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EFECTO DE LA CONDICIÓN CORPORAL SOBRE LA EFICIENCIA REPRODUCTIVA DE VACAS EN SISTEMAS INTENSIVOS Y CABRAS EN SISTEMAS EXTENSIVOS

Tesis

Que presenta ARIADNA VANESSA ALVARADO ESPINO

como requisito parcial para obtener el Grado de

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Tesis

Elaborada por ARIADNA VANESSA ALVARADO ESPINO como requisito parcial para obtener el grado de Doctor en Ciencias en Producción Agropecuaria con la supervisión y aprobación del Comité de Asesoría

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Cartas de aceptación de los artículos

Artículo 1.

Body condition score and serum metabolites and minerals concentrations as indicators of ovarian activity and pregnancy success in goats on rangeland

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Articulo 2.

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Thank you very much for your attention.

Miguel Mellado

Índice general

Resumen

Efecto de la condición corporal sobre la eficiencia reproductiva de vacas en sistemas intensivos y cabras en sistemas extensivos

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Palabras clave: Tasa de preñez, condición corporal, fertilidad, sistema de producción, metabolitos.

El principal objetivo de la presente investigación fue medir el efecto que tiene la condición corporal (CC) en la fertilidad en cabras y vacas en un sistema extensivo e intensivo respectivamente. En el primer trabajo se comparó la CC, los metabolitos sanguíneos y minerales en el apareamiento de las cabras que quedaron preñadas vs no preñadas, también se evaluó las diferencias entre las estructuras ováricas los metabolitos y minerales en el apareamiento. Las variables se compararon entre grupos (gestantes vs no gestantes; perdida de gestación vs no perdida de gestación; preñez gemelar vs no gemelar) utilizando el procedimiento GLM de SAS. La CC en cabras gestantes fue significativamente mayor que en cabras no gestantes, al igual que la glucosa fue 13 mg/kg más alto para cabras gestantes que las no gestantes. Los demás metabolitos séricos no fueron diferentes entre cabras gestantes y no gestantes. En vacas, el estudio tuvo como objetivo evaluar la relación entre la pérdida de CC antes y después del parto y la producción de leche, el desempeño reproductivo y la aparición de metritis y cetosis en vacas. Fueron evaluados para la CC 15 días antes del parto, al parto y en el primer servicio. La producción de leche a los 305 días fue más alta en vacas con ΔCC <0,25 entre 15 días antes del parto y parto (11526 ± 1088 kg), y más baja (10878 ± 1114) en vacas con ΔCC antes del parto < 0,75.

Abstract

Effect of body condition on the reproductive efficiency of cows in intensive systems and goats in extensive systems

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Key words: Pregnancy rate, body condition, fertility, production system, metabolites.

The main objective of this research was to measure the effect of body condition on fertility in goats and cows in an extensive and intensive system, respectively. In the first work, the body condition, blood metabolites and minerals in the mating of the goats that became pregnant vs. Non-pregnant were compared, the differences between the ovarian structures, the metabolites and minerals in the mating were also evaluated. Variables were compared between groups (pregnant vs. non-pregnant; pregnancy los vs. no pregnancy los; twin vs. non- twin pregnancy) using the SAS GLM procedure. Body condition in pregnant goats was significantly higher than in non-pregnant goats, just as glucosa was 13 mg/kg higher for pregnant than non-pregnant goats. The other serum metabolites were not different between pregnant and non-pregnant goats. In cows, the study aimed to evaluate the relationship between the loss of body condition before and after calving and milk production, reproductive performance and the ocurrence of metritis and ketosis in cows. They were assessed for body condition 15 before calving, at calving and first service. Milk production at 305 days was highest in cows with ΔBCS <0.25 between 15 days before calving and calving (11526 ± 1088 kg), and lowest (10878 ± 1114) in cows with ΔBCS before calving < 0.75.

Introducción

Producción de cabras en agostadero

Las cabras juegan un papel esencial en las economías en desarrollo y son una fuente de subsistencia, sustento y empleo para muchos hogares rurales en el mundo. Las cabras producen carne, leche, piel y estiércol en varios hábitats con escasa vegetación, lo que las convierte en animales de granja ideales para agricultores de escasos recursos (Patel *et al*., 2020). En los países en desarrollo, los sistemas de producción de cabras se caracterizan por bajos insumos y producción en pastizales degradados que contribuyen a una alimentación y nutrición inadecuadas (Monau *et al*., 2020; Patrick Baenyi *et al*., 2020), lo que resulta en una baja productividad (Thomas y Rangnekar, 2004). El ramoneo y el pastoreo en pastizales o matorrales naturales son las principales fuentes de alimentación en las zonas de pastoreo áridas y semiáridas del mundo, y ocasionalmente utilizan residuos de cultivos en sistemas agrícolas donde se practica una producción mixta de cultivos y ganado (Nair *et al*., 2021). La estacionalidad de la distribución de las lluvias, la cantidad y la calidad del suministro de forraje es marcadamente estacional en los pastizales áridos (Larsen *et al*., 2021), con una grave escasez de suministro de forraje y una calidad inferior durante la estación seca, lo que limita producción caprina en pastos (Chebli *et al*., 2022).

La mala nutrición de las cabras en pastoreo da como resultado una baja tasa de crecimiento de los animales en crecimiento, la producción de carne y leche, el rendimiento reproductivo, la pérdida de la condición corporal y una mayor susceptibilidad a enfermedades y parásitos (Zhou *et al*., 2019; Flores-Najera *et al*., 2020). Esto se ve agravado por la práctica de crianza que no contempla la suplementación alimenticia en ninguna época del año, debido principalmente al alto costo de estos suplementos alimenticios.

La cría de cabras juega un papel esencial en los medios de vida y empleo de agricultores en regiones áridas y semiáridas de países en desarrollo (McDermott *et al*. 2010; Kahi y Wasike 2019). En ecosistemas áridos, las cabras tienen ventajas sobre el ganado porque son animales oportunistas en cuanto a su alimentación (Nyamu kanza y Sebata, 2020), y la reducción de forraje en pastizales tiene un impacto reducido en su ingesta de nutrientes (Nair *et al*., 2021). Sin embargo, los forrajes en estado latente en invierno justifican la suplementación alimenticia porque la cría de cabras en pastoreo y el período de gestación en muchos países ocurre durante la época seca del año. Al mejorar la nutrición de las cabras, principalmente a través de concentrados o suplementos de subproductos de cultivos, la productividad de cabras locales puede mejorarse sustancialmente (Berhane y Eik, 2006; Yahya *et al*., 2020). Por lo tanto, para mejorar la productividad de la cabra explotada en pastizales, algunos productores han pasado de operaciones de cosecha oportunistas a sistemas de producción cada vez más enfocados a una mejor alimentación de sus (Charambira *et al*. 2021).

En los sistemas extensivos de producción caprina en zonas áridas, la agricultura de bajos insumos se practica debido a los bajo ingresos económicos; por lo tanto, la condición del pastizal determina su nivel productivo (Shinde y Mahanta, 2020). En estos ecosistemas, las cabras ingieren una gran diversidad de forrajes (Mphinyane *et al*., 2015; Pahl, 2019), lo que permite un uso más eficiente de la recursos forrajeros naturales disponibles. Además, en sistemas de pastoreo mixto que combinan ganado vacuno y caprino, la presión del pastoreo se distribuiría más equitativamente entre las especies forrajeras debido a su comportamiento de alimentación complementaria en los pastizales (Osoro *et al*. 2017).

Los temas clave para el éxito de los productores de cabras en ambientes áridos se centran en un desempeño reproductivo moderado, una producción de leche limitada para la elaboración de queso, bajo costo de producción, y un precio de mercado adecuado para los productos caprinos (Nair *et al*. 2021). La mayoría de las cabras en este ambiente árido subsisten únicamente de pastizales naturales comunales; por lo tanto, enfrentan escasez en el suministro de alimento suficiente para una producción óptima (Mellado *et al*. 2020). Por lo tanto, la producción caprina está limitada por el alimento consumido limitado y el contenido de nutrientes reducido de los forrajes durante la estación seca (Ali *et al*. 2019;

García-Mon jaras *et al*. 2021). Esta alimentación inadecuada conduce a una reducción en las tasas de crecimiento, madurez sexual tardía, primer parto a los 2 años edad, bajas tasas de parto, altas tasas de aborto vinculadas a edades cortas de energía, alta mortalidad de cabritos y producción limitada de leche en lactancias menores de 6 meses (Mellado *et al*., 1996; Idamokoro *et al*., 2017). Ante esto, es imperativo mejorar el suministro de alimentos para las cabras criadas en pastizales. Algunos de los esfuerzos de investigación se han dirigido a mejorar los nutrientes suministrados a cabras en pastoreo, incluido el uso de concentrado como alimentos complementarios (Mahfuz *et al*., 2018; Mellado *et al*., 2020). Sin embargo, se sabe menos sobre los subproductos de los cultivos.
y uso de sal para complementar los forrajes de los pastizales en los rebaños de cabras en ambientes áridos.

Debido a las limitantes nutricionales de las cabras, es importante conocer cómo los metabolitos sanguíneos indicativos del estatus nutricional de las cabras, y los micro y macrominerales afectan la reproducción de las cabras. También, es importante conocer cómo afecta la condición corporal de las cabras la fertilidad de estos animales en agostadero.

Vacas lecheras en sistemas intensivos

El periparto en vacas lecheras de alto rendimiento es una etapa fisiológica crítica porque las vacas sufren un balance energético negativo, lo que lleva a la movilización de grasa de los tejidos adiposos (Arfuso *et al*., 2016; Mann, 2022), aminoácidos del músculo (McCabe y Boerman, 2020) y macro y microelementos de depósitos minerales (Drackley *et al*., 2005; Grala *et al*., 2022). El aumento de las demandas de energía para la última etapa del desarrollo del feto y la Hproducción de calostro y leche (van Hoeij *et al*., 2017), la ingesta voluntaria insuficiente de alimentos (Pascottini *et al*., 2020), los cambios en la rutina diaria, el grupo social y la dieta. predisponen a las vacas a enfermedades infecciosas y metabólicas (Fiore *et al*., 2017) y alteran la fertilidad y la producción de leche (Meikle *et al*., 2018; Mezzetti *et al*., 2021). Además, una interacción compleja de múltiples vías, incluidas las adaptaciones metabólicas y hormonales, implica la mayoría de las enfermedades metabólicas e infecciosas posparto (Sundrum, 2015), y estos problemas de salud durante el período de transición constituyen un factor de riesgo importante para la producción de leche y rendimiento reproductivo (Barletta *et al*., 2017).

La condición corporal (CC) es un método simple para evaluar las reservas de energía de las vacas lecheras (Hoedemaker *et al*., 2009) y constituye una medida indirecta del metabolismo de las grasas y su correlación con el metabolismo energético (Ghanem *et al*., 2016). La incidencia de trastornos metabólicos y su relación con la CC se ha estudiado ampliamente debido a que se relaciona con el estado de fertilidad de las vacas lecheras (Studer *et al*., 1998; Chagas *et al*., 2007; Hoedemake *et al*., 2009). Se sabe que los metabolitos séricos, las concentraciones de calcio y la CC se alteran durante la lactancia temprana. La relación de los metabolitos sanguíneos y iones sanguíneos con el grado de pérdida de CC durante el período seco puede proporcionar información importante para el manejo y la reproducción del hato (Kim and Suh, 2003). La pérdida de CC preparto ha sido investigada en algunos artículos, sin embargo, sus consecuencias en el período pre y posparto aún no se conocen a la perfección (Kim and Suh, 2003, Sheehy *et al*., 2017). Por lo anterior, es importante investigar el impacto de la condición corporal poco antes y después del parto, para definir esquemas de manejo efectivos en hatos de vacas lecheras en sistemas intensivos, para maximizar la eficiencia reproductiva de las vacas.

Revisión de literatura

Importancia de la caprinocultura en México

La cría de cabras y ovejas en México es una de las más importantes porque se practican en casi todo el país y nos aportan productos básicos en nuestra dieta. La producción de cabras por lo general se concentra en zonas rurales de bajos recursos y en las zonas áridas de la región de la comarca lagunera. La producción de estos sistemas aporta un ingreso económico a muchas familias de escasos recursos de esas zonas. Contribuyendo así de manera sustancial al mantenimiento de las familias. México ocupa el primer lugar en producción de carne de origen caprino en el continente americano con el 30.5% de la producción total (SADER, 2019).

Sistemas de producción pecuaria

México cuenta con tres sistemas principales de producción animal, los cuales se diferencian con base en el esquema tecnológico que utilizan. El sistema de producción extensivo es el que predomina más en la esta región de la comarca lagunera, este sistema se desarrolla en zonas de baja producción vegetal para el aporte de los nutrientes que estos animales necesitan, principalmente se centra en zonas áridas de esta región (Ahedo *et al*., 2008; Galvan-Golzalez, 2008).

Los sistemas semi-intensivos se concentran cerca de las áreas urbanas. Los rasgos de producción son altos en comparación con los sistemas extensivos, los productores tienen más acceso a la asistencia técnica y están más abiertos a adoptar nuevas innovaciones (Escareño *et al*., 2011).

El sistema intensivo comprende no más del 2% de la población caprina total, pero contribuye con alrededor del 15 al 20% de la producción total. El número de cabras por unidad productiva varia de 200-300 a 1000-1200 o más animales. Los rasgos de producción son significativamente más altos que los dos sistemas productivos anteriores (Echavarría *et al*., 2006).

Cabras en sistemas extensivos

Estos sistemas se caracterizan por el uso de grandes extensiones de tierra y que poseen baja cantidad de vegetación. Estos sistemas de producción caprina se caracterizan porque en la mayor parte de los casos se trabajan con mano de obra familiar. Son sistemas que se encuentran en zonas con alta marginación y de escasos recursos. Por lo tanto, la demanda de asesoría técnica tiende a ser baja o escasa (Escareño *et al.,* 2011).

Vacas lecheras en un sistema intensivo

La fertilidad es el resultado de tantos factores que la definición de Fromageot (1978) no sorprende: la reproducción puede considerarse una función de “lujo”. De hecho, varios experimentos han demostrado cuán numerosas y diferentes son las causas de la reducción de la fertilidad. Entre ellos, la nutrición tiene un papel relevante (Bertoni, 1990; Ferguson, 1991; Melendez y Bartolome, 2017) relacionado con la deficiencia (y en ocasiones exceso) de energía, proteína, fibra, macro y oligoelementos. Los riesgos reales de cada causa potencial pueden ser diferentes dependiendo de muchos factores de los cuales el sistema de reproducción es de gran importancia. De hecho, desde un punto de vista nutricional, los sistemas de cría intensiva tienden a reducir muchas de las causas anteriores por mejores tecnologías de conservación de los alimentos y por una selección más precisa de la dieta en ingredientes que ofrezcan una mejor satisfacción de los requerimientos nutricionales.

Condición corporal en vacas lecheras y cabras

La condición corporal animal considerada como un indicador de las reservas de grasa (Russel *et al*.,1969), ha sido estudiada principalmente en vacas y ovejas.

Las evaluaciones de la condición corporal son subjetivas, visuales o físicas de la cantidad de energía metabolizable almacenada en grasa y músculo en un animal vivo. Se ha considerado una herramienta eficaz para monitorear la ingesta de energía de vacas y hatos (Jeffrey y James, 1989). Hasta la década de 1970, no había una medida simple de las reservas de energía corporal o condición corporal de una vaca. El peso corporal por sí solo es un mal marcador porque las reservas de energía pueden variar hasta en un 40 % en vacas con un peso corporal similar

(Andrew *et al*., 1994). Por lo tanto, la CC se ha utilizado como una herramienta en el manejo reproductivo (Bedere *et al*., 2018; Çolakoğlu *et al*., 2019), nutricional (Roche *et al*., 2009) y de salud (Roche *et al*., 2015) en sistemas de producción lecheros.

La movilización de grasa es un proceso común en las vacas lecheras para soportar la alta demanda de energía durante el período de transición. Este proceso implica la lipólisis, donde los ácidos grasos no esterificados (NEFA) se generan a partir de triacilgliceroles (TAG) en los adipocitos por la acción de varias hormonas sensibles a las lipasas. En consecuencia, los NEFA se liberan en el torrente sanguíneo para ser utilizados como sustrato para la síntesis de grasa láctea en la ubre y también como fuente de energía en muchos tejidos (Contreras y Sordillo, 2011).

Sin embargo, entre el 15 y el 20% de todos los NEFA se oxidan parcialmente a cuerpos cetónicos o se reesterifican a TAG en el hígado (Drackley y Andersen, 2006). Así, varios estudios indican que el exceso de lipólisis y el consiguiente aumento en concentraciones de NEFA puede predisponer a la acumulación de TAG en el hígado, al estrés oxidativo y a una respuesta inflamatoria disfuncional, con todos estos eventos que conducen a una mayor lipólisis, deterioro de la salud animal (Huzzey *et al*., 2011; Esposito *et al*., 2014), bienestar (Loor *et al*., 2013; Roche *et al*., 2013) y productividad (Ospina *et al*., 2010; Barletta *et al*., 2017) después del parto.

El grado de movilización de grasa depende de muchos factores como la raza, el nivel de producción de leche, paridad y nutrición (Nielsen *et al*., 2003). Sin embargo, bajo condiciones de manejo similares, las vacas lecheras muestran una alta variabilidad individual (Kessel *et al*., 2008; Weber *et al*.,2013). Varios estudios han asociado esta variabilidad con el desarrollo de resistencia a la insulina (IR) (Bel *et al*., 1995; De Koster *et al*., 2013; Humer *et al*., 2016), que se define como un estado en el que una concentración normal de insulina induce una disminución de la respuesta biológica en los tejidos sensibles a la insulina (Kahn *et al*., 1978). Además, IR puede interferir con las vías de señalización de la insulina relacionadas con la supresión de las lipasas del tejido adiposo, que favorecer una respuesta lipolítica (Sordillo y Mavangira, 2014). Este escenario ha sido ampliamente estudiado en los últimos años y actualmente la investigación sugiere que la RI puede verse exacerbada por varios mecanismos. Según Abuelo *et al*. (2014), el estrés oxidativo y la pérdida de la homeostasis de reducción-oxidación (redox) dan como resultado la acumulación de radicales de oxígeno que favorecen una respuesta inflamatoria a través de la activación del factor nuclear NF-kB. Como resultado, las células inmunitarias aumentan la expresión de citocinas proinflamatorias, que a su vez aumentan la producción de especies reactivas de oxígeno (ROS) e interrumpen la señalización de insulina y el aumento de la lipólisis (Sordillo y Raphael, 2013).

Para minimizar los efectos generados por una mayor movilización de grasa, las granjas lecheras deben controlar la CC durante el preparto (Bewley y Schutz, 2008; Roche et. Al 2013). La CC es una herramienta de rutina que da una evaluación cualitativa de la grasa corporal y permite la identificación de animales con mayor riesgo de sufrir trastornos posparto (Pires *et al*.,2013; Barletta *et al*., 2017; Gärtner *et al*., 2019).

Existe amplia evidencia que relaciona la pérdida excesiva de condición corporal durante el período de transición con el desempeño reproductivo posparto y las enfermedades puerperales en las vacas lecheras (Roche *et al*., 2009). La pérdida de condición corporal también tiene efectos negativos en la reproducción: las vacas que perdieron una o más unidades de condición corporal en la lactancia temprana tenían un mayor riesgo de infertilidad, con una reducción en la tasa de concepción del 17% al 38% (Butler, 2000). Se acepta que las señales endocrinas que regulan el eje reproductivo respecto al estado metabólico incluyen la insulina y el factor de crecimiento similar a la insulina I (IGF-I; Spicer *et al*., 1993; Lucy, 2000; Kawashima *et al*., 2007). La mayoría de los informes sobre el efecto de la CC en los parámetros productivos y reproductivos se basan en una clasificación de las vacas según la CC al parto (Gallo *et al*., 1996; Meikle *et al*., 2004; Patton *et al*., 2007) y/o al inicio del período de transición (Shrestha *et al*., 2005; Chagas *et al*., 2006).La CC en vacas lecheras es determinada en escala de cinco puntos. Donde, uno es igual a una vaca emaciada, y cinco es igual a una vaca con condición obesa (Edmondson *et al*., 1989). Esta medida se da con incrementos de 0.25 puntos. En cabras la puntuación se realiza utilizando una CC que varía de 1.0 a 5.0, con incrementos de 0.5. La asignación del incremento de puntuación de 0.5 se realiza cuando el animal evaluado es intermedio a la CC descrita. Una CC de 1.0 es una cabra extremadamente delgada sin reservas de grasa y una CC de 5.0 es una cabra muy obesa. En la mayoría de los casos, las cabras saludables deben tener una CC de 2.5 a 4.0 (Villaquiran *et al*., 2004).

El período de transición, definido como el período desde 3 semanas antes hasta 3 semanas después del parto, representa un desafío para las vacas lecheras ya que la producción de leche y el consumo de materia seca (MS) aumentan drásticamente (Grummer, 1995; Bruckmaier Gross, 2017). Durante el período de transición, las vacas lecheras se adaptan a numerosos cambios hormonales y metabólicos relacionados con el final de la gestación y el comienzo de la lactancia (Grummer, 1995; Drackley, 1999.). Cambios metabólicos y hormonales que ocurren durante el periodo transición en vacas lecheras conlleva a numerosos cambios, con efectos directos sobre la salud, la productividad y el desempeño reproductivo. De hecho, aproximadamente el 50% de las vacas sufren de diversos trastornos metabólicos, nutricionales e infecciosos (Mulligan y Doherty, 2008; LeBlanc, 2010). Durante el período de transición, las vacas lecheras pasan por un período de balance energético negativo (BNE), caracterizado por una mayor movilización de reservas energéticas, especialmente grasas y proteínas, para satisfacer las demandas de la alta producción de leche. Las vacas lecheras de alta producción, en promedio, van a través de un período de NEB durante las primeras semanas de lactancia, cuando las demandas de energía para la producción de leche superan la ingesta de energía obtenidos de la dieta. Así, durante la lactancia temprana, las reservas de grasa en algunas vacas se movilizan hacia el torrente sanguíneo en forma de ácidos grasos no esterificados (NEFA) y contribuyen a los requerimientos energéticos generales (Ospina *et al*., 2003). En el hígado, algunos NEFA se oxidan o reesterifican en triglicéridos que se liberan como lipoproteínas de muy baja densidad o se almacenan (Drackley *et al*., 2000). La medición de NEFA y betahidroxibutirato (BHBA) se puede realizar como índices de NEB o cetosis en vacass en transición (Ospina *et al*., 2003) y la elevación excesiva de NEFA o BHBA puede indicar problemas metabólicos (Herdt, 2000). Las concentraciones circulantes de NEFA y DMI suelen tener una relación inversa (Overton y Waldron, 2004). Un exceso en la movilización de grasa y NEB pueden atenuar la función del sistema inmunológico (Pascottini y LeBlanc, 2020), y están asociados con efectos negativos en los animales, salud y producción (Hammon *et al*., 2006; Scalia *et al*., 2006). Mantener la salud y la productividad durante el período de transición es uno de los mayores desafíos lecheros para los hatos lecheros.

La evaluación de la puntuación de CC es una herramienta de manejo útil para evaluar las reservas de grasa corporal de las vacas lecheras Holstein (Otto *et al*., 1991; Waltner *et al*., 1993; Bewley y Schutz, 2008). La puntuación de la CC ha recibido una atención considerable como herramienta para ayudar en el manejo de programas nutricionales en hatos lecheros (Waltner *et al*., 1993; Roche *et al*., 2009). Roche *et al*. (2009) notaron que la CC de las vacas al parto, el nadir de la CC y la pérdida de CC posparto están asociados con diferencias en la producción de leche, reproducción y salud. Las vacas sobreacondicionadas con una CC superior a 4.0 al parto tenían concentraciones circulantes más altas de NEFA en la lactancia temprana hasta 7 semanas posparto en comparación con vacas con CC moderada o baja (Pires *et al*., 2013). La cetonemia, a su vez, causó resistencia a la insulina en vacas lecheras (Pires *et al*., 2007), en consonancia con los estudios que relacionan un BCS alto con una reducción de la sensibilidad a la insulina periferica en el estado de lipomovilización (Hayirli, 2006; Holtenius *et al*., 2003, 2007).

Múltiples estudios han reportado una relación negativa de NEFA con la eficiencia reproductiva. La CC baja y las reducciones más pronunciadas en CC que ocurren más cerca de la primera inseminación artificial dieron como resultado menores probabilidades de preñez por inseminación artificial (Pinedo *et al*., 2022). Otro experimento encontró que el aumento de concentraciones de NEFA durante el período de transición se asociaron con una disminución de la tasa de preñez a los 70 días después del período de espera voluntario (Holtenius y Holtenius, 2007), mientras que otro encontró que una alta circulación de NEFA se asoció con una tasa de preñez de 21 días reducida en las evaluaciones a nivel de hato de 60 hatos lecheros (Ospina *et al*., 2010). Además, un tercer estudio con 156 vacas lecheras lactantes (Garverick *et al*., 2013) reportó que la probabilidad de preñez en la primera IA a tiempo fijo (TAI) disminuyó a medida que las concentraciones séricas de NEFA en el día 3 después del parto aumentó. También hay otros estudios que han descrito una relación negativa entre NEFA posparto o pérdida de CC y fertilidad (Chapinal *et al*., 2012, Carvalho *et al*., 2014). La recuperación tardía de la actividad ovárica se asocia con una mala condición corporal al momento del parto. Esta situación aparece cuando las ingestas de alimento en el último tercio de la gestación son insuficientes. Prácticamente para vacas multíparas, no existe un efecto real de CC al parto sobre la ciclicidad, pero se determinó un efecto significativo de la pérdida del estado posparto (Banos *et al*., 2004). Según Crowe *et al*. (2008), las vacas que perdieron más de 1,5 puntos de su CC entre 0 y 60 días después del parto se caracterizan por no ciclicidad o fase lútea prolongada. Pivko *et al*. (2012) indicaron que una mala CC (principalmente CC 1.0) en las vacas puede incluso resultar en el mal funcionamiento de la actividad ovárica en forma de atresia quística de los folículos ováricos. Existe una estrecha relación entre los rasgos de la condición corporal de las vacas no solo desde el punto de vista de los parámetros de cría de animales, sino también en relación con la actividad ovárica Bezdicek *et al*. (2020). Para optimizar la producción de leche, es necesario maximizar la producción de leche al comienzo de la lactancia, pero no necesariamente durante la última etapa de la lactancia. Las vacas en lactancia temprana utilizan reservas de tejido adiposo para apoyar la producción de leche (Mishra *et al*., 2016). Las vacas de alta producción no pueden satisfacer sus necesidades energéticas a través del consumo de alimento al comienzo de la lactancia. Hay balance energético negativo con movilización de reservas corporales y pérdida de CC. El ganado lechero no debe perder más de un punto en su BCS durante el período inicial de lactancia. BCS al parto sería mejor alrededor de 3.5-3.75 (Gobikrushanth *et al*., 2019). Además, Jilek *et al*. (2008) mostró que las vacas con BCS inferior a 3.5

en el primer mes de lactancia tienen la mayor producción de leche durante los primeros 5 meses de lactancia. Esto puede explicarse por la alta movilización de reservas corporales en vacas de alto rendimiento. El nivel de condición corporal en el último mes del período seco influyó en su posterior descenso en la primera fase de lactancia. Las vacas con el nivel más alto de BCS antes del parto mantuvieron un nivel alto de CC en los primeros 5 meses de lactancia. Sin embargo, las vacas con una CC más baja en el primer mes de lactancia tuvieron el BCS más bajo en los siguientes 4 meses. Es necesario que las vacas no pierdan más de un punto de condición corporal al principio de la lactancia. Las vacas con pérdidas excesivas de condición corporal tendrán celos irregulares, tendrán más tiempo hasta la primera ovulación y pueden no concebir. Estas vacas también serán menos persistentes en la producción de leche. Las vacas con un BCS superior a 6.5 (3.5 en una escala de 5 puntos) a las 2 semanas antes del parto están sujetas a ingesta reducida de alimento, pérdida de peso, hígado graso, cetosis, niveles altos de ácidos grasos no esterificados (NEFA), parto y problemas reproductivos (Shin *et al*., 2015).

El periodo de transición en la vaca lechera

El periodo de transición, que comprende de la última etapa de la gestación, tres o cuatro semanas antes del parto y la lactancia temprana tres o cuatro semanas después del parto, representa grandes desafíos para la vaca en el peri-parto (Zhou *et al*., 2017). En esta etapa se presentan grandes cambios nutricionales, metabólicos, hormonales e inmunológicos. Además, este periodo es acompañado de una mayor susceptibilidad de enfermedades metabólicas e infecciosas (Wankhade *et al*., 2017). Al final de la gestación, el eje somatotrópico es el principal involucrado en el mecanismo de adaptación del fin de la gestación a la siguiente lactancia (Piechotta *et al*., 2013). En este periodo, la resistencia a la acción de la insulina es un proceso de adaptación clave que facilita la utilización de la glucosa en la producción de leche, la recuperación progresiva de la sensibilidad a la insulina conforme avanza los días en leche, van acompañados de reducción en los niveles de ácidos grasos no esterificados circulantes y mayor producción de leche (Rico *et al*., 2016).

Aspectos reproductivos

Ciclo estral en las cabras

Las cabras son animales poliéstricos estacionales, es decir, presentan actividad estral solo durante una época específica del año. En regiones templadas la actividad estral inicia al final del verano y continua hasta el final del invierno (Amoah *et al.,* 1996).

En la región árida del norte de México, específicamente en la Comarca Lagunera (26 °N) la temporada de reproducción varía desde finales de julio hasta principios de febrero, con una temporada de anestro desde fines de febrero hasta principios de junio (Luna-Orozco *et al.,* 2012). Sin embargo, algunas cabras pueden reproducirse todo el año (Mellado *et al.,* 2014).

El ciclo estral consiste en todos los cambios morfológicos y fisiológicos en los ovarios y el tracto genital que conducen a la expresión del estro o celo (fase de receptividad a los machos), la ovulación y la preparación del tracto genital para la cópula, la fertilización y la implantación de embriones (Fatet *et al.,* 2011). Este patrón cíclico de la actividad sexual se alcanza durante la pubertad, que en la hembra se refiere a la edad en la que se presenta el estro por primera vez (Greyling, 2000).

En la cabra la duración del ciclo estral es de 21 días, pudiendo variar de 18 a 22 días dependiendo de la raza, el medio ambiente y la temporada reproductiva (Rahman *et al.,* 2008).

El ciclo estral se puede dividir en fases: la fase folicular que dura entre 4 y 6 días y la fase lútea de aproximadamente 15 días (Rahman *et al.,* 2008; Fatet *et al.,* 2011). La fase folicular abarca desde la desaparición del cuerpo lúteo hasta la ovulación. Durante la fase folicular, uno o más folículos de un grupo comienzan a crecer hasta convertirse en dominante y ovular mientras que el resto de los folículos presentan atresia. Luego de la ovulación, el folículo ovulatorio se transforma en el cuerpo lúteo (CL) dando inicio a la fase lútea (Forde *et al.,* 2011).

La regulación hormonal del ciclo estral está gobernada por el eje hipotálamo-hipófisis-gonadas (HHG). El hipotálamo, sintetiza y libera la hormona liberadora de gonadotropinas (GnRH). La GnRH estimula la secreción de las hormonas gonadotrópicas: La hormona folículo estimulante (FSH) y la hormona luteinizante (LH). Ambas hormonas son secretadas por la hipófisis anterior o adenohipófisis y liberadas al torrente sanguíneo para alcanzar su órgano blanco que es el ovario. En el ovario, la FSH estimula el crecimiento de un grupo de folículos de los cuales uno o más alcanzaran la fase de dominancia y eventualmente ovular. Por su parte la LH es la encargada del crecimiento final de los folículos preovulatorios y de la ovulación (Palermo, 2007).

Cuando los folículos comienzan a crecer empiezan a producir 17β-estradiol (E2). Las concentraciones de E_2 comienzan a aumentar lo que induce la aparición del estro y estimula el pico preovulatorio de la LH (Llewelyn *et al.,* 1993). Este pico preovulatorio de LH es el responsable de la ovulación que ocurre 22-26 h después del pico preovulatorio de LH, o bien hacia el final del estro. Tras la ovulación, la LH transforma a las células del folículo (células de la teca y granulosa) en el CL el cual produce y secreta P_4, esencial para el establecimiento y mantenimiento de la gestación (Fatet *et al.,* 2011). Conforme avanza el ciclo estral, el cuerpo lúteo comienza a crecer y las concentraciones sanguíneas de P_4 aumentan (Medan *et al.,* 2003). Cuando los niveles de P_4 son altos, bloquean la secreción pulsátil de LH por lo que no ocurren ni el estro ni la ovulación (Llewelyn *et al.,* 1993; Caraty y Skinner, 1999). Alrededor del día 8-9 del ciclo estrual el tamaño del CL, así como los niveles sanguíneos de P_4 alcanzan su máximo nivel y permanecen constantes hasta el día en que comienza la regresión del cuerpo lúteo (de Castro *et al.,* 1999).

Si la cabra queda gestante, el embrión previene la regresión del CL y, por lo tanto, el CL y los niveles sanguíneos de P4 permanecen elevados durante toda la gestación hasta el momento del parto; si no, el cuerpo lúteo regresa y la P4 comienza a descender (Niswender *et al.,* 2000). La regresión del cuerpo lúteo o luteolisis inicia aproximadamente el día 15 del ciclo estral y es provocada por la acción de la prostaglandina F2α ($PGF_{2α}$) la cual es secretada por el útero (de Castro *et al.,* 1999), dando lugar a un nuevo ciclo estral.

Dinámica folicular en las cabras

El crecimiento de los folículos ocurre en forma de oleadas (Rubianes y Menchaca, 2003). El número de oleadas u ondas foliculares durante un ciclo estral es en promedio de cuatro, pero puede variar de 2 a 5 (Rubianes y Menchaca, 2003). El intervalo entre una oleada y otra es de 4 a 6 días y el surgimiento de la primera oleada folicular generalmente coincide con la ovulación (de Castro *et al.,* 1999; Medan *et al.,* 2003; Rubianes y Menchaca, 2003; Simões *et al*., 2006).

Una oleada se caracteriza por la secuencia de tres eventos en el crecimiento folicular dependientes de gonadotropinas conocidos como reclutamiento, selección y dominancia (Driancourt, 2001). El reclutamiento o emergencia ha sido definido como el crecimiento sincronizado de un grupo de folículos antrales de 2-3 mm de diámetro estimulado por un aumento en las concentraciones de la FSH (Medan *et al.,* 2003). A este punto, todos los folículos son dependientes de FSH y tienen el mismo potencial de ovular; sin embargo, solo uno (o dos) serán seleccionados y se convertirán en el folículo dominante (Driancourt, 2001; Fatet *et al*., 2011). El folículo seleccionado continúa creciendo por acción de la LH convirtiéndose en el folículo dominante mientras que el resto de los folículos sufren atresia (Ginther, 2016). Si esto sucede durante la última oleada del ciclo estral o durante la luteólisis del cuerpo lúteo, el folículo dominante ovulará; si no, también sufre atresia y surgirá una nueva onda folicular (Menchaca y Rubianes, 2004; Gonzalez-Bulnes *et al.,* 2005).

Enfermedades posparto en vacas lecheras

Metritis y Endometritis

La metritis puerperal (PM) es una infección común en el ganado lechero y la segunda más común motivo del tratamiento de una vaca con antimicrobianos (USDA, 2018). La metritis reduce la rentabilidad del rebaño debido a la disminución de la producción de leche y la eficiencia reproductiva y al aumento del riesgo de sacrificio temprano (Dubuc *et al*., 2011; de Oliveira *et al*., 2020). La metritis también ha sido asociada negativamente con el bienestar animal (Stojkov *et al*. otros, 2015; Barragán *et al*., 2018). El costo estimado de PM incluye el uso de antimicrobianos terapéuticos, la leche desechada, la disminución de la producción de leche y disminución de la eficiencia reproductiva, entre otros (Lima *et al*., 2019).

La incidencia de infecciones uterinas en el ganado lechero va desde el 10 hasta el 50% (LeBlanc *et al*., 2011); estas infecciones causan inflamación, alteraciones histológicas, retraso en la involución uterina, reducción de secreción de LH y alteración del crecimiento folicular (Williams *et al*., 2005). La metritis se caracteriza por secreción uterina fétida de color marrón rojizo dentro de los primeros 21 días en leche (DIM; Sheldon *et al*., 2006), y afecta alrededor 20,0% de las vacas lecheras lactantes, con la incidencia oscilando entre 8 y >40% en algunas granjas lecheras (Goshen y Shpigel, 2006; Hammon *et al*., 2006; Huzzey *et al*., 2007; Galvão *et al*., 2009b).

La endometritis clínica se caracteriza por la presencia de fluido con sangre y purulento después de 21 DIM o mucopurulenta (50% pus, 50% moco) después de 26 DIM (Sheldon *et al*., 2006), y también afecta a alrededor del 20% de las vacas lactantes, con una prevalencia que va del 5 al >30% en algunos rebaños (LeBlanc *et al*., 2002; McDougall *et al*., 2007; Galvão *et al*., 2009b). La endometritis subclínica se define por la presencia de >18% de neutrófilos (PMN) en el útero en muestras de citología recolectadas entre 21 y 33 DIM o >10% PMN entre 34 y 47 DIM (Sheldon *et al*., 2006), y es la más prevalente de todas las enfermedades uterinas; afecta aproximadamente al 30% de las vacas lecheras lactantes, con una prevalencia que oscila entre 11 y >70% en algunos hatos (Gilbert *et al*., 2005; Hammon *et al*., 2006; Barlund *et al*., 2008; Galvão et al., 2009a; Cheong *et al*., 2011). Estas enfermedades se han asociado con la disminución de la tasa de preñez, intervalo prolongado hasta la gestación, mayor sacrificio y pérdidas económicas (Sheldon y Dobson, 2004; Gilbert *et al*., 2005; Overton y Fetrow, 2008; Galvão *et al*., 2009a, b).

Aunque el 95% de los animales en el parto son expuestos a patógenos, el principal factor predisponente a la infección es el estado del animal. Principalmente el estado energético. Evidentemente, la prevención y el tratamiento temprano de la infección es menos costoso que el tratamiento cuando la infección ya fue establecida (Haimerl y Heuwieser, 2014). Por lo tanto, predecir los eventos de enfermedad mediante biomarcadores se vuelve relevante (Manimaran *et al*., 2016). Las vacas que presentan un balance energético más pronunciado son más susceptibles a padecer infecciones uterinas, las concentraciones más elevadas de NEFAS y BHBA se asocian con la incidencia de metritis y endometritis, esto, mediado por el deterioro de la función de los neutrófilos (Kim *et al*., 2005). También se ha sugerido que la disminución de glucógeno en los neutrófilos y calcio en la sangre disminuyen la función de los neutrófilos (Manimaran *et al*., 2016). En estudios realizados por Magnus y Lali (2009) donde se compararon los parámetros metabólicos de vacas con metritis y los parámetros normales, encontraron que las vacas con metritis presentaban hipocalcemia, hipoglucemia y fracción reducida de globulina. Mientras que la proteína total, albumina, creatinina y urea en la sangre no mostraron variación.

Cetosis clínica

La cetosis es un trastorno metabólico común que ocurre con frecuencia durante el período de transición. Se caracteriza por un aumento de las concentraciones de cuerpos cetónicos, incluido el acetoacetato (AcAc), acetona (Ac) y βOHB en sangre, orina y leche al inicio de la lactancia (Oetzel, 2004; Tehrani-Sharif *et al*., 2011). La tasa de incidencia de la cetosis ha superado la de la acidosis ruminal y la fiebre de la leche y ha surgido como una de las perturbaciones metabólicas más importantes de las vacas lecheras en América del Norte desde fines de la década de 1990 (Oetzel, 2007). De hecho, casi el 40% de las vacas lecheras en América del Norte tienen diferentes grados de cetosis dentro de las primeras semanas después del parto, con una incidencia que varía ampliamente entre granjas y alcanza hasta el 80%, en algunos hatos lecheros (Duffield, 2000).

Los impactos negativos de la cetosis pueden incluir baja producción de leche, comportamiento reproductivo disminuido (p. ej., infertilidad), mayor riesgo de otras enfermedades del periparto incluyendo abomaso desplazado, cojera, mastitis, metritis y placenta retenida, y una mayor tasa de sacrificio (Duffield, 2009; Ospina *et al*., 2010; McArt *et al*., 2011; Raboisson *et al*., 2014). Aunque la cetosis se ha revisado ampliamente a lo largo del tiempo (Duffield, 2000; Ospina *et al*., 2010; Gordon, 2013), las causas precisas y la patobiología de la cetosis sigue siendo desconocida. Las vacas lecheras generalmente experimentan un estado de NEB alrededor del parto caracterizado por la movilización excesiva de ácidos grasos libres del tejido adiposo debido a la baja ingesta de materia seca (Herdt, 2000). Los ácidos grasos siguen cuatro vías en el hígado: (1) oxidación completa a través del ciclo del ácido tricarboxílico para generar H_2O, CO_2 y energía; (2) oxidación incompleta resultante en la liberación de cuerpos cetónicos y menos energía; (3) exportado fuera del hígado como parte de VLDL; y (4) esterificación de ácidos grasos no esterificados (NEFA) a triacilgliceroles (TAG) y acumulación dentro de los hepatocitos (Goff y Horst, 1997; Grummer, 2008).

La patobiología exacta de la hipercetonemia no se conoce por completo (Herdt, 2000). La hipótesis más dominante es que hay un déficit de energía (es decir, glucosa) inmediatamente después del parto. Aparentemente, la capacidad gluconeogénica del hígado no puede satisfacer las demandas de glucosa de la vaca posparto, porque la glándula mamaria utiliza del 60% al 85% de la glucosa disponible para la síntesis de la leche (Knowlton *et al*., 1998). La hipoglucemia puede deberse a precursores gluconeogénicos inadecuados o a una tasa limitada de gluconeogénesis (Knowlton *et al*., 1998; Gordon, 2013). Las bajas concentraciones de glucosa en sangre se asocian con hipoinsulinemia, que posteriormente desencadena la movilización de ácidos grasos del tejido adiposo, lo que aumenta la formación de cuerpos cetónicos. En el hígado, los ácidos grasos se oxidan a dióxido de carbono y cuerpos cetónicos o reesterificados en triglicéridos (TG) para su almacenamiento e incorporación en lipoproteínas de muy baja densidad (VLDL) (Zhang y Ametaj, 2020). La acumulación excesiva de

TG conduce a hígado graso, lo que deteriora aún más las funciones hepáticas, limitando el proceso de gluconeogénesis.

La cetosis clínica es una enfermedad poco común, pocos estudios recientes han informado de su incidencia y se estima que ocurre en alrededor del 2 al 8% del ganado lechero en la lactancia temprana (Duffield, 2000.) En los últimos años, mucha investigación se ha centrado en el impacto de la cetosis subclínica (SCK), que se sabe que es más frecuente que la forma clínica. El ganado en SCK parece clínicamente normal; la prueba estándar de oro es la determinación de betahidroxibutirato sérico (ABHB), realizado en un laboratorio acreditado o con análisis de campo. El umbral comúnmente utilizado para definir SCK es ≥1.2 mmol/ L, y la mayoría de las investigaciones coinciden en que el marco de tiempo óptimo para tomar muestras es en las primeras 2 semanas de lactancia, con cuerpos cetónicos que alcanzan un máximo de 5 a 14 días (LeBlanc, 2010; McArt *et al*., 2013). La cetosis bovina ocurre típicamente en la lactancia temprana. Los signos clínicos incluyen disminución del apetito, disminución de la producción de leche, pérdida de peso, hipoglucemia e hipercetonemia (Baird, 1982). Desde 1991 Veenhuizen *et al*. (1991) ya reportaban un aumento considerable de las concentraciones de NEFA en sangre de vacas lecheras. Incluso, dos semanas antes de que apareciera la cetosis clínica. De la misma forma, los valores de ABHB en la sangre aumentaban hasta 8.6 veces. Se pueden presentar cuatro tipos de cetosis en vacas lecheras: cetosis primaria y secundaria con subalimentación, cetosis alimentaria y cetosis espontánea. La cetosis primaria de subalimentación resulta porque la vaca no recibe suficiente alimento de buena calidad; la cetosis secundaria por subalimentación ocurre porque el consumo de alimento de la vaca se ha reducido como resultado de otra enfermedad. La cetosis alimentaria resulta porque la ingesta de alimentos fermentados que contienen precursores cetogénicos es alta. La cetosis espontánea se refiere a una condición bajo la cual una vaca tiene cuerpos cetónicos en sangre elevados a pesar de que la dieta parece ser nutricionalmente adecuada (Kronfeld, 1982).

Artículos

1. Body condition score and serum metabolites and minerals concentrations as indicators of ovarian activity and pregnancy success in goats on rangeland

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RESEARCH ARTICLE

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Body condition score and serum metabolites and minerals concentrations as indicators of ovarian activity and pregnancy success in goats on rangeland

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Abstract

Aim of the study: To investigate potential differences in ovarian structures relative to serum metabolite and mineral concentrations at mating. Also, body condition score (BCS), serum metabolites, and mineral profiling at mating were compared between pregnant and non-pregnant goats.

Area of study: Hot zone of northern Mexico (26 °N).

Material and methods: Mixed-breed goats (n= 89) on arid rangeland were exposed to bucks during the non-breeding season. Ovarian structures were recorded at mating and ten days after breeding using ultrasonography. Pregnancy was detected at 30 and 120 days post-mating. BCS, blood metabolites, and minerals were determined at mating.

Main results: Pregnant goats had higher BCS at mating than non-pregnant goats. The mean serum glucose concentration was higher (p<0.05) for pregnant goats than that for non-pregnant ones (87.3 ± 12.1 *vs.* 74.4 ± 11.6 mg/dL). Significantly lower (p<0.01) serum urea nitrogen levels at mating were recorded in non-pregnant (10.7 ± 3.5 mg/dL) than in pregnant goats (12.4 ± 3.7 mg/dL). Lower serum glucose (72.2 ± 6.9 *vs.* 89.4 ± 11.2) and higher non-esterified fatty acids concentrations (NEFA; 0.43 ± 0.23 *vs.* 0.18 ± 0.12) were significantly associated (p<0.05) with pregnancy loss. Higher serum total protein concentrations were associated with a greater number and larger ovulatory follicles. High serum phosphorus was significantly associated with larger ovulatory follicles. Goats with ovulatory follicles ≥7.6 mm were more likely (p<0.05) to get pregnant than goats with smaller ovulatory follicles.

Research highlights: Monitoring BCS, serum glucose, blood urea nitrogen, and NEFA could be used to identify goats at risk for infertility.

Additional keywords: blood urea nitrogen; blood glucose; ovulatory follicle; follicle size; corpus luteum size.

Abbreviations used: BCS (body condition score); BUN (blood urea nitrogen); NEFA (non-esterified fatty acids); TP (total proteins).

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Introduction

Goats play an essential role in developing economies and are a source of subsistence, livelihood, and employment for many rural households. Goats produce meat, milk, skin, and manure under various habitats with scarce vegetation, making them ideal farm animals for resource-poor farmers (Patel *et al.*, 2020). In developing countries, goat production systems are characterized by low input and production on degraded rangelands that contribute to inadequate feeding and nutrition (Monau *et al.*, 2020; Patrick Baenyi *et al.*, 2020), resulting in low productivity (Thomas & Rangnekar, 2004). Browsing and grazing on natural rangelands or shrublands are the primary feed sources in the world's arid and semi-arid pastoral areas, occasionally using crop residues in farming systems where mixed crop-livestock production is practiced (Nair *et al.*, 2021).

Seasonality of rainfall distribution, quantity, and quality of forage supply is markedly seasonal in arid rangelands (Larsen *et al.*, 2021), with a severe shortage of forage supply and inferior quality during the dry season, which constrains goat production on pasture (Chebli *et al.*, 2022). Poor nutrition results in a low growth rate of growing animals, meat and milk production, reproductive performance, loss of body condition, and increased susceptibility to diseases and parasites (Zhou *et al.*, 2019; Flores-Najera *et al.*, 2020). This is further aggravated by the rearing practice that does not contemplate feed supplementation at any season of the year, due mainly to the high cost of these supplementation feed. Thus, improving nutrition and maximizing the available forage resources should be the primary goal for enhancing goat productivity under marginal rangelands and/or in poor rural households (Mellado *et al.*, 2020).

In traditional goat production systems in developing countries, bucks run freely with does; therefore, natural mating occurs most of the year because below 25° north latitude anestrous in goats is almost inexistent (Mellado J *et al.*, 2014). However, due to nutritional constraints, goats typically have a great reproductive wastage (Robertson *et al.*, 2020; Mellado, 2022). Therefore, proper feeding is key to high fertility in grazing goats. In goats raised in arid ecosystems, reproductive performance is suboptimal, and milk production is low. Even so, these goat production systems are sustainable, meet the dairy and meat demands of low-income communities (Silanikove *et al.*, 2010), and provide a significant income source for goat farmers (Mayberry *et al.*, 2018; Murali *et al.*, 2020).

There are marked variations in the capacity of goats to graze in harsh environments; therefore, some animals are better able to ingest enough nutrients to reproduce successfully (Mellado M *et al.*, 2014). Meeting the nutrient requirements for optimum reproductive performance in grazing/ browsing goats is challenging in the dry season on rangeland (Safari *et al.*, 2011). Therefore, assessing the goats' energy status at mating via blood metabolites indicative of body energy reserves is a useful tool to attain an acceptable pregnancy rate of goats on rangeland (Mellado *et al.*, 2003; Sarıbay *et al.*, 2020). Thus, it would be convenient to find out which goats in a herd can consume a better diet to become pregnant and avoid pregnancy loss.

We hypothesized that grazing goats' fertility would be increased in those animals with higher body condition score (BCS), blood metabolites and minerals indicative of good body energy reserves and that blood metabolites would interact with follicular and corpus luteum development.

Therefore, the present study in mixed-breed goats aimed to investigate potential differences in follicle and corpus luteum number and size and the number of these structures at mating between goats that conceived and those unable to get pregnant during the breeding season. Additionally, this study aimed to investigate the effect of follicle size, BCS, and blood metabolites and minerals concentrations at mating on pregnancy establishment and maintenance.

Material and methods

Study area

The experimental site is located in northeast Mexico (25° 32' N, 103° 40' W) at 1150 m above sea level. Mean annual precipitation is 225 mm, most of which falls as high-intensity thunderstorms from June to October. The mean annual temperature is 22.3° C. The overstory was predominantly *Prosopis* spp., *Larrea tridentata*, and *Atriplex canescens*. Other important shrubs present were *Agave lechuguilla*, and *Opuntia rastrera*. The most abundant forbs are *Sphaeralcea angustifolia*, *Solanum elaeagnifolium*, *Salsola kali*, and *Lepidium virginicum*. Grasses constitute only a small part of the vegetation and grow mainly beneath shrubs. The principal species are *Munroa pulchella*, *Setaria macrostachya*, and *Muhlenbergia porteri*.

Goats and their management

Animal procedures were agreed upon and performed following the Institutional Animal Care and Use Committee of the Agrarian Autonomous University Antonio Narro (Protocol # 03001-2258) and carried out following FASS (2010). The study was conducted from May to October 2021 in a large goat herd in a microphyll desert scrub ecosystem of northern Mexico. A total of 89 mixed-breed (Central Europe dairy breeds × criollo) goats were used in the present study. Goats did not present any physical defects, had not given birth in the previous five months, were not pregnant, and had BCS ranging from poor to good (BCS 1–3 on a scale of 1–5). Goats grazed on open degraded Chihuahuan desert rangeland in plain terrain, yearround, driven by a herdsman for 6 h per day (from 1100 to 1700 h). Goats were confined after returning from grazing

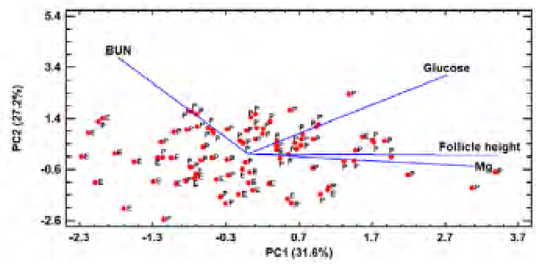

Figure 1. Results of the principal components analysis from some serum metabolites, minerals, and ovarian follicle size. The two principal components with the largest eigenvalues are shown as the x, -and y-axes, respectively. In addition, the loading for each of the input variables concerning these two dimensions is shown. For each point: P= pregnant, and E= "empty".

in an unshaded pen, without access to feed supplementation and water. No salt mineral mix was provided to the goats throughout the year; goats had access to water from a pond only once a day. Goats were not treated against gastrointestinal and external parasites or vaccinated against endemic diseases.

Reproductive management

Four adult (64.5 ± 7.3 kg BW) mixed-breed bucks with adequate BCS (3.5; scale 1-5) with previous mating experience and an account of satisfactory kidding percentages were joined to dry goats for 30 days in May 2021. Approximately thirty days after the end of the mating season, pregnancy was detected using ultrasonography. Pregnancy detection was again assessed 120 days after mating. At kidding, kidding rate and litter size were recorded.

Ultrasound examination

At mating, trans-rectal ovarian ultrasonographic evaluations were performed using an ultrasound scanner (Aloka 500V, Corometrics Med. Syst. Inc., Wallingford, CT, USA) equipped with a linear array transrectal probe (7.5 MHz transducer) by a single experienced operator. Follicles were counted, and their height was recorded on a frozen image. Follicles were classified according to follicular height as small (<3 mm in size), growing mid-sized follicles (3 to 5 mm), and large follicles (>5 mm) (Rateb *et al.*, 2019). The ovulation rate was determined by identifying the corpus luteum and the disappearance of the previously observed mature follicle(s) 10 days after mating.

Blood metabolites and minerals determination

Blood was sampled from the selected goats by jugular venipuncture in non-anticoagulation gel separator vacuum tubes (Vacuntainer®). Immediately after collection, the samples were centrifuged, and the serum was placed in Eppendorf tubes and stored at −20 °C until it was assayed. Serum glucose, total protein (TP), cholesterol, blood urea nitrogen (BUN), creatinine, and phosphorus (P) concentrations were determined using colorimetric methods following protocols supplied by the kits' manufacturers (Sigma Diagnostics Inc., Livonia, MI, USA). Non-esterified fatty acids (NEFA) were determined using a commercial kit (WAKO; Mountain View, CA, USA). In addition, serum minerals were determined by atomic absorption spectrophotometry.

Statistical analyses

Continuous variables were tested for normality and group homogeneity using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC, USA, vers. 9.4); continuous data were normally distributed. The variables were compared between groups (pregnant *vs.* non-pregnant; pregnancy loss *vs.* non-pregnancy loss, single *vs.* twin pregnancy) using the GLM procedure of SAS. Variables were described as mean values ± standard deviation, differences between groups with 95% confidence intervals were computed (TTEST procedure of SAS), and significance was declared when α was 5%.

These variables were dichotomized for the effect of serum metabolites and minerals on ovarian structures, using their mean as a cutting point for classifying concentrations below or above the mean. Then, the GLM procedure of SAS was used to detect differences between levels of metabolites and minerals on the number of total follicles and ovulatory follicles, mean ovulatory follicles height, number of corpus luteum, and average corpus luteum height. Parity was included in the model as a covariate.

Canonical correlations for exploring the relationships between two multivariate sets of variables were applied

Table 1. Between-group comparison of body condition score (BCS), serum metabolites, and minerals of non-pregnant and pregnant goats at about 30 days post-service on a desert rangeland. Values for groups are means ± standard deviations.

Variables	Non-pregnant (NP; n= 25)	Pregnant (P; n= 64)	NP-P difference 95% CI	*p*-value
BCS (units)	2.1 ± 0.56	2.2 ± 0.45	-0.1 (-0.33 – 0.11)	0.035
Age (years)	3.5 ± 1.1	3.2 ± 1.4	0.3 (-0.27 – 0.96)	0.662
Glucose (mg/dL)	74.4 ± 11.6	87.3 ± 12.1	-12.9 (-18.5 – 7.2)	0.019
BUN (mg/dL)	10.7 ± 3.5	12.4 ± 3.7	-1.7 (-3.5 – -0.02)	0.008
Creatinine (mg/dL)	2.5 ± 0.4	2.5 ± 0.5	0.09 (-0.12 – 0.30)	0.471
Cholesterol (mg/dL)	133.3 ± 37.5	131.5 ± 30.4	1.8 (-13.5 – 17.0)	0.702
Total protein (mg/dL)	5.8 ± 1.9	5.8 ± 2.0	0.006 (-0.9 – 0.9)	0.381
NEFA (mmol/L)	0.41 ± 0.28	0.40 ± 0.23	0.02 (-0.09 – 0.13)	0.441
Copper (mg/L)	0.38 ± 0.11	0.43 ± 0.18	-0.04 (-0.12 – 0.03)	0.075
Zinc (mg/L)	1.13 ± 0.28	1.10 ± 0.31	0.01 (-0.14 – 0.16)	0.639
Magnesium (mg/dL)	1.89 ± 0.69	2.07 ± 0.76	-0.24 (-0.62 – 0.13)	0.131
Phosphorus (mg/dL)	4.17 ± 1.43	4.37 ± 1.38	-0.09 (-0.81 – 0.62)	0.257

BUN: blood urea nitrogen. NEFA: non-esterified fatty acids. CI: confidence intervals.

to select follicular traits to identify groups of metabolites with a related biological role in ovarian structures using Statgraphics Centurion 19 (Statgraphics Technol. Inc., The Plains, VA, USA). Also, principal component analyses were carried out to understand the sources of variation of data for pregnancy of goats and see distances between important serum variables affecting pregnancy rate. Significance was declared at $p<0.05$.

Results

In the present study, of the 89 experimental goats, 64 were confirmed as pregnant (72% pregnancy rate) on day 30 post-service using ultrasonography. Upon reexamination on day 120 of mating, ultrasonography indicated eight pregnancy losses, and consequently kidding rate was 63%, with a mean litter size of 1.5 ± 0.59 (± SD). Principal components derived from serum metabolites, ovulatory follicle height, minerals, and ovarian variables showed a clear separation between pregnant and non-pregnant goats (Fig. 1). The first two principal components explained 58.8% of the variation in the data.

Data for BCS, serum metabolites, and minerals for pregnant and non-pregnant goats are shown in Table 1. The univariate general linear model analyses showed that BCS was significantly higher ($p<0.05$) in pregnant than non-pregnant goats. No significant effect of the confounding variable age on pregnancy outcome was observed. Mean serum glucose concentration was 13 mg/kg higher ($p<0.05$) for goats that became pregnant compared with non-pregnant goats. There was a significant ($p<0.01$) effect of pregnancy on serum BUN concentrations, which indicated that high blood BUN levels were associated with pregnancy outcomes. All other serum metabolites indicative of body energy reserves and minerals were not different for non-pregnant compared with pregnant goats. No effect was observed for BCS, serum metabolites, and minerals concentration on litter size of goats ($p > 0.05$).

Mean serum glucose concentrations at mating were much higher ($p<0.01$) in goats that did not lose their pregnancy than in goats that experienced a pregnancy loss before 120 days post-mating (Table 2). In addition, serum NEFA concentration at mating was 2.4 times higher ($p<0.05$) in goats that did not lose their pregnancy than in goats that lost their pregnancy. All other serum metabolites and minerals were not different at mating for goats with pregnancy loss and animals with no pregnancy loss. Regarding ovarian structure characteristics at mating, the mean ovulatory follicular height was significantly higher ($p<0.01$) in goats that became pregnant than in non-fecundated goats (Table 3).

High BCS, serum glucose, and BUN concentrations did not significantly affect the number or size of ovulatory follicles and corpus luteum. The total number of ovulatory follicles at mating was significantly higher ($p<0.01$) in goats with high serum TP than in goats with lower blood TP levels (Table 4). Likewise, higher serum TP concentrations led to more prominent follicles ($p<0.05$). Goats with higher serum P concentration presented significantly bigger ($p<0.05$) ovulatory follicles than goats with lower serum P levels. None of the variables studied affected the number of corpus luteum. The average height of the corpus luteum was larger ($p<0.05$) in goats with lower serum creatinine levels than in goats with high serum creatinine concentrations. Lower serum magnesium concentration

Table 2. Between-group comparison of body condition score (BCS), serum metabolites, and minerals of goats that maintained their gestation to term or goats that suffered pregnancy loss on a desert rangeland.

Variable	Pregnancy to term (PT; n= 56)	Pregnancy loss (PL; n= 8)	PT-PL difference 95% CI	*p*-value
BCS (units)	2.19 ± 0.51	1.92 ± 0.34	0.27 (-0.13 – 0.65)	0.628
Age (years)	3.4 ± 1.3	2.7 ± 1.6	0.73 (-0.34 – 1.81)	0.393
Glucose (mg/dL)	89.4 ± 11.2	72.2 ± 6.9	17.2 (9.1 – 25.4)	0.004
BUN (mg/dL)	12.6 ± 3.4	11.3 ± 5.9	1.26 (-1.75 – 4.27)	0.592
Creatinine (mg/dL)	2.46 ± 0.47	2.38 ± 0.14	0.08 (-0.28 – 0.44)	0.759
Cholesterol (mg/dL)	130.1 ± 30.7	143.6 ± 27.5	-13.5 (-37.8 – 10.8)	0.593
Total protein (mg/dL)	5.8 ± 1.9	5.8 ± 2.5	0.06 (-1.5 – 1.6)	0.581
NEFA (mmol/L)	0.18 ± 0.12	0.43 ± 0.23	-0.25 (-0.38 – 0.41)	0.018
Copper (mg/L)	0.43 ± 0.18	0.43 ± 0.17	-00.2 (-0.15 – 0.14)	0.795
Zinc (mg/L)	1.12 ± 0.29	0.91 ± 0.36	0.21 (-0.02 – 0.44)	0.110
Magnesium (mg/dL)	2.30 ± 0.68	2.06 ± 0.46	0.25 (-.28 – 0.78)	0.906
Phosphorus (mg/dL)	4.41 ± 1.31	4.29 ± 1.01	0.12 (-0.97 – 1.20)	0.447

BUN: blood urea nitrogen. NEFA: non-esterified fatty acids. CI: confidence intervals.

was associated with a shorter corpus luteum ($p<0.05$). Additionally, the canonical correlation showed that follicle traits, BCS, and some blood metabolites were moderately correlated ($r = 0.45$; $p<0.05$), which indicates that serum glucose, creatinine, and NEFA had a significant but moderate association with the number of follicles and size.

Discussion

Optimization of reproductive efficiency of goat herds on arid rangelands is a continuous challenge to goat producers. In the present study kidding rate of unsupplemented goats bred during the non-breeding season was 63%, a figure close to 72% reported in the same environment and nutritional conditions (De Santiago-Miramontes *et al.*, 2011; Mellado *et al.*, 2020). The suboptimal reproductive performance observed in this study is attributable to the arid conditions under which the goats are reared.

The present study evaluated the variations in BCS, serum metabolites, and mineral concentrations in pregnant and non-pregnant goats on rangeland fecundated during the non-breeding season (May). The results indicated that BCS at mating was higher in pregnant than in non-pregnant goats. These findings align with previous works showing that adequate body energy reserves, mainly represented by body fat and muscle content in goats, are required for maximum estrus response (Rivas-Muñoz *et al.*, 2010) and pregnancy rate (Serin *et al.*, 2010). In addition, BCS in goats is associated with blood glucose concentration (Milosevic-Stankovic *et al.*, 2020; Sitaresmi *et al.*, 2020), BUN (Sitaresmi *et al.*, 2020) and NEFA (Lunesu *et al.*, 2021), which means that BCS vary with the change of energy balance. In goats, reduced BCS leads to ovarian dysfunction (inactive or acyclic; Widiyono *et al.*, 2020). Thus, goats with higher body energy reserves had more energy for reproductive function, which was reflected in higher odds of getting pregnant.

Table 3. Between-group comparison of ovarian structures of non-pregnant and pregnant goats on a desert rangeland.

Variables	Non-pregnant (NP; n= 25)	Pregnant (P; n= 64)	NP-P difference 95% CI	*p*-value
Total follicles	5.20 ± 2.10	4.67 ± 1.67	0.53 (-0.34 – 1.40)	0.663
Ovulatory follicles	2.36 ± 1.63	2.26 ± 0.97	0.09 (-0.46 – 0.65)	0.838
Average ovulatory follicle size (mm)	6.70 ± 1.74	7.63 ± 1.57	-0.93 (-1.69 – -0.17)	0.016
Number of corpus luteum	1.48 ± 0.91	1.60 ± 0.63	-0.13 (-0.46 – 0.21)	0.450
Average corpus luteum size (mm)	13.00 ± 2.10	12.30 ± 3.64	0.69 (-0.85 – 2.23)	0.375

CI: confidence intervals.

Table 4. Between-group comparison of body condition score (BCS), serum metabolites, and minerals of non-pregnant and pregnant goats at about 30 days post-service on a desert rangeland. Values for groups are means ± standard deviations.

Variables	Ovulatory follicles		Corpus luteum	
	Number	Height	Number	Height
BCS (units)				
≥ 2.5 (n=42)	2.36 ± 1.32	7.40 ± 1.53	1.69 ± 0.78	12.98 ± 2.81
< 2.5 (n=47)	2.23 ± 1.06	7.36 ± 1.78	1.46 ± 0.65	12.07 ± 3.63
Glucose (mg/dL)				
≥ 85 (n=40)	2.43 ± 1.17	7.62 ± 1.71	1.53 ± 0.64	12.52 ± 3.72
< 85 (n=49)	2.13 ± 1.20	7.07 ± 1.57	1.62 ± 0.80	12.48 ± 2.70
BUN (mg/dL)				
≥ 11.5 (n=49)	2.31 ± 1.06	7.20 ± 1.38	1.53 ± 0.70	12.72 ± 3.09
< 11.5 (n= 40)	2.28 ± 1.33	7.59 ± 1.96	1.62 ± 0.70	12.24 ± 3.52
Creatinine (mg/dL)				
> 2.4 (n= 40)	2.18 ± 1.15	7.30 ± 1.84	1.55 ± 0.81	11.67 ± 4.25[a]
< 2.4 (n= 49)	2.28 ± 1.02	7.44 ± 1.52	1.59 ± 0.64	13.18 ± 2.01[b]
Cholesterol (mg/dL)				
> 132 (n= 43)	2.26 ± 1.05	7.35 ± 1.81	1.53 ± 0.82	12.34 ± 3.87
< 132 (n= 46)	2.22 ± 1.11	7.40 ± 1.52	1.61 ± 0.61)	12.65 ± 2.66
Total protein (mg/dL)				
> 5.8 (n= 47)	2.53 ± 1.06[A]	7.74 ± 1.85[a]	1.53 ± 0.65	12.85 ± 2.63
< 5.8 (n= 42)	1.90 ± 1.01[B]	7.06 ± 1.41[b]	1.62 ± 0.79	12.11 ± 3.88
NEFA (mmol/L)				
> 0.4 (n= 51)	1.97 ± 0.97[a]	7.71 ± 1.84	1.53 ± 0.60	12.18 ± 3.96
< 0.4 (n= 38)	2.43 ± 1.12[b]	7.13 ± 1.84	1.61 ± 0.80	12.74 ± 2.69
Copper (mg/L)				
> 0.41 (n= 32)	2.25 ± 1.08	7.38 ± 1.41	1.59 ± 0.66	12.38 ± 3.04
< 0.41 (n= 57)	2.22 ± 1.09	7.38 ± 1.80	1.56 ± 0.75	12.57 ± 3.43
Zinc (mg/L)				
> 1.1 (n= 45)	2.24 ± 1.13	7.38 ± 1.88	1.58 ± 0.75	12.79 ± 1.90
< 1.1 (n= 44)	2.23 ± 1.03	7.38 ± 1.43	1.57 ± 0.69	12.21 ± 4.26
Magnesium (mg/dL)				
> 2.2 (n= 45)	2.20 ± 0.99	7.61 ± 1.79	1.60 ± 0.68	11.83 ± 3.67[a]
< 2.2 (n= 44)	2.27 ± 1.16	7.13 ± 1.49	1.55 ± 0.76	13.19 ± 2.71[b]
Phosphorus (mg/dL)				
> 4.3 (n= 38)	2.29 ± 1.04	7.83 ± 1.64[a]	1.52 ± 0.82	12.32 ± 3.39
< 4.3 (n= 51)	2.20 ± 1.11	7.03 ± 1.60[b]	1.61 ± 0.63	12.64 ± 3.2

BUN: blood urea nitrogen. NEFA: non-esterified fatty acids. [a,b]Means with different superscripts in the same column and within variable differ ($p<0.05$). [A,B]Means with different superscripts in the same column and within variable differ ($p<0.01$).

A comparison of the mean serum glucose concentrations between pregnant and non-pregnant goats also indicated that the higher circulating glucose concentrations occurred in goats that become pregnant. Glucose is the primary source of energy for the body's cells (Milosevic-Stankovic *et al.*, 2020) and the primary indicator of energy status in goats (Khan & Ludri, 2002). Improved nutrition directly affects animal metabolism by providing substrates for metabolism and cellular processes (Scaramuzzi *et al.*, 2006). Well-fed goats show higher serum glucose concentration than underfed animals (Mellado *et al.*, 2020).

Glucose availability for ovarian follicles can be used for energy production (Sutton-McDowall *et al.*, 2010), and circulating glucose, insulin, and glucagon levels affect folliculogenesis and the intrafollicular environment (Ying *et al.*, 2011; Al-Hamedawi *et al.*, 2017). Additionally, glycemia is critical in regulating ovarian follicle responsiveness to gonadotropins (Selvaraju *et al.*, 2003). In this context, the present study confirmed that high serum glucose availability at mating in grazing goats increases the odds of pregnancy. Furthermore, short-term nutritional supplementation rises the number of ovulatory follicles, and the ovulation rate is associated with blood glucose levels in goats (Zabuli *et al.* 2010). This explains the higher proportion of pregnant goats with higher serum glucose concentration when joined to bucks.

These results showed that low serum BUN in goats resulted in a reduction in pregnancy rate. BUN reflects a higher nitrogen intake, as a positive correlation exists between protein intake and BUN concentration in goats (Rondina *et al*., 2005; Senosy *et al*., 2017). Pregnancy was more likely in goats that had a mean BUN value of 12.6 mg/dL, suggesting that high BUN in goats grazing arid rangeland is favorable for conception as the increased serum BUN in goats on rangeland indicates a positive effect of diet on rumen ammonia-nitrogen concentration (Zhu *et al*., 2020).

Serum cholesterol concentrations were not significantly different among pregnant, non-pregnant, and goats that experienced pregnancy loss or those whose pregnancy was carried to term. Also, this metabolite did not affect the number or size of ovarian structures. This response could be explained by the fact that serum cholesterol concentrations do not differ among BCS grades (Moeini *et al*., 2014; Sitaresmi *et al*., 2020) and, therefore, under the current nutritional conditions, may not have influenced the reproductive outcome.

Blood metabolites and minerals were not different at mating between single and twin-bearing goats. These results align with observations of Cepeda-Palacios *et al.* (2018), who documented that the number of developing fetuses did not affect any measured hematochemical parameters. However, other studies have found differences between goats carrying singles or twins (Cappai *et al*., 2019; Sarıbay *et al*., 2020). However, in these previous studies, blood metabolite concentrations were not determined at the time of fecundation.

Regarding pregnancy losses, low serum glucose concentration at mating led to higher spontaneous loss of a pregnancy. Of the several possible mechanisms bringing non-infectious gestational failure in goats, hypoglycemia in the mother and subsequently in the fetus trigger the premature eviction of fetuses (Mellado *et al*., 2004, 2020). Energy-deficient diets during gestation, especially in young goats or bearing double fetuses, are important factors triggering fetal losses (Waideland & Loken, 1991; Cronjé, 1998). The few aborted fetuses observed in these grazing goats did not show signs of decomposed fetuses or placentitis, which suggests that malnutrition at mating and subsequent weeks of pregnancy caused pregnancy loss. Goats that maintain their gestation to term in this ecosystem select diets higher in nutrients than goats suffering pregnancy loss (Mellado M *et al*., 2014); therefore, goats' genotypes unable to ingest nutrient-rich diets would present low serum blood glucose, which eventually leads to fetal expulsion.

Another blood metabolite at mating linked to pregnancy loss was NEFA. Goats with high serum NEFA concentrations were more likely to lose their pregnancy than goats with low circulating NEFA. This finding is in line with Hussain *et al.* (1996) who observed higher blood NEFA concentrations in goats with nonviable pregnancy than in goats with no pregnancy loss. This suggests increased lipolysis in goats with pregnancy loss, which presented elevated blood NEFA concentrations, indicative of acute energy restriction and mobilization of body reserves when the glucose level decreased (Veerkamp *et al*., 2003). Perhaps, the higher serum NEFA concentration was related to deficient nutrition for non-adapted goats to lower forage quality or a high fiber diet on rangeland, and they had lower energy status to sustain pregnancy than their better-adapted counterparts (Mellado M *et al*., 2014).

Ovulatory follicle size affected fertility when ovulation occurred after the buck stimulus. Contreras-Solís *et al.* (2021) observed that large follicles from prepubertal ewes had higher estradiol and progesterone concentrations, more competent oocytes, and blastocyst produced in vitro than less developed follicles. Also, it has been reported that GnRH-induced ovulation of follicles ≤11 mm results in lower pregnancy rates and augmented late embryonic/fetal mortality, associated with lower circulating estradiol concentrations and decreased circulating progesterone concentrations (Perry *et al*., 2005). Therefore, ovulatory follicle size is a robust indicator of fertility (Perry *et al*., 2007) and follicular growth stimulation with equine chorionic gonadotropin leads to greater pregnancy rate in goats (Hameed *et al.*, 2020).

Lower serum creatinine concentrations were associated with larger corpus luteum. High blood creatinine concentrations are a reliable biomarker of body protein breakdown and muscle mass change (Patel *et al*., 2013), and therefore, creatinine concentrations change in response to body protein mobilization. In goats, creatinine increased linearly with the decreasing crude protein concentration in the diet (Zhu *et al*., 2020). Therefore, researchers have used this metabolite to monitor nutrient status and muscle mass (Turner *et al*., 2005).

Higher serum TP concentrations were associated with a greater number of ovulatory follicles and their size. This metabolite accommodated both the variations in the albumin and globulins, showing a clear separation for the undernourished and well-fed sheep (Caldeira *et al*., 2007). Thus, this study reaffirms the effects of energy level during the antral phase and subsequent follicular development on follicle recruitment and size. This response has been observed in goats, where dietary energy levels positively influence oocyte follicular development and meiotic competence (Kabir *et al*., 2022).

The fewer ovulatory follicles in goats with elevated serum NEFA concentrations clearly show the effect of the well-known decrease in basal metabolic rate in animals in a state of undernutrition. Energy supplementation in sheep has increased the number of follicles and the amount of double ovulation (Habibizad *et al*., 2015), which are connected to a rise in the number and size of preovulatory follicles (Cuadro *et al*., 2018). Also, greater serum P concentration resulted in larger preovulatory follicles, a singularity of this mineral that improves reproductive performance of anestrus sheep restoring their ovarian activity, increasing the number and size of ovarian follicles and size of corpora lutea (Senosy *et al*., 2018).

In summary, this study showed that high serum BUN and glucose, greater follicular development, and better BCS at mating are sensitive biochemical and physical markers to detect grazing goats capable to become pregnant. Further, high serum glucose and low NEFA concentration at mating are predictive of goats maintaining pregnancy on rangeland.

Authors' contributions

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2. Fertility, milk yield, and health of Holstein cows as affected by body condition score in the transition period

Fertility, milk yield, and health of Holstein cows as affected by body condition score in the transition period

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Running title: Body condition score and Productivity and health of cows

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Abstract

This study aimed at assessing the relationship between body condition score (BCS) loss precalving and postcalving and milk yield, reproductive performance, and occurrence of metritis and ketosis in cows. Holstein cows (n = 5026) from a single dairy operation were assessed for BCS (5-point scale; 0.25-point increments) 15 days precalving, at calving, and first service. 305-d milk yield was highest in cows with ΔBCS <0.25 between 15-d precalving and parturition (11526 ± 1088 kg), and lowest (10878 ± 1114) in cows with precalving ΔBCS <0.75. Total milk yield was highest in cows with ΔBCS <0.25 between 15-d precalving and parturition (13861 ± 2541 kg), and lowest (13214 ± 3174) in cows with precalving ΔBCS >0.75. Overall pregnancy rate was least [281/836 (33.6%); $p<0.01$] for cows that lost > 0.75 units of BCS, and greatest for cows that lost <0.25 BCS [477/615 (77.6%)]. Puerperal metritis occurred more often in cows that lost >0.75 BCS between calving and first AI [175/836 (20.9%); $p<0.01$). Cows with reduced BCS loss between calving and first AI were less likely to present metritis [67/615 (10.9%); $p<0.01$], whereas cows with ≥ 0.75 BCS loss between calving and first AI were 2.3 times more likely [175/836 (20.9%)] to suffer metritis. In conclusion, avoiding high BCS loss during the transition period is a main factor in preventing reduced milk yield and reproductive performance. Also, greater changes in BCS between calving and first AI increased 305-d and total milk yield, and occurrence of puerperal metritis and clinical ketosis, although fertility was reduced.

Key words: pregnancy rate; milk yield; body condition score; metritis; ketosis

Introduction

The peripartum period in high-yielding dairy cows is a critical physiological stage because cows suffer from a negative energy balance, leading to the mobilization of fat from adipose tissues (Arfuso et al., 2016; Mann, 2022), amino acids from muscle (McCabe and Boerman, 2020) and macro and microelements from mineral stores (Drackley et al., 2005; Grala et al., 2022). The increased energy demands for the last stage of the fetus development and colostrum and milk production (van Hoeij et al., 2017), insufficient voluntary feed intake (Pascottini et al., 2020), changes in daily routine, social grouping, and diet changes, predispose cows to infectious and metabolic diseases (Fiore et al., 2017) and alter fertility and milk yield (Meikle et al., 2018; Mezzetti et al., 2021). Also, a complex interplay of multiple pathways, including metabolic and hormonal adaptations, entails the majority of the metabolic and infectious diseases post-partum

(Sundrum, 2015), and these health problems during the transition period constitute a major risk factor for subsequent milk yield and reproductive performance (Barletta et al., 2017).

Body condition scoring (BCS) provides a subjective assessment of the amount of body energy reserves in dairy cows, regardless of body weight and frame. Therefore, BCS has been used as a tool in the reproductive (Bedere et al., 2018; Çolakoğlu et al., 2019), nutritional (Roche et al., 2009), and health (Roche et al., 2015) management of dairy herds. There is extensive evidence that links excessive BCS loss during the transition period to postpartum reproductive performance and puerperal diseases in dairy cows (Roche et al., 2009).

Given that the changes in body energy reserves have a substantial influence on fertility, milk yield, and health of dairy cows, monitoring BCS in dairy cows is very important (Thorup et al., 2012). This assessment has been extensively recommended to evaluate the nutritional management of dairy cows (Adrien et al., 2012) because this determination is strongly correlated with body energy reserves, reflecting the fat and protein reserves of individual dairy cows. It has been shown that BCS of dairy cows can predict metabolic diseases due to the strong association between the BCS and these diseases (Wang et al., 2019).

Eluding over-conditioning and avoiding cows from over-consuming energy relative to their nutrient requirements in late pregnancy causes a higher dry matter intake and less negative energy balance after parturition (Drackley and Cardoso, 2014) which leads to improved fertility (Gobikrushanth et al., 2019) and milk yield (Jamali Emam Gheise et al., 2017). On the other hand, thin cows do not necessarily have reduced fertility, but the loss of BCS in early lactation led to low reproductive performance (Bastin and Gengler, 2013; Carvalho et al., 2014) and reduced milk yield.

Although previous studies have observed the effect of different levels of BCS change postpartum and fertility, milk yield, and health of dairy cows, there is a lack of studies in commercial farms in hot environments looking at associations between BCS change from 15 days precalving to parturition and calving to first service in high-yielding cows subjected to heat stress for the most of the year. Additionally, many studies on this topic have been carried out on pasture and cow numbers at the upper and lower end of the BCS scale have been scarce. Thus, it was hypothesized that BCS loss prepartum and at calving, as well as ΔBCS from calving to first service is associated with the occurrence of postpartum health disorders, and reduction of milk yield, and reproductive performance. This study aimed to evaluate the associations between precalving BCS change, BCS at calving, and ΔBCS from calving to first service on milk production, reproductive performance, and puerperal health of high-yielding Holstein cows.

Material and methods

Animals, housing, and feeding of cows

This retrospective observational study was approved by the Ethics Committee of the Research Department of the Autonomous Agrarian University Antonio Narro (protocol 3001-2423). Milk yield, fertility, and health records for 2019 to 2022 (5026 observations) were obtained from a single large commercial dairy farm (2500 milking animals) in a hot environment for most of the year in northern Mexico (25° N, 103° W, mean annual rainfall 230 mm, mean annual temperature 23.7 °C).

Cows were kept in open-dirt pens equipped with metal framework shades in the center of the pens. Additional shades covered the feed alleys, which had fans and sprinklers. Cows were fed a total mixed ration twice daily. Diet was formulated to meet the nutrient requirements for Holstein cows weighing 660 kg and producing 38 kg of 3.5% FCM (NRC, 2001). The forage: concentrate ratio was 50:50 and the primary ingredients were alfalfa hay, corn silage, soybean meal, corn grain, and a mineral premix. Diets were formulated to provide at least 1.62 Mcal/kg NEl and contained 18% crude protein. Cows were given sufficient feed for maximum ad libitum intakes for a daily feed refusal of approximately 8% of that offered. The herd's annual daily milk yield was 34.3 kg/day, and the mean annual culling rate was 32.5%. The average (±SD) duration of the dry period was 74 ± 35 days.

Body condition score and disease recording

BCS was recorded for all cows based on the visual and tactile technique using the 5-point scale with a 0.25 increment, with 1 being too thin and 5 being too obese (Ferguson et al., 1994). Cows were body condition scored at the time of enrollment (15 days prepartum, in the preparturient pen), at parturition, and first artificial insemination (approximately 60 d postpartum). BCS was recorded by two well-trained personnel who had completed a course training and had plenty of practical procedure experience in commercial dairy farms, before the morning feeding with cows kept in a normal standing posture.

The farm veterinarians diagnosed and treated all postparturient disorders. Puerperal metritis was diagnosed by rectal palpation and was defined as the presence of watery red-brown and extremely smelly vaginal discharge within 21 days of calving (Sheldon et al., 2006). Ketosis was defined as depressed appetite with evidence of elevated urine ketones using ketone strips (Ketostix, Bayern Corporation, Elkhart, IN), which were soaked with urine obtained by manual stimulation of the escutcheon (area below the vulva). The amount of acetoacetate in mg/dL was estimated according to the color intensity of the Ketostix diagnostic test.

Reproductive management

The vaccination program against diseases affecting the reproductive performance was typical for dairy farms in the zone. All cows included in this investigation were vaccinated against brucellosis at 6 months of age and every year thereafter. Cows were vaccinated annually against bovine respiratory syncytial virus, bovine viral diarrhea types 1 and 2, para-influenza 3, infectious bovine rhinotracheitis, and leptospirosis caused by five Leptospira serovars (CattleMaster Gold FP5®, Zoetis, Mexico DF, Mexico). Cows were also annually vaccinated against leptospirosis (5-serovars; LEPTAVOID-H®; Merck Sharp & Dohme Corp., Mexico DF) 30 days postpartum.

Estrus was detected by direct visual observation for about 25 min before the morning and afternoon milkings. After a voluntary waiting period of 50 days postpartum, cows in estrus were artificially inseminated following the a.m./p.m. guide. Fixed-time AI using the Ovsynch program was used in all repeat-breeding cows. Commercial frozen-thawed semen from multiple high genetic merit bulls from the USA was used. Pregnancy diagnosis was performed at 45±3 days from their last recorded AI by the herd veterinarians. The fertility measures included: first-service pregnancy rate, second-service pregnancy rate, pregnancy at three to five services, and pregnancy rate at all services, and services per pregnancy (only pregnant cows).

Milk yield recording

Cows were milked three times a day at 0:00 a.m., 08:30, and 16:00 Milk recording was made with electronic milk meters and electronic cow identification interfaced with Dairy Comp 305 (Valley Agricultural Software, Tulare, CA) in the milking facility. Milk yield data were recorded until 305 d postpartum in cows pregnant at around 100 days postcalving, or until cows were dried off, in many occasions, beyond 500 days in milk. 305-d milk yield, total milk yield, days in milk, peak milk yield, and days at peak and milk yield were recorded. Also, the entire lactation [total milk yield/(peak milk yield x 305) x 100], and 305-d lactation milk yield persistence [305-d milk yield/(peak milk yield x 305) x 100] were estimated.

Statistical analyses

This study was a retrospective observational study. The data were checked for biological plausibility (e.g., lactations starting with abortion or induced hormonally were deleted; 305-d lactations <8500 kg or lactations from cows with dry periods <30 days were removed). Because lactations of the same cow cannot be considered independent events, for cows with various lactations, the sampling unit (lactation) was nested within cows to account for the cluster effect.

Milk yield traits (305-d milk yield, total milk yield, peak milk, days to peak milk yield, and persistency yield were analyzed using a mixed linear model (PROC GLIMMIX of SAS; SAS Institute Inc., Cary, NC, USA) with groups (ΔBCS <0.25, 0.25-0.5, 0.5-0.75 and >0.75 from 15 days precalving to parturition and from calving to first artificial insemination. BCS classes at parturition were <3.5, 3.5-3.75, and >3.75. BCS were considered as fixed effects, cows as a random effect, and season of calving, year of parturition, the occurrence of periparturient diseases, and parity (primiparous or pluriparous) were incorporated in the model as covariates. The PDIFF adjust=tukey option of SAS was used to compare the group's means.

The GENMOD procedure of SAS was used to assess the effect of BCS in the periparturient period and the change in BCS between calving and AI on reproductive metrics. Season of calving, year of parturition, the occurrence of periparturient diseases, and the number of lactation (primiparous or pluriparous) were included in the model as covariates. After limiting the number of services per pregnancy to pregnant cows, the outcome of group of cows according to BCS on the number of services per pregnancy was analyzed by the Wilcoxon rank-sum test (PROC NPAR1WAY of SAS).

Multivariate mixed logistic regression models produced odds ratios (OR) as estimates of the strength of association between the periparturient BCS and the occurrence of metritis and ketosis. The response variable for the cow-level risk factors was binomial, with cows classified as presenting or not puerperal metritis and ketosis. The multivariate model contained, in addition to the BCS class, season of calving, parity, degree of calving assistance, and year of parity for controlling for these confounders. For all statistical analyses, values with $p<0.05$ were regarded as statistically significant.

Results and discussion

Milk yield

There are limitations and potential bias in this observational research due to the lack of randomization and the existence of factors that could have influenced the result. However, because of the numerous database data, it is deemed that the results can distinguish the potential causal association. Table 1 shows the lactation traits of cows experiencing different BCS changes from 15 days prepartum to calving. Lactation length did not differ (P>0.05) among cows with BCS changes from <0.25 to >0.75. 305-d milk yield decreased (p<0.01) linearly with increasing changes in BCS from 15 days precalving to calving.

It was unknown the causes of loss of BCS during the prepartum period, but these changes in BCS in this phase may occur because of inadequate nutrition, poor management, or controlled feeding in over-conditioned cows (Roche, 2006; Cardoso et al., 2013), and more importantly, the spontaneous reduction in feed intake before parturition (Pascottini et al., 2020). Thus, these results suggest that the degree of BCS reduction before calving is a dependable predictor of 305-d milk yield. It has been observed a greater effect of prepartum BCS loss on metabolic activity in the postpartum period than in the postpartum period. Also, serum concentrations of IGF-I one wk postcalving decrease in thinner cows prepartum (Sheehy et al., 2017). These responses explain in part the detrimental consequence of prepartum BCS loss on 305-d milk yield. The present findings concur with Roche et al. (2015), who found that thinner cows one-month precalving produced less milk than cows in moderate BCS. Also, Chebel et al. (2018) find that loss of BCS during the dry period was associated with reduced milk yield. These findings disagree with Sheehy et al. (2017) who found no differences in milk production among cows that maintained BCS between d −15 and d 0 and those that lost BCS, although milk yield in this study was recorded only for 75 days.

Total milk yield did not differ between cows with changes in BCS from <0.25 to 0.75, but cows with a change >0.75 units had a lower (p<0.01) total milk yield than cows with a less severe change in BCS before calving. Peak milk yield was higher (p<0.01) in cows with the lowest change in BCS precalving than in cows with more pronounced changes in BCS. Total and 305-d lactation persistency was greater in cows with a lower decrease in precalving BCS than cows in the higher BCS loss groups.

The average BCS at calving was 3.2 ± 0.3, a value within the boundary for optimum BCS (3.0-3.5) reported by Roche et al. (2004) and Samarütel et al. (2006). Cows in high BCS at calving (i.e., >3.75) produced more milk than cows in good and moderate BCS (Table 2). This favorable response of high BCS at calving on milk production was in line with previous findings on pasture (Roche et al., 2009, 2013) and confinement (Domecq et al., 1997) studies. Results of this study are contrary to the collective literature findings indicating that the optimum calving BCS for milk production is between 3.0 and 3.5 in Holstein cows and that further increases in BCS at calving result in reduced milk yield (Roche et al., 2009). BCS at calving <3.5 resulted in fewer ($p<0.01$) days in milk than cows with BCS >3.5 (Table 2). The group with the highest BCS at calving produced more milk in 305-d or total lactation than the group with the lowest BCS at calving. Peak milk yield increased by 1.6 kg in cows with >3.75 BCS than in cows with a BCS <3.5 at calving. 305-d and total lactation persistency was higher in cows with BCS <3.5 at calving than cows with BCS >3.5 at calving.

Lactation length was 25 days shorter in cows with the lightest change in BCS between calving and first service, compared to cows with a BCS change >0.75 units (Table 3). For both 305-d and total lactation, milk yield increased ($p<0.01$) with increasing BCS loss between calving and first artificial insemination. Lactation persistency (305-d and total) was higher in cows with the lowest BCS change than cows with the greatest BCS loss between calving and first service. These results were consistent with findings of Roche et al. (2015) who showed a greater BCS loss in fatter cows, combined with higher serum BHB concentrations and higher milk yield. Also, Gobikrushanth et al. (2019) reported a higher 305-d mature equivalent milk yield for extreme BCS loss compared with cows that gained BCS postpartum. Berry et al. (2007) corroborated the previous studies because they found that cows that lost more BCS in early lactation produced more milk. A negative association is, therefore, expected between the degree of BCS loss postpartum and milk production. This association between BCS loss postpartum and milk production is consistent with fitted functions reported by Berry et al. (2006) and Roche et al. (2007) which depicted BCS profiles as mirror images of lactation curves.

Reproductive performance

The percentage of cows pregnant with one or two services was extremely low and was not affected by the BCS change between 15 days prepartum and calving (Table 4). Pregnancy rate with three to five services was highest ($p<0.01$) for cows with moderate BCS change compared with other groups with low and high changes in BCS. Likewise, moderate change in BCS before calving resulted in the highest ($p<0.01$) pregnancy rate for all services; cows with the highest BCS change precalving presented the lowest pregnancy rate. These results are consistent with a previous study where prepartum BCS loss of 0.25 or ≥ 0.5 points reduced overall pregnancy rate in dairy cows (Çolakoğlu et al., 2019). This response could be due to the more drastic energy shortage reflected by unfavorable BCS change early in lactation. Also results of the current study concurs with Pryce et al. (2000) who observed that thinner cows had longer calving intervals. Likewise, Kadarmideen (2004) reported that cows with a good BCS had shorter intervals to first service after calving and were more likely to be pregnant within 56 days after the first service. Another study by Kim and Suh (2003) showed that losing BCS (1.0–1.5 points) from the dry to near calving periods increases the number of days to first breeding after calving in comparison with the moderate BCS loss (0–0.75 points). Services per pregnancy were lowest for the lowest BCS change prepartum and highest for cows with the highest BCS change before calving.

Table 5 shows the reproductive performance of cows as a function of BCS at calving. Surprisingly, cows with the highest BCS at calving had the lowest ($p<0.01$) pregnancy rate at first service than cows with lower BCS at calving. However, pregnancy rate at second and 3 to 5 services was consistently lower in cows with the greatest BCS at calving. The lowest services per pregnancy were for cows with BCS 3.25-3.5 and cows with BCS <3.25 required the highest number of services to get pregnant.

Cows with a BCS change <0.25 between calving and first AI had higher pregnancy rates at first AI than all other groups with higher BCS change postpartum (Table 6). Pregnancy rate at second, 3 to 5, and total services decreased with increasing BCS change between calving and first AI. Services per pregnancy increased with increasing BCS change between calving and first AI. Although inconsistent across studies, there has been a tendency for a deleterious effect of BCS loss postcalving on measures of reproductive success in dairy cows (Santos et al., 2009; Torres et al., 2020; Manríquez et al., 2021); moreover, cows present higher pregnancy rate when they gain or maintain BCS during the first 3 wk postpartum (Carvalho et al., 2014). Few technicians in intensive dairy farms register BCS at calving and the first service. However, the recording of BCS at parturition and first service presents a valuable practice to evaluate whether BCS change will limit the fertility of dairy cows.

Association between ΔBCS and health outcomes

The ΔBCS-group-specific odds ratios for metritis and ketosis are presented in Table 7. The risks of puerperal metritis increased with BCS change between calving and AI. Also, compared to all other cows, the cows with >0.75 BCS change between calving and AI were 2.1 times more likely to have clinical ketosis. Occurrence of periparturient diseases is associated with changes in BCS in early lactation (Barletta et al., 2017), but this confounder was introduced in the model as covariate, thus, cow health effects were isolated; therefore, the detrimental effect of BCS loss postpartum seems to be due only to the reduced feed intake coupled with higher nutrient demands for milk synthesis, resulting in insufficient energy intake for lactation (Gross et al., 2011). Thus, managing cattle to predetermined levels of BCS loss postpartum is important in high-yielding cows. Additionally, BCS loss between calving and first artificial insemination may be more significant as an indicator of reproductive outcome than BCS recorded on a single occasion (i,e., at calving).

The present study was carried out in a large commercial dairy herd; therefore, cows were exposed to similar herd-level factors such as feeding, management, quantity and quality of feedstuff, and environmental effects, which enhanced the validity of the association between postpartum BCS change and periparturient diseases. In the case of clinical ketosis, its higher incidence in cows with the greatest BCS loss arises from the fact that high-mobilizing cows are less able to overcome metabolic challenges in the early postpartum period which increases their serum β-hydroxybutyrate (BHB) concentrations early postpartum (Gärtner et al., 2019), and the greater the lipid mobilization in early lactation the higher the odds of metritis (Torres et al., 2020). In line with the current results, Stevenson et al. (2020) reported increased risk of ketosis in cows with greater loss of BCS postcalving, which corroborates that high-mobilizing cows are less able to overcome metabolic challenges during the puerperium, reflected by higher postpartum blood fatty acids and BHB concentrations (Gärtner et al., 2019).

In the case of metritis, it has been found a positive association between BCS loss and the incidence of infectious diseases (Sheehy et al., 2014; Chebel et al., 2018), particularly metritis (Kim and Suh, 2003), apparently derived from the fact that thinner cows before calving are prone to an accentuated reduction in peripartum immune competence, which increases the risk of infectious diseases (Sheehy et al., 2017; Beltman et al., 2020). Thus, as it has been previously shown (Kadivar et al., 2014; Stevenson et al., 2020), low BCS is a risk factor for postpartum metritis in dairy cows. Additionally, the increased demand for nutrients for the onset of lactation results in insufficient energy intake to meet the energetic requirements for lactation (Gross et al., 2011) and decreased feed intake (Hayirli et al., 2002; Hayirli and Grummer, 2004) in the weeks immediately before calving have been associated with the occurrence of two common transition diseases: metritis (Huzzey et al., 2007; Dubuc et al., 2010) and subclinical ketosis (Goldhawk et al., 2009; Ospina et al., 2010).

Conclusions

This study showed that pre-calving BCS loss was a major factor influencing 305-d milk yield and reproductive outcome, with lower milk production and reduced pregnancy rate as precalving BCS loss increased. Thus, in high-yielding Holstein cows in a hot environment, the optimum precalving BCS loss should not exceed 0.25 units to maximize milk yield and fertility. Also, postpartum BCS loss of >0.75 points positively affected 305-d and total milk yield, but decreased reproductive performance. These findings reinforce the view that a high milk yield starts during the dry period and higher ΔBCS within 60 days in milk positively influences subsequent milk yield but hampered cows´ fertility. Finally, there was an association between the degree of BCS loss postpartum and the occurrence of puerperal metritis and ketosis which suggests that ensuring a moderate loss of BCS in early lactation can reduce the incidence of these periparturient diseases. Overall, these results indicate that cows with higher losses of BCS postpartum have increased milk production potential but poorer health status and reproductive performance. Thus, monitoring BCS loss during the calving and first service could be useful to identify cows susceptible to metabolic and infectious diseases and lower reproductive success.

Declaration of competing interest

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Ethics statement

The Autonomous Agrarian University Antonio Narro Institutional Animal Care and Use Committee approved all actions connected with cows used for this study (protocol number 3001-2423).

Credit authorship contribution statement

Data adquisición: A.V Alvarado, F.G. Véliz, V. Contreras. Study design and drafted the manuscript: M. Mellado. Analyzed the results: M. Mellado, A. de Santiago. Revised the manuscript and reviewed the pertinent literature: A.V Alvarado, F. Arellano. All authors read and approved the final version of the manuscript.

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Table 1. Change of body condition score (BCS) from 15 days precalving to calving in relation to milk yield of high-yielding Holstein cows in a hot environment. Values are means ± standard deviations.

Variables	<0.25	0.25 - 0.5	0.5 - 0.75	>0.75
Lactation length, days	393 ± 98	399 ± 113	403 ± 125	395 ± 121
305-d milk yield, kg	11526 ± 1088[a]	11320 ± 1147[b]	11082 ± 1127[c]	10878 ± 1114[d]
Total milk yield, kg	13861 ± 2541[a]	13727 ± 2829[a]	13571 ± 3067[a]	13214 ± 3174[b]
Peak milk yield, kg	48.8 ± 7.5[a]	47.8 ± 7.9[b]	47.4 ± 7.8[b]	47.3 ± 7.9[b]
Days to peak milk yield	76 ± 29	74 ± 30	75 ± 30	74 ± 29

Persistency 305-d milk yield	63.0 ± 9.7[a]	62.7 ± 10.2[ab]	61.8 ± 10.7[b]	61.7 ± 9.9[b]
Persistency total milk yield	74.6 ± 9.5[a]	74.6 ± 9.8[a]	73.8 ± 9.6[ab]	73.2 ± 10.3[b]

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 2. Body condition score (BCS) at calving in relation to milk yield of high-yielding Holstein cows in a hot environment.

Variables	<3.5	3.5 - 3.75	>3.75
Lactation length, days	393 ± 115[b]	405 ± 122[a]	403 ± 110[a]
305-d milk yield, kg	11154 ± 1558[b]	11205 ± 1115[b]	11363 ± 1084[a]
Total milk yield, kg	13376 ± 2876[c]	13758 ± 3019[b]	13970 ± 2827[a]
Peak milk yield, kg	47.2 ± 7.9[b]	47.7 ± 8.3[b]	48.8 ± 7.1[a]
Days to peak milk yield	74.2 ± 30.0[b]	73.2 ± 29.5[b]	77.3 ± 30.3[a]
Persistency 305-d milk yield	63.6 ± 10.4[a]	61.5 ± 9.4[b]	61.2 ± 10.9[b]
Persistency total milk yield	74.7 ± 9.8[a]	74.1 ± 10.3[ab]	73.4 ± 9.1[b]

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 3. Change of body condition score (BCS) from calving to first artificial insemination in relation to milk yield of high-yielding Holstein cows in a hot environment.

Variables	<0.25	0.25 - 0.5	0.5 – 0.75	> 0.75
Lactation length, days	345 ± 58^{b}	406 ± 118^{a}	406 ± 125^{a}	410 ± 118^{a}
305-d milk yield, kg	11061 ± 1066^{c}	11130 ± 1147^{c}	11296 ± 1127^{b}	11422 ± 1071^{a}
Total milk yield, kg	12145 ± 1756^{c}	13664 ± 2956^{b}	13935 ± 3033^{a}	14134 ± 2992^{a}
Peak milk yield, kg	47.4 ± 4.8^{c}	47.0 ± 8.7^{c}	48.1 ± 8.1^{b}	49.2 ± 6.6^{a}
Days to peak milk yield	67.9 ± 28.6^{a}	75.0 ± 29.7^{b}	74.9 ± 30.4^{b}	77.5 ± 29.8^{b}
Persistency 305-d milk yield	69.2 ± 10.0^{a}	61.8 ± 8.8^{b}	61.5 ± 10.2^{b}	60.4 ± 12.0^{c}
Persistency total milk yield	75.2 ± 8.1^{a}	$74.6 \pm 10.4a^{b}$	74.2 ± 9.8^{b}	72.4 ± 9.0^{c}

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 4. Change of body condition score (BCS) from 15 days precalving to calving in relation to reproductive performance of high-yielding Holstein cows in a hot environment. Values are means ± standard deviations.

Variables	<0.25	0.25 - 0.5	0.5 – 0.75	> 0.75
First-service pregnancy rate, %	18/420 (4.3)	120/2574 (4.9)	69/1452 (4.8)	21/580 (3.6)
Second-service pregnancy rate, %	40/420 (9.5)	305/2574 (11.9)	159/1452 (11.0)	57/580 (9.8)
3 to 5 service pregnancy rate, %	95/420 (22.6)[b]	760/2574 (29.5)[a]	387/1452 (26.7)[b]	134/580 (23.1)[b]
Overall pregnancy rate, %	233/420 (55.5)[b]	1585 /2574 (61.6)[a]	757/1452 (52.1)[b]	237/580 (40.9)[c]
Services per pregnancy	5.1 ± 3.6[d]	5.6 ± 3.7[c]	6.2 ± 3.9[b]	6.6 ± 4.0[a]

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 5. Body condition score (BCS) at calving in relation to the reproductive performance of high-yielding Holstein cows in a hot environment.

Variables	<3.25	3.25 - 3.5	>3.5
First-service pregnancy rate, %	115/2247 (5.1)^{a}	76/1675 (4.5)^{a}	37/1104 (3.4)^{b}
Second-service pregnancy rate, %	287/2247 (12.8)^{a}	175/1675 (10.5)^{b}	99/1104 (9.0)^{b}
3 to 5 service pregnancy rate, %	636/2247 (28.3)^{a}	280/1675 (28.2)^{a}	165/1104 (24.3)^{b}
Overall pregnancy rate, %	1206/2247 (53.7)^{A}	987 /1675 (58.9)^{B}	619/1104 (56.1)^{B}
Services per pregnancy	6.4 ± 4.0^{A}	5.4 ± 3.6^{B}	6.2 ± 4.0^{A}

Values within a row with different superscript letters differ at $P < 0.05$.

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 6. Change of body condition score (BCS) from calving to first artificial insemination at calving in relation to the reproductive performance of high-yielding Holstein cows in a hot environment.

Variables	<0.25	0.25 - 0.5	0.5 – 0.75	> 0.75
First-service pregnancy rate, %	42/615 (6.8)^{a}	105/2158 (4.9)^{b}	56/1417 (4.0)^{b}	25/836 (3.0)^{b}
Second-service pregnancy rate, %	111/615 (18.1)^{A}	281/2158 (13.0)^{B}	121/1417 (8.5)^{C}	48/836 (5.7)^{D}
3 to 5 service pregnancy rate, %	636/615 (28.3)^{A}	280/2158 (28.2)^{B}	337/1417 (23.8)^{C}	102/836 (12.2)^{D}
Overall pregnancy rate, %	477/615 (77.6)^{A}	1334 /2158 (61.8)^{B}	720/1417 (50.8)^{C}	281/836 (33.6)^{D}
Services per pregnancy	5.4 ± 3.4^{C}	5.8 ± 3.8^{BC}	5.9 ± 3.9^{B}	6.6 ± 4.3^{A}

Values within a row with different superscript letters differ at $P < 0.05$.

Values within a row with different superscript letters differ at $P < 0.01$.

Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 7. Multivariate logistic regression model for factors associated with the incidence of metritis and ketosis in high-yielding Holstein cows in a hot environment.

Variables		Odds ratio (OR)	95% CI OR	*p*
	Metritis			
BCS change calving-AI				
>0.75	175/836 (20.9)	2.3	1.5 – 3.6	0.0002
0.5 – 0.75	265/1417 (18.7)	1.9	1.4 – 2.5	<.0001
0.25 - 0.5	348/2158 (16.1)	1.6	1.2 – 2.1	0.0013
<0.25	67/615 (10.9)	Reference		
	Ketosis			
>0.75	70/836 (8.4)	2.1	1.3 – 3.3	0.0025
0.5 – 0.75	71/1417 (5.0)	1.2	0.8 – 1.9	0.4524
0.25 - 0.5	115/2158 (5.3)	1.3	0.8 – 2.0	0.2777
<0.25	26/615 (4.2)	Reference		

BCS= Body condition score (1 to 5 scale scoring system, 0.25 points increment)

AI= first artificial insemination postcalving

Conclusión general

Una evaluación de la condición corporal de las cabras en un sistema extensivo permite darnos un panorama general de la nutrición, monitorear los niveles de glucosa sérica, nitrógeno ureico en sangre y NEFA podría usarse para identificar cabras en riesgo de infertilidad. Además, evitar una pérdida alta de la condición corporal durante el período de transición es un factor principal para prevenir la reducción de la producción de leche y el rendimiento reproductivo. Además, mayores cambios en la condición corporal entre el parto y la primera IA aumentaron la producción de leche total y los 305 días, y la aparición de metritis puerperal y cetosis clínica, aunque se redujo la fertilidad.

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