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ORIGINAL ARTICLE

Relationship between chronic diseases, hair cortisol concentration and welfare of housed dairy goats

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ABSTRACT. The aim of this study was to evaluate the relationship between seroprevalence of chronic diseases, hair cortisol concentration (HCC), and welfare of dairy goats housed throughout a productive cycle. Sixty multiparous dairy goats, over four years old, were selected. An animal welfare assessment was conducted using health indicators for goats, according to the AWIN protocol. Blood samples were also collected for haematology and determination of seroprevalence of chronic diseases, hair samples for determination of HCC, milk samples for chemical composition and somatic cell counts, and faecal samples for parasite load. Small Ruminant Lentivirus (SRLv) had a prevalence of 71.66%, *Mycobacterium avium* subspecies *paratuberculosis* (MAP) of 5%, *Leptospira interrogans* of 40% and *Ovine Gammaherpesvirus* type 2 (OvHV-2) of 50%. The percentages of goats that tested positive for one, two or three diseases were 31.67%, 50% and 11.66% respectively. Haematological alterations included hyperproteinaemia (84.94 ± 1.58 g/L) and hyperfibrinogenaemia (6.11 ± 0.65 g/L) for those with one or two diseases, with significant differences being found ($P < 0.05$). The welfare indicators related to health and the number of diseases were poor body condition, poor coat, poor udder conformation, and mucosal lesions ($P < 0.05$). However, no significant differences were observed between HCC and the number of chronic diseases in dairy goats ($P > 0.05$). Higher concentrations of cortisol in hair were found at 150 days of lactation (16.65 ± 1.39 pg/mg) compared to the mating season (9.55 ± 0.04 pg/mg) ($P < 0.05$). No associations were found ($P > 0.05$) between the production, composition, and somatic cell counts in milk and cortisol concentrations and diseases. It was concluded that the presence of chronic diseases in goats did not influence hair cortisol concentrations, possibly due to an effect of adaptive tolerance to diseases, as occurs in other domestic species; however, there was an effect of the productive stage.

Keywords: chronic stress, caprine arthritis and encephalitis, paratuberculosis, leptospirosis

INTRODUCTION

The presence of chronic diseases in goat production can seriously threaten goat homeostasis, welfare, and productivity. These diseases produce inflammatory lesions in different organs and tissues, which reduce the productivity and well-being of animals (Licitra *et al*., 2021). The disease tolerance of an animal is the ability to preserve homeostasis while limiting the detrimental impact of infection on health and performance without affecting the pathogen load *per se* (Nakov *et al*., 2019). The main chronic infectious diseases of economic importance in intensive goat rearing systems are caprine arthritis and encephalitis, paratuberculosis, caseous lymphadenitis, leptospirosis and parasitosis caused by gastrointestinal nematodes (Muri *et al*., 2016; Fontaine & Baird, 2008; Alberti *et al*., 2012). When these diseases are not diagnosed and controlled in a timely manner, they represent a threat to health and well-being, negatively impacting production (Muri *et al*., 2016; Di Cerbo *et al*., 2010; Luna *et al*., 2018). The presence of diseases in production animals is an indicator of deterioration in animal welfare, which implies that they experience continuous stress with physiological and behavioural responses, exerting an immunosuppressive effect. In livestock production, stress has been considered an inevitable reaction that occurs when animals are exposed daily to adverse environmental conditions, and is the cause of many unfavourable consequences, ranging from discomfort to death (Etim *et al*., 2013).

Hair cortisol concentration (HCC) has been proposed as an indicator of chronic stress, as it is incorporated into the hair from the bloodstream and skin through passive diffusion during its growth stage, being a reliable long-term indicator to retrospectively evaluate the activity of the hypothalamic-pituitary-adrenal axis and the response to chronic stressors (González de la Vara *et al*., 2011; Heimburge *et al*., 2019; Russell *et al*., 2012; Moya *et al*., 2013). The stability of hair cortisol concentrations over time has been demonstrated, suggesting that it may be a reliable measure of long-term cortisol secretion (Davenport *et al*., 2006; Stalder *et al*., 2012) and useful in humans and wild and domestic animals

(Gow *et al.*, 2010; Koren *et al.*, 2002; Tekin *et al.*, 2023; Casal *et al.*, 2017). Although it is not completely clear whether HCC can serve as a retrospective indicator of the history of non-specific diseases in animals, preliminary studies in dairy cattle have reported higher concentrations of cortisol in the hair of sick cows (metritis, laminitis, and mastitis) than in clinically healthy cows (Comin *et al.*, 2013). Other investigations in dairy cattle have not found the usefulness of HCC as an indicator of stress in dehorning, bronchopneumonia, or laminitis, considering these as acute processes (Braun *et al.*, 2017; Braun, *et al.*, 2019; Fischer-Tenhagen *et al.*, 2018). In a study on hair cortisol concentrations in adult goats, no significant differences were observed between rough hair (poor nutrition) and normal hair (healthy goats) (Battini *et al.*, 2015).

Welfare assessments of goat farms have gained relevance in recent decades, especially in intensive systems, because animals face greater exposure to stressors (Arsoy, 2020). Animal welfare assessment protocols have been developed at farm level, where they incorporate valid and reliable indicators that include direct indicators (measurable in the animal) and indirect indicators (measurable in the environment and in the management of livestock workers) (Caroprese *et al.*, 2009; Battini, *et al.*, 2015; Spigarelli *et al.*, 2020).

Information on the impact of chronic diseases in dairy goats and their effects on welfare and productivity is limited compared with other domestic species. Therefore, it was hypothesised that chronic diseases in housed dairy goats would have a significant effect on hair cortisol concentrations as an indicator of chronic stress, producing a negative impact on the welfare and productivity of the goats. The aim of this study was to evaluate the relationship between the seroprevalence of chronic diseases, hair cortisol concentrations, and welfare of dairy goats housed throughout a productive cycle.

MATERIAL AND METHODS

Description of the productive unit

The present work was carried out in an intensive goat production unit located in Querétaro, Mexico, characterised by a temperate semi-dry climate, with summer rains (climate type BS1k (x')), altitude of 1920 m above sea level, north latitude 20° 54' 29'', west longitude 99° 55' 51'', average annual temperature of 17.6°C and average annual rainfall of 538 mm (INEGI, 2021). An evaluation instrument was used to assess the productive, nutritional, and health management of the animals. The goat farm had a history of clinical cases of caprine arthritis, encephalitis, paratuberculosis, and herpesvirus.

Animals and housing

This research project was evaluated and approved by the Institutional Subcommittee for the Care and Use of Experimental Animals (SICUAE.DC-2020/4-4, FMVZ, UNAM). This study was observational, analytical, and prospective (Noordzij *et al.*, 2009). Initially, 60 dairy genotype goats, multiparous, over four years of age, average body weight of 56.45 ± 1.48 kg, were randomly selected. Each animal received a diet based on its nutritional requirements (NRC, 2007), consisting of alfalfa and oat hay, corn silage, and a vitamin-mineral mixture. The animals were housed in two pens connected to each other with a total area of 330 m^2, two automatic bowl drinkers, a linear feeder with 34 individual feeders, a dirt floor, and a metal shade. Goats were evaluated during different productive stages, including mating, gestation, postpar-

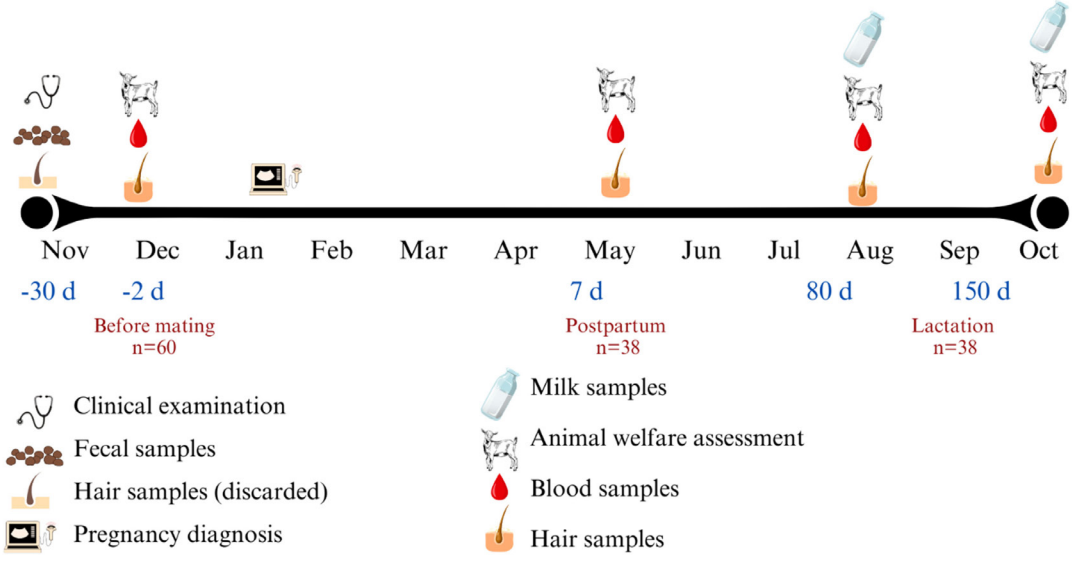

Figure 1.
Schematic representation of the experimental design for a productive cycle in housed dairy goats.

tum, and lactation (Figure 1). Thirty days before starting the study, 10 g of faecal samples were collected rectally from each animal to determine parasite load using the McMaster technique (Figueroa-Castillo *et al*., 2015). A general clinical examination was performed for each of the selected animals (Duguna, 2016).

Reproductive management included synchronisation of oestrus with 150 µg intramuscular prostaglandin F2α (Lutalyse®, Zoetis), and mating was carried out 48 hours later. Forty-five days later, pregnancy was diagnosed using transrectal ultrasound (Mindray®). After birth, the kids were reared with their dams and weaned at 80 days. Milking was performed daily using a Flaco® carousel mechanical milking machine with 24 units, once a day at 07:00 h.

Health evaluation

Two days prior to mating, 10 ml of blood was collected from the jugular vein, and the serum was recovered by centrifugation and stored at -20°C until processing. The Luminex® Multiplex technique (Bio-plex 200 System) was used for the detection of Small Ruminant Lentivirus (recombinant proteins p16 and gp38), *Mycobacterium avium* subspecies *paratuberculosis* (PPA3 protoplasmic antigen), and *Brucella melitensis* (native hapten) (Nájera-Rivera *et al*., 2023). The Microscopic Agglutination technique (WHO, 2012) was performed using 70 µL of serum to identify 10 serovars of *Leptospira interrogans* (Autumnalis, Bratislava, Canicola, Gryppotyphosa, Hardjo, Icterohaemorrhagiae, Pomona, Pyrogenes, Serdjo, and Tarassovi). We were provided with previous results of an outbreak of herpesvirus due to *ovine gammaherpesvirus* type 2, diagnosed using ELISA and PCR (Madrigal-Valencia *et al*., 2023). Goats were then grouped into one, two, and three disease groups and evaluated throughout the study.

For haematology, 4 ml of blood with EDTA anticoagulant was extracted 2 days before mating, 7 days postpartum, and at 80 and 150 days of lactation. The analytes determined were haematocrit, total protein, fibrinogen, total leukocyte count, and its differential (neutrophils, lymphocytes, monocytes, eosinophils, and basophils).

Hair cortisol analysis

The samples were recovered from the chest region, considering that it is one of the body areas that suffers less aggression from the environment and contamination (saliva, faeces, and urine). The hair of a 7 x 7 cm area of the chest region was shaved and discarded using an electric machine (Andis®) one month before starting the first sampling, since at that time the animals were housed in new pens for adaptation and observation. Hair sampling periods were performed by shaving the same chest area, 2 days before mating, 7 days postpartum, and at 80 and 150 days of lactation. The samples were stored in a dry room temperature bag and protected from sunlight until processing.

The HCC was determined using an adaptation of the cortisol extraction methodology proposed by Davenport *et al.* (2006) and Koren *et al.* (2002). In this process, 300 mg of hair was washed with 5 ml of isopropyl alcohol to remove any dirt, followed by drying at room temperature for 2 h. Subsequently, the hair was finely cut (approximately 0.2 cm) with surgical scissors, and 200 mg of hair was weighed on an analytical scale (Denver Instrument PI-314®). These samples were placed in 20 ml borosilicate bottles, and 10 ml of methanol was added. After shaking the samples for 3 h, they were left to rest overnight and finally shaken again for 3 h (Vortex Mixer, UltraCruz®). The supernatant was transferred to other borosilicate bottles and allowed to evaporate for 5–7 days at room temperature, keeping the samples in an extraction chamber. Cortisol adhering to the walls of the bottles was reconstituted with 200 µL of phosphate-buffered saline (PBS) and shaken for 3 min. Subsequently, a 1:20 dilution was carried out to determine hair cortisol (pg/mg) using the enzyme-linked immunosorbent assay (indirect ELISA) test in duplicate, using 50 µL of the diluted extract, following the instructions for the Arbor Assays Cortisol commercial kit (K003-H1/H5) DetectX ® (antibody cross-reactivity for prednisolone 7.8%, cortisone 1.21%, dexamethasone 18.8%, corticosterone 1.2%, progesterone, and oestradiol < 0.1%). The intra- and inter-assay coefficients of variation (CV) were 8.76% and 8.13%, respectively.

Animal welfare assessment

Individual evaluations of animal welfare were carried out 2 days before mating, 7 days postpartum, and 80 and 150 days of lactation, selecting indicators related to health: body condition score (-1: thin, 0: optimal, 1: fat), hair coat condition (0: good coat, -1: bad coat); for abscesses, lameness, nasal and ocular discharge, and faecal soiling, they were scored by assigning 0: absent and 1: present (AWIN, 2015). In addition, other indicators related to animal health were considered: coughing, lymphadenomegaly, udder disorders (asymmetry, wounds, and hardening), arthritis, mucosal lesions (oral and vaginal), and vaginal discharge, which were scored as 0 (absent) and 1 (present) (Table 1).

Milk analysis.

Milk production was recorded individually every 15 days from 80 to 150 days of lactation. To analyse milk composition, a 150 ml sample was collected in a glass container by manual milking from each teat at 80 and 150 days of lactation. Analytes measured included somatic cell count (cells/µL), using a DeLaval® automatic counter; determination of acidity (°Dornic) with an acidimeter; and milk composition, including percentage of fat, protein, lactose, and non-fatty solids, using a MilkoScan® infrared spectrophotometre. The reference values used for the chemical composition of goat milk were in accordance with Mexican standard NMX-F-728-COFOCALEC-2007.

Statistical analysis

SAS® statistical package (v. 9) was used to analyse the data. Univariate procedure was used for each variable

Table 1.
Health indicators for the assessment animal welfare in housed dairy goats (AWIN, 2015).

Welfare indicator	Assessment criteria
Body condition score	Is visually assessed at the rear of individual goat, using a three-level scoring method.
Hair coat condition	Goats with poor hair coat condition (described as: matted, rough, scurfy, uneven, shaggy hair coat, frequently longer than normal) are recorded.
Abcesses	The presence of abscesses (ruptured or not) is recorded.
Lymphadenomegaly	Increase in the size of the lymph nodes, which are easy to observe and palpate, are recorded.
Udder disorders	Three characteristics are evaluated (asymmetry, wounds, and mammary gland hardening). The presence of one half of the udder that is at least 25% longer than the other is recorded.
Fecal soiling	The presence of soft fecal matter below the tail head and on both sides of the tail is visually assessed on individual goats, as a sign of diarrhea.
Coughing	One or a combination of the following: paroxismal coughing, respiratory distress including abdominal effort associated with breathing or wheezing. A single cough that may occur as part of a normal reflex when grazing not included.
Nasal discharge	The presence of any mucous or purulent discharge (white or yellowish) from the nose is visually assessed on individual goats.
Ocular discharge	The presence of clearly visible flow from one or two eyes is visually assessed on individual goats.
Vaginal discharge	The presence of any mucous or purulent discharge (white or yellowish) from the vaginal is visually assessed on individual goats.
Mucosal lesions	Ulcerative lesions of the oral and vaginal mucosa were recorded by evaluating each goat.
Lameness	Goats showing signs of severe lameness (based on abnormal gait, head nodding, spine curvature, kneeling) are recorded.
Arthritis	Articular inflammations in the front and hind legs of the goats were evaluated.

collected to obtain measures of central tendency and dispersion. The Shapiro-Wilk normality test and Bartlett's test for homogeneity of variance were used. A completely randomised design was carried out using analysis of variance and Tukey's test to evaluate the differences between the productive stages. In addition, analysis of variance with repeated measurements over time (proc MIXED) was used to evaluate HCC and the number of diseases per productive stage; the level of significance was $P < 0.05$. The non-parametric chi-square test was used for the qualitative variables of the individual indicators related to health in different productive stages. To evaluate the degree of association between variables, Pearson and Spearman correlation analyses were performed, and the level of significance was set at $P < 0.05$.

RESULTS

Health evaluation

Table 2 shows the seroprevalences of Small Ruminant Lentivirus (SRLv), *Mycobacterium avium* subspecies *paratuberculosis* (MAP), *Brucella melitensis*, *Leptospira interrogans* and *Ovine Gammaherpesvirus* type 2 (OvHV-2) in housed dairy goats. The pathogenic serovars of *Leptospira interrogans* (Lepto) most frequently observed in dairy goats were Icterohaemorrhagiae (9/24), Hardjo (6/24), and Canicola (4/24). Table 3 presents the frequency of goats that were seropositive for one, two, or three chronic diseases, and their combinations. Only 38 goats were delivered, representing 63.33% of fertility. It should be noted that goats without disease did not become pregnant. Of the seropositive goats, 50% showed at least one clinical sign related to the diagnosed disease. Before mating, a low parasite load of 253.57 ± 87.46 eggs per gram of feces was recorded for strongylids, and 146.42 ± 49 oocysts per gram of feces for coccidia.

On the other hand, significant differences were observed by disease number and haematological alterations ($P < 0.05$), with one and two diseases were hyperproteinaemia (84.94 ± 1.58 g/L) and hyperfibrinogenaemia (6.11 ± 0.65 g/L), leukocytosis (13.95 ± 0.64 x 109/L) and neutrophilia (8.42 ± 0.44 x 109/L) were also observed for goats that had one disease.

Hair cortisol analysis

Figure 2 shows the HCC in dairy goats at different productive stages. Highly significant differences ($P < 0.0001$) were observed by productive stage, finding a lower concentration before mating (9.55 ± 0.04 pg/mg) and the highest concen-

Table 2.
Seroprevalence of chronic diseases in housed dairy goats (n=60).

Etiology	N° of goats	%
SRLv	43	71.66
MAP	3	5
Brucella melitensis	0	0
Leptospira interrogans *	24	40
OvHV-2	30	50

SRLv, Small Ruminant Lentivirus; MAP, *Mycobacterium avium* subspecies *paratuberculosis*; OvHV-2, *Ovine Gammaherpesvirus* type 2.
*Serial double microscopic agglutination test. A dilution cut-off of 1:100 was considered positive.

Table 3.
Frequency of dairy goats seropositive with one, two or three chronic diseases (n=60).

Diseases	Etiology	N° of goats	%
Without diseases	-	4	6.67
1	MAP	1	1.67
	SRLv	10	16.66
	OvHV-2	7	11.67
	Lepto	1	1.67
2	SRLv + Lepto	14	23.33
	SRLv + OvHV-2	12	20
	Lepto+ OvHV-2	4	6.66
3	SRLv + Lepto + OvHV-2	5	8.33
	SRLv + MAP + OvHV-2	2	3.33

SRLv, Small Ruminant Lentivirus; Lepto, *Leptospira interrogans*; OvHV-2, *Ovine Gammaherpesvirus* type 2; MAP, *Mycobacterium avium* subspecies *paratuberculosis*.

tration was at 150 days of lactation (16.65 ± 1.39 pg/mg), which corresponds to the accumulation of cortisol from 81 to 150 days of lactation, during this period the goats were subjected to the stress of weaning (80 days postpartum) and mechanical milking. Cortisol concentrations in hair did not show significant differences ($P > 0.05$) in the number of diseases (Figure 3). At the mating period, goats with zero, one or three diseases recorded cortisol concentrations less

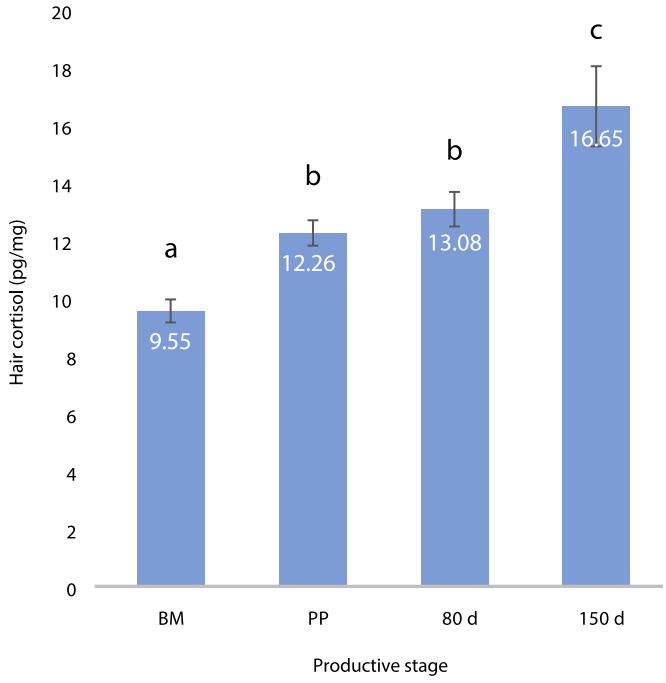

Figure 2.
Mean ± SE of hair cortisol concentrations (pg/mg) of housed dairy goats at different productive stages. BM, before mating (n = 60); PP, postpartum; 80 d and 150 d, days of lactation (n = 38). a, b, c: Different letters indicate differences between productive stages ($P < 0.001$).

than 10 pg/mg ($P > 0.05$) and goats with two diseases had an average of 12.18 ± 0.87 pg/mg ($P > 0.05$). In the postpartum period, the goats with two diseases recorded the highest concentrations of cortisol 15.57 ± 3.51 pg/mg compared to those with 1 or 3 diseases ($P > 0.05$).

Table 4 shows HCC and disease seroprevalence in housed dairy goats, no significant association was found ($P > 0.05$) with milk production (r = 0.2154, $P > 0.05$), chemical composition: fat (r = 0.1168, $P > 0.05$), protein (r = 0.1024, $P > 0.05$), lactose (r = 0.0863, $P > 0.05$) and non-fat solids (r = 0.0568, $P > 0.05$); and milk somatic cells (r = 0.0268, $P > 0.05$).

Animal welfare assessment

Individual evaluations of welfare related to health showed significant differences ($P < 0.05$) between the productive stages. In the two days period before mating, 38.3% of the animals (23 goats) had a poor body condition score (BCS) and coat; abscesses occurred in nine goats (15%), and locomotion problems associated with arthritis, mainly in the carpal region with the presence of mild to moderate lameness in six goats (10%). In addition, one case of ulcerative vulvovaginitis was observed, and 19 cases of ulcerative stomatitis were associated with *Ovine Gammaherpesvirus* type 2. Seven days postpartum, the animals presented with a poor coat condition (41%) and BCS (25%). At 80 days of lactation, 76% of the animals had a good BCS and coat condition, 8.33% of the goats had arthritis and hardening of the udder, and at

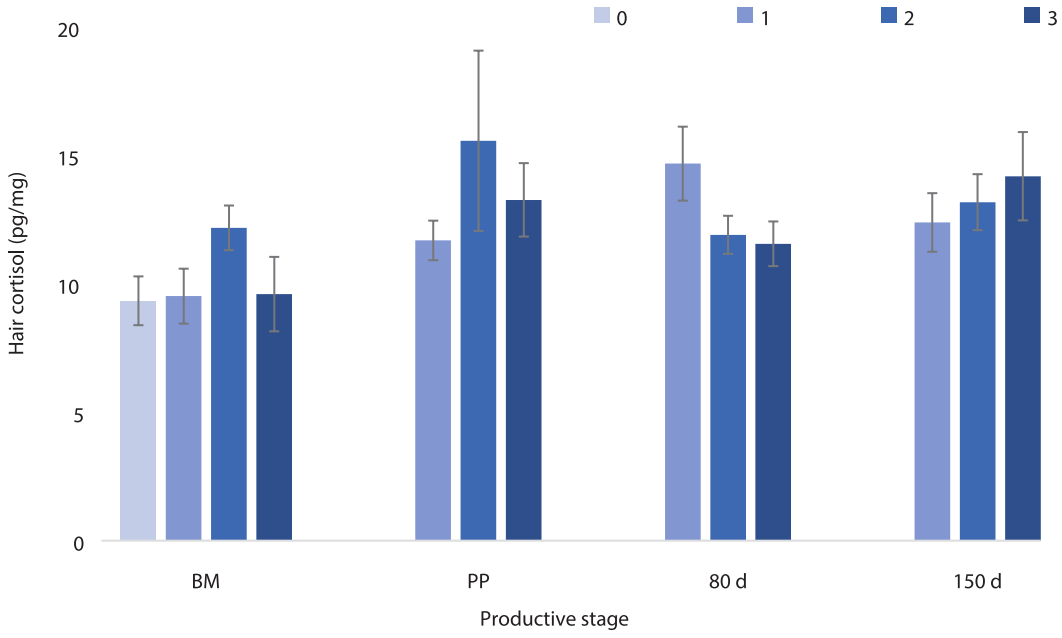

Figure 3.
Mean ± SE of hair cortisol concentrations (pg/mg) of housed dairy goats with different seropositive diseases and productive stages ($P > 0.05$). BM, before mating; PP, postpartum; 80 d and 150 d, days of lactation; 0, without disease; 1, one disease; 2, two diseases; 3, three diseases.

Table 4.
Milk production and chemical composition of milk in dairy goats housed according to the number of diseases.

	One disease (n = 13) (Mean ± SE)	Two diseases (n = 17) (Mean ± SE)	Three diseases (n = 5) (Mean ± SE)	r	*P-value*
Total milk yield (L)	186 ± 23.05	233 ± 21.48	192.81 ± 37.80	0.2154	> 0.05
Protein (%)	4.14 ± 0.24	4.31 ± 0.25	4.48 ± 0.47	0.1168	> 0.05
Fat (%)	4.62 ± 0.20	4.98 ± 0.29	5.01 ± 0.95	0.1024	> 0.05
Lactose (%)	4.06 ± 0.19	3.99 ± 0.13	4.10 ± 0.25	0.0863	> 0.05
Non fat solids (%)	9.12 ± 0.24	9.47 ± 0.27	9.55 ± 0.55	0.0568	> 0.05
SCC (cells/ µL)	824 ± 233.49	986 ± 136.08	925 ± 216.50	0.0268	> 0.05

SCC: somatic cells count

150 days of lactation, 27 goats showed mild to severe lesions in the oral mucosa. Figure 4 shows the frequencies of the different health indicators with the number of diseases, in which significant differences ($P < 0.05$) were found with poor BCS, poor udder conformation, and mucosal lesions in goats with the two diseases. Animals positive for the two diseases had ulcerative stomatitis, with percentages of 30.3%, 33.3%, and 46.7% during the mating period, postpartum period, and 150 days of lactation, respectively ($\chi^2 = 14.595$, $P = 0.002$). Goats positive for the three diseases presented lameness and arthritis at 33.3% ($\chi^2 = 14.156$, $P = 0.048$) throughout the production cycle. Goats positive to one disease ($P < 0.05$) had a higher frequency of poor coat condition than those with two or three diseases.

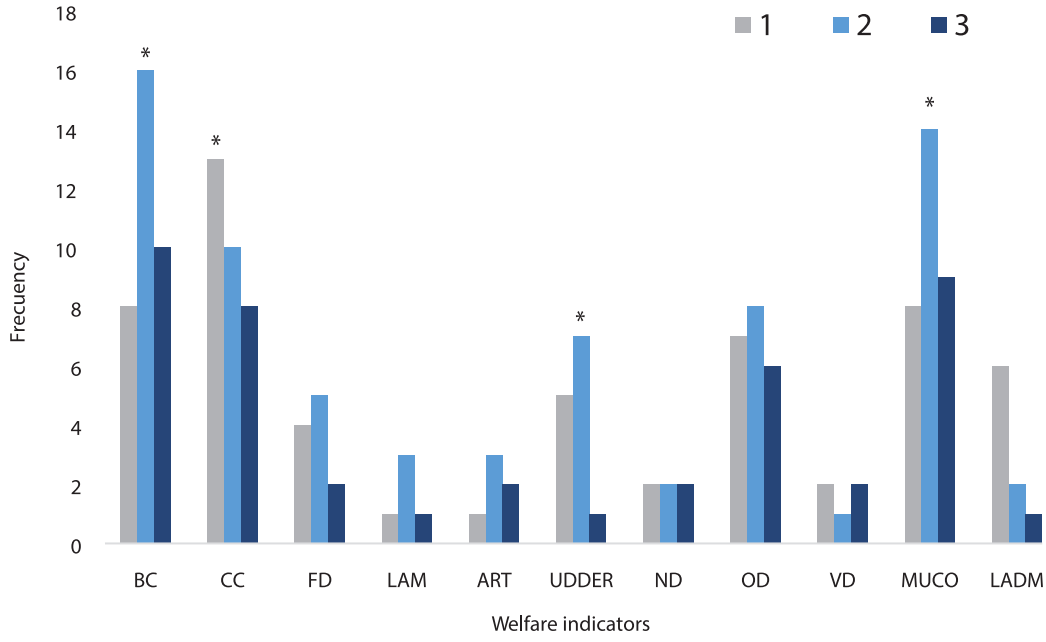

Figure 4.
Frequency of animal welfare indicators related to health in a productive cycle in housed dairy goats with different numbers of diseases: 1, one disease; 2, two diseases; 3, three diseases. BC, Thin body condition; CC, Poor coat condition; FD, Faecal dirt; LAM, Lameness; ART, Arthritis; UDDER, Udder characteristics; ND, Nasal discharge; OD, Ocular discharge; VD, Vaginal discharge; MUCO, Mucosal lesions; LADM, Lymphadenopathy.
* Significant difference within each indicator by number of diseases ($P < 0.05$)

DISCUSSION

In the present study, the prevalence of causal agents of chronic diseases in goats was 71.66% for SRLv, which was higher than that reported by Martínez *et al.* (2020), who obtained a seroprevalence of 22.3% for SRLv in goat farms in Mexico. Other studies carried out in Mexico reported a paratuberculosis prevalence of 9.87% (Guzmán *et al*., 2016) and for *Leptospira interrogans* between 16.4% and 65.6%; the most frequent serovars were Icterohaemorrhagiae, Bratislava, Canicola, and Hardjo (Luna *et al*., 2018), as in this study. It is important to mention that most epidemiological studies in goats have focused on detecting the prevalence of a single infectious agent; however, the interactions with other diseases and their effects on welfare and production are unknown. In the present study, HCC was not influenced by the prevalence of diseases, despite the fact that 50% of the animals showed signs of disease, mainly ulcerative stomatitis and less frequently, mammary hardening and arthritis. These were the main clinical alterations observed at 7 days postpartum and at 150 days of lactation.

Considering that stress describes non-specific responses of the body to all types of challenges (social, environmental, metabolic, immunological, etc.) that threaten homeostasis, individual variations in any contributor to the stress response can determine resilience or vulnerability to stress (Martínez-Miro *et al*., 2016). Goats are well known for their resistance to diseases; compared to other domestic ruminants, they have a greater number of lymphocytes than neutrophils in the circulatory system, which suggests a good development of their immune system (Daramola *et al*., 2005); however, there are few studies on this subject. In this research, no differences were found between the number of chronic diseases and hair cortisol concentrations; however, differences were found in the productive stage.

Currently, there are some investigations in dairy cows with different lesions that present with an increase in HCC, such as clinical endometritis (Burnett *et al*., 2015), endometritis, mastitis, and lameness (Comin *et al*., 2013). On the other hand, a study carried out in healthy calves and those with chronic bronchopneumonia did not find significant differences in hair cortisol concentrations (Braun *et al*., 2019), suggesting that endogenous stress related to the disease varies depending on the severity and that the measurement of cortisol in hair is not adequate for the detection of lower magnitude stress situations, such as those generated by subclinical disease.

The health indicators of the welfare protocol in dairy goats (AWIN, 2015) contributed to the detection of some lesions related to the diseases that were evaluated in this study, such as lameness, low body condition score, poor coat, and other indicators, such as hardening of the udder in the postpartum period (associated with SRLv), lymphadenomegaly (associated with abscesses), and lesions in the vaginal mucosa suggestive of *Caprine Herpesvirus* type 1, and

in the oral mucosa due to *Ovine Gammaherpesvirus* type 2. Some of the observed injuries may be multifactorial in origin (physiological, nutritional, and seasonal status) and cannot be analysed alone. Arsoy (2020) identified different health indicators related to loss of welfare in dairy goat farms in Cyprus, the most frequent being the presence of abscesses, hoof overgrowth, lameness (arthritis due to SRLv), and mastitis; these indicators are related to pain behaviour and can reduce productivity and fertility in the flock. Battini *et al.* (2015), studied the characteristics of the coat condition in dairy goats (silky, shiny, rough, homogeneous, matted) also related to body condition, concluding that the coat condition is a practical, valid and reliable health indicator of goat welfare, that should be included in assessment protocols and be a useful tool for livestock producers. Studies carried out in goats and other ruminants (Di Cerbo *et al*., 2010; Manfredi *et al*., 2010; Waller, 2006) have mentioned that infection by gastrointestinal parasites can influence indicators of body condition and coat condition. However, in this study, the parasite load was low before mating, and no significant association between the parasite effect and body condition and coat were found.

According to the obtained results, we can conclude that goats are resilient in the presence of chronic diseases. They can maintain their productive performance when faced with different pathogens (Doeschl-Wilson *et al*., 2021). Resilience to disease in production animals can be measured in terms of a reduction in health, physical condition, or productive performance. The magnitude of the reduction depends on different factors related to the host (resistance and tolerance) and the pathogen (virulence and burden on the animal) (Knap & Doeschl-Wilson, 2020). Furthermore, hair cortisol measurements in cattle could contribute to stress monitoring and animal well-being by assessing individual resilience to stressors (Ghassemi-Nejad *et al*., 2019; Nair *et al*., 2021). In this study, it is possible that the goats had an adaptive effect on the stress caused by diseases as a protective process by not maintaining permanently high cortisol levels in daily life (Heimburge *et al*., 2019).

Regarding the production parameters, chemical composition, and somatic cell count in goat milk, no association was observed with the presence of diagnosed chronic diseases. Our findings differ from those obtained by Kaba *et al.* (2012), who indicated that SRLv-seropositive goats tend to have a lower percentage of fat, protein, and lactose; however, milk production and somatic cell counts were not affected. Another study carried out by Martínez-Navalón *et al.* (2013) mention that goats seropositive to SRLv tended to have shorter lactation periods, lower production and higher somatic cell count.

It was concluded that the seroprevalence of different diseases, with and without clinical manifestations, did not influence hair cortisol concentrations; however, differences were observed at the productive stage. Goats may have an adaptive effect on disease-induced stress as a protective process by not maintaining permanent high cortisol concentrations. It was found that welfare indicators such as coat condition, body condition score, udder characteristics, and mucosal lesions aided the detection of signs related to health problems in dairy goats in a practical manner. This is the first study carried out in housed dairy goats that investigated the effect of chronic infectious diseases, with hair cortisol concentrations in a productive cycle (from breeding to lactation), as well as the use of health-related welfare indicators, which allowed us to detect health problems in a practical, timely, and objective manner.

Conflict of interest

All authors declare that there is no conflict of interest.

Author contributions

IECA, AMTG, YMDH contributed to the conduct and design of the study. MSG, ADPM, JGPM, ADRC executed the experiment and analysed the blood, serum, fecal and hair samples. MSG analysed the data. All authors interpreted the data, critically revised the manuscript for important intellectual content, and approved the final version.

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REFERENCES

Alberti, G. E., Zanzani, A. S., Ferrari, N., Bruni, G., & Manfredi, M. T. (2012). Effects of gastrointestinal nematodes on milk productivity in three dairy goat breeds. *Small Ruminant Research*, *106S*, S12–S17. https://doi.org/10.1016/j.smallrumres.2012.04.027

Arsoy, D. (2020). Herd management and welfare assessment of dairy goats farms in Northern Cyprus by using breeding, health, reproduction and biosecurity indicators. *Tropical Animal Health and Production*, *52*, 71-78. https://doi.org/10.1007/s11250-019-01990-3

AWIN. 2015. AWIN Welfare Assessment Protocol for Goats. European Animal Welfare Indicators Project (AWIN). https://doi.org/10.13130/AWIN_GOATS_2015

Battini, M., Peric, T., Ajuda, I., Vieira, A., Grosso, L., Barbieri, S., Stilwell, G., Prandi, A., Comin, A., Tubaro, F., & Mattiello, S. (2015). Hair coat condition: A valid and reliable indicator for on-farm welfare assessment in adult dairy goats. *Small Ruminant Research*, *123*(2-3), 197-203. https://doi.org/10.1016/j.smallrumres.2014.12.009

Braun, U., Michel, N., Baumgartner, M. R., Hassig, M., & Binz, T.M. (2017). Cortisol concentration of regrown hair and hair from a previously unshorn area in dairy cows. *Research in Veterinary Science*, *114*, 412–415. https://doi.org/10.1016/j.rvsc.2017.07.005

Braun, U., Wiest, A., Lutz, T. A., Riond, B., Hilbe, M., Baumgartner, M., & Binz, T. (2019). Hair cortisol concentration in clinically healthy slaughter calves with and without chronic bronchopneumonic lesions. *Schweizer Archiv für Tierheilkunde*, *161*(10), 639-647. https://doi.org/10.17236/sat00226

Burnett, T. A., Madureira, A. M. L, Silper, B. F., Tahmasbi, A., Nadalin, A., Veira, D. M., & Cerri, R. L. A. (2015). Relationship of concentrations of cortisol in hair with health, biomarkers in blood, and reproductive status in dairy cows. *Journal Dairy Science*, *98*(7), 4414–4426. https://doi.org/10.3168/jds.2014-8871

Caroprese, M., Casamassima, D., Giacomo, S., Napolitano, F., & Sevi, A. (2009). Monitoring the on-farm welfare of sheep and goats. *Italian Journal of Animal Science*, *8*(1), 343-354. https://doi.org/10.4081/ijas.2009.s1.343

Casal, N., Manteca, X., Peña, R., Bassols, A., & Fabrega, E. (2017). Analysis of cortisol in hair samples as an indicator of stress in pigs. *Journal of Veterinary Behavior*, *19*, 1-6. https://doi.org/10.1016/j.jveb.2017.01.002

Comin, A., Peric, T., Corazzin, M., Veronesi, M. C., Meloni, T., Zufferli, V., Cornacchia, G., & Prandi, A. (2013). Hair cortisol as a marker of hypothalamic-pituitary-adrenal axis activation in Friesian dairy cows clinically or physiologically compromised. *Livestock Science*, *152*, 36–41. http://dx.doi.org/10.1016/j.livsci.2012.11.021

Daramola, J. O., Adeloye, A. A., Fatoba, T. A., Soladoye, A. O. (2005). Haematological and biochemical parameters of West African Dwarf goats. *Livestock Research for Rural Development*, *17*(8), 95. http://www.lrrd.org/lrrd17/8/dara17095.htm

Davenport, M. D., Tiefenbacher, S., Lutz, C. K. Novak, M. A., & Meyer, J. S. (2006). Analysis of endogenous cortisol concentrations in the hair of rhesus macaques. *General and Comparative Endocrinology*, *147*(3), 255–261. https://doi.org/10.1016/j.ygcen.2006.01.005

Di Cerbo, A. R., Manfredi, M. T., Zanzani, S., & Stradiotto, K. (2010). Gastrointestinal infection in goat farms in Lombardy (Northern Italy): Analysis on community and spatial distribution of parasites. *Small Ruminant Research*, *88*(2-3), 102–112. https://doi.org/10.1016/j.smallrumres.2009.12.017

Doeschl-Wilson, A., Knap, P. W., & Opriessing, T. (2021). Review: Livestock disease resilience: from individual to herd level. *Animal*, *15* (Suppl 1), 100286. https://doi.org/10.1016/j.animal.2021.100286

Duguna, A. (2016). Practical manual on veterinary clinical diagnostic approach. *Journal Veterinary Science Technology*, *7* (4), 1-10. http://dx.doi.org/10.4172/2157-7579.1000337

Etim, N. N., Williams, M. E., Evans, E. I., & Offiong, E. E. (2013). Physiological and Behavioural Responses of farm animals to stress: Implications to animal productivity. *American Journal of Advanced Agricultural Research*, *1*(2), 53-61.

Figueroa-Castillo, J. A., Jasso-Villazul, C., Liébano-Hernández, E., Martínez-Labat, P., Rodríguez-Vivas, R. I., & Zárate-Ramos, J. J. (2015). Capítulo 3: Examen coproparasitoscópico En: *Técnicas para el diagnóstico de parásitos con importancia en salud pública y veterinaria*. Rodríguez Vivas R. I. Ed, AMPAVE-CONASA, Mexico, DF, pp: 78-128.

Fischer-Tenhagen, C., Ladwig-Wiegard, M., Heuwieser, W., & Thone-Reineke, C. (2018). Short communication: Is hair cortisol a potential indicator for stress caused by chronic lameness in dairy cows? *Journal Dairy Science*, *101*(6), 5439–5443. https://doi.org/10.3168/jds.2017-13967

Fontaine, M. C., & Baird, G. J. (2008). Caseous lymphadenitis. *Small Ruminant Research*, *76*(1-2), 42–48. https://doi.org/10.1016/j.smallrumres.2007.12.025

Ghassemi-Nejad, J., Bae-Hun, L., Ji-Yung, K., & Byong-Wan, K. (2019). Comparing hair cortisol concentrations from various body sites and serum cortisol in Holstein lactating cows and heifers during thermal comfort zone. *Journal of Veterinary Behavior*, *30*, 92-95. https://doi.org/10.1016/j.jveb.2018.12.007

González de la Vara, M. R., Valdez, R. A., Lemus-Ramírez, V., Vázquez-Chagoyán, J. C., Villa-Godoy, A., & Romano, M.C. (2011). Effects of adrenocorticotropic hormone challenge and age on hair cortisol concentrations in dairy cattle. *Canadian Journal Veterinary Research*, *75*(3), 216-221.

Gow, R., Thomson, S., Rieder, M., Van Uum S., & Koren G. (2010). An assessment of cortisol analysis in hair and its clinical applications. *Forensic Science International*, *196*(1-3), 32-7. https://doi.org/10.1016/j.forsciint.2009.12.040

Guzmán, R. C., Santillán, F. M. A., & Córdoba, L. D. (2016). Prevalence and possible risk factors for caprine paratuberculosis in intensive dairy production units in Guanajuato, México. *Journal of Veterinary Medicine and Animal Health*, *8*(11), 156-162. https://doi.org/10.5897/JVMAH2016.0497

Heimburge, S., Kanitz, E., & Otten, W. (2019). The use of hair cortisol for the assessment of stress in animals. *General and Comparative Endocrinology*, *270*, 10-17. https://doi.org/10.1016/j.ygcen.2018.09.016

INEGI. 2021. Instituto Nacional de Estadística y Geografía. Dirección General de Geografía y Medio Ambiente. Catálogo Único de Claves de Áreas Geoestadísticas Estatales, Municipales y Localidades. https://www.inegi.org.mx/app/ageeml/

Kaba, J., Strzatkowska, N., Jozwik, A., Krzyzewski, J., & Bagnicka, E. (2012). Twelve-year cohort study on the influence of caprine arthritis-encephalitis virus infection on milk yield and composition. *Journal of Dairy Science*, *95*(4), 1617-1622. https://doi.org/10.3168/jds.2011-4680

Knap, P. W., & Doeschl-Wilson, A. (2020). Why breed disease-resilient livestock, and how? *Genetics Selection Evolution*, *52*, 1–18. https://doi.org/10.1186/s12711-020-00580-4

Koren, L., Mokady, O., Karaskov, T., Klein, J., Koren, G., & Geffen, E. (2002). A novel method using hair for determining hormonal levels in wildlife. *Animal Behaviour*, *63*, 403–406. https://doi.org/10.1006/anbe.2001.1907

Licitra, F., Perillo, L., Antoci, F., Piccione, G., Giannetto, C., Salonia, R., Giudice, E., Monteverde, V., & Cascone, G. (2021). Management factors influence animal welfare and the correlation to infectious diseases in dairy cows. *Animals*, *11*(11), 3321. https://doi.org/10.3390/ani11113321

Luna, A. M., Socci, E. G., & Morales, A. J. (2018). Anticuerpos contra Leptospira spp en caprinos lecheros en Guanajuato, México. *Revista de Investigaciones Veterinarias del Perú*, *29*(2), 611-618. http://dx.doi.org/10.15381/rivep.v29i2.14525

Madrigal-Valencia, T., Saavedra-Montañez, M., Pérez-Torres, A., Hernández, J., Segalés, J., Domínguez Hernández, Y., Candanosa-Aranda, I. E., Pérez-Guiot, A., & Ramírez-Mendoza, H. (2023). First identification and characterization of *ovine gammaherpesvirus* type 2 in horses and artiodactyla from an outbreak of malignant catarrhal fever in Mexico. *Plos One*, *18*(9), 1-23. https://doi.org/10.1371/journal.pone.0290309

Manfredi, M. T., Di Cerbo, A. R., Zanzani, S., & Stradiotto, K. (2010). Breeding management in goat farms of Lombardy, northern Italy: risk factors connected to gastrointestinal parasites. *Small Ruminant Reseach*, *88*(2), 113–118. https://doi.org/10.1016/j.smallrumres.2009.12.018

Martínez, H. I., Villagoméz, C. J., & Hernández, R. G. (2020). Seroprevalencia y factores de riesgo para artritis encefalitis caprina en el estado de Veracruz, México. *Agrociencia*, *54*(1), 15-29.

Martínez-Navalón, B., Peris, C., Gómez, E. A., Peris, B., Roche, M., Caballero, C., Goyena, E., & Berriatua, E. (2013). Quantitative estimation of the impact of caprine arthritis encephalitis virus infection on milk production by dairy goats. *The Veterinary Journal*, *197*(2), 311-317. https://doi.org/10.1016/j.tvjl.2012.12.020

Martínez-Miró, S., Tecles, F., Ramón, M., Escribano, D., Hernández, F., Madrid, J., Orengo, J., Martínez-Subiela, S, Manteca, X., & Cerón, J. J. (2016). Causes, consequences and biomarkers of stress in swine: an update. *BMC Veterinary Research*, *12*, 171. https://doi.org/10.1186/s12917-016-0791-8

Moya, D., Schwartzkopf-Genswein, K.S., & Veira, D.M. (2013). Standardization of a non-invasive methodology to measure cortisol in hair of beef cattle. *Livestock Science*, *158*(1-3), 138–144. https://doi.org/10.1016/j.livsci.2013.10.007

Muri, K., Leine, N., & Valle, P.S. (2016). Welfare effects of a disease eradication program for dairy goats. *Animal*, *10*(2), 333–341. https://doi.org/10.1017/S1751731115000762

Nair, M. R. R., Sejian, V., Silpa, M. V., Fonseca, V. F. C., Melo-Costa C. C., Devaraj, C., Krishnan, G., Bagath, M., Nameer, P. O., & Bhatta, R. (2021). Goat as the ideal climate-resilient animal model in tropical environment: revisiting advantages over other livestock species. *International Journal Biometeorology*, *65*, 2229–2240. https://doi.org/10.1007/s00484-021-02179-w

Nájera-Rivera, H., Rodríguez-Cortez, A., Anaya-Santillán, M., Díaz-Aparicio, E., Ramos-Rodríguez, A., Siliceo-Cantero, I., Vázquez-Franco, N., Nieto-Patlán, E., De Las Peñas, A., Valdés-Vázquez, L., & Cobos-Marín, L. (2023). Multiplex assay for the simultaneous detection of antibodies against small ruminant lentivirus, *Mycobacterium avium* subsp. *paratuberculosis*, and *Brucella melitensis* in goats. *Veterinary World*, *16*(4), 704–710. https://doi.org/10.14202/vetworld.2023.704-710

Nakov, D., Hristov, S., Stankovic, B., Pol, F., Dimitrov, I., Ilieski, V., Mormede, P., Hervé, J., Terenina, E., Lieubeau, B., Papanastasiou, D. K., Bartzanas, T., Norton, T., Piette, D., Tullo, E., & van Dixhoorn, I. D. E. (2019). Methodologies for assessing disease tolerance in pigs. *Frontiers in Veterinary Science*, *5*, 329. https://doi.org/10.3389/fvets.2018.00329

Noordzij, M., Dekker, F. W., Zoccali, C., & Jager, K. J. (2009). Study designs in clinical research. *Nephron Clinical Practice*, *113*(3), c218–c221. https://doi.org/10.1159/000235610

NRC. (2007). Nutrient requirements of small ruminants: sheep, goats, cervids, and New World camelids. In National Research Council of the National Academies (Washington, DC, The National Academies Press), 2007.

Russell, E., Koren, G., Rieder, M., & Van-Uum, S. (2012). Hair cortisol as a biological marker of chronic stress: Current status, future directions and unanswered questions. *Psychoneuroendocrinology*, *37*(5), 589-601. https://doi.org/10.1016/j.psyneuen.2011.09.009

Spigarelli, C., Zuliani, A., Battini, M., Mattiello, S., & Bovolenta, S. (2020). Welfare assessment on pasture: A review on animal-based measures for ruminants. *Animals*, *10*(4), 609. https://doi.org/10.3390/ani10040609

Stalder, T., Steudte, S., Miller, R., Skoluda, N., Dettenborn, L., & Kirschbaum, C. (2012). Intraindividual stability of hair cortisol concentrations. *Psychoneuroendocrinology*, *37*(5), 602-610. https://doi.org/10.1016/j.psyneuen.2011.08.007

Tekin, M., Camara, D. R., Binz, T. M., Bruckmaier R. M., Bollwein, H., & Wagener, K. (2023). Relationship between periparturient diseases, metabolic markers and the dynamics of hair cortisol concentrations in dairy cows. *Research Veterinary Science*, *158*, 134-140. https://doi.org/10.1016/j.rvsc.2023.03.016

Waller, P. J. (2006). Sustainable nematode parasite control strategies for ruminant livestock by grazing management and biological control. *Animal Feed Science and Technology*, *126*(3), 277–289. https://doi.org/10.1016/j.anifeedsci.2005.08.007

WHO–World Health Organization. (2012). Leptospirosis. In http://www.wpro.who.int/mediacentre/factsheets/fs_13082012_leptospirosis/en/ (accessed 26.05.14).