a significant scientific contribution to the understanding of protozoal diseases in dromedaries in Algeria. It highlights the potential role of *T. gondii* in reproductive disorders in camel herds in southeastern Algeria and emphasizes the importance of incorporating abortive protozoal infections into herd health management strategies. The data generated provide a valuable scientific basis for improving reproductive health in camelids and for developing sustainable strategies to reduce the impact of parasitic infections in Saharan camel production systems.

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Appendix

Souk Ahras University
Institute of Agronomic and Veterinary Sciences (ISAV), Taoura
Questionnaire
Epidemiological and Pathological Study of Abortions in Camels
Prepared by: Dr. Hind HOUSSOU and Amira DJEDDOU BENABID

Breeder:....................Province:.........................District: ....Municipality:................

General Herd Information

1. Camel Herd Composition

Animals	Number
She-camels	
Adult male	
Camel calves	
Total	

1. Other Animal Species Present on the Farm

Animals	Number
Cattle	
Sheep	
Goats	
Dogs	
Cats	
Others (specify)	

2. Herd Management

- Production system

Extensive		Intensive		Semi-intensive	

- Herd replacement strategy

Purchase	Self-replacement	Mixed

Récent introductions:…………………...…………..

Reproductive disorders

- Abortions

☐ History **yes** **No**
☐ Frequence

Rare	Frequent	High rate

- Month of abortion

- Recent abortions

Nbr of reproductive females	Parity	2022	2023	2024	2025
Births	primiparous				
	multiparous				
Abortions	primiparous				
	multiparous				

- Gestational stage

1st trimester		2ed trimester		3rd trimester		4th trimester	

Observed clinic sings:…………………………………………….......................

…………………………………………………………………………………….....................….

- Appearance of the aborted fetus

Normal		Mommified		Hemorrhagic		Malformed	

- Delivrance/Expulsion

Complete		incomplete	

- Appearance of the placenta

Normal		Hemorrhagic		Necrotic	

Disposal of the placenta and the aborted fetus ……………………………………………

- Measures taken following an abortion

No action		Isolation		Veterinary assistance	

- Stilbirths / frequence / observed symptoms ………………….........................

…………………………………………………………………………………………
…………………………………………………………………………………………

* Possible causes of abortion according to the breeder……...

……………………………………………………………………………….....................

Scientific Outputs

This doctoral work has led to international publications and has been presented at both national and international conferences:

International publications

- Djeddou-Benabid, A., Houssou, H., Djeddi, K., & Ouachtati, D. (2025). Toxoplasmosis in camelids: the last 20 years. *Brazilian Journal of Animal and Environmental Research*, 8(1), e76696-e76696.

- Djeddou-Benabid, A; Houssou, H; Bennoune, O; Nouicer, F; & Djaout, A (2026). Epidemiological survey of abortion in camels *(Camelus dromedarius)* and histopathological investigation of Toxoplasmosis and Neosporosis in those animals from slaughterhouses in Southeastern Algeria, *The Thai Journal of Veterinary Medicine:* Vol. 56: Iss. 2, Article 7.

International conferences

- The 9th International Seminar of BIODIVERSITY: Food Security & Health (MGIBR 2024). April 20-21-22, 2024 (University of Tlemcen, Algeria).

- The 1st International Seminar of AgriFood and lndustrial Biotechnology (ISABI 2024). June 26-27, 2024 (University of Khmis Meliana, Algeria).

- Mediterranean Conference on Environment, Risks and Health (MCERH 2024). October 15-16, 2024 (University of Souk-Ahras, Algeria).

National conferences

- 1er Séminaire national de Biodiversité, Risques environnementaux (SNBRESP 2024). April 23-24, 2024 (Université d'El Taref, Algerie).

- 1 st National online Seminar on the Restoration and Rehabilitation of Natural Ecosystems in the face of global change in Algeria (RRNE 2024). June 24, 2024 (University of Relizane, Algeria).

Toxoplasmosis in camelids: the last 20 years

Toxoplasmose em camelídeos: os últimos 20 anos

Toxoplasmosis en camélidos: los últimos 20 años

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ABSTRACT
Toxoplasmosis is a universal zoonosis caused by an obligate intracellular parasite, *Toxoplasma gondii*. One of its main manifestations is abortion in humans and animals. The present review aims to clarify the situation of the disease in camelids in different countries across the four continents of the world (Africa, Asia, America and Europe) over the past twenty years. The research strategy involved collecting all published data during this period, focusing on the prevalence of *Toxoplasma gondii* infection and genotyping in different camelid species, as well as analyzing the various identified risk factors. This review provides a comprehensive epidemiological analysis of *Toxoplasma gondii* infection worldwide, making it a valuable resource for researchers. In total, 81 studies published between 2004 and 2024 involving 22040 camelids from 23 countries were included for the final analyses (Seropositivity studies covered 21844 camelids, while genotyping studies were performed on 585 camelids). The overall global seroprevalence of *Toxoplasma gondii*

Original Article

Epidemiological survey of abortion in camels (*Camelus dromedarius*) and histopathological investigation of Toxoplasmosis and Neosporosis in those animals from slaughterhouses in Southeastern Algeria

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Abstract

Toxoplasma gondii and *Neospora caninum* are heteroxenous apicomplexan parasites recognized as major causes of reproductive disorders in numerous mammalian species. The present study aimed to assess through an epidemiological survey, the prevalence of reproductive losses in 75 dromedary herds during the period 2022-2025, as well as the associated risk factors, and to detect these protozoa by histopathological analysis in 63 dromedaries slaughtered at the slaughterhouse of El Oued province (126 samples: 63 hearts and 63 diaphragms). The survey revealed that 80% of the herds had a history of abortions, of which 60% also reported cases of stillbirth. Risk factor analysis showed a significant association exclusively with the presence of domestic cats and dogs (P < 0.05). Histological examination revealed forms compatible with *T. gondii* exclusively in the cardiac muscle of adult females, with tachyzoites detected in one animal (1.6%) and tissue cysts in two animals (3.17%). No evidence of *N. caninum* was detected. Cardiac lesions were characterized by mononuclear cell infiltrates, focal hemorrhages and areas of necrosis, indicating marked inflammatory and vascular reactions. These findings suggest that *T. gondii*, may be involved in reproductive losses in dromedaries and effective parasite control strategies specific to dromedary camels need to be developed.

Keywords: abortion, *Toxoplasma gondii*, *Neospora caninum*, dromedaries, histopathology

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Abstract

Abortions represent one of the major challenges faced by dromedary breeders in Algeria due to their economic, health, and zoonotic implications. Among the causative agents, *Toxoplasma gondii* and *Neospora caninum*, two heteroxenous apicomplexan parasites, are recognized as major causes of reproductive disorders in numerous mammalian species. In this context, the present study aimed, through an integrated epidemiological approach, to assess the extent of reproductive losses using a breeder-based survey and to identify the associated risk factors; to determine the seroprevalence of *T. gondii* and *N. caninum* in dromedaries (*Camelus dromedarius*) as well as the risk factors associated with seropositivity; and to investigate the presence of these parasites through histopathological analysis in order to characterize the associated lesions. The epidemiological survey conducted in 75 herds revealed that 80% had a history of abortion, of which 60% also reported cases of stillbirth. Abortion rates ranged from 8.5% to 11.1% in primiparous females and from 9.3% to 10.3% in multiparous females. Most abortions (90%) occurred between mid and late gestation, with a marked seasonal concentration from August to November. Furthermore, fetal and placental lesions compatible with *T. gondii* and *N. caninum* infections were observed in 28% and 40% of abortion cases, respectively. Multiple correspondence analysis (MCA) identified three distinct herd classes characterized by different health and epidemiological profiles. Risk factor analysis for reproductive losses showed a significant association with the presence of domestic cats and dogs ($p < 0.05$). In parallel, a serological study carried out on 184 apparently healthy dromedaries revealed no seropositivity for *N. caninum*, providing the first available data for this species in Algeria. In contrast, an overall seroprevalence of 8.69% (95% CI: 5.1–13.7) was observed for *T. gondii*. Analysis of risk factors for seropositivity showed a significant association with age, the presence of cats, and a history of abortion ($p < 0.05$). Finally, histopathological analysis performed on 126 samples (63 hearts and 63 diaphragms) collected from 63 slaughtered dromedaries revealed structures compatible with *T. gondii* exclusively in the cardiac muscle of adult females. Tachyzoites were observed in one animal (1.6%), and tissue cysts in two animals (3.17%), whereas no structures compatible with *N. caninum* were detected. Cardiac lesions were characterized by mononuclear cell infiltration, focal hemorrhages, and areas of necrosis, indicating marked inflammatory and vascular responses. Overall, these findings suggest a potential involvement of *T. gondii* in reproductive losses in dromedaries in Algeria and highlight the need to implement appropriate surveillance and control strategies.

Keywords

Abortion, *Toxoplasma gondii*, *Neospora caninum*, risk factors, Algeria, *Camelus dromedarius*

Résumé

Les avortements constituent l'un des principaux défis auxquels sont confrontés les éleveurs de dromadaires en Algérie, en raison de leurs répercussions économiques, sanitaires et zoonotiques. Parmi les agents incriminés, *Toxoplasma gondii* et *Neospora caninum*, deux parasites apicomplexes hétéroxènes, sont reconnus comme des causes majeures de troubles de la reproduction chez de nombreuses espèces de mammifères. Dans ce contexte, la présente étude avait pour objectif, à travers une approche épidémiologique intégrée d'évaluer l'ampleur des pertes de reproduction à l'aide d'une enquête menée auprès des éleveurs et d'identifier les facteurs de risque associés, de déterminer la séroprévalence de *T. gondii* et *N. caninum* chez le dromadaire *(Camelus dromedarius)* ainsi que les facteurs de risque de la séropositivité, et de rechercher la présence de ces parasites par analyse histopathologique afin de caractériser les lésions associées. L'enquête épidémiologique menée auprès de 75 troupeaux a révélé que 80 % d'entre eux présentaient des antécédents d'avortement, dont 60 % étaient également concernés par des cas de mortinatalité. Les taux d'avortement variaient de 8,5 % à 11,1 % chez les femelles primipares et de 9,3 % à 10,3 % chez les femelles multipares. La majorité des avortements (90 %) survenaient entre le milieu et la fin de la gestation, avec une concentration saisonnière marquée entre août et novembre. Par ailleurs, des lésions fœtales et placentaires compatibles avec des infections à Toxoplasma gondii et Neospora caninum ont été observées respectivement dans 28 % et 40 % des cas d'avortement. L'analyse des correspondances multiples (ACM) a permis d'identifier trois classes distinctes de troupeaux, caractérisées par des profils sanitaires et épidémiologiques différenciés.L'analyse des facteurs de risque liés aux pertes de reproduction a mis en évidence une association significative avec la présence de chats et de chiens domestiques ($p < 0,05$). Parallèlement, une étude sérologique réalisée sur 184 dromadaires apparemment sains a montré l'absence de séropositivité vis-à-vis de *N. caninum*, constituant ainsi les premières données disponibles chez cette espèce en Algérie. En revanche, une séroprévalence globale de 8,69 % (IC 95 % : 5,1–13,7) a été observée pour *T. gondii*. L'analyse des facteurs de risque de la séropositivité a révélé une association significative avec l'âge, la présence de chats et les antécédents d'avortement ($p < 0,05$). Enfin, l'étude histopathologique réalisée sur 126 prélèvements (63 cœurs et 63 diaphragmes) issus de 63 dromadaires abattus a permis de mettre en évidence des formes compatibles avec *T. gondii* exclusivement au niveau du muscle cardiaque des femelles adultes. Des tachyzoïtes ont été observés chez un animal (1,6 %) et des kystes tissulaires chez deux animaux (3,17 %), tandis qu'aucune structure parasitaire compatible avec *N. caninum* n'a été détectée. Les lésions cardiaques étaient caractérisées par des infiltrats de cellules mononucléées, des hémorragies focales et des zones de nécrose, traduisant une réponse inflammatoire et vasculaire marquée. Dans l'ensemble, ces résultats suggèrent une implication potentielle de *T. gondii* dans les pertes de reproduction chez le dromadaire en Algérie et soulignent la nécessité de mettre en place des stratégies de surveillance et de contrôle adaptées.

Mots clé

Avortement, *Toxoplasma gondii*, *Neospora caninum*, facteurs de risque, Algérie, *Camelus dromedarius*

الملخـــــــص

تُعد حالات الإجهاض من أبرز التحديات التي تواجه مربي الإبل في الجزائر، نظرًا لانعكاساتها الاقتصادية والصحية والوبائية المشتركة. ومن بين العوامل المسببة، يُعتبر كل من *Toxoplasma gondii* و *Neospora caninum*، وهما طفيليان من الأبيكومبلكسا ذات دورة حياة غير مباشرة، من الأسباب الرئيسية لاضطرابات التكاثر لدى العديد من أنواع الثدييات. في هذا السياق، هدفت هذه الدراسة، من خلال مقاربة وبائية متكاملة، إلى تقييم مدى خسائر التكاثر اعتمادًا على استبيان موجه للمربين وتحديد عوامل الخطر المرتبطة بها؛ وتحديد الانتشار المصلي لكل من *T. gondii* و *N. caninum* لدى الإبل (*Camelus dromedarius*)، بالإضافة إلى تحديد عوامل الخطر المرتبطة بالإيجابية المصلية؛ وكذلك البحث عن وجود هذه الطفيليات من خلال التحليل النسيجي المرضي بهدف توصيف الآفات المرتبطة بها . أظهرت الدراسة الوبائية التي شملت 75 قطيعًا أن 80٪ منها سجلت سوابق إجهاض، من بينها 60٪ سجلت أيضًا حالات ولادة جنين ميت. وتراوحت نسب الإجهاض بين 8.5٪ و11.1٪ لدى الإناث البِكر، وبين 9.3٪ و10.3٪ لدى الإناث متعددة الولادات. كما لوحظ أن معظم حالات الإجهاض (90٪) حدثت خلال منتصف ونهاية فترة الحمل، مع تركز موسمي واضح بين شهري أوت ونوفمبر. كما تم تسجيل آفات جنينية ومشيمية متوافقة مع الإصابة بـ *T. gondii* و *N. caninum* بنسبة 28٪ و40٪ على التوالي من حالات الإجهاض. وأظهر تحليل المراسلات المتعددة (ACM) وجود ثلاث فئات متميزة من القطعان، تتميز بخصائص صحية ووبائية مختلفة. كما أظهر تحليل عوامل الخطر المرتبطة بخسائر التكاثر وجود علاقة ذات دلالة إحصائية مع وجود القطط والكلاب المنزلية ($p < 0.05$). بالتوازي، كشفت الدراسة المصلية التي أُجريت على 184 رأسًا من الإبل السليمة ظاهريًا عن عدم وجود إيجابية مصلية لـ *N. caninum*، مما يمثل أول بيانات متاحة لهذه الفصيلة في الجزائر. في المقابل، تم تسجيل نسبة انتشار مصلي إجمالية قدرها 8.69٪ (95% CI: 5.1–13.7) بالنسبة لـ *T. gondii*. كما أظهر تحليل عوامل الخطر للإيجابية المصلية وجود علاقة معنوية مع العمر، ووجود القطط، وسوابق الإجهاض ($p < 0.05$). وأخيرًا، أظهرت الدراسة النسيجية المرضية، التي شملت 126 عينة (63 قلبًا و63 حجابًا حاجزًا) من 63 رأسًا من الإبل المذبوحة، وجود تراكيب متوافقة مع *T. gondii* على مستوى العضلة القلبية لدى الإناث البالغة فقط. حيث تم الكشف عن التاكيزويتات لدى حيوان واحد (1.6٪) والأكياس النسيجية لدى حيوانين (3.17٪)، في حين لم يتم تسجيل أي دليل على وجود *N. caninum.* وتميزت الآفات القلبية بوجود ارتشاحات خلوية أحادية النواة، ونزيف بؤري، ومناطق نخر، مما يدل على استجابة التهابية ووعائية ملحوظة. تشير هذه النتائج إلى احتمال تورط *T. gondii* في خسائر التكاثر لدى الإبل في الجزائر، وتؤكد ضرورة وضع استراتيجيات ملائمة للمراقبة والسيطرة على هذا الطفيلي.

الكلمات المفتاحية

الإجهاض، *Toxoplasma gondii*، *Neospora caninum*، عوامل الخطر، الجزائر، الإبل