EN CABRAS SUBTROPICALES PARIDAS EN EL OTOÑO, LOS DÍAS LARGOS ARTIFICIALES INCREMENTAN LA PRODUCCIÓN DE LECHE, LA PROPORCIÓN DE HEMBRAS QUE OVULAN Y EL PESO DE LAS CRÍAS AL DESTETE

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TESIS

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POR

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La posibilidad de realizar un sueño es lo que hace que la vida sea interesante…
Paulo Coelho

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RESUMEN

El objetivo general fue investigar la influencia que tiene el fotoperiodo de días largos artificiales sobre la producción de leche, la actividad ovárica postparto y el peso de las crías de cabras paridas en el otoño en el subtrópico Mexicano. Se diseñaron cuatro estudios usando como modelo experimental las cabras locales de la Comarca Lagunera mantenidas en condiciones de confinamiento y en condiciones de pastoreo extensivo de alimentación. En el primer estudio, se determinó que en las cabras confinadas y ordeñadas una vez/día, el fotoperiodo de días largos (16 h luz; 8 h oscuridad) incrementó ($P < 0.05$) la producción de leche (2.6 ± 0.1 kg) durante la fase temprana de ordeño (día 29 al 84 de lactación), en comparación con las cabras mantenidas bajo fotoperiodo natural (2.1 ± 0.1 kg). Se observó, que además, los días largos artificiales incrementaron ($P < 0.05$) aún más la producción de leche cuando las cabras se ordeñaron dos veces al día (3.3 ± 0.2 kg), en comparación con las cabras mantenidas bajo fotoperiodo natural y ordeñadas 2 veces/día (2.8 ± 0.2 kg). En ambos experimentos el fotoperiodo de días largos no modificó la composición de la leche (grasa, proteína y lactosa; $P>0.05$). Se concluye que en las cabras subtropicales mantenidas en confinamiento y que paren en el otoño, la exposición a días largos artificiales estimula la producción de leche, sin afectar la calidad de la misma.

Estos resultados muestran de la efectividad del tratamiento de días largos artificiales para incrementar la producción de leche en las cabras subtropicales paridas en otoño. No obstante este hallazgo, no se conoce si en las cabras que son mantenidas en condiciones de pastoreo extensivos (sistema predominante en la Región Lagunera), en donde existen variaciones importantes en la cantidad y calidad del alimento, los días largos en las mismas condiciones puedan estimular la producción de leche. Por ello, en un segundo trabajo se

estudió en 2 grupos (control y tratado, 11/grupo) de cabras manejadas bajo condiciones de pastoreo extensivo sin complementación alimenticia, si los días largos artificiales incrementan la producción de leche. Además, se utilizaron otros 2 grupos mantenidos bajo el mismo esquema pero que recibieron una complementación alimenticia diaria desde el día 30 de lactancia (control+comp y tratado+comp, 11/grupo). El promedio de producción de leche durante las primeras 12 semanas de lactación no difirió ($P > 0.05$) entre los grupos control y tratado que no recibieron complementación (0.8 ± 0.1 kg/día vs. 0.9/día ± 0.1 kg, respectivamente). Sin embargo, el promedio de producción de leche fue más alta en las cabras del grupo tratado+comp (1.1 kg/día) que en las cabras del grupo control+comp (0.82 kg/día). Los contenidos de grasa, proteína y lactosa en la leche, fueron mayores en los grupos control que en los grupos tratados. Se concluye, que en las cabras mantenidas bajo condiciones de pastoreo extensivo la exposición a un fotoperiodo de días largos artificiales incrementa la producción de leche, únicamente si las hembras reciben una complementación nutricional.

En un tercer estudio se investigó si la exposición continua a un fotoperiodo de días largos artificiales en cabras que paren en el otoño induce el establecimiento de un estado refractario y así, el reinicio de la actividad ovulatoria postparto. Para ello, a partir del día 10 de lactancia se comparó la proporción de cabras que ovularon en dos grupos de cabras paridas en el otoño. Un grupo de cabras estuvo expuesto a días largos artificiales (n=16), mientras que el otro grupo se mantuvo bajo fotoperiodo natural (n=16). La actividad ovulatoria de las hembras fue monitoreada mediante ultrasonografía transrectal desde el día 10 hasta el día 158 postparto. Los resultados muestran que a partir del día 108 y hasta el día 158, la proporción acumulada de hembras que ovularon fue mayor ($P<0.01$) en el grupo de hembras expuestas a días largos (11/16, 69 %) que en el grupo mantenido bajo fotoperiodo natural (2/16, 12.5 %). Se concluye que en las cabras lactantes paridas en el otoño, la exposición continua a días largos induce el reinicio de la actividad ovulatoria postparto a través del establecimiento de un estado refractario a los días largos después de 150 días de tratamiento.

Finalmente, en un cuarto estudio se investigó la influencia que tienen los días largos artificiales sobre el peso de los cabritos al destete cuando nacen durante el otoño y alimentados de manera natural o artificial. En este estudio, se evaluó el peso de las crías al destete y la ganancia diaria promedio, así como las concentraciones de glucosa en sangre en 4 grupos de crías. Un primer grupo de cabritos (n=17) fue mantenido bajo fotoperiodo natural y amamantado por sus madres (grupo control natural). Un segundo grupo de cabritos (n=15) fue mantenido bajo el mismo fotoperiodo que el primer grupo, solo que estos cabritos fueron separados de sus madres desde el día 4 y diariamente fueron amamantados de manera artificial hasta el día 28 de edad (grupo control artificial). El tercer grupo de cabritos (n=19) fue sometido a partir del día 4 de edad a un fotoperiodo de días largos artificiales y las crías fueron amamantados por sus madres (grupo tratado natural). El cuarto grupo de cabritos (n=15) fue expuesto al mismo tratamiento fotoperiódico que el tercer grupo, solo que las crías de este grupo fueron separadas de su madre desde el día 4 y diariamente fueron amamantadas de manera artificial hasta el día 28 de edad (grupo tratado artificial). Los resultados indican que el peso corporal de los cabritos al destete, fue más alto ($P<0.01$) en las crías sometidas a días largos (amamantamiento artificial, 6.9 ± 0.2 kg y natural, 8.2 ± 0.2 kg) que en las mantenidas bajo fotoperiodo natural (amamantamiento artificial, 6.2 ± 0.2 kg y natural, 7.6 ± 0.3 kg). Así mismo, las concentraciones de glucosa

fueron más altas en los grupos de cabritos expuestos a días largos que en los cabritos mantenidos bajo fotoperiodo natural, independientemente del tipo de amamantamiento. Se concluye que el peso al destete fue más alto en los cabritos expuestos a días largos fue que en los cabritos mantenidos bajo fotoperiodo natural, independientemente si son criados bajo amamantamiento natural o artificial.

SUMMARY

The general objective of this thesis was to investigate in goats from subtropical Mexico the influence of the exposition to an artificial long-day photoperiod on milk production, postpartum ovarian activity and on the body weight of kids at weaning. Four studies were designed using as experimental model local goats from the Comarca Lagunera managed under intensive and extensive conditions. In a first study realized under intensive conditions and milked once-daily, the artificial long days increased milk yield (2.6 ± 0.1 kg; $P<0.05$) during early milking phase (day 29 to day 84 of lactation) in comparison to goats maintained under natural photoperiod (2.1±.0.1kg). In this same study it was observed that artificial long days increased even more the milk yield when goats were milked twice daily (3.3± 0.2 kg), in comparison to goats maintained under natural photoperiod (2.8 ± 0.2 kg). In both experiments, milk composition (fat, protein and lactose), were not modified by long days treatment. It is concluded that in subtropical female goats that start lactation during autumn and maintained under intensive conditions, exposure to an artificial long-day photoperiod stimulates milk production, even if goats are milked once daily. In addition, combining exposure to long days with twice-daily milking will increase further milk production in such goats without affecting milk components.

Nevertheless, if these previous findings may also apply to goats maintained under extensive grazing conditions, remain unknown; therefore, the second objective was to determine whether exposure of natural grazing goats to artificial long days can increase milk production. For this, in a second study 2 goats groups managed under extensive grazing conditions without to receive a nutritional supplementation: one was submitted to an

artificial long-day photoperiod (treated; n=11) whereas the other was under the natural photoperiod (control; n=11). Other 2 groups of goats were maintained under the same photoperiodic regimens, however, animals from 2 groups receive daily a nutritional supplementation from day 30 to day 110 of lactation (control+suppl, n=11 and treated+suppl, n=11). Mean milk production during first 12 weeks of lactation did not differ ($P > 0.05$) between control and treated groups without fed supplementation (0.8 ± 0.1 kg/day vs. 0.9/day ± 0.1 kg, respectively). However, mean milk production was greater ($P < 0.05$) in goats from treated+suppl group (1.1 ± 0.1 kg/d) than in goats from control group+suppl (0.82± 0.1 kg/d). The milk components (fat, protein and lactose) were greater in goats control than in goats treated. It is concluded, that in goats maintained under extensive grazing conditions, exposure to an artificial long-day photoperiod increase milk production only if goats receives a nutritional supplementation.

In a third study, it was investigated whether the continuous application of an artificial long-day photoperiod in goats giving birth in autumn induces the establishment of a refractory state and thus, the recovery of the post-partum ovulatory activity. For this purpose, one group of does was kept during the entire study under a natural photoperiod characteristic from autumn (Control; n=16), whereas the other group was submitted to an artificial long-day photoperiod (16 h light: 8 h darkness: Experimental; n=16) from day 10 to 158 of lactation. Over the first 96 days post-partum, the cumulative proportion of does that had ovulation was not different amongst the treatments ($P > 0.05$). However, from day 108 to 156 post-partum, the cumulative proportion of does that had ovulation was greater ($P < 0.01$) in the experimental group (11/16, 69%) than in the control group (2/16, 12.5%). The body weight and body condition were not affected by the photoperiodic treatment (P >

0.05). It is concluded that for subtropical lactating does kidding in autumn, the continuous exposure to an artificial long-day photoperiod induces the post-partum ovulatory activity after 150 days of exposition, probably due to the establishment of a refractory state by the continuous exposure to the artificial long days.

Finally, to determine whether exposure to artificial long-days in the subtropics increases body weight at weaning of goats kids born in autumn, sixty-six goat kids were allocated to one of following four treatments. A first group of goat kids, was maintained under natural photoperiod and remained daily suckling with their mothers from 18:00 h to 9:00 h (natural control group; n=17). A second group of goat kids, was reared as the first one, but it group was submitted to an artificial long-day photoperiod (16 h light; 8 h darkness; natural treated group n=19). In the third group of goat kids, they were under natural photoperiod and were weaned from their mothers at d 4 of age. Goat kids were fed artificially using the natural milk (artificial control group n=15). Finally, a fourth group of goat kids was reared as the third one, but it group was submitted to an artificial long-day photoperiod (artificial treated group; n=15). The results indicate that body weight of kids at weaning was higher in offspring submitted to long days (artificial 6.9 ± 0.2 kg and natural, 8.2 ± 0.2 kg) than in those maintained under natural photoperiod (artificial 6.2 ± 0.2 kg and natural, 7.6 ± 0.3 kg). Similarly, glucose concentrations were higher in the groups of kids exposed to long days than in the goat kids kept under natural photoperiod, regardless of type of rearing. It was concluded that kids exposed to an artificial long-day photoperiod gain more weight at weaning than kids kept under natural photoperiod regardless if they are raised under natural or artificial suckling.

TABLA DE CONTENIDO

CAPITULO 1

INTRODUCCIÓN

Los factores medioambientales con mayor influencia para la reproducción de los mamíferos son la disponibilidad de alimento, la temperatura, la lluvia, el fotoperiodo y una variedad de señales sociales (Bronson, 1985). Estos factores interactúan con el potencial genético de los individuos, determinando los tiempos adecuados de reproducción durante el año, así como la duración de estos periodos (Chemineau, 1992). En las zonas templadas, existe la estricta necesidad de criar a los animales durante el periodo más favorable del año, lo que ha conducido a las especies silvestres a limitar el periodo de nacimientos a una cierta época del año, cuando la temperatura es menos drástica y la disponibilidad de alimento es abundante (Ortavant *et al*., 1985). Los pequeños rumiantes como las ovejas y las cabras, reciben información del medio ambiente que les permite anticipar la aparición de estaciones adecuadas para el nacimiento y el desarrollo de la cría (Lincoln y Short, 1980). Para sincronizar la estación reproductiva y así, la época de nacimientos, estas especies usan las variaciones naturales del fotoperiodo que se presentan a través del año para predecir los eventos reproductivos (Ortavant *et al*., 1985). La señal de luz en estas especies, genera un ciclo de reproducción circanual, el cual inicia con una fase de actividad sexual durante los días decrecientes del otoño, seguido de una fase de inactividad sexual durante los días crecientes de invierno (Malpaux, 2006). Este ciclo reproductivo estacional es causado por cambios en la duración de secreción de melatonina, la cual induce la retroacción negativa del estradiol para inhibir la secreción de LH (Chemineau *et al*., 1988).

Así como el fotoperiodo sincroniza el ciclo anual de reproducción de las ovejas y las cabras de latitudes templadas, otros ciclos fisiológicos como la muda del pelo, el metabolismo y el crecimiento corporal son también sincronizados por esta señal (Malpaux, 2006). Aunque hasta hoy no se ha estudiado si la fase de lactancia en pequeños rumiantes sea modulada al someter a los animales a alternancias de periodos de días largos y cortos artificiales, existen estudios que indican que el fotoperiodo puede modificar el nivel de producción de leche de las hembras. En la cabra, Linzell, (1973) reportó por primera vez una asociación entre el fotoperiodo y la producción de leche. Este autor describió que la tasa de secreción de leche de las cabras fluctuó de una manera estacional; siendo alta durante los días largos del verano y baja durante los días cortos del invierno. A partir de estos hallazgos y en las diferentes razas lecheras, se han realizado diversos estudios comprobando la efectividad de los días largos para incrementar la producción de leche. En las vacas, ovejas y cabras lactantes originarias de latitudes templadas, la exposición a un fotoperiodo de día largo artificial incrementó la producción de leche comparado a las hembras mantenidas bajo fotoperiodo natural (Delouis y Mirman, 1984; Bocquier *et al*., 1997; Dahl *et al*., 2000). También en las ovejas explotadas en latitudes subtropicales, manejadas intensivamente los días largos artificiales son efectivos para incrementar la producción de leche. En efecto, la exposición de ovejas lactantes a un fotoperiodo de día largo artificial durante los días decrecientes de otoño, produjeron un 15% más de leche que las hembras mantenidas bajo fotoperiodo natural (Morrisey *et al*., 2008).

En el norte de México, la actividad sexual anual de las cabras locales es estacional similar a la observada en otras regiones subtropicales (Restall *et al*., 1992; Delgadillo *et al*., 2004). Esta variación en la actividad sexual de las hembras, provoca que los partos y en consecuencia el inicio de la producción láctea ocurra en cierta época del año. En efecto, en esta región, el 80% de los partos en cabras bajo condiciones extensivas de manejo se presentan de noviembre a febrero (Salinas y Quiroga, 1991). Además, en este sistema, las crías son separadas definitivamente de sus madres hasta los 30 días de edad y posteriormente, las hembras son ordeñadas una vez al día. Actualmente, no existen estudios que determinen si en estas cabras subtropicales, la exposición a un fotoperiodo de días largos artificiales pueda incrementar la producción de leche de las hembras. Sí esto aplica para esos animales subtropicales, ello resultaría en mayores ingresos para los productores por mayor venta de leche. Por lo cual, resulta interesante estudiar primero si el fotoperiodo de días largos artificiales aplicado a las cabras que paren en el otoño incrementa la producción láctea. Posteriormente, y debido a que la mayor parte de los caprinos se explotan de manera extensiva, entonces sería también interesante si en esas condiciones de alimentación los animales pueden responder al fotoperiodo incrementando su producción láctea o si es necesaria una complementación alimenticia para observar dicho efecto.

En cabras originarias o adaptadas a latitudes templadas y subtropicales, está bien documentado que el inicio de la actividad sexual anual durante los días decrecientes del otoño se debe al establecimiento de un estado refractario a los días largos de primavera y verano (Gómez-Brunet *et al*., 2010; Delgadillo *et al*., 2011). En estas hembras, el inicio de la actividad sexual ocurre después de percibir 90 días largos continuos a partir del solsticio de verano. Sin embargo, cuando las ovejas y las cabras son expuestas a días largos continuos en otra época del año, estas muestran un estado refractario, después de 150 días de exposición a dicho fotoperiodo (Maeda *et al*., 1988; Malpaux *et al*., 1989). En estas mismas especies, la continua aplicación de 75 días largos artificiales a partir del parto, inhibió la actividad ovulatoria postparto (Bocquier *et al*., 1993; Mejía 2007). Es probable que estos animales lactantes, requieran de más tiempo de exposición a los días largos continuos para el establecimiento del estado refractario y de esa manera reinicien su actividad ovulatoria. Por ello, en esta tesis se estudió el inicio de la actividad ovulatoria en cabras que parieron en otoño mantenidas en días decrecientes naturales y en cabras expuestas por tiempo prolongado a un fotoperiodo de días largos artificiales.

Otra variable que es susceptible de ser modificada por el fotoperiodo en los animales domésticos, es el crecimiento corporal. En corderos y vaquillas, está ampliamente demostrado que los días largos incrementan la ganancia diaria de peso corporal. En un estudio publicado por Forbes *et al*. (1975), demostraron que los corderos expuestos a un fotoperiodo de días largos, ganaron más peso que los corderos expuestos a un fotoperiodo de días cortos artificiales. En vaquillas Holstein, la ganancia de peso fue de un 10 a un 15% más de peso en las expuestas a un fotoperiodo de días largos que las mantenidas en un fotoperiodo de días cortos naturales (Peters *et al*., 1978). En las cabras, recientemente se demostró que las crías mantenidas con sus madres durante los primeros 30 días de edad y expuestas a un fotoperiodo de días largos ganaron más peso al finalizar el estudio que las crías mantenidas con sus madres y expuestas a un fotoperiodo natural decreciente (Mejía, 2007). Sin embargo, no se conoce si este mayor peso de los cabritos se debió a un efecto directo del fotoperiodo sobre el metabolismo de las crías, o bien por la elevada producción láctea de sus madres. Entonces en el presente trabajo también se evaluó el efecto del fotoperiodo de días largos sobre el metabolismo de las crías, al comparar el peso de las crías amamantadas por sus madres o de manera artificial y mantenidas bajo días naturales decrecientes o expuestas a un fotoperiodo artificial de días largos.

Tomando en consideración los argumentos antes descritos, el objetivo general del presente trabajo de tesis fue investigar en las cabras del subtrópico, la influencia que tienen los días largos artificiales sobre la producción láctea, la actividad ovárica postparto y el crecimiento de las crías cuando los partos ocurren en el otoño.

CAPITULO 2

REVISIÓN DE LITERATURA

1. La lactancia en rumiantes

La presencia de glándulas mamarias es una de las características morfológicas distintiva de los mamíferos y ello, tiene una participación crucial en la clasificación taxonómica de los animales (Capuco y Akers, 2009). Existen tres subclases de mamíferos; los monotremados (ornitorrinco, equidna), los marsupiales (canguro, zarigüeya) y los euterios o mamíferos placentarios (perros, caballo, ratón, cabra, vaca y oveja; Blackbrun, 1993). La gestación es mucho más corta en las especies de montremados y marsupiales (12 a 38 días) que en los mamíferos placentados (hasta 660 días en el elefante Africano; Blackbrun, 1993). La corta gestación en los mamíferos monotremados y marsupiales, les confiere tener crías altriciales, por lo que la duración de la fase del amamantamiento es más prolongada (150 y 120 días, respectivamente) que en los mamíferos placentarios (20-50 días; Hayssen, 1993).

Los rumiantes (vacas, ovejas y cabras), se encuentran dentro del grupo de los artiodáctilos, las cuales son especies que se caracterizan por poseer un estómago dividido en compartimientos para rumiar, tienen un número par de dedos cubiertos por una capa llamada pezuña, y con presencia de cornamentas (Akers, 2002). En estas especies, la glándula mamaria a través de su ciclo lactacional sufre una serie de transformaciones anatómicas y endocrinas que culmina con la secreción de leche. En la vida adulta de una hembra por ejemplo, este ciclo se puede dividir en 4 estados: mamogénesis, lactogénesis, galactopoyesis conocida también con el nombre de lactación y la involución (Svennersten-

Sjaunja y Olsson, 2005; Neville, 2009). Cada una de estas fases es coordinada principalmente por el sistema endocrino, el cual involucra tres categorías de hormonas que actúan directamente en la glándula mamaria. Entre éstas, se encuentran las hormonas reproductivas como el estrógeno y la progesterona, además, el lactógeno placentario, la prolactina y la oxtocina. Las hormonas metabólicas como la hormona de crecimiento (GH), las hormonas adrenocorticotropas (ACTH), las hormonas tiroideas, la insulina, y otras hormonas gastrointestinales participan indirectamente (Neville *et al*., 2002).

1.1 Fase de lactogénesis y galactopoyesis

La lactogénesis se define como el proceso de diferenciación celular por la cual la células mamarias se modifican de un estado no secretor a un estado secretor (Tucker, 1981). Esta etapa del ciclo lactacional ha sido dividida en dos fases, y la duración de cada una de estas fases depende de la especie (Forsyth, 1986). En rumiantes, la primera fase se caracteriza por un incremento en la diferenciación citológica y enzimática de las células alveolares, lo que incrementa el volumen de la ubre. Por lo general, la segunda fase se inicia de 2 a 3 días antes del parto, y se caracteriza por un incremento en el ingreso de glucosa hacia la glándula mamaria, así como un incremento de 3 a 11 veces en la secreción de citrato. Estas condiciones promueven el inicio de una secreción copiosa de leche alrededor del momento del parto (Hartmann, 1973; Fleet *et al*., 1975; Davis *et al*., 1979; Tucker, 1981; Akers, 2006).

La producción continua de leche se conoce formalmente como galactopoyesis. Esta fase del ciclo lactacional consta de dos etapas. Una etapa llamada calostral, durante la cual el producto de la secreción contiene grandes cantidades de inmunoglobulinas y otras sustancias. La otra etapa llamada de secreción láctea, en la que se producen grandes cantidades de leche (Neville, 2006).

2. Control hormonal de la secreción de leche

2.1 Participación de la prolactina (PRL)

La PRL, es una hormona polipeptídica de 23kDa sintetizada y liberada por las células lactotropas de la glándula pituitaria anterior o adenohipófisis (Tindal, 1974). La secreción de la PRL de la glándula pituitaria está bajo el control inhibitorio del hipotálamo mediado por la dopamina, un neurotransmisor que es predominantemente liberado por las neuronas dopaminérgicas tuberoinfundibulares ubicadas en el núcleo arcuato con terminales nerviosas en la eminencia media (Andrew, 2005). La secreción de la PRL es regulada mediante un feedback corto, inducido principalmente por el amamantamiento de las crías o la frecuencia de ordeño (Akers, 2002). La PRL ha sido involucrada en un número importante de procesos biológicos en vertebrados, incluyendo la reproducción, crecimiento y desarrollo, osmorregulación, metabolismo e inmunorregulación (Nicoll, 1974). Sin embargo, la acción biológica de la PRL ha sido más extensivamente caracterizada en la glándula mamaria, donde tiene un papel esencial en la diferenciación celular al final de la gestación y posteriormente, participa en la secreción de leche al inicio de lactación (Houdebine *et al*., 1985). Durante esta etapa, el papel de la PRL en la secreción de leche es indispensable en roedores (Oakes *et al*., 2008). En la coneja y la rata por ejemplo, una reducción de la PRL durante el inicio de la lactación, disminuye la secreción de leche de un 80 % a un 90% (Taylor y Peaker, 1975; Knight *et al*., 1986; Flint *et al*., 1992). En cambio, en las especies lecheras como la vaca, la oveja y la cabra, el papel de la PRL durante la galactopoyesis es menos importante que en los roedores. La disminución de esta hormona durante la lactancia, reduce la producción de leche en una pequeña cantidad (Knight, 2001). En efecto, en vacas y ovejas tratadas con bromocriptina (un antagonista de la PRL) antes del parto, se reduce la secreción de leche de un 10 % a un15% (Schams *et al*., 1972; Akers *et al*., 1981). El estímulo a la glándula mamaria por el amamantamiento de las crías induce la secreción de PRL en las hembras (vacas, Karg and Schams *et al*., 1974; ovejas, Lamming *et al*., 1974; cabras, Hart, 1974). Durante la lactancia establecida, la liberación de PRL de la glándula pituitaria, en ocasiones ha sido correlacionada positivamente con la producción de leche en vacas (Koprowoski y Tucker, 1973; Akers, 1980). De hecho, el ordeño de las hembras ya sea manual o mecánico, el cual causa un reflejo neuroendocrino, induce la liberación de PRL (Tucker, 1979). En cabras lactantes, la administración de bromocriptina mediante dos inyecciones diarias antes de cada ordeño, redujo la producción de leche de un 15 % a un 20% (Knight, 1993). A pesar de que conforme avanza la lactación la cantidad de PRL liberada durante el ordeño disminuye gradualmente, esta hormona sigue contribuyendo en la secreción láctea (Koprowoski y Tucker, 1973).

2.2 Influencia de la hormona de crecimiento (GH)

La GH llamada también somatotropina, está constituida de 191 aminoácidos y posee una cadena polipéptidica simple con un peso molecular de 21 kDa. La secreción de la GH de las células somatotropas de la glándula pituitaria ocurre en respuesta a un estímulo de la hormona liberadora de la hormona de crecimiento (GHRH), y es inhibida por la hormona inhibidora de la hormona de crecimiento llamada somatostatina liberada en el sistema portal hipofisial de la glándula pituitaria (Tuggle y Trenkle, 1996). En rumiantes, la actividad biológica de la GH se ejerce de manera directa e indirecta, estimula el crecimiento del músculo esquelético, el crecimiento del hueso, en el metabolismo de los lípidos, el incremento de la glucosa en el hígado e incrementa la absorción de calcio en el intestino delgado y de la síntesis de IGF-I por el hígado (factor de crecimiento similar a la insulina-I) a nivel sistémico (Etherton y Bauman, 1998). A nivel de la glándula mamaria, la GH estimula la diferenciación y multiplicación celular y estos efectos son mediados por la IGF-I (Rechler y Nissley, 1990). Además, la GH participa en la distribución de nutrientes hacia la glándula mamaria para la síntesis de leche (Etherton y Bauman, 1998). De manera indirecta promueve el crecimiento y la lactación, así la GH una vez liberada al torrente sanguíneo, se une a sus receptores en los hepatocitos del hígado y estimula la síntesis de la IGF-I. Este factor de crecimiento se une a sus receptores en las células epiteliales mamarias facilitando el efecto estimulatorio de la GH (Gluckman *et al*., 1987).

El efecto galactopoyético de la hormona de crecimiento ha sido extensivamente estudiado en vacas lecheras y con menor frecuencia en ovejas, cabras y cerdos. En vacas, la aplicación comercial de somatotropina bovina (bST) durante la lactación incrementa la producción de leche de un 10 a un 15%, aunque puede incrementarse aún más cuando el cuidado de los animales es eficiente (Bauman *et al*., 1992). Este efecto galactopoyético no sólo ha sido demostrado en vacas, sino también en ovejas (Hart *et al*., 1985) y cabras (Mepham *et al*., 1984). El mecanismo exacto mediante el cual la GH estimula la producción de leche aún no está bien definido. Sin embargo, la GH tiene una participación directa sobre la producción de leche mediante la adaptación de algunos tejidos para sostener la lactancia (homeorresis; Bauman y Currie, 1980). En el tejido graso por ejemplo, la GH se une a sus receptores ubicados en los adipocitos y estimula la lipólisis (movilización de lípidos). Mediante este proceso metabólico, los lípidos del organismo son transformados para producir ácidos grasos y glicerol para cubrir las necesidades energéticas de la lactancia (Vernon, 1989). La activación de esta ruta metabólica para la producción de energía para la lactancia se lleva a cabo en hembras que se encuentran en un estado energético negativo (Bauman *et al*., 1990). Sin embargo, si las hembras se encuentran en un estado energético positivo, se activa otra ruta metabólica llamada lipogénesis, en la cual la GH promueve la producción de ácidos grasos a partir de la absorción de nutrientes (Bauman *et al*., 2000). La adaptación coordinada en la tasa de lipogénesis y lipólisis en el tejido graso, son ejemplos importantes del control homeorrético de la partición de nutrientes que son necesarios para las necesidades de la glándula mamaria para sostener la síntesis de leche (Bauman y Currie, 1980).

2.3 Efecto del factor de crecimiento similar a la insulina (IGF-I)

La primera fuente de IGF-I circulante en el organismo es obtenida principalmente del hígado, la cual es particularmente inducida por la hormona de crecimiento (GH) (Giustina *et al*., 2008). La liberación de la IGF-I por el hígado hacia la circulación puede actuar de manera endocrina o directamente sobre los tejidos, como en la glándula mamaria (Akers, 2006). Sin embargo, la expresión de mRNA para IGF-I se encontró también en la glándula mamaria de bovinos (Glimm *et al*., 1992; Sharma *et al*., 1994), lo cual indica que su síntesis puede ser de manera local ejerciendo una comunicación parácrina o autócrina. En efecto, uno de los sitios de síntesis de la IGF-I en la glándula mamaria se ubican en las células del estroma (fibroblastos y adipocitos; Marshman and Streuli, 2002).

En cabras, la participación de la IGF-I en la secreción de leche aun no está bien determinada. Sin embargo, se piensa que su efecto puede ser a través de la acción directa sobre la glándula mamaria (IGF-I producida por el hígado en respuesta a la GH; Prosser *et al*., 1991) o es a través de una comunicación autócrina a nivel tejido mamario. En el primer caso, está bien documentado que el incremento de la producción de leche está asociado a un incremento de la IGF-I previamente inducido por la GH (Davis *et al* 1987). En el segundo caso, se ha demostrado también que la administración de IGF-I vía arteria mamaria incrementó un 25% la producción de leche (Prosser *et al*., 1990).

2.4 Participación de la triyodotironina (T3) y tiroxina (T4)

La síntesis y liberación de las hormonas tiroideas T3 y T4 está bajo la influencia del eje hipotálamo-pituitaria-glándula tiroides. La hormona liberadora de tirotropinas (TRH) es un neuropéptido producido en el núcleo paraventricular del hipotálamo, controla la liberación de la hormona estimulante de la tiroides (TSH) de la pituitaria anterior. A su vez la TSH, estimula síntesis y liberación de las hormonas tiroideas (tiroxina y triyodotironina) de la glándula tiroides. La tiroxina, (hormona tiroidea predominante en la circulación), tiene poca o nula actividad biológica (Chopra *et al*., 1978), mientras que la T3 es la hormona tiroidea más activa metabólicamente, ésta es catalizada a partir de la T4 por la enzima desyodinasa-5-DI dentro de la glándula tiroides (Leonard y Visser, 1986). Durante el periodo de lactancia, la actividad de la desyodinasa-5-DI en ratas, disminuye su expresión en hígado y riñón (Kahl *et al*., 1987), e incrementa en glándula mamaria (Valverde y Aceves, 1989). Este opuesto cambio en la actividad de la desyodinasa en la glándula mamaria e hígado se debe probablemente a un incremento en el gasto de energía por la glándula mamaria (Slebodzinski *et al*., 1999).

En vacas, la desyodinación de la T4 a su forma activa T3 en la glándula mamaria es llevada a cabo por la enzima desyodinasa-5 de tipo I (Kahl *et al*., 1993). Esta regulación extratiroidal de la enzima desyodinasa-5 tipo I a nivel glándula mamaria, puede estar involucrada en el efecto galactopoyético de la somatotropina sobre la producción de leche en vacas (Capuco *et al*., 1989).

Las hormonas tiroideas son importantes reguladoras para el mantenimiento normal de la lactancia (Tucker *et al*., 1981). En ausencia de estas hormonas, el crecimiento y la diferenciación de las células epiteliales mamarias se reducen considerablemente (Vonderhaar y Greco, 1979). En vacas lecheras, la administración de tiroxina aumenta la producción láctea en un 27%, la producción de lactosa en un 25% y el porcentaje de grasa en un 42% (Davis *et al* 1988). En cabras, las concentraciones de T3 y T4 son más altas al final de la gestación que durante las primeras tres semanas de lactación; posteriormente se incrementan alcanzando su máximo nivel de 4 a 5 meses después del parto (Riis y Madsen, 1985). Durante este tiempo se encontró una mayor proporción de T4 en comparación a T3, pero también una mayor conversión de T4 a T3 para la producción de leche (Salah, 1996).

3 Factores físicos que regulan la secreción de leche

3.1 Efecto de la presión intramamaria

La acumulación de leche en la glándula mamaria producto de la síntesis y secreción por las células epiteliales es regulada por un mecanismo local intramamario (Linzell y Peaker, 1971). Estudios desarrollados en cabras indican que la acumulación de leche a nivel cisternal y alveolar producto del cese del ordeño, ejerce una presión intramamaria ocasionando con ello una distensión del tejido mamario (Fleet y Peaker, 1978). Estos autores reportaron inicialmente que la distensión mamaria redujo la tasa de secreción de leche, debido en parte a una disminución en el flujo sanguíneo, bajo consumo de oxigeno, glucosa y lactato por la glándula mamaria. Sin embargo, la disminución de la secreción de leche no es debido a una disminución del flujo sanguíneo o del consumo de oxígeno o glucosa, si no que la distensión física perjudicó la estructura física de las células epiteliales provocando la pérdida de su actividad secretora (Peaker, 1980). Posteriormente, Henderson y Peaker, (1984) propusieron que la secreción de leche no era regulada por la distención física de la glándula mamaria, si no que más bien a que el agente regulador estaba propiamente incluido en la leche almacenada en la glándula mamaria.

3.2 Efecto del factor inhibidor de la lactancia (FIL)

Al inicio de los años setentas, Linzell and Peaker, (1971) ya mencionaban la existencia de un agente químico almacenado en leche que actuaba como un feedback negativo inhibidor sobre la lactancia. Para identificar este agente activo, diferentes fracciones de proteína (10-30 kDa) de leche de cabra fueron incluidos en extractos de tejido mamario de conejas y ellas inhibieron la síntesis de lactosa y caseína (Wilde *et al*., 1987). Resultados similares fueron observados en experimentos en vivo, en el cual la fracción de proteína fue inyectada vía intramamaria (Wilde *et al*., 1988). El constituyente activo fue posteriormente purificado por cromatografía. Una de ocho fracciones de proteína fue potencialmente inhibitoria sobre la síntesis de proteína y caseína de la leche. La fracción de proteína identificada resultó ser una glicoproteína de 7.6 kDa sintetizada y secretada por las células epiteliales de la glándula mamaria (Wilde *et al*., 1995). La acumulación de esta glicoproteína en la glándula mamaria entre intervalos de ordeño, provoca un feedback negativo sobre las células epiteliales productoras de leche (Peaker and Wilde, 1996). La frecuencia de ordeño, entonces, es una manera de eliminar el FIL e incrementar la producción de leche.

4. Factores externos que modifican la producción de leche

4.1 Efecto de la frecuencia de ordeño

Tradicionalmente, el incremento en la frecuencia de ordeño ha sido una herramienta práctica implementada en razas lecheras (vacas, ovejas y cabras) con el propósito de incrementar la producción de leche por animal por día (Stelwagen, 2001). Esta técnica, no solo incrementa la producción de leche, sino que además, cuando es aplicada apropiadamente dentro del ciclo lactacional, ejerce un efecto persistente previniendo el declive de la producción de leche (Hale *et al*., 2003; Dahl *et al*., 2004). Lo anterior ocurre, sin subestimar el efecto benéfico que también tiene sobre la salud de la glándula mamaria (Kelly *et al*., 1998; Smith *et al*., 2002).

Con fines experimentales, se han realizado diversos estudios para determinar el potencial de producción de leche de las hembras y el número de ordeños aplicados por día varía según la especie. En vacas por ejemplo, se han reportado estudios donde la frecuencia de ordeño varía de 2 a 6 veces por día (Bar-Peled *et al*., 1995), mientras que en ovejas y cabras, la frecuencia de ordeño fluctúa de 1 a 3 veces por día (Wilde *et al*., 1987; Negrao *et al*., 2001). En vacas, el incremento en la producción de leche varía de un 35 a un 50 % cuando la frecuencia de ordeño se incrementa de una a dos veces por día (Stelwagen and Knight, 1997; Davis *et al*., 1999; Remond y Pomies, 2005). Sin embargo, el incrementar el número de ordeños por día, no necesariamente maximiza la respuesta. En efecto, cuando la frecuencia de ordeño se aumentó de 2 a 3 veces al día durante la primera lactancia, el incremento en la producción de leche debido a las tres ordeñas es menor (6%) al observado en aquellas vacas que pasan de una a dos ordeñas al día (13 a 17 % %; DePeters et al., 1985).

En ovejas, el incremento de la producción de leche debido a la frecuencia de ordeño es menos marcado que en vacas. En esta especie, el incremento varía de un 5 a un 36%, cuando las ovejas son ordeñadas de una a dos veces al día (Morag, 1968; Casu y Labussiere, 1972; Papachristoforou *et al*., 1982; Negrao *et al*., 2001; Castillo *et al*., 2005; Santibañez *et al*., 2009). Sin embargo, cuando se incrementa la frecuencia de ordeños a 3 veces por día, la respuesta en la producción de leche no difiere estadísticamente de las ovejas ordeñadas dos veces al día (Morag, 1968; Negrao *et al*., 2001).

En cabras, el incremento en la producción de leche entre una y dos ordeñas al día varían de un 6 a un 35% (Mocquot, 1978; Wilde y Knight, 1990; Salama *et al*., 2003). Sin embargo, cuando se incrementa la frecuencia de ordeño de dos a tres veces al día, el incremento en la producción de leche en ocasiones es menor al 10% (Henderson *et al*., 1983; Knight, 1992).

4.2 Influencia de la nutrición sobre la lactancia de los rumiantes

En vacas, ovejas y cabras, está bien documentado que el estado nutricional de las hembras antes y después del parto tiene un efecto importante sobre la producción de leche (Treacher, 1970; Morand-Fehr y Sauvant, 1980). Durante esta fase, la demanda de nutrientes para su oxidación en energía, es más alta en la glándula mamaria que en otros tejidos (Bauman *et al*., 1980). En vacas, por ejemplo, el incremento en la demanda de nutrientes va de un 30 a un 50% (Bell, 1995), mientras que en cabras lecheras, el incremento es de un 47% (Annison y Linzell, 1964). Sin embargo, la demanda de nutrientes por la glándula mamaria depende mucho de la cantidad y calidad de la leche producida por los animales (Oftedal, 2000). Así, las hembras con alto potencial genético para la producción de leche, requieren una mejor calidad de nutrientes que los animales con bajo valor genético (Lefryleux *et al*., 2008). El efecto de la nutrición sobre la producción de leche, depende de entre otros factores de la proporción forraje/concentrado, el contenido de nutrientes en la dieta, la proporción energía/proteína y la cantidad de materia seca consumida (Kesler y Spahr, 1964; Morand-Fehr y Sauvant, 1978).

En vacas con 305 días de lactancia, la producción de leche fue más alta (8295 kg) en hembras alimentadas con una proporción forraje/concentrado de 38:62 que en aquellas que fueron alimentadas con una proporción de 68:32 (6849 kg; Tessmann *et al*., 1991). En cabras, la proporción 35:65 de forraje/concentrado, produjo más leche/ día (1.83 kg) que las cabras alimentadas con una proporción de 65:35 (1.55 kg; Tufarelli *et al*., 2009). En un estudio realizado por Min *et al*. (2005), reportaron un incremento de 22% en la producción de leche, cuando las cabras pasaron de recibir 0 kg de concentrado a 0.66 kg/día por cada 1.5 kg de leche producida.

El nivel de energía y proteína incluido en la dieta, es otro factor que puede limitar la cantidad de leche producida (Clark y Davis, 1980). En cabras de la raza Damascus y Zaraibi por ejemplo, la producción de leche fue más alta en las cabras que consumieron un nivel alto de energía en la dieta (Damascus, 0.960 kg/día y Zaraibi, 0.730 kg/día), que en aquellas que recibieron un nivel bajo (Damascus, 0.743 kg/día y Zaraibi, 0.691 kg/día; Gihad *et al*., 1987). En otro estudio desarrollado por Sahlu *et al*. (1995), en cabras de la raza Alpina, se demostró que el aporte de 2.53 Mcal/kg de materia seca de energía metabolizable produjo más leche (3.26 kg/d) que un aporte de 1.8 Mcal/kg de materia seca de energía metabolizable (2.63 kg/d).

La cantidad de proteína en la dieta, es otro factor que modifica la producción de leche. En vacas Holstein Fresian, Oldham *et al*. (1979), reportaron que una reducción en el porcentaje de proteína de 22.3 a 10.7% redujo hasta 4 litros de leche por día, durante los primeras 10 semanas de lactancia. En ovejas de la raza Aragonesa, se reportó que la producción de leche fue más alta en las hembras que consumieron un nivel alto de proteína en la dieta (1.19 kg: 216 g PC/día; 16.1% PC), que en aquellas que consumieron un nivel bajo de proteína (0.90 kg de leche: 175 g PC/día; 13.1% PC; Purroy, 1995).

5. Influencias del fotoperiodo sobre la lactancia, la actividad ovárica postparto y el crecimiento de las crías

5.1 Vías nerviosas para la transmisión de la señal fotoperiódica

La información fotoperiódica es transmitida a la glándula pineal a través de una vía neural multisináptica (Malpaux, 2006). Primeramente la señal luminosa es percibida por los fotorreceptores ubicados en la retina del ojo de los animales. De ahí, la señal de luz es transmitida hacia la zona ventrolateral del núcleo supraquiasmático vía el tracto retinohipotalámico. En este sitio localizado en el hipotálamo, una ruta monosináptica glutaminergica originada desde la retina hasta el núcleo supraquiasmático, regula la expresión de genes involucrados en la generación de ritmos circadianos en la neurona del núcleo supraquiasmático sincronizando los ciclos del día y la noche (Richter *et al*., 2004). En el interior del hipotálamo, las fibras eferentes del núcleo supraquiasmático inervan al área preóptica medial, al núcleo subparaventricular, al núcleo dorsomedial y al núcleo paraventricular. Posteriormente, la señal es transmitida hacia la columna intermediolateral de la parte torácica del cordón espinal y hacia el ganglio cervical superior. Finalmente, la información es transmitida vía las neuronas simpatéticas postganglionares a la glándula pineal (Reiter, 1983). Esta glándula responde a los efectos del fotoperiodo secretando su principal hormona, la melatonina, la cual es liberada con un marcado ritmo circadiano. Normalmente, la máxima secreción de esta hormona ocurre durante la fase de oscuridad del día y es inhibida durante la fase de luz. Por lo tanto, una larga duración secreción de melatonina corresponde a un día corto y viceversa (Arendt, 1998). En ovejas y cabras originarias de latitudes templadas, el fotoperiodo a través de la secreción de melatonina, regula la actividad del eje hipotálamo-hipófisis-gónadas. Para efectuar esta regulación, la melatonina actúa en el área premamilar del hipotálamo medio basal para controlar la secreción de GnRH, y en consecuencia, la de la LH, que a su vez controla la actividad de las gónadas (Malpaux *et al*., 1989; Malpaux *et al*., 1998). Por ello, cuando los animales se encuentran percibiendo los días cortos del otoño, esta información fotoperiodica es traducida por la glándula pineal en una mayor duración de secreción de melatonina, la cual en turno induce el inicio de la actividad sexual. En cambio, cuando los animales se encuentran percibiendo los días crecientes del invierno, la glándula pineal traduce la señal fotoperiodica como un día largo y en consecuencia una menor duración de secreción de melatonina, la cual en turno induce cambios en la frecuencia de pulsos liberación del GnRH (Vigue *et al*., 1995).

5.2 Efecto de los días largos artificiales sobre la producción de leche

Linzell, en 1973, reportó por primera vez en caprinos, el efecto del fotoperiodo (duración del ciclo de luz-oscuridad en un día) sobre la producción de leche. Este autor observó que la producción de leche oscila de una manera estacional, siendo alto durante el verano (días largos) y baja durante el invierno (días cortos). Esta variación estacional en la producción de leche persistió independiente de la alimentación de las hembras, lo cual sugiere que la variación en la producción de leche en cabras, depende de la duración del día. Posteriormente, en condiciones de fotoperiodo artificial, el efecto de los días largos fue demostrado en ganado lechero. Al respecto, Peters *et al*. (1978), demostraron que cuando las vacas son sometidas a un fotoperiodo de días largos artificiales (16 h luz: 8 h oscuridad), la producción de leche es mayor que en aquellas hembras mantenidas bajo condiciones de fotoperiodo natural. A partir de ese tiempo, se iniciaron una serie de estudios encaminados a determinar el efecto galactopoyético de los días largos sobre la producción de leche. En vacas, se han encontrado incrementos en la producción de leche que van de 2 a 3 kg por vaca por día, cuando las hembras se encuentran bajo un fotoperiodo de días largos artificiales, en comparación con las hembras mantenidas en un fotoperiodo de días cortos naturales o artificiales (Dahl *et al*., 2000, 2003).

En ovejas, el fotoperiodo también ejerce un efecto galactopoyético. Por ejemplo, en ovejas de la raza Préalpes du Sud, la producción de leche se incrementó hasta un 52% cuando fueron sometidas a un fotoperiodo de días largos 6 semanas antes del parto y 8 semanas después, en comparación a las hembras mantenidas en fotoperiodo de días cortos (Bocquier *et al*., 1986). En otro estudio desarrollado en ovejas de la raza East Fresian de Australia, la producción de leche fue mayor (21%) en las ovejas sometidas a un fotoperiodo de días largos artificiales en comparación a las hembras mantenidas bajo fotoperiodo natural decreciente (Morrisey *et al*., 2008).

En cabras de la raza Saanen en Francia, Delouis y Mirman (1984) demostraron un efecto de los días largos artificiales sobre la producción de leche. Estos autores encontraron un incremento de un 33% en la producción de leche cuando sometieron las cabras a un fotoperiodo de días largos artificiales durante el invierno, en comparación a las cabras mantenidas bajo condiciones de fotoperiodo natural. En cabras originarias de latitudes subtropicales, Garcia-Hernandez *et al*. (2007) encontraron que la exposición de las hembras a un fotoperiodo de días largos incrementó la producción de leche.

5.2.1 Mecanismo galactopoyético del fotoperiodo

El mecanismo mediante el cual los días largos incrementan la producción de leche no está bien definido. Sin embargo, el efecto galactopoyético de los días largos ha sido asociado a un incremento en la GH y en consecuencia de la IGF-I. En efecto, en carneros como en machos cabríos la exposición al fotoperiodo de días largos incrementan las concentraciones de la GH (Barenton *et al*., 1989; Gazal *et al*., 2002), lo cual en las hembras podría promover la producción láctea. En vacas lecheras por ejemplo, Dahl *et al*. (1997) encontraron que las vacas expuestas a un fotoperiodo de días largos artificiales incrementaron su producción de leche, pero también mostraron un incremento en la secreción de IGF-I. Es probable que el incremento en la producción de leche, provocado por los días largos sea mediado por la IGF-I a nivel de la glándula mamaria. Por ejemplo, cuando las cabras son inyectadas vía intramamaria utilizando IGF-I, la producción de leche se incrementa en la glándula mamaria inyectada en comparación a la glándula no tratada (Prosser *et al*., 1990). La GH, al parecer es otra hormona por la cual los días largos podrían inducir un efecto galactopoyético. Sin embargo, existe poca evidencia del efecto del fotoperiodo sobre la producción de leche a través de la secreción de GH (Peters y Tucker, 1978; Miller *et al*., 1999). De hecho, en vacas lecheras, se demostró que el incremento de la IGF-I como consecuencia del efecto del fotoperiodo de días largos, fue independiente de la secreción de la GH y del IGF-I hepático. Por lo tanto, el incremento de la IGF-I en animales expuestos a un fotoperiodo de días largos es regulado a nivel glándula mamaria y no por la liberación de estos factores a nivel sistémico (Kendall *et al*., 2003).

La PRL es otra hormona mediante la cual los días largos podría ejercer un efecto galactopoyético (Dahl *et al*., 2000). Las concentraciones de esta hormona son mayores durante los días largos y disminuyen cuando se reduce la duración del día. Similarmente, cuando los animales son sometidos a una alternancia de días cortos artificiales seguido de días largos artificiales la secreción de la PRL es mayor en días largos que en días cortos (Mabjeshh *et al*., 2007; Morrisey *et al*., 2008). Como esta hormona es parte del complejo hormonal galactopoyético, entonces es posible que a mayor concentración de ésta también la producción láctea sea mayor. Sin embargo, los estudios realizados en rumiantes sobre la participación de esta hormona en la lactancia establecida no apoyan consistentemente esta última afirmación.

5.3 Efecto de la época del parto y del fotoperiodo sobre la actividad ovárica postparto

El anestro postparto es el periodo que transcurre desde el parto hasta la primera ovulación después del parto. En rumiantes, la duración de este periodo depende entre otros factores, de la raza, del amamantamiento de las crías, de la estación de parto, de la producción de leche y del fotoperiodo (Mauléon y Dauzier, 1965; Bocquier *et al*., 1993; Delgadillo *et al*., 1998; Freitas *et al*., 2004; Montiel y Ahuja, 2005).

En ovejas y cabras originarias de latitudes templadas y subtropicales, está bien establecido que el inicio de la actividad sexual postparto depende de la época en que ocurren los partos (Mauleon y Mauzier, 1965; Delgadillo *et al*., 1998). Así, cuando los partos ocurren durante la estación reproductiva, la duración del anestro postparto es más corto que cuando los partos ocurren al final de la estación reproductiva o al inicio del anestro estacional (Amir *et al*., 1987). Por ejemplo, en ovejas de la raza Muflón que parieron al final de la estación reproductiva, el 46% de las ovejas reiniciaron su actividad sexual antes de terminar este periodo, mientras que el resto (54%) reiniciaron su actividad sexual hasta la próxima estación reproductiva (Santiago-Moreno *et al*., 2000). En las cabras originarias de latitudes templadas, la actividad sexual postparto es también modificada por la estación de parto, y este periodo puede variar de 200 a 300 días (Ricordeau *et al*., 1984). En cabras criollas explotadas en regiones subtropicales, el anestro postparto también es influenciado por la estación de parto. Así, la duración del anestro postparto es más corto cuando los partos ocurren durante la estación reproductiva (50 días) que cuando ocurren al final (100 días) o al inicio del anestro estacional (200 días; Delgadillo *et al*., 1998). La diferencia en la duración del anestro postparto reportado en estas especies, claramente refleja la existencia de una estacionalidad reproductiva que es sincronizada por el fotoperiodo (Ortavant *et al*., 1985).

En animales ovariectomizados y no lactantes bajo condiciones de fotoperiodo artificial, los días cortos (8 h luz; 16 oscuridad) inducen un periodo de reproducción, mientras que los días largos (16 h luz; 8 h oscuridad) lo inhiben (Legan y Karsch, 1980). En condiciones experimentales (naturales o artificiales), el inicio de la actividad sexual se presenta debido a que los animales se hacen refractarios a los días largos de verano. Similarmente, la finalización de la actividad sexual se debe a que los animales se hacen refractarios a los días cortos de invierno (Robinson y Karsch, 1988; Delgadillo *et al*., 2011). Este fenómeno de refractariedad que determina el inicio y el final de la estación sexual se define como una condición en la cual los animales ya no responden adecuadamente a la duración del día al que fueron expuestos (Hamner, 1968; Robinson y Follett, 1982). Además, cuando las cabras y ovejas son expuestas previamente a un fotoperiodo de días cortos y después a días largos artificiales, el estado refractario en estos animales ocurre aproximadamente a los 150 días (Maeda *et al*., 1988; Malpaux *et al*., 1989).

En ovejas y cabras lactantes existen pocos estudios que reporten el efecto de los días largos artificiales sobre el reinicio de la actividad sexual postparto. En ovejas de la raza Préalpes du Sud paridas durante los días decrecientes del otoño, la exposición a un fotoperiodo de días largos después del parto, inhibió la actividad ovárica de las hembras durante los primeros 60 días de lactancia, en cambio, en las ovejas mantenidas bajo un fotoperiodo de días cortos artificiales, el 80% de ellas mostró ovulación (Bocquier *et al*., 1993). En otro estudio desarrollado por Amir y Zaralisa (1990), reportaron que la exposición a un fotoperiodo de días largos (aplicando 1 hora de luz después de 16 a 17 horas del alba) durante los primeros tres meses después del parto, no modificó el porcentaje de hembras que ovularon (20%), comparado con el grupo de hembras mantenidas bajo fotoperiodo natural. En cabras del subtrópico Mexicano páridas en el otoño, la exposición de las hembras a un fotoperiodo de días largos a partir del día 7 de lactancia, inhibió la actividad ovárica postparto, mientras que en las cabras mantenidas bajo fotoperiodo corto natural, más del 90% de ellas mostró al menos una ovulación (Mejía, 2007). Es probable que dichas cabras lactantes requieran de más tiempo de exposición a días largos para que se muestre el periodo refractario y así iniciar su actividad sexual postparto.

5.4 Influencia del nivel de producción de leche sobre la duración del anestro postparto

En especies como la vaca, la oveja y la cerda, la duración del periodo anovulatorio postparto ha sido asociada con la lactancia (Edgerton, 1980). En vacas Holstein por ejemplo, el anestro postparto es más largo en aquellas vacas altas productoras de leche (76 días) que en aquellas las vacas bajas productoras (46 días; Harrison *et al*., 1989). En esta especie, el periodo de inactividad sexual después del parto ha sido asociado a una disminución de la condición corporal provocada por la aportación de reservas corporales hacia la glándula mamaria debido a la elevada producción láctea; ello para soportar el incremento de la producción de leche ocurrido durante las primeras semanas de lactancia (Butler *et al*., 2003). En ovejas, la duración del anestro postparto es más largo en las ovejas altas productoras de leche que en las ovejas bajas productoras (Pollot y Gootwine, 2004). En cabras, la duración del anestro postparto es más largo en las cabras altas productoras (raza Saanen) que en aquellas cabras bajas productoras (raza Nubia; Freitas *et al*., 2004).

5.5 Efecto del fotoperiodo sobre el crecimiento corporal

Al igual que el fotoperiodo de días largos artificiales ejerce un efecto galactopoyético en razas lecheras (vacas, ovejas y cabras), también esta señal está asociada a una mayor ganancia diaria de peso de las crías. En efecto, en un estudio realizado con corderos de un mes de edad se demostró que la exposición a días largos resultó en mayor peso que los corderos expuestos a un fotoperiodo de días cortos artificiales (Forbes *et al*. 1975). Este mismo efecto fue encontrado en vaquillas Holstein Fresian, en las que la exposición a un fotoperiodo de días largos incrementó un 10 a 15% más peso que las mantenidas en un fotoperiodo de días cortos naturales (Tucker *et al*., 1978). En cabras, recientemente se demostró que las crías expuestas junto con sus madres a un fotoperiodo de días largos desde el nacimiento hasta el destete (30 días de edad), ganaron más peso por día que las crías mantenidas con sus madres y expuestas a un fotoperiodo natural decreciente (Mejía, 2007). Lo anterior se debió posiblemente a la mayor producción láctea de sus madres por los días largos.

CAPITULO 3

PLANTEAMIENTO DEL PROBLEMA

En vacas lecheras, está bien documentado que la aplicación de un fotoperiodo de días largos artificiales durante la lactancia establecida incrementa la producción de leche en comparación a las hembras mantenidas bajo fotoperiodo de días cortos naturales o artificiales. Esta misma respuesta fue demostrada posteriormente en animales que son más sensibles al fotoperiodo como las ovejas y las cabras que son criadas en latitudes templadas (48°N). Así, bajo condiciones controladas de alimentación, ambas especies respondieron favorablemente al tratamiento de días largos artificiales incrementando su producción de leche comparado a las hembras mantenidas bajo fotoperiodo de días cortos artificiales. Sin embargo, en animales criados en latitudes más cercanas al ecuador, como las cabras locales del subtrópico Mexicano, que por lo general son manejadas de manera extensiva, no se sabe si los días largos artificiales pueden incrementar la producción de leche, tal como ocurre en los animales de latitudes templadas. También, el efecto podría variar dependiendo del tipo de manejo de la lactancia en los animales de los estudios mencionados (ordeñados 2 veces/ día) y los animales de las zonas subtropicales. Así, en el norte de México la mayoría de los partos se presentan entre noviembre y febrero y las cabras son ordeñadas una vez al día después de la separación definitiva de sus crías a los 30 días de edad, aproximadamente. Por lo tanto, en este trabajo de tesis, en un primer estudio se propuso investigar si los días largos artificiales pueden incrementar la producción de leche en las cabras locales subtropicales ordeñadas una o dos veces al día y mantenidas con una alimentación constante. Sin embargo, considerando que la alimentación en la mayoría de los sistemas de explotación de los caprinos en el subtrópico es bajo condiciones de pastoreo extensivo, entonces es interesante estudiar si también el fotoperiodo de días largos incrementa la producción láctea en esas condiciones. Por lo tanto, en un segundo estudio se propuso investigar si los días largos artificiales pueden incrementar la producción de leche, en cabras alimentadas bajo condiciones de pastoreo extensivo o si es necesario que las hembras reciban un complemento alimenticio para observar el efecto de los días largos artificiales sobre la producción de leche.

Otro efecto que ejerce el fotoperiodo sobre la fisiología de las cabras lactantes es sobre la actividad ovárica postparto. Como fue mencionado anteriormente, se sabe que el inicio de la actividad sexual anual que se presenta durante los días decrecientes del otoño, se debe al establecimiento de un estado refractario a la continua percepción de los días largos naturales de primavera y verano. Por lo anterior, en la presente tesis se plantea investigar si la continua aplicación de días largos artificiales induce en las hembras lactantes el establecimiento de dicho estado refractario a los días largos artificiales y así, sobre el reinicio de la actividad ovárica postparto. Por lo cual en un tercer estudio se determinó el reinicio de la actividad ovárica en dos grupos de cabras que parieron en el otoño: uno mantenido bajo condiciones de fotoperiodo natural y otro grupo expuesto a partir del día 10 de lactancia a días largos artificiales.

Por último, un efecto del fotoperiodo largo se ha observado sobre el crecimiento de las crías rumiantes. Así, se tiene evidencia que en vaquillas y corderos expuestos a días largos artificiales a partir del destete y alimentados con dietas sólidas, ganan más peso que las crías mantenidas bajo días cortos artificiales. Además, existe evidencia en cabras de que los cabritos expuestos junto con sus madres desde el nacimiento hasta el destete a días largos artificiales ganaron 1 kg más de peso al final del estudio, que los cabritos mantenidos en días cortos naturales. Sin embargo, en ese estudio no se reportó si la ganancia de peso fue debido al efecto directo del fotoperiodo sobre el crecimiento de los animales o a la elevada producción de leche de sus madres. Tomando en consideración estas evidencias, se planteó investigar, si los días largos artificiales pueden incrementar la ganancia de peso de los cabritos durante la fase de lactancia cuando son alimentados naturalmente o no por sus madres.

CAPITULO 4

OBJETIVOS E HIPÓTESIS DEL PROYECTO DE TESIS

Objetivo general

Investigar en las cabras subtropicales paridas en el otoño, la influencia que tienen los días largos artificiales sobre la lactancia, la actividad ovárica postparto y el crecimiento de las crías.

Objetivos específicos

Experimento 1

El objetivo fue para determinar si los días largos artificiales incrementan la producción de leche en las cabras subtropicales paridas en el otoño ordeñadas una o dos veces al día.

Experimento 2

Determinar si los días largos artificiales pueden incrementar la producción de leche en las cabras subtropicales manejadas bajo condiciones de pastoreo extensivo o si es necesaria una complementación nutricional para observar dicho efecto.

Experimento 3

Investigar si la prolongada exposición a un fotoperiodo de días largos artificiales en las cabras del subtrópico que paren en el otoño induce el establecimiento de un estado refractario a los días largos artificiales y así, el reinicio de la actividad ovárica postparto.

Experimento 4

Determinar si la exposición a un fotoperiodo de día largo artificial puede incrementar la ganancia de peso diaria y el peso al destete de los cabritos nacidos en el otoño cuando son amamantados o no por sus madres.

Hipótesis de trabajo

Hipótesis experimento 1

La exposición a un fotoperiodo de días largos artificiales en las cabras del subtrópico mantenidas intensivamente y paren en el otoño incrementa la producción de leche, independientemente si los animales son ordeñados 1 ó 2 veces por día.

Hipótesis experimento 2

En las cabras del subtrópico Mexicano, manejadas bajo pastoreo extensivo y que paren en el otoño, la exposición a un fotoperiodo de días largos artificiales incrementa la producción de leche.

Hipótesis experimento 3

En cabras subtropicales que paren durante el otoño, la prolongada exposición a un fotoperiodo de días largos artificiales induce el establecimiento de un estado refractario y con ello una elevada proporción de cabras inician su ovulación postparto.

Hipótesis experimento 4

En las crías caprinas que nacen durante el otoño, la exposición a un fotoperiodo de días largos artificiales incrementa el peso al destete.

CAPITULO 5

ARTÍCULOS CIENTÍFICOS OBTENIDOS DEL PROYECTO DE TESIS

Artículo 1. Flores, M.J., J.A. Flores, J.M. Elizundia, A. Mejía, J.A. Delgadillo, and H. Hernández. 2011. Artificial long-day photoperiod in the subtropics increases milk production in goats giving birth in late autumn. J. Animal Sci. 89:856-862.

Artículo 2. Flores, M.J., J.A. Flores, G. Duarte, J. Vielma, J.A. Delgadillo, F. Pastor, and H. Hernández. In subtropical lactating goats managed under extensive grazing conditions a nutritional supplementation is necessary to increase milk production using artificial long days.

Artículo 3. Flores, M.J., J.A. Flores, G. Duarte, J. Vielma, J.A. Delgadillo, and H. Hernández. 2011. Long-day photoperiod exposure in lactating goats induces the postpartum ovulatory activity through the establishment of a refractory state. Small Rumin. Res. (Sometido).

Artículo 4. Flores, M.J., J.A. Flores, G. Duarte, J. Vielma, J.A. Delgadillo, and H. Hernández. Artificial long days in the subtropics increases body weight at the weaning of goats kids birth in the autumn.

Artículo 1

Artificial long-day photoperiod in the subtropics increases milk production in goats giving birth in late autumn. 2011. J. Animal Sci. 89:856-862.

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Artificial long-day photoperiod in the subtropics increases milk production in goats giving birth in late autumn

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Artificial long-day photoperiod in the subtropics increases milk production in goats giving birth in late autumn[1,2]

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ABSTRACT: Two experiments were conducted to determine whether exposure to a photoperiod of artificial long days in autumn increased milk yield in subtropical goats milked once (Exp. I) or twice daily (Exp. II). In Exp. I, starting at d 10 of lactation, 1 group of does was kept under naturally decreasing photoperiod (DD1X; n = 8), whereas the other group was submitted to an artificial photoperiod of long days (LD1X; n = 8; 16 h light:8 h darkness). The kids were weaned 28 d after parturition, and dams were manually milked once daily. Milk yield and milk components (fat, protein, and lactose) were assessed up to 140 d of lactation. From d 0 to 28 of lactation (suckling phase), mean daily milk yield did not differ between DD1X and LD1X goats (2.3 ± 0.2 kg vs. 2.4 ± 0.2 kg; $P = 0.717$). However, between d 29 and 84 (early milking phase), mean daily milk yield was greater in LD1X does than in DD1X does (2.6 ± 0.1 kg vs. 2.1 ± 0.1 kg; $P = 0.001$). Finally, between d 85 and 140 (late milking phase), mean daily milk yield was greater in LD1X goats than in DD1X goats ($P \leq 0.05$) only during the first 2 wk. In Exp. II, one group of goats was exposed to a photoperiod of naturally decreasing days (DD2X; n = 8) and another group was submitted to an artificial photoperiod of long days (LD2X; n = 7). In both groups, kids were weaned on d 28 of lactation and the dams were manually milked twice daily. During the nursing phase, mean daily milk yield did not differ between the DD2X and LD2X groups (2.5 ± 0.3 kg vs. 2.6 ± 0.2 kg; $P = 0.767$). In the early milking phase, mean daily milk yield was greater in LD2X than in DD2X goats (3.3 ± 0.2 kg vs. 2.8 ± 0.2 kg; $P = 0.022$), whereas during the late milking phase, milk yield did not differ between the 2 groups ($P = 0.946$). In both experiments, milk composition was not significantly influenced by exposure to long-day photoperiod. We conclude that, in subtropical female goats that start lactation in late autumn, exposure to an artificial long-day photoperiod stimulates milk yield, even if goats are milked once daily. In addition, combining exposure to long days with twice-daily milking will increase further milk yield in such goats without affecting milk components.

Key words: goat, lactation, milk component, milking frequency

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INTRODUCTION

In ruminants, season of parturition influences milk production (Linzell, 1973). Milk yield is greater during the long days of summer than during the short days of autumn and winter. In addition, females exposed to artificial long days in winter produce more milk than females exposed to natural short days. This has been shown in cows exposed to artificial long days at the latitude of 39°N, where they produced 2 kg more milk/cow daily than cows exposed to natural short days (Dahl, 2008). In a study in France at latitude of about 48°N, milk yield was increased by 33% by exposing does to artificial long days, even though milk contents of fat and N were reduced (Delouis and Mirman, 1984).

These increases in milk yield by long days were obtained under temperate latitudes, where animals experience large natural variations of day length during the year. This may apply also in the subtropics, despite the smaller seasonal variations of photoperiod. Thus,

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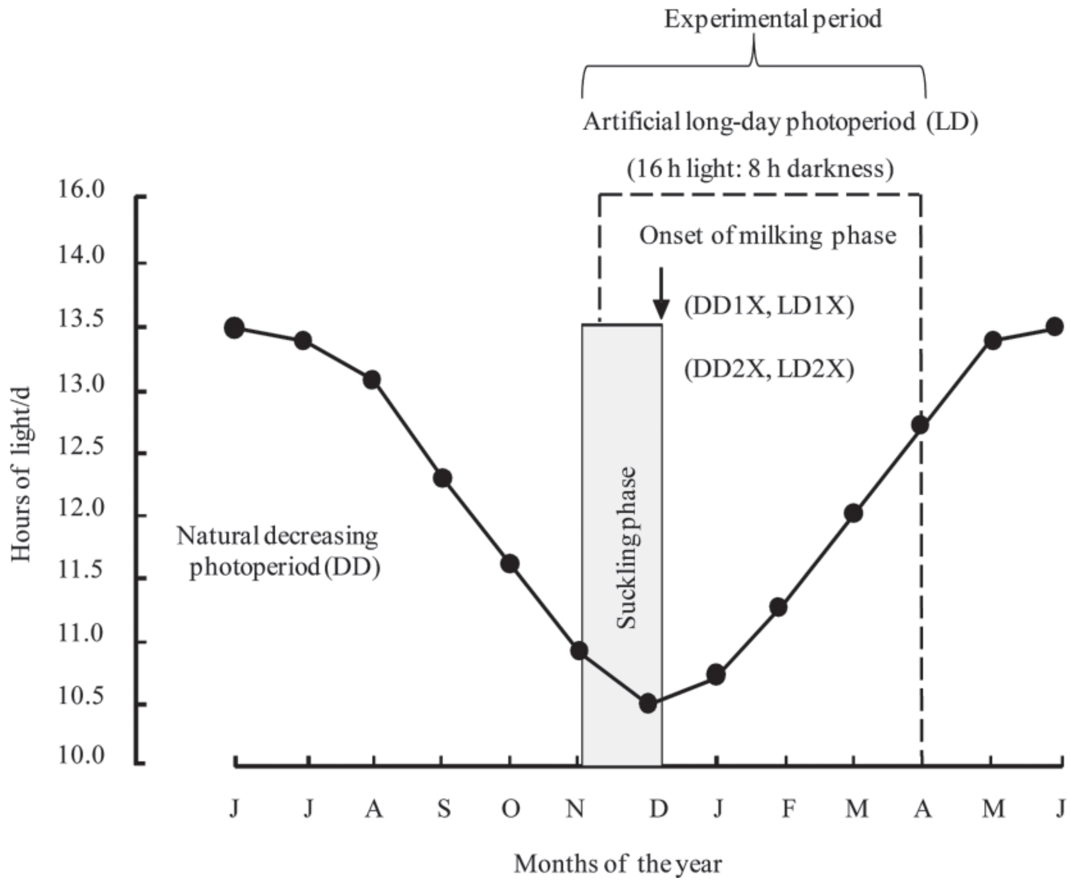

Figure 1. Experimental design showing the natural and artificial long-day (LD) photoperiod setup (i.e., h of light/d) to which goats of the 2 experiments were subjected. The suckling and the milking phases are indicated by the gray area and an arrow, respectively. Goats were maintained under naturally decreasing days (DD) or under an artificial LD photoperiod and were manually milked once (1X) or twice daily (2X).

at a latitude of 30°N, Garcia-Hernandez et al. (2007) reported an increase in milk yield by exposing goats milked twice daily to long days. However, this finding remains to be confirmed closer to the tropics. Also, the effect may vary depending on the different type of management between temperate and subtropical regions. Thus, in northern Mexico (26°N), most does give birth between November and February and are milked only once daily, after weaning of the kids at 30 d (Hoyos, 1988). If the increase in milk yield by long days applies also under such subtropical latitudes and management, it would represent a substantial gain of productivity for goat breeders. Therefore, we investigated if exposure to an artificial long-day photoperiod could increase milk production of goats giving birth in late autumn at a latitude of 26°N. Two separate experiments were conducted to assess the efficacy of the treatment in goats milked once or twice daily, to verify that milk yield could be increased independent of milking frequency.

MATERIALS AND METHODS

The procedures used in the experiments reported here were in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

General Conditions of Study

Location. The studies were conducted on a commercial farm in the Laguna region, state of Coahuila, Mexico (latitude, 26°23′ N; longitude, 104°47′ W). In this region, variations of photoperiod range from 10 h, 19 min of light at the winter solstice to 13 h, 41 min at the summer solstice. During the experiments, the mean time for sunrise was 0724 h and the mean time for sunset was 1845 h, resulting in an average duration of the day of 11 h, 21 min (Figure 1).

Animals and Maintenance Conditions. Thirty-one multiparous mixed-breed Creole goats selected from a commercial flock of 100 animals maintained permanently in pens under intensive conditions. The phenotypic characteristics of these animals have been previously reported by Delgadillo et al. (1999). Goats were mated in June, using a male effect with sexually active males (Flores et al., 2000; Delgadillo et al., 2009). The mean date of parturition (±SEM) for all goats was November 6 ± 1.0 d, and the number of kids per doe averaged 1.8 ± 0.1. Goats were fed 4.0 kg on humidity base of sorghum silage/goat daily (2.17 Mcal of ME/kg of DM; 9.4% CP) and 1.0 kg/goat of a commercial concentrate containing 14% CP. Goats had free access to water and mineral salts, which were provided in 25-kg blocks (Cebú, Salinas del Rey, Torreón, México) containing at least 17% P, 3% Mg, 5% Ca, and 75% NaCl, as recommended by NRC (2007).

After parturition, all goats and their kids remained together during the first 10 d postpartum and were kept under naturally decreasing photoperiod. On d 10, females were allocated to their respective experiment and group, balanced for initial milk yield, body condition, and litter size. At d 28 postpartum, kids were weaned and dams were manually milked up to d 140 of lactation.

Experimental Design and Groups

Exp. I. The main objective was to investigate if exposure to artificial long days at a latitude of 26°N would increase milk yield in goats kidding under decreasing day conditions (late autumn) and milked once daily after weaning. The first treatment served as control and was continuously exposed to the naturally decreasing photoperiod [decreasing days, 1 milking daily (**DD1X**), n = 8; Figure 1]. At d 28 postpartum, kids were weaned and dams were manually milked once daily at 0700 h up to d 140 of lactation. The second group of goats [long days, 1 milking daily (**LD1X**), n = 8] was managed in the same way as the control group, except that the females of this group were submitted to an artificial long-day photoperiod of 16 h of light and 8 h of darkness, starting at d 10 of lactation and up to the end of the study.

Exp. II. The study of Garcia-Hernandez et al. (2007), which investigated the effect of long days on milk production of goats, was performed in Texas at a latitude of 30°N and used goats that were milked twice daily from the beginning of lactation. Considering this, a second experiment was conducted parallel to Exp. I. Specifically, goats were also milked twice daily to verify if the results obtained by these authors would apply closer to the tropics. To this end, 1 control group of goats milked at 0700 and 1900 h was exposed continuously to the naturally decreasing photoperiod [decreasing days, 2 milkings daily (**DD2X**) n = 8; Figure 1], whereas a second group, also milked twice daily, was exposed to artificial long days as in Exp. I [long days, 2 milkings daily (**LD2X**), n = 7].

Photoperiodic Treatment. In both experiments, control goats and those exposed to artificial long days were kept in outside pens (12 × 6 m, 1 pen/group), which were 75 m apart and each provided with an open shed. To provide the photoperiod of long days to the light-treated groups, pens were equipped with daylight-type lamps that emitted a minimum luminous intensity of 400 lx at the eye level of the goats. Lights were on from 0600 to 0900 h and from 1700 to 2200 h to extend the duration of the natural day and obtain a total of 16 h light/d. In addition to a distance of 75 m separating the control and light-treated pens, a curtain made of opaque material was placed around the light-treated pens to avoid any perception of light at night by the control females from the short-day groups.

Measurements

Milk yield, milk components, BW, and BCS were taken throughout the study during 3 successive phases of lactation (suckling, early milking, and late milking). The suckling phase consisted of the period during which the dams nursed their kids, from the day of parturition (d 0) to d 28 of lactation. The early milking phase consisted of the first part of lactation after the kids were weaned, from d 29 to 84 of lactation, and the late phase consisted of the later period of milking, from d 84 to 140 of lactation.

Milk Yield. During the suckling phase, goats were not milked and milk yield was assessed using the method of weigh-suckle-weigh over a 24-h period (Ricordeau et al., 1960). The day before initiating the measurements, does were hand-milked at 1800 h. The next day, 2 controlled sucklings of 4 min each were performed, at 0700 and 1900 h. Furthermore, after each suckling, exogenous oxytocin (**OT**, 2 IU; Oxilac, Proquivet, Guadalajara, México) was injected into a jugular vein, followed by hand-milking to extract residual milk. The weight of the residual milk was added to the corresponding difference in the BW measurements of the kid. For this phase, the procedure was the same in Exp. I and II.

During the early and late milking phases, all goats were milked by the same person throughout the experiment. During each phase (d 29 to 84 and d 85 to 140, respectively), milk yield was measured every 7 d. In Exp. I, does were milked at 0700 h, the day before initiating each measurement. The next day, goats were hand-milked at 0700 h and the collected milk was weighed. Then, OT (2 IU) was injected into a jugular vein of each female and the residual milk was extracted by hand-milking. This residual milk was weighed and added to the quantity obtained from hand-milking.

In Exp. II, milk yield in a 24-h period was measured every 7 d as in Exp. I. Females were milked twice daily, a first emptying of the udder was performed at 1900 h the day before starting each measurement, followed by 2 hand-milkings at 12-h intervals (at 0700 and 1900 h) the next day. After each hand-milking, OT (2 IU) was injected into a jugular vein of each female to extract residual milk. This milk was weighed and added to the amount previously obtained from hand-milking.

In addition, in both experiments, the difference of milk collected between goats exposed to naturally decreasing days and goats exposed to the artificial long-day photoperiod was estimated by computing the difference of average daily milk yield per goat between the 2 groups for each week, multiplied by 7, and all were added to obtain the total difference of milk yield between the 2 groups for the entire period of milking. The general formula to compute this difference can be summarized as follows:

$$\text{difference in MY} = \Sigma \text{ wk 5 to 20}$$
$$(\text{MYLD} - \text{MYDD} \times 7),$$

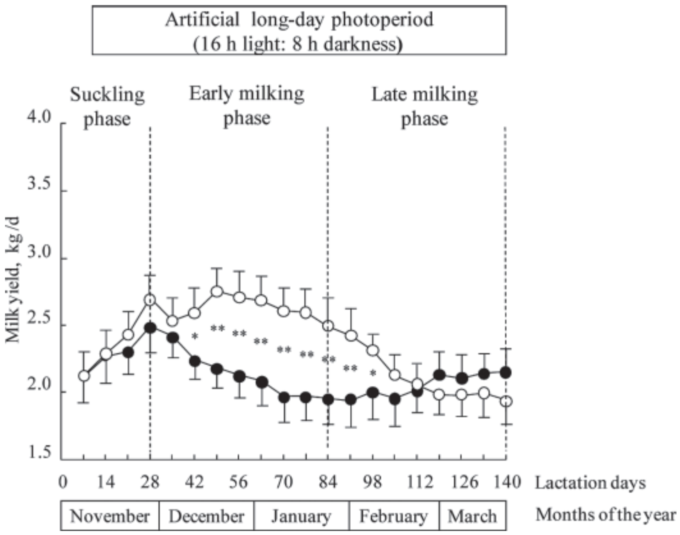

Figure 2. Mean (±SEM) daily milk yield of goats manually milked once daily and exposed to a naturally decreasing photoperiod (DD1X; ●) or exposed to an artificial long-day photoperiod (LD1X; ○) starting on d 10 of lactation and up to d 140 of lactation. Mean daily milk yield during early milking phase was greater ($P = 0.002$) in LD1X than in DD1X does. Significant differences between treatments (photoperiod) at each time point are indicated by an asterisk (*$P < 0.05$ and **$P < 0.01$).

where MY = milk yield, LD = long-day group, and DD = decreasing-day group.

Milk Composition. In all goats and in each phase, a sample of milk was collected weekly at the time of milk yield determination (20 mL from each udder half) in plastic sterile tubes. Samples were kept on ice and transported to the laboratory for the determination of fat, protein, and lactose using a Milkoscan 6000 (Foss Electric, Hillerød, Denmark).

BW and BCS. Body weight and BCS of all females were determined every 2 wk up to the end of the experiment. Females were weighed on a mobile scale with a 200-kg capacity and a precision of 0.05 kg. The BCS was determined by palpating spinous and lateral processes, as well as the musculature, of the lumbar region of the spine, according to the method described previously by Walkden-Brown et al. (1997) and using a scale ranging from 1 (very lean) to 4 (fat) with a precision of 0.5.

Statistical Analyses

In both experiments, milk yield and its components (fat, protein, and lactose) were analyzed during each phase of lactation using the MIXED MODELS procedure of SYSTAT 13 (Chicago, IL). The procedure included the fixed effects of photoperiodic treatment (2 levels: natural and artificial, the error term being goat within treatment), week of lactation (the residual error being the error term), their interaction, and the random effects of goat and residual. The individual goat was the experimental unit. All dependent variables were included as repeated measures. Separate individual independent *t*-tests were also performed to compare weekly milk yield. Changes in BW were analyzed using the GLM procedure of SYSTAT with treatment in the model statement. Because of the ordinal nature of the data for BCS, this variable was analyzed for week effect within each group by the Friedman test and by the Mann-Whitney test for comparison between the 2 groups at a given time. Data were presented as means ± SEM, and the results were considered significant when $P \leq 0.05$.

RESULTS

Exp. I

Milk Yield. During the suckling phase, mean daily milk yield did not differ between DD1X and LD1X goats ($P = 0.717$; Figure 2). On the other hand, in both groups there was an increase of the milk yield resulting in an effect of week ($P = 0.006$). No interaction was detected ($P = 0.143$) between photoperiod and week for milk yield. During the early milking phase, no effect of photoperiod was observed ($P = 0.135$). Nonetheless, milk yield in the LD1X group was stable, whereas in the DD1X group it decreased across weeks (week effect, $P = 0.002$), resulting in a significant interaction between photoperiod and week ($P = 0.001$; Figure 2).

In the late milking phase, mean daily milk yield was greater in LD1X goats than in DD1X goats during the first 2 wk of this phase (Figure 2; $P \leq 0.05$). Week of the experiment did not affect mean daily milk yield ($P = 0.358$), although milk yield tended to increase in the DD1X group and tended to decrease in the LD1X group. Thus, as in the early milking phase, there was an interaction between photoperiod and week in the late milking phase ($P = 0.0001$). The calculated difference in total milk yield per goat during all milking phases (from wk 5 to 20) was 62 ± 5 kg more milk in the LD1X group than in the DD1X group.

Milk Composition. During the 3 phases of this experiment, week affected mean percentage of fat, protein, and lactose contents in milk ($P = 0.0001$). Thus, in the 2 groups all milk components tended to decrease until onset of the early milking phase; thereafter, these contents had slight changes. However, photoperiod had no effect and there was no significant interaction between photoperiod and week for percentage of fat, protein, or lactose ($P \geq 0.444$ for all components; Figure 3).

BW and BCS. In the 3 phases of this experiment, week affected mean goat BW and mean BCS of the goats, both variables increasing between the beginning and end of the study ($P = 0.001$). On the other hand, photoperiod had no effect ($P = 0.345$), and no interactions between photoperiod and week were found for these variables (Table 1; $P = 0.445$).

Exp. II

Milk Yield. During the suckling phase, the mean daily milk yield did not differ ($P = 0.767$) between

Table 1. Mean (±SEM) of doe BW and BCS in 4 groups of goats manually milked once (1X) or twice (2X) daily and exposed to naturally decreasing photoperiod (DD) or to artificial long-day photoperiod (LD) in 3 phases of lactation (suckling: 0 to 28 d; early: 29 to 84 d; late: 85 to 140 d)

Experiment	Group	Corporal measurement	Suckling phase	Early milking phase	Late milking phase	P-value[1]
I	DD1X	BW, kg	47.3 ± 3.2[a]	48.3 ± 2.9[b]	50.0 ± 3.0[c]	0.001
		BCS[2]	1.6 ± 0.1[a]	1.8 ± 0.1[b]	2.2 ± 0.2[c]	0.001
	LD1X	BW, kg	48.1 ± 1.0[a]	47.7 ± 0.9[b]	49.8 ± 1.2[c]	0.001
		BCS	1.7 ± 0.1[a]	1.9 ± 0.1[b]	2.4 ± 0.1[c]	0.001
II	DD2X	BW, kg	46.7 ± 4.2[ab]	46.4 ± 3.5[a]	47.9 ± 3.0[b]	0.001
		BCS	1.7 ± 0.1[a]	1.8 ± 0.1[b]	2.2 ± 0.1[c]	0.001
	LD2X	BW, kg	50.0 ± 4.7[ab]	51.2 ± 4.2[a]	52.8 ± 3.2[b]	0.001
		BCS	1.6 ± 0.1[a]	1.7 ± 0.1[b]	2.2 ± 0.1[c]	0.001

[a–c]Within the same row, means without a common superscript differ ($P < 0.05$).
[1]P-value refers to time.
[2]BCS scale ranged from 1 (very lean) to 4 (fat).

goats from DD2X and LD2X, and no interaction between photoperiod and week was found ($P = 0.143$). On the other hand, mean daily milk yield increased in both groups over time (week effect, $P = 0.002$). During the early milking phase, there was a main effect of photoperiod ($P = 0.022$; Figure 4). In addition, daily milk yield increased in the LD2X group, whereas it remained stable in the DD2X group, resulting in an effect of week ($P = 0.001$). Nonetheless, there was no interaction between the factors ($P = 0.631$). During the late milking phase, there was no effect of photoperiod on milk yield ($P = 0.946$), whereas there was an effect of week of the experiment ($P = 0.0001$). Milk yield decreased in the LD2X group, whereas it tended to remain stable in the DD2X group, resulting in an interaction between week and photoperiod ($P = 0.001$). As in Exp. I, the calculated difference in total milk yield per goat during all milking phases (from wk 5 to 20) was 89 ± 7 kg more milk in the LD2X group than in the DD2X group.

Milk Composition. As in Exp. I, milk contents of fat, protein, and lactose were not affected ($P \geq 0.586$) by photoperiod, whereas week affected the mean percentage of fat, protein, and lactose content ($P = 0.0001$) during the 3 phases of Exp. II. Thus, in the 2 groups, all milk components tended to decrease until the onset of early milking phase; thereafter, these contents underwent slight changes. However, no interactions between week and photoperiod were found for percentages of fat, protein, or lactose ($P \geq 0.441$; Figure 5).

BW and BCS. As in Exp. I, photoperiod had no effect ($P = 0.335$) on mean goat BW and mean BCS. Both variables increased with time (week effect, $P = 0.001$). Finally, no interaction was found between week and photoperiod for any of these 2 variables (Table 1; $P = 0.526$).

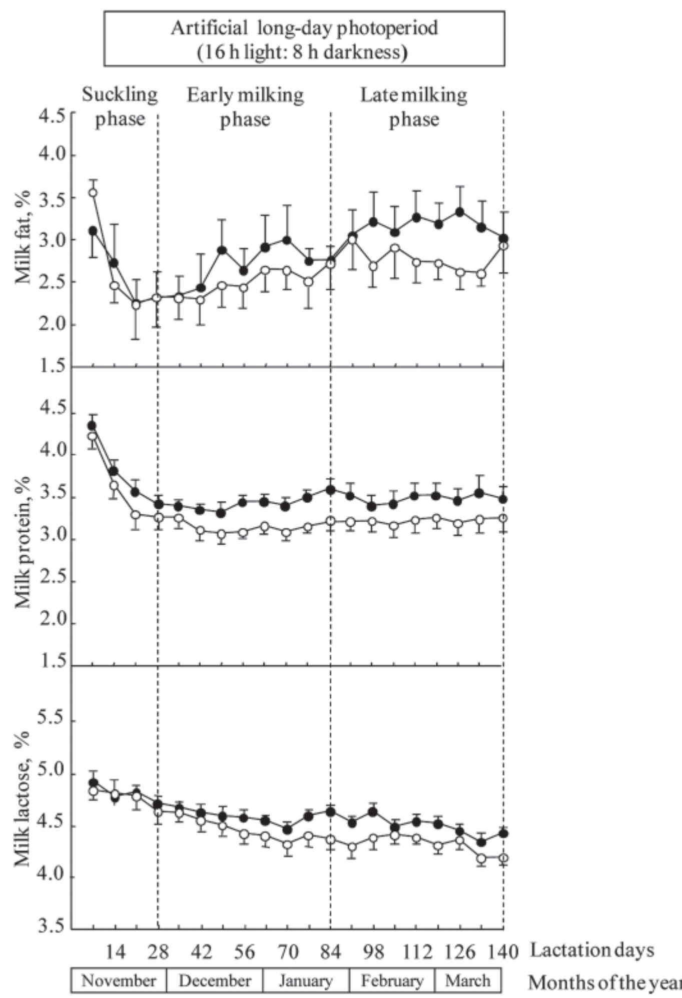

Figure 3. Mean (±SEM) percentages of fat, protein, and lactose in milk of goats manually milked once daily and maintained under a naturally decreasing photoperiod (DD1X; ●) or exposed to an artificial long-day photoperiod (LD1X; ○) starting on d 10 of lactation and up to d 140 of lactation. There were no differences ($P = 0.444$) in milk composition between treatments (photoperiod); only milk components were affected by week ($P = 0.0001$ for each component).

DISCUSSION

In the 2 experiments of the present study, goats exposed to an artificial long-day photoperiod produced more milk than goats exposed to the natural decreasing

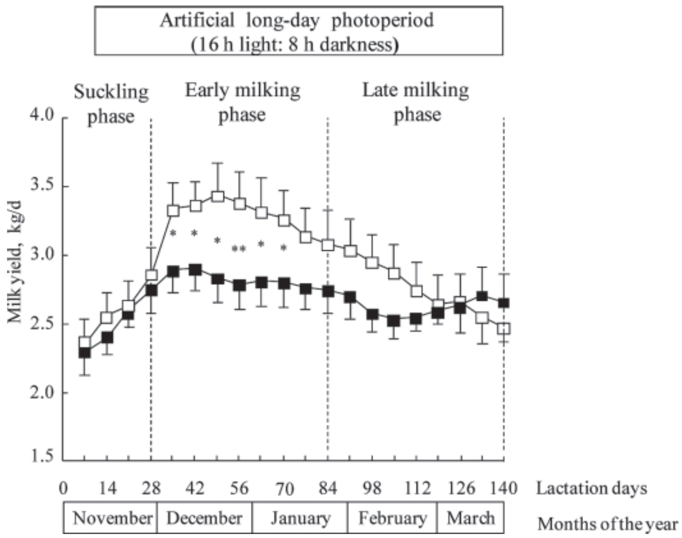

Figure 4. Mean (±SEM) daily milk yield of goats manually milked twice daily and exposed to a naturally decreasing photoperiod (■; DD2X group) or exposed to an artificial long-day photoperiod (□; LD2X group) starting on d 10 and up to d 140 of lactation. Mean daily milk yield during early milking phase was greater ($P = 0.022$) in LD2X than in DD2X does. Significant differences between treatments (photoperiod) at each time point are indicated by an asterisk (*$P <$ 0.05 and **$P < 0.01$).

days of late autumn and winter. This finding shows for the first time that the stimulatory effect of a long-day photoperiod on milk yield can be obtained in goats, even very close to the tropics and if does are milked only once daily. As a whole, our results are in agreement with those of the literature but also extend their validity to latitudes closer to the tropics and to management conditions different from those reported previously in goats and other species (Dahl et al., 2000; Garcia-Hernandez et al., 2007; Morrissey et al., 2008).

Although our results are congruent with the literature mentioned above, they differ from those reported in ewes by Bocquier (1985). Indeed, this author found that, at d 70 of lactation, milk yield decreased in ewes subjected to a long-day photoperiod compared with control ewes maintained under natural short days. Nonetheless, this apparent discrepancy is likely to depend on the fact that the light treatment did not begin at the same time in the 2 studies. In the study of Bocquier (1985), exposure to the long-day photoperiod started 42 d before lambing, whereas in our work exposure started only on d 10 of lactation. In fact, in both studies the decrease in milk yield occurred after a similar duration of exposure to long days, 105 d in our study and 112 d in that of Bocquier (1985). This interpretation is also congruent with the interaction found between photoperiod and week of lactation in our study during the milking phases. The results of both studies are consistent with the possible induction of a refractory state on prolactin secretion due to the continuous long-day exposure (Maeda et al., 1988).

In our study, the exposure to long-day photoperiod did not affect milk concentrations of fat, protein, or lactose, which is consistent with the results of Salama et al. (2003). On the other hand, our results differ from some reports in other ruminants. For example, in cows, Stanisiewski et al. (1985) found a slight reduction in the percentage of milk fat during exposure to long days, and in ewes, Bocquier et al. (1990) found that protein content of milk was reduced under long days compared with short days, whereas lipid percentage remained unchanged. Similarly, Delouis and Mirman (1984) found that fat and N contents of milk were decreased in goats exposed to a long-day photoperiod, whereas Garcia-Hernandez et al. (2007) reported a decrease only for fat content. Nonetheless, others found that milk composition is unaffected by photoperiod (Dahl et al., 1997, 2000; Morrissey et al., 2008). In any case, our present results under subtropical latitude suggest that artificial photoperiod of long days affected milk content.

Finally, our results on goats milked twice daily agree with the well-documented fact that increasing milking frequency increases milk production. This has previ-

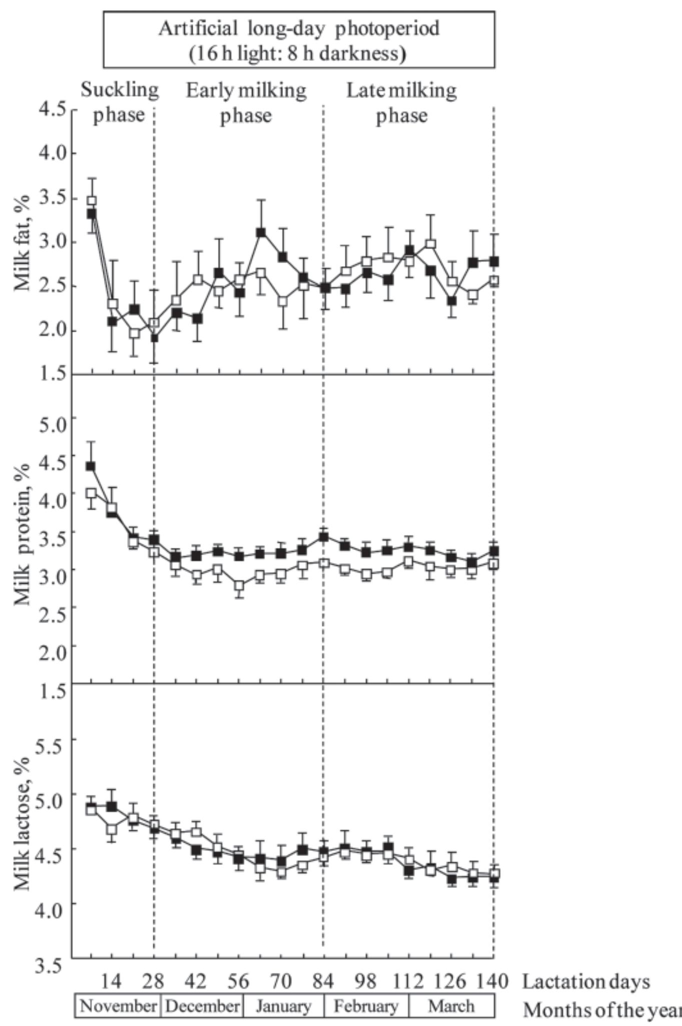

Figure 5. Mean (±SEM) percentages of fat, protein, and lactose of goats manually milked twice daily and maintained under a naturally decreasing photoperiod (DD2X; ■) or exposed to an artificial long-day photoperiod (LD2X; □) starting on d 10 of lactation and up to d 140 of lactation. There were no differences ($P = 0.441$) in milk composition between treatments (photoperiod); only milk components were affected by week ($P = 0.0001$ for each component).

ously been reported in goats, cows, and sheep (Negrão et al., 2001; Stelwagen, 2001; Salama et al., 2003). Our results are not surprising in this respect. However, from a practical viewpoint, the gain of milk yield in goats milked twice daily was at least as large as that in goats milked only once daily. This indicates that goats milked twice daily kept all their capacity to respond to light stimulation, despite the fact that their milk yield was closer to their full milk potential because of the increased milking frequency. Therefore, our results emphasize the practical interest for goat farmers close to the tropics to use exposure to a long-day photoperiod as a practical and nonhormonal tool to increase milk yield of goats under these latitudes, regardless of whether animals are milked once or twice daily. The fact that more than 80% of goats live under subtropical or tropical latitudes makes this finding even more relevant.

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Artículo 2

In subtropical lactating goats managed under extensive grazing conditions a nutritional supplementation is necessary to increase milk production using artificial long days

Long days and milk production in grazing goats

In subtropical lactating goats managed under extensive grazing conditions a nutritional supplementation is necessary to increase milk production using artificial long days

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ABSTRACT: The objective of this study was to determine whether exposure to an artificial long-day photoperiod can increase milk production in goats from northern Mexico maintained under extensive grazing conditions receiving or not a nutritional supplement. A first group of local goats (n=11) was maintained under natural photoperiod and from d 30 of lactation, additional to grazing they did received daily a nutritional supplement (supplemented control group). A second group of grazing goats (n=11), also was maintained under natural photoperiod, except that this group did not received the nutritional supplement (non-supplemented control group). The third group of grazing goats (n=11), was continuously exposed starting on d 15 of lactation to an artificial long-day photoperiod and from d 30 of lactation goats received daily the same amount of supplement as in the first group (supplemented treated group). A fourth group of grazing goats (n=11), was subject to the same photoperiodic treatment as in the third group, except that this goats did not receive supplementation (non-supplemented treated group). Milk yield was assessed at d 10 of lactation and thereafter each 10 days up to d 110 of lactation. Plasma IGF-I concentrations were determined at d 5, 25, 45, 65 and 85 after the onset of photoperiodic treatment. Mean milk yield was greater in goats from non-supplemented treated group (0.92 kg/d) than those from non-supplemented control group (0.78 kg/d; $P < 0.001$). This effect was even greater when females received a nutritional supplementation being milk production greater for supplemented treated group (1.1 kg/d) than for supplemented control group (0.82 kg/d; $P < 0.001$). The plasma IGF-I concentrations were greater in goats submitted to long days than in those maintained under natural photoperiod only if females received a nutritional supplementation ($P < 0.001$). It is concluded, that in subtropical goats maintained under extensive grazing conditions exposure to an artificial long-day

photoperiod increases milk yield and the plasma IGF-I circulating concentrations only if females received a nutritional supplementation.

Keywords: Goats, long days, milk production, grazing, nutritional supplementation.

INTRODUCTION

In lactating cows, ewes, and goats originated from breeds located in temperate latitudes, exposure to an artificial long-day photoperiod increased milk production compared to females maintained under artificial or natural short-days photoperiod (Dahl *et al*., 2000; Bocquier *et al*., 1997; Delouis and Mirman, 1984). In small ruminants adapted or originated from subtropical latitudes, artificial long days are also effectiveness to increase milk production. In fact, ewes and goats exposes to an artificial long-day photoperiod during natural decreasing days of autumn, produced about 15 % more milk than those kept under naturally decreasing photoperiod (Morrisey *et al*., 2008; Flores *et al*., 2011). These results were obtained in well-nourished animals maintained indoors and milked twice daily. In this confined management conditions, the well-nourished animals exposed to the artificial long days photoperiod not only increased their milk production, but they also had elevated IGF-I plasma concentrations (Dahl *et al*., 1997). Therefore, it is thought that this growth factor mediate the effects of artificial long days on milk production (Prosser *et al*., 1990; Dahl *et al*., 1997). Indeed, plasma IGF-I concentrations were higher in heifers and lactating cows exposed to artificial long-days than kept under artificial short-days or natural decreasing day (Dahl *et al*., 2000; Spicer *et al*., 2007). Above suggest that a long-day photoperiod increases circulating concentrations of IGF-I, which in turn, stimulates milk production in mammary gland of lactating cows. At the present, the effectiveness of the long days treatment to increase milk production or IGF-I blood concentrations has not been investigated in goats maintained under extensive natural grazing conditions, where animals eat only the available natural vegetation without a nutritional supplementation.

In Northern Mexico (26° N) as in other subtropical latitudes as South Western Australia (29º S; Martin *et al*., 2004), most of goats are under natural grazing conditions eating only the available natural vegetation which depend mainly on rainfall. In this Mexican subtropical latitude, the non-raining or dry season lasts from December to May, provoking a dramatic decrease in natural food availability (Delgadillo, 2011). Importantly, about 80% of parturitions of goats from subtropical Mexico occur from November to February, during which the dry season coincide whit the more critic period of the year and in consequence a dramatic reduction availability of food in grazing areas. At this time, the rearing of kids and lactation of females take place, which causes a low rate in the survival of kids and a decrease in the milk production. Under these management conditions, it would be interesting to investigate whether artificial long-days treatment may increase milk production in goats that receive or not a nutritional supplementation from 30 day of lactation.

MATERIALS AND METHODS

Experimental design

Forty-four multiparous local goats maintained permanently under natural extensive grazing conditions were used. The phenotypic characteristics of these animals have been previously reported by Delgadillo *et al*. (2011). Goats were mated in May, using a male effect with sexually active males (Flores *et al*., 2000; Delgadillo *et al*., 2009). The mean date of parturition (± SEM) for all goats was October 9 ± 2.0 d. After parturition, all goats and their kids remained together during the first 15 d of lactation and were kept under natural photoperiod. From d 15, females were allocated into two groups balanced for initial milk yield and body condition. One group of goats was maintained under natural photoperiod conditions (n = 22), whereas other group of goats (n = 22) was continuously exposed to an artificial long-day photoperiod of 16 h of light and 8 h of darkness. Goats were maintained under natural grazing conditions, eating only the available natural vegetation. Animals graze daily from 0900 to 1800 h, and during the night they were sheltered in open pens. The available flora consisting mainly by grasses, buffel (*Cenchrus ciliare*), bermuda (*Cynodon dactylon*), Switchblade (*Bouteloua ssp.*), Johnson (*Sorghum halepense*), trees like mesquite (*Acacia farnesiana*) and huizache (*Prosopis granulosa*) and other native herbs and shrubs.

At d 30 of lactation, kids were weaned and thereafter dams were manually milked once a day. At this time, additional to grazing, half of the females (n = 11) from group maintained under natural photoperiod received daily a nutritional supplement composed of 300 g of rolled corn (12 % CP and 1.95 Mcal ME) and 200 g of soya bean (49 % CP) per animal (Supplemented control Group), whereas the other 11goats did not received any fed supplement (Non-Supplemented control Group). The treated goats with artificial long days were separated in the same way as goats maintained under natural photoperiod. Thus, half of the females (n = 11) received a nutritional supplementation (Supplemented treated Group) whereas the other 11 goats did not received the nutritional supplement (Non-supplemented treated Group).

Daily when the females of all groups returned from grazing (at 1800 h), they were separated and placed in their respective pens (10 x 5 m each one). Additionally, all females had free access to water and mineral salts, which were freely provided in 25-kg blocks (Cebú, Salinas del Rey, Torreón, Mexico) containing at least 17% P, 3% Mg, 5% Ca, and 75% NaCl, as recommended by NRC (2007).

Photoperiodic treatment. To provide the photoperiod of long days to the light-treated groups, pens were equipped with daylight type lamps that emitted a minimum luminous intensity of 400 lx at the eye level of the goats. Lights were on from 0600 to 0900 h and from 1700 to 2200 h to extend the duration of the natural day and obtain a total of 16 h light/d. A distance of 20 m separates the light-treated groups from natural photoperiod groups. Additionally, a curtain made of opaque material was placed around the light-treated pens to avoid any perception of light at night by the animals in the natural photoperiod groups.

The study was conducted on a commercial farm in the Laguna region, state of Coahuila, Mexico (latitude, 26° 23’ N; longitude, 104° 47’ W). In this region, variations of photoperiod range from 10 h 19 min of light at the winter solstice to 13 h 41 min at the summer solstice.

Measurements

Milk yield. During the suckling period, goats were not milked and milk yield was assessed using the method of weigh-suckle-weigh over a 24-h period (Ricordeau *et al*., 1960). The day before initiating the measurements at 1900 h, udder was empty by means of nursing and intravenous oxitocin (2 IU; Oxilac, Proquivet, Guadalajara, Mexico) application followed by hand-milking. The next day, 2 controlled nursing of 4 min each were performed, at 0700 and 1900 h. Moreover, after each nursing, exogenous oxytocin was injected into a jugular vein, followed by hand-milking to extract residual milk. The weight of the residual milk was added to the corresponding difference in the BW measurements of the kid.

During the milking period, all goats were hand-milked by the same person throughout the experiment. During this period (d 31 to d 110), milk yield was measured every 10 d. In each occasion, does were hand-milked at 0600 h (to empty the udder), the day before initiating each measurement. The next day, goats were hand-milked at 0600 h and the collected milk was weighed. Subsequently, OT (2 IU) was injected into a jugular vein of each female and the residual milk was extracted by hand-milking. This residual milk was weighed and added to the quantity obtained from the hand-milking.

Milk composition. In all goats, a sample of milk was collected each 10 days at the same time of milk yield determination (20 mL from each udder half) in plastic sterile tubes. Samples were kept on ice and transported to the laboratory for the determination of fat, protein, and lactose using a Milkoscan Expert Automatic 2964 (Scope Electric, Regensburg, Germany).

Plasma IGF-I concentrations. The plasma IGF-I concentrations were determined on eight females from each group at d 5, 25, 45, 65 and 85 after the onset of photoperiodic treatment. During this time, a blood sample (5 mL) were collected by jugular venipuncture in tubes containing sodium heparin (130 µL) and immediately placed on ice. Plasma was harvested by centrifugation at 2000 x *g* for 30 min and stored at -15° C until hormonal concentrations were measured in single samples using method of ELISA (Porstmann and

Kiessig, 1992). For they, it is used a kit from ALPCO (catalog number 22-IGFHU-E01) according to the manufacturer's protocol. Intra and interassay coefficients of variations were 5.8 and 5.0 % respectively.

BW and BCS. Body weight and BCS of all females were determined every 2 weeks from parturition up to the end of the experiment. Females were weighed on a mobile scale with a 200-kg capacity and a precision of 0.05 kg. The BCS was determined by palpating spinous and lateral processes, as well as the musculature, of the lumbar region of the spine, according to the method described previously by Walkden-Brown *et al*. (1997) and using a scale ranging from 1 (very lean) to 4 (fat) with a precision of 0.5.

Statistical analyses

Data from milk yield were analyzed using the MIXED MODELS procedure of SYSTAT 13 (Chicago, IL). The procedure included the fixed effects of the photoperiodic treatment (2 levels: natural and artificial, the error term being goat within treatment), nutritional treatment (2 levels: non supplemented and supplemented) and day of lactation their interactions, the random effects of goat and residual. The same statistic procedure was utilized for variables: components in milk (fat, protein and lactose), BW, BCS and IGF-I concentrations. The individual goat was the experimental unit. All dependent variables were included as repeated measures. Data were presented as means ± SEM, and the results were considered significant when $P \leq 0.05$.

The procedures used in the experiments reported here were in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

RESULTS

Milk yield

During the study, mean milk yield not was different between goats from non-supplemented treated group (0.92 kg/d) and goats from non-supplemented control group (0.78 kg/d; effect photoperiod; $P > 0.05$). However, when goats received a nutritional supplementation, mean milk production was greater supplemented treated group (1.1 kg/d) than supplemented control group (0.82 kg/d; interaction photoperiod x nutritional supplementation; $P < 0.001$). Moreover, mean milk production was greater in the goats that were supplemented than in goats that were non-supplemented (effect nutritional supplementation; $P < 0.001$: Table 1). The milk yield obtained in goats from the 4 groups was affected by time ($P < 0.001$; Figure1) and these variations were different between non-supplemented and supplemented groups as reveled by the supplement x time interaction, ($P < 0.001$). Finally, there was not interaction between photoperiod and time for milk yield ($P = 0.562$).

Milk composition

The mean percentages of fat, protein and lactose contents in milk were greater in control groups (supplemented or non-supplemented) than in treated groups (supplemented or non-supplemented; effect photoperiod; $P = 0.001$; Table 1). However, when goats were supplemented, only protein content in milk was greater in supplemented groups (control, 4.8 %; treated, 4.5 %) than in non-supplemented (control, 3.3 %; treated, 3.1 %: interaction photoperiod x nutritional supplementation; $P = 0.029$). Moreover, only the protein and lactose contents in milk were greater in supplemented groups (control or treated) than in non-supplemented groups (control or treated; protein, $P = 0.028$; lactose, P = 0.001).

Moreover, the fat, protein and lactose contents in milk had fluctuations over time of the study (P= 0.001) and these changes were different between groups maintained under natural photoperiod and those submitted to long days (photoperiod x time interaction, P = 0.01) and between supplemented and non-supplemented groups (supplementation x time, interaction, P = 0.001).

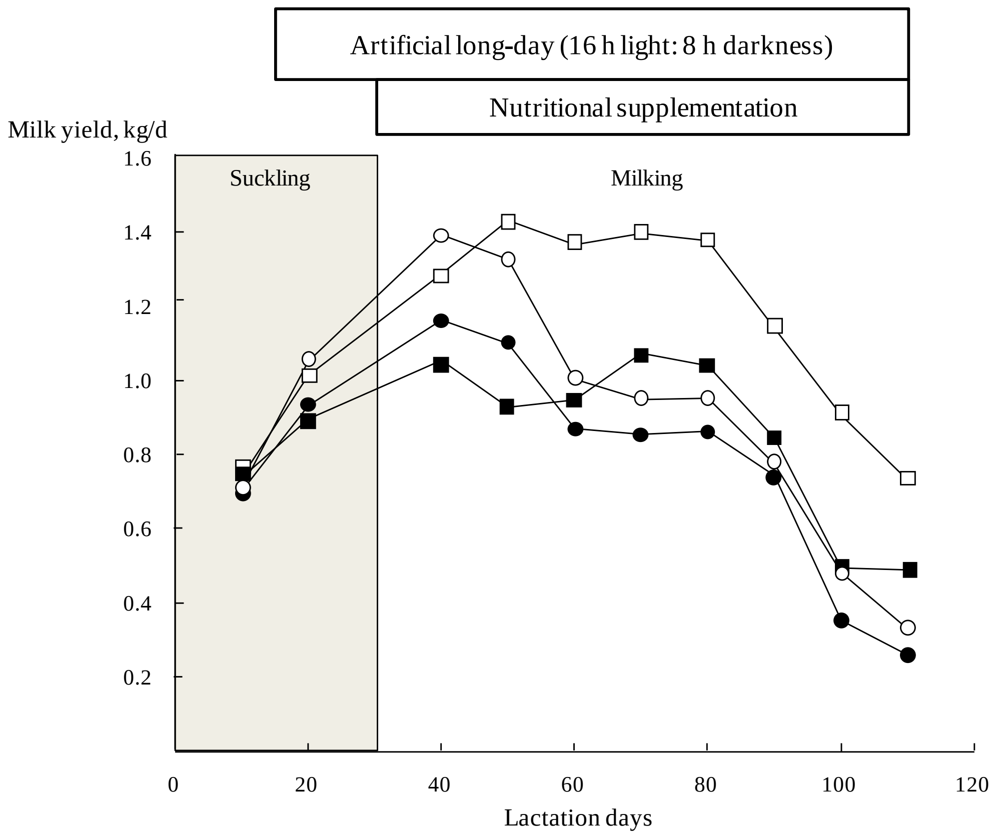

Figure 1. Effects of exposure to a long-day photoperiod starting on d 10 of lactation on mean daily milk yield of grazing goats (○, n = 12) and grazing goats receiving a nutritional supplement (□, n =11). Other 2 groups of grazing goats were maintained under natural photoperiod without nutritional supplementation (●, n = 11) or receiving a nutritional supplement (■, n = 11). The grey area represents the time when kids remained with its mother.

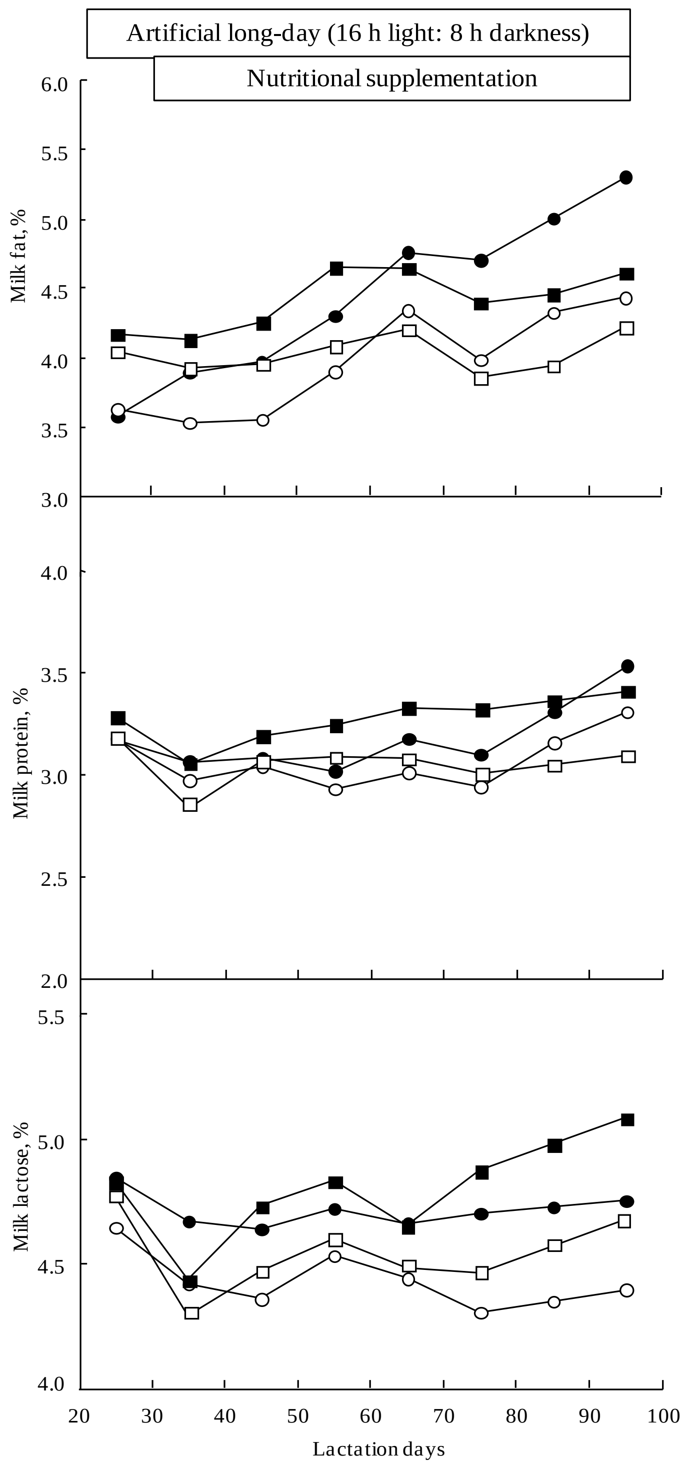

Figure 2. Effect of exposure to a long-day photoperiod starting on d 25 of lactation on mean percentages of fat, protein, and lactose contains in goats milk maintained under grazing (○, n =11) and of grazing goats receiving a nutritional supplement (□, n =11). Other 2 groups of grazing goats were maintained under natural photoperiod without to receive a nutritional supplement (●, n =11) and grazing goats receiving a nutritional supplement (■; n = 11).

Table 1. Data mean of milk yield and its components (fat, protein and lactose), BW and BCS and plasma IGF-I concentrations from goats submitted to an artificial long-day photoperiod and maintained only of grazing (group non-supplemented treated) and grazing goats receiving a nutritional supplement (group supplemented treated). Other 2 groups of grazing goats were maintained under natural photoperiod without to receive a nutritional supplement (group non-supplemented control) and grazing goats receiving a nutritional supplement (group supplemented control).

	Control		Treated		Probability		
Measurements	Non supplemented	Supplemented	Non supplemented	Supplemented	PP	S	PPXS
Milk yield, kg/d	0.78	0.82	0.92	1.1	0.001	0.001	0.005
Fat, %	4.4	4.4	4.0	4.0	0.001	0.740	0.266
Protein, %	3.3	4.8	3.1	4.5	0.001	0.028	0.029
Lactose, %	4.7	4.8	4.4	4.5	0.001	0.001	0.651
BW, kg	37.1	39.6	36.9	38.8	0.465	0.001	0.687
BCS	1.7	1.8	1.9	2.0	0.001	0.001	0.001
IGF-I, ng/mL	149.5	183.5	119.8	263.8	0.001	0.001	0.001

PP= Photoperiod effect; S= nutritional supplementation effect; PPXS= Interaction between photoperiod and nutritional supplementation.
BCS scale ranged from 1 (very lean) to 4 (fat).

Plasma IGF-I concentrations

The mean plasma IGF-I concentrations were greater in non-supplemented control group (149.5 ng/mL) than in non-supplemented treated group (119.8 ng/mL; photoperiod effect; P = 0.001; Table1). However, when goats received a nutritional supplementation, plasma IGF-I concentrations were greater in supplemented treated group (263. 8 ng/mL) than in supplemented control group (183.5 ng/mL; photoperiod effect, P = 0.001 and an interaction photoperiod x nutritional supplementation; P = 0.005). The plasma IGF-I concentrations were greater in supplemented groups than in non-supplemented groups independently of photoperiod (effect of supplementation; P = 0.001). On the other hand, plasma IGF-I concentrations of goats from the four groups had fluctuations through study (P = 0.001) and these fluctuations were different between non-supplemented groups and supplemented, resulting in an (interaction supplementation x time, $P = 0.001$). No interaction was detected ($P = 0.156$) between photoperiod and time for IGF-I concentrations.

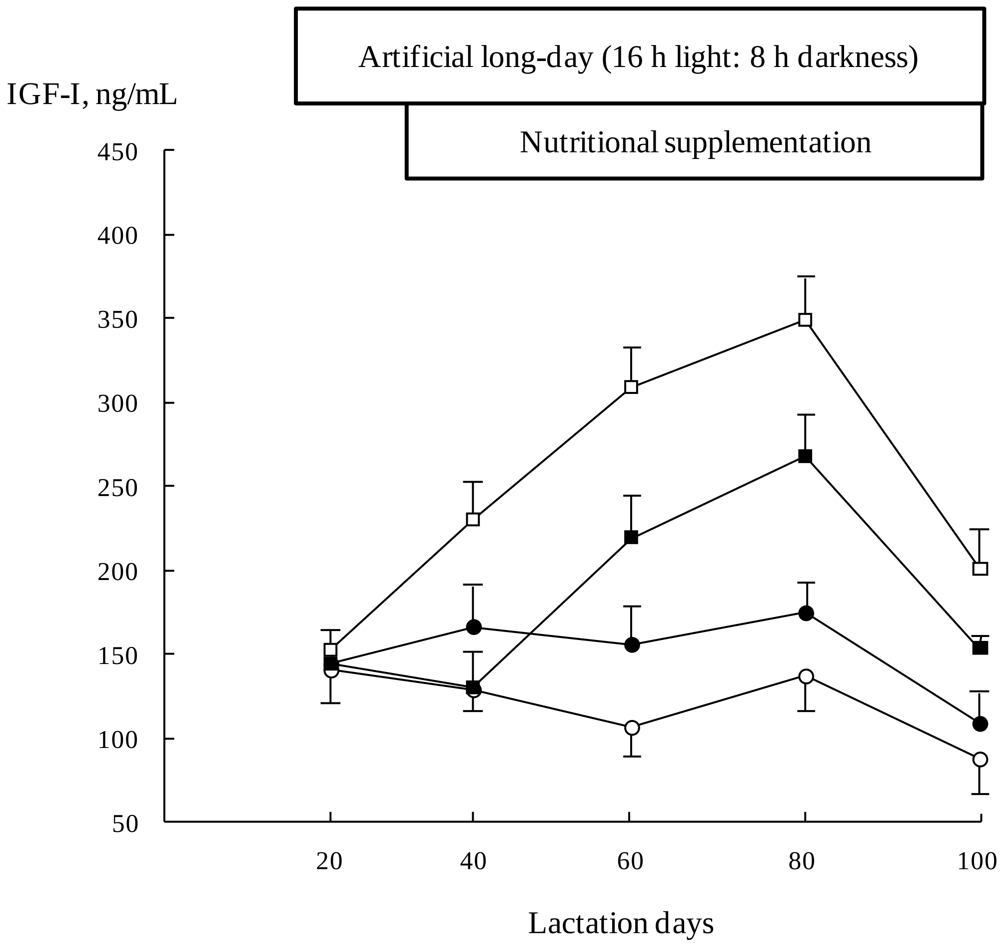

Figure 3. Effect of exposure to a long-day photoperiod starting on d 20 of lactation on mean (± SEM) IGF-I plasma concentrations from goats maintained only of grazing (○, n = 8) and grazing goats receiving a nutritional supplement (□, n = 8). Other 2 groups of grazing goats were maintained under natural photoperiod without to receive a nutritional supplement (●, n =11) and grazing goats receiving a nutritional supplement (■; n = 11).

BW and BCS

During the experimental period, BW was not affected neither by photoperiodic treatment nor by the time of the study ($P = 0.465$ and $P = 0.948$, respectively; Table 1). Moreover, an interaction between photoperiod or nutritional supplementation with time was not detected (*P* > 0.997 and *P* > 0.0.321, respectively). In goats maintained under natural or artificial long days, nutritional supplementation increased BW by 2.5 and 2.7 kg relative to non-supplemented groups, maintained under natural or artificial photoperiod, respectively.

BCS was affected by photoperiodic treatment being greater for groups exposed to long days than for groups maintained under natural photoperiod (*P* = 0.001; Table 1). Also, nutritional supplementation had an effect on BCS, being greater in supplemented groups than in non-supplemented groups (*P* = 0.001). Moreover, an interaction between photoperiod and nutritional supplementation was detected for this variable (*P* < 0.002). Thus, in general way, BCS was greater in supplemented groups than in non- supplemented and at the same time this variable was greater in goats submitted to artificial long days than goats maintained under natural photoperiod (Table 1). In the 4 groups BCS had fluctuations over time of the study (*P* = 0.001) and these changes were different between supplemented and non supplemented groups. In fact, an interaction between supplementation and time of the study (*P* = 0.001) was found. No interaction between photoperiod and time was detected for BCS (*P* = 0.562).

DISCUSSION

The results obtained in the present study shows that in lactating goats maintained under extensive grazing conditions exposure to artificial long days increases milk production and the plasma IGF-I circulating concentrations only if females received a nutritional supplementation.

In the present study where goats had only access to the natural vegetation without to receive a nutritional supplementation, the artificial long-days treatment increased milk production although their effect was observed by short time. However, when these treated goats received a nutritional supplementation the milk production increased even more and interestingly, this increase in milk yield was sustained by more than 90 days of lactation. This finding shows for the first time that the stimulatory effect of a long-day photoperiod on milk yield in goats fed under extensive grazing conditions occurs whenever females receive a nutritional supplementation. This result agree with previous studies reported in cows, ewes and goats maintained under constant nutrition, which artificial long days increased milk production than females under natural photoperiod (Dahl *et al*., 2000; Morrisey *et al*., 2008; Flores *et al*., 2011). In subtropical Mexico, as in other subtropical latitudes, most of the goat herds are managed extensively, fed with native grasslands and occasionally with crops waste. Indeed, a dry period runs from the end of autumn to the end of spring, causing a reduction in the amount and quality of the available feed in the areas grazed by the animals (Delgadillo *et al*., 2011). Therefore, during this dry period, the amount of protein and metabolic energy intake is insufficient to meet the minimum nutritional requirements of goats (Juarez *et al*., 2004). Under these feeding conditions, was not possible to observe the galactopoietic effect of the artificial long days on milk production such as was recently reported in well nourished lactating subtropical goats (Flores *et al*., 2011). On this way, a nutritional supplementation was necessary to increase the nutrients required for lactation. Nevertheless, the nutritional treatment by itself in females kept in natural days was not as effective as it was in females exposed to artificial long days. Thus, in goats maintained under natural photoperiod the nutritional supplementation increased milk production only on average 40 g of milk/d, whereas in goats submitted to long days, the increase was four times greater. This difference in response of milk yield due to the nutritional supplementation, leads us to thought that goats subjected to long days are more efficient to transform nutrients in milk than goats maintained under natural photoperiod. This interpretation agrees with results previously reported in the dairy cows in which females submitted to a long-day photoperiod tended to be more efficient in use of nutrients for milk yield than females maintained under natural photoperiod (Dahl *et al*., 2000). In our goats, it is probable that long-day photoperiod acts as reported in the sheep on the partition of nutrients toward mammary gland than to body reserves (Bocquier *et al*., 1986).

In the current study, the plasma IGF-I circulating concentrations were greater in goats submitted to long days than in goats maintained under natural photoperiod only if females received a nutritional supplementation. Data from plasma IGF-I obtained in this study, confirm two findings previously reported. First, this result agrees with previously reported in dairy cows, in which the plasma IGF-I concentrations were greater in cows submitted to long days than cows maintained under natural photoperiod (Dahl *et al*., 1997). Second, low plasma IGF-I circulating concentrations observed in non-supplemented goats confirms that the nutritional status at which goats were submitted affects the IGF-I circulating levels, such as it has been observed in other ruminants (ewe, Hodgkinson *et al*., 1987; heifers, Lacasse *et al*., 1994). In the current study, was unexpected to found that in non-supplemented goats, the plasma IGF-I circulating concentrations were lower in goats submitted to long days than in females maintained under natural photoperiod. The precise mechanism by which photoperiod decreases the IGF-concentrations in these non-supplemented goats is unknown. However, it is well known that at the onset of lactation in goats as in cows, the females go into a state of negative energy balance due to the rising demand of energy for milk production (Dunshea and Bell, 1990). In our study, despite to have the same feeding conditions, non supplemented goats submitted to long days did lose more weight (52 g/d) than goats maintained under natural photoperiod (30 g/d). It is possible that these considerable weight loses in non supplemented goats provoke a negative energy balance, which is characterized by reduced blood glucose and insulin concentrations and elevated blood GH concentrations (Butler *et al*., 2003). In cows, it has been demonstrated that the liver is refractory to GH during negative energy balance and this uncoupling of the GH-IGF-I axis results in diminished plasma concentrations of IGF-I (Vicini *et al*., 1991). Therefore in our study, this decrease in BW are possibly associated to the low plasma IGF-I circulating concentration found in non supplemented goats exposed to the long days.

Independently of nutritional supplementation, fat, protein and lactose contents in milk were lower in goats submitted to artificial long days than in goats maintained under natural photoperiod. These results differ from recently reported in goats from these same latitudes (Flores *et al*., 2011), in which the fat, protein and lactose contents in milk were not modified by artificial long-day photoperiod. This difference was possibly due to the type of farming system (Morand-Fehr et al., 2007). In fact, in our previous study (Flores *et al*., 2011), goats were fed under constant nutrition regimen and photoperiod does not affected milk components, whereas in the Figure 2 of the present work it is clear that in a general way photoperiod reduced the milk components independently if the animals were supplemented or not. Our results agree with results obtained in lactating goats and in others ruminants which long-day photoperiod reduces various milk components. For example, in goats Garcia-Hernandez *et al*. (2007) reported a decrease only for fat content. In cows, Stanisiewski *et al*., (1985) found a slight reduction in the percentage of milk fat during exposure to long days. Similarly, in ewes protein content in milk was reduced when they were under long days compared with short days (Bocquier *et al*., 1990). As a whole, our results and these from literature show that under some conditions exposure to the artificial long-day photoperiod can modify the milk components.

From the results obtained in the present study it is concluded that in subtropical lactating goats maintained under extensive grazing conditions exposure to an artificial long-day photoperiod increases milk yield and plasma IGF-I circulating concentrations only if females received a nutritional supplementation.

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Artículo 3

Long-day photoperiod exposure in lactating goats induces the postpartum ovulatory activity through the establishment of a refractory state. Small Rumin. Res. (submitted)

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Abstract: The present study investigated whether the continuous application of an artificial long-day photoperiod in goats giving birth in autumn induces the establishment of a refractory state and thus, the recovery of the post-partum ovulatory activity. For this purpose, one group of does was kept during the entire study under a natural photoperiod characteristic from autumn (Control; n=16), whereas the other group was submitted to an artificial long-day photoperiod (16 h light: 8 h darkness: Experimental; n=16) from day 10 to 158 of lactation. Over the first 96 days post-partum, the cumulative proportion of does that had ovulation was not different amongst the treatments ($P > 0.05$). However, from day 108 to 156 post-partum, the cumulative proportion of does that had ovulation was greater ($P < 0.01$) in the experimental group (11/16, 69%) than in the control group (2/16, 12.5%). Additionally, does from the experimental group produced an average 15% more milk than does from the control group ($P < 0.001$). The body weight and body condition were not affected by the photoperiodic treatment ($P > 0.05$). It is concluded that for subtropical lactating does kidding in autumn, the continuous exposure to an artificial long-day photoperiod induces the post-partum ovulatory activity after 150 days of exposition, probably due to the establishment of a refractory state by the continuous exposure to the artificial long days. Additionally, this photoperiodic treatment also increased the milk production level.

Long-day photoperiod exposure in lactating goats induces the postpartum ovulatory activity through the establishment of a refractory state

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ABSTRACT

The present study investigated whether the continuous application of an artificial long-day photoperiod in goats giving birth in autumn induces the establishment of a refractory state and thus, the recovery of the postpartum ovulatory activity. For this purpose, one group of does was kept during the entire study under a natural photoperiod characteristic from autumn (Control; n=16), whereas the other group was submitted to an artificial long-day photoperiod (16 h light: 8 h darkness: Experimental; n=16) from day 10 to 158 of lactation. Over the first 96 days post-partum, the cumulative proportion of does that had ovulation was not different amongst the treatments ($P > 0.05$). However, from day 108 to 156 postpartum, the cumulative proportion of does that had ovulation was greater ($P < 0.01$) in the experimental group (11/16, 69%) than in the control group (2/16, 12.5%). Additionally, does from the experimental group produced an average 15% more milk than does from the control group ($P < 0.001$). The body weight and body condition were not affected by the photoperiodic treatment ($P > 0.05$). It is concluded that for subtropical lactating does kidding in autumn, the continuous exposure to an artificial long-day photoperiod induces the post-partum ovulatory activity after 150 days of exposition, probably due to the establishment of a refractory state by the continuous exposure to the artificial long days. Additionally, this photoperiodic treatment also increased the milk production level.

Keywords: goat, photoperiod, post-partum anovulation, milk production, body condition.

1. Introduction

The post-partum anovulation period (AVPP) is the period that takes place between the parturition and the first postpartum ovulation. In breeds of sheep and goats that display a reproductive seasonality, the AVPP depends on the season of parturitions. In these seasonal breeds, the AVPP is shorter when the females gave birth close to or during the natural breeding season than those kidding at the end or mid-anestrous (Santiago-Moreno *et al*., 2000). Similarly, in the local female goat from subtropical México, the length of the AVPP was also dramatically modified by the season of parturition. Thus, the AVPP period was longer when the females kidded in January (about 200 days) than in those kidding in May (about 100 days) or in October (about 50 days; Delgadillo *et al*., 1998). In this breed, the annual reproductive activity of female goats is controlled by photoperiod (Duarte *et al*., 2010; Delgadillo *et al*., 2011). Indeed, under artificial conditions, short days stimulate the ovarian activity, while long days inhibit it (Duarte *et al*., 2010). However, when non-lactating females are submitted continuously to artificial long days, they became refractory to this inhibitory photoperiod. Consequently, the ovulatory or endocrine activities start between 150 to 200 days from the onset of the long-day signal (Malpaux *et al*., 1988; Maeda *et al*., 1988).

Another factor that modifies the length of the AVPP in females is the milk production level. The AVPP is longer in high-producing than in low-producing dairy females (cows: Butler, 2003; ewes: Pollot and Gootwine, 2004; goats: Freitas *et al*., 2004).

Long-day photoperiod can also modulate the milk production level in ruminants. For instance, ewes and goats from temperate and subtropical latitudes, an artificial long-day photoperiod increased the milk production by 25% and 18%, respectively (Bocquier *et al*., 1997; Flores *et al*., 2011). However, in these lactating females exposed to the artificial long-day treatment during the first 75 days of lactation induced a complete inhibition in their post-partum ovulatory activity (Bocquier *et al*., 1993; Hernández *et al*., 2006). One probable explanation of this result could be that the long-day photoperiod inhibited the recovery of the ovulatory activity, as mentioned in the non lactating goats (Duarte *et al*., 2010). Another probable explanation could be that the lactating goats could require an exposition to a long photoperiod for more than 75 days to express their refractoriness to long days and thus to initiate their post-partum ovulatory activity. The possible existence of an interaction between lactation and the long-day photoperiod exposition is not excluded. Indeed, long days increase the milk production, and it in turn could inhibit the recovery of the post-partum ovulatory activity. Therefore, the present study investigated whether the continuous application to an artificial long-day photoperiod in goats giving birth in autumn induces the establishment of a refractory state and thus, the recovery of the post-partum ovulatory activity. For this purpose, a group of goats kidding in autumn was submitted continuously to artificial long days and another group of goats was maintained under a natural photoperiod.

2. Materials and Methods

2.1Location

The present study was carried out in the Region Laguna in the state of Coahuila, Mexico (Latitude, 26° 23’ N; Longitude, 104° 47’ W). In this region, the photoperiod varied from

10 h 19 min of light in the winter solstice to 13 h 41 min in the summer solstice (Delgadillo *et al*., 1999).

2.2 Animals and management conditions

Thirty-two Creole goats obtained from a commercial flock of 100 animals were used in the present experiment. The phenotypic characteristics of these animals have been previously reported by Delgadillo *et al*. (1999). In females, isolated from the male goats, the ovulatory activity starts in September and finishes in February, whereas a period of anovulation is observed from March to August (Duarte *et al*., 2008). To obtain parturitions during the autumn season, the anovulatory goats were exposed to the sexually active males in June to stimulate ovulations by the so-called male effect (Delgadillo *et al*., 2002; Bedos *et al*., 2010). The mean date of parturition (± SEM) for all the goats was November 8 ± 2 days and the prolificacy (mean number of kids/female) was 1.8 ± 0.1. Goats were fed 4.0 kg of sorghum silage/goat daily (2.17 Mcal ME/kg DM; 9.4% CP) and 1.0 kg/goat of a commercial concentrate containing 14% CP. Goats had free access to water and mineral salts, which were provided in 25-kg blocks (Cebú, Salinas del Rey, Torreón, México) containing at least 17% P, 3% Mg, 5% Ca, and 75% NaCl, as recommended by NRC (2007).

2.3 Experimental groups

During the first 9 post-partum days, all the females and their kids were kept under the natural photoperiod and from day 10 post-partum, the goats were divided in two homogeneous groups, in accordance with their milk production, body condition and prolificacy (Table 1). The control group (n=16) was kept under the natural photoperiod variations and at day 28 post-partum, kids were weaning and all the goats were milked manually twice a day (0700 h and 1900 h up to day 140 of lactation). The experimental group (n=16) was exposed from day 10 post-partum to an artificial long day photoperiod (16 h light: 8 h darkness) and submitted to the same milking regimen like the control group. To provide the photoperiod of long days to the light-treated group, the open shaded pen was equipped with daylight-type lamps that emitted a minimum luminous intensity of 400 lx measured at the eye level of the goats. Lights were on from 0600 h to 0900 h and from 1700 h to 2200 h, to extend the duration of the natural day-length and obtain a total of 16 h light/d. In addition to the distance of 75 m separating the control and light-treated pens, a curtain made of an opaque material was placed around the light-treated pens to avoid any perception of light at night by the control females from the natural photoperiod group.

Table 1 Initial measurements (mean ± SEM) considered in the goats to conform the (control) natural photoperiod and (experimental) long day photoperiod groups.

Groups	n	Milk (kg)	Kids/female	BCS[1]	BW (kg)
Control	16	2.2 ± 0.2	1.7	1.6 ± 0.1	48.5 ± 2.6
Experimental	16	2.2 ± 0.2	1.7	1.7 ± 0.1	49.8 ± 2.3

[1] BCS scale ranged from 1 (very lean) to 4 (fat).

2.4 Measurements

2.4.1 Post-partum ovulatory activity

In both groups, the post-partum ovulatory activity was determined at day 12 post partum and thereafter each 12 days up to day 154 post-partum. For this end, the transrectal ultrasonography was used (Ginther and Kot, 1994). A goat was considered to have initiated her post-partum ovulatory activity when at least one corpus luteum was observed on one of the two ovaries.

2.4.2 Milk production

The milk production was measured at day 7, 30, 60, 90, 120 and 150 of lactation. During the first 2 measures the milk production was assessed using the method of weigh-suckle-weigh over a 24-h period (Ricordeau *et al*., 1960). Subsequently, the milk production was measured by means of hand-milking realized twice a day. For this purpose, a first emptying of the udder was performed at 1900 the day before initiating each measurement, followed by two hand-milking at 12-h intervals (at 0700 and 1900) the next day. After each hand-milking, oxytocin (2 IU) was injected into the jugular veins of all the females in order to extract the residual milk. This milk was weighed and added to the amount previously obtained from hand-milking.

2.4.3 Body weight (BW) and body condition score (BCS)

Body Weight and BCS of all the females were determined every 2 wk up to 158 days post-partum. Females were weighed on a mobile scale with a 200-kg capacity and a precision of 0.05 kg. BCS was determined by palpating the spinous and lateral processes, as well as the musculature of the lumbar region of the spine, according to the method previously described by Walkden-Brown *et al*. (1997), which considered a scale ranging from 1 (very lean) to 4 (fat) with a precision of 0.5.

3. Statistical Analyses

The cumulative percentage of does showing ovulation was compared using the Kolmogorv-Smirnov test. The milk production, BW and the BCS were analyzed using a two-way analysis of variance (ANOVA) with repeated measurements (time and group as within-and between-factors, respectively). The data from milk production, BW and BCS were presented as mean ± SEM. and the results were considered significant when $P \leq 0.05$. Analyses were computed using the statistical package SYSTAT 13.

The procedures used in the experiments reported here were in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

4. Results

4.1Post partum ovulatory activity

The proportion of goats that ovulated during the first 96 days post-partum was not different between the control and experimental groups ($P > 0.05$). However, from day 108 to day 156 post-partum, the proportion of does that ovulated was greater in the experimental group than in the control group ($P < 0.01$; Figure 1).

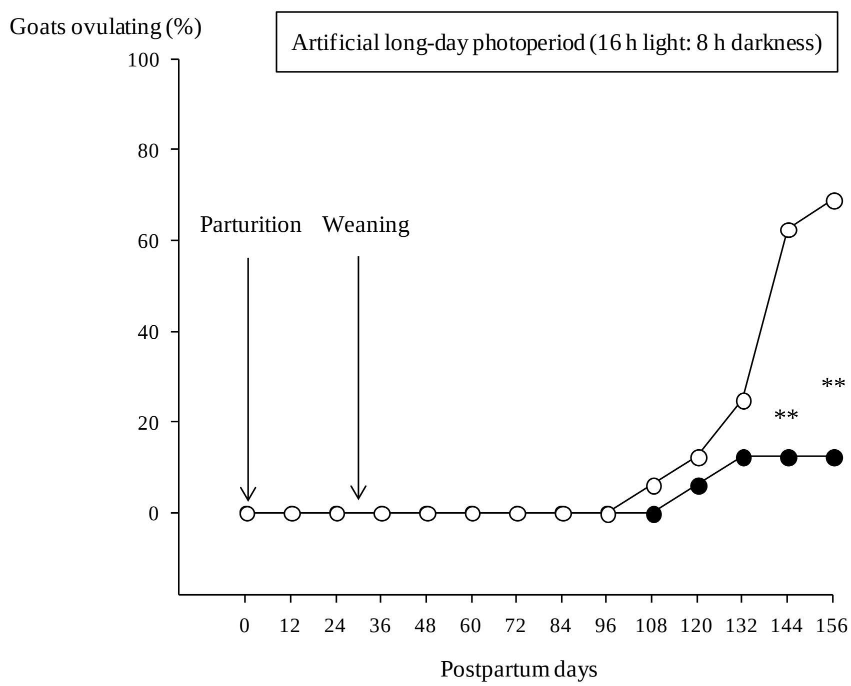

Figure 1 Cumulative percentage of lactating goats that ovulated during first 156 days postpartum. Does group maintained under natural photoperiod (control; n=16 ●) or submitted to an artificial long-day photoperiod (experimental; n=16 ○). Significant differences between treatments (photoperiod) at each time point are indicated by an asterisk (**$P < 0.01$).

4.2 Milk production.

The mean daily milk production obtained during the first 30 days of lactation was not different between the groups ($P > 0.05$; Figure 2). However, after the kids were weaned there was a main effect of photoperiod ($P < 0.001$), as well as an effect of the time of experiment (week effect; $P < 0.001$), resulting in a significant interaction between the photoperiod and the week on the milk production ($P < 0.001$). In does from the experimental group, milk production was greater than in goats from the control group in the measures made at day 60 and 90 of lactation. Subsequently, any difference was found between the groups until the end of the present study.

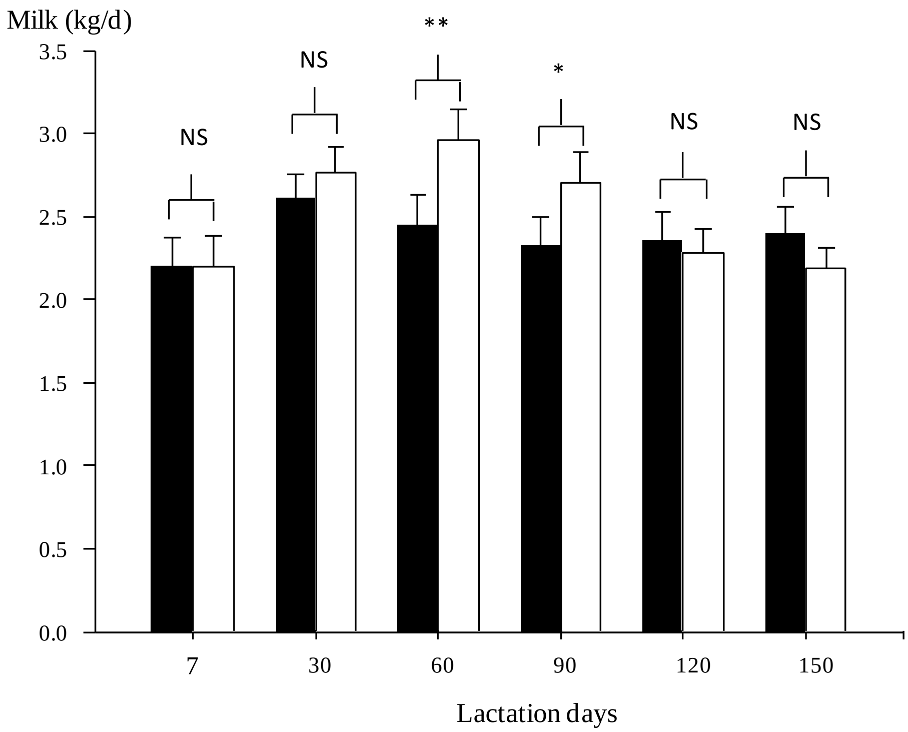

Figure 2 Mean (± SEM) daily milk production of does maintained under natural photoperiod (control; n=16 ●) or submitted to an artificial long-day photoperiod (experimental; n=16 ○). Mean daily milk yield after weaning of the kids was greater ($P = 0.002$) in experimental group than in control group. Significant differences between treatments (photoperiod) at each time point are indicated by an asterisk (*$P < 0.05$ and **$P < 0.01$).

4.3 BW and BCS

Body weight and BCS varied across the time of the study (P <0.001), but these variations were not affected by the photoperiod treatment (P >0.05). No interaction between time of the experiment and the photoperiodic treatment was found for these two variables (Table 2).

Table 2 Changes in BW and BCS (mean ± SEM) during the first 158 days postpartum in female goats maintained in a natural photoperiod (control; n=16) or submitted to an artificial long-day photoperiod (experimental; n=16).

			Postpartum days			
Groups	**Measurement**	**Parturition**	**35**	**100**	**158**	***P*–value**[1]
Control	BW (kg)	48.5 ± 2.7	46.3 ± 2.4[a]	47.8 ± 2.2[b]	49.3 ± 2.1[bc]	0.001
	BCS[2]	1.7 ± 0.10	1.6 ± 0.04[a]	1.9 ± 0.06[b]	2.2 ± 0.10[c]	0.001
Experimental	BW (kg)	49.8 ± 2.4	48.1 ± 2.2[a]	49.4 ± 2.0b	51.2 ± 2.1[c]	0.001
	BCS	1.7 ± 0.10	1.7 ± 0.10[a]	1.9 ± 0.06[b]	2.4 ± 0.10[c]	0.001

[1]*P*-value refers to time
[a, b, c] Within a same row, means without a common superscript letter differ (P < 0.05).
[2] BCS scale ranged from 1 (very lean) to 4 (fat).

5. Discussion

The obtained results show that in subtropical does kidding in autumn, the continuous exposure to an artificial long-day photoperiod exerts considerable effects on the post-partum physiology. On one hand, most (69%) of the experimental goats initiate their post-partum ovulatory activity after 150 days of exposition, probably by the establishment of a refractory state due to the continuous exposure to artificial long days. On the other hand, the photoperiodic treatment induces an increase in the milk production level.

The high proportion of does that had ovulated after about 150 days of light exposure in the experimental group in comparison to the controls was probably due to the expression of a refractory state to continuous perception of artificial long days. In the ovariectomized sheep and goats, the onset of the breeding season assessed by the ovulatory activity or LH secretion is due to the establishment of refractoriness to natural long days and not to the reduction in the day-length after the summer solstice (Robinson *et al*., 1985; Robinson and Karsh, 1988; Gebbie *et al*., 1999; Delgadillo *et al*., 2011). However, in all these studies, females were submitted to artificial long days initiating at the onset of summer solstice, and the refractoriness occurs after 90 days after light exposure. By the contrary, when non lactating ovariectomized females previously were under an artificial short-day photoperiod, they become refractory to long days after 150-200 days of exposure (Malpaux *et al*., 1988; Maeda *et al*., 1988). In the present experiment, the lactating does showed a refractory state to long days after 150 days of exposure, when a high proportion of females ovulated. Also, in our study does were under natural decreasing days before they were exposed to long days and therefore, the refractoriness to this photoperiod occurs at the same time that in previous studies (Malpaux *et al*., 1988; Maeda *et al*., 1988).

Interestingly, the onset of the ovulatory activity occurred in April during the natural anestrous season (Duarte *et al*., 2008), after 5 months of lactation. This interval parturition-onset of ovulations gives the opportunity to breed females to have parturitions out of the natural parturition season. The obtained results showed that the lactating state of the goats does not affect the establishment of refractoriness to the long days in females, which kidded in autumn.

Ovarian inactivity observed during the first 75 days post-partum in the control group differed from that reported in ewes and goats by Bocquier *et al*. (1993) and Hernández *et al*. (2006), respectively. Thus, in these studies, 81% and 90% of females under artificial and natural short days had ovulated at 60 and 75 days post-partum, respectively. By the contrast, in the present study no female from control group had an ovulation during this time, only 12% of the does have ovulation at the end the study. This difference could be explained by two facts. First, milk production level observed in the goats of the present study was higher than the reported in the goats of the study of Hernández *et al*. (2006). It is likely that high milk production produced by females may have an effect on ovulation in does control. For example, Freitas *et al*. (2004) found that milk selected breeds had longer post-partum intervals (as Saanen) than non-milk selected breeds (as Anglo-Nubian). Second, is probable that elevated nutritional requirements for this high milk production in control goats reduces the corporal reserves and thus come into a negative energetic balance that delayed the postpartum ovulation. This same effect has been widely studied in dairy cows (Butler and Smith, 1989).

The milk production was greater in the photoperiod-treated females than in those kept under natural photoperiod variations. The increase of milk production obtained in the group of does submitted to an artificial long-day photoperiod confirms the previous results and agrees with those described in sheep, cows and goats. Indeed, in these species, females under an artificial long-day photoperiod produce more milk than females under natural or artificial short days (10%,15% and 18%, respectively; Dahl *et al*., 2008; Morrisey *et al*., 2008; Flores *et al*., 2011). In the present study, the high proportion of female goats that ovulated as well as the milk production appears to be independent of the animal BW or BCS since these variables were not modified by the photoperiodic treatment.

6. Conclusion

The obtained results show that for subtropical lactating does kidding in autumn, the continuous exposure to an artificial long-day photoperiod exerts considerable effects on post-partum physiology. On one hand, this photoperiodic treatment induces the post-partum ovulatory activity after 150 days of exposition, probably by the establishment of a refractory state due a continuous exposure to the artificial long days. On the other hand, the photoperiodic treatment induces an increase in the milk production level.

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Artículo 4

Artificial long days in the subtropics increases body weight at weaning and blood glucose concentrations of goat kids to be born in the autumn

Artificial long days in the subtropics increases body weight at weaning and blood glucose concentrations of goat kids to be born in the autumn

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Abstract

To determine whether exposure to artificial long-days in the subtropics increases body weight at weaning of goats kids born in autumn, sixty-six goat kids were allocated to one of following four treatments. A first group of goat kids, was maintained under natural photoperiod and remained daily suckling with their mothers from 18:00 h to 9:00 h (natural control group; n=17). A second group of goat kids, was reared as the first one, but it group was submitted to an artificial long-day photoperiod (16 h light; 8 h darkness; natural treated group n=19). In the third group of goat kids, they were under natural photoperiod and were weaned from their mothers at d 4 of age. Goat kids were fed artificially using the natural milk (artificial control group n=15). Finally, a fourth group of goat kids was reared as the third one, but it group was submitted to an artificial long-day photoperiod (artificial treated group; n=15). Body weight of all kids was determined twice a week, from birth up to d 28. Milk composition (fat, protein and lactose) ingested by kids was assessed at d 10, 15 and 20 of the study. The blood glucose concentrations were determine on 14 kids from each

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experimental group at d 6, 10, 13, 17, 20, 24 and 27 of study. At weaning, an effect of photoperiod on mean body weight was found (P< 0.01), thus, this weight was greater in the treated groups (artificial, 6.9 ± 0.2 kg and natural, 8.2 ± 0.2 kg) than in the control groups (artificial, 6.2 ± 0.2 kg and natural, 7.6 ± 0.3 kg). Average daily weight gain was greater (P<0.01) in groups treated with light (artificial, 137 g/d and natural, 182 g /d) than in controls (artificial, 116 g/d and natural 160 g/d). Fat, protein and lactose contents in milk ingested by kids did not differ between four groups of study. Blood, glucose concentrations were greater (P<0.001) in the treated groups with natural (98.9 ± 2.1 mg/dL) or artificial (105.1± 2.3 mg/dL) suckling than in the control groups with (93.4 ± 1.9, natural and 89.6 ± 2.7 mg /dL, artificial suckling). The results obtained in the present study shows that goat kids exposed to an artificial long-day photoperiod gained more weight at the weaning than kids maintained under natural photoperiod independently if the kids are fed under natural or artificial suckling.

Introduction

In ewes and cows, it is well documented that increasing daily light exposure from 8 to 16 h increases average daily weight gain (Tucker *et al*., 1984). In cows for instance, average daily weight gain is greater in heifers exposed to long days (980 g/d) than those maintained under natural photoperiod (840 g/d; Peters *et al*., 1980). Similarly in lambs, average daily weight gain was greater in lambs submitted to an artificial long-days photoperiod (260 g/d), than in the lambs maintained under artificial short days photoperiod (157 g/d; Forbes *et al*., 1975). In these previous experiments, animals were fed ad libitum a high plane of nutrition during peripubertal period (Forbes *et al*., 1979; Petitclerc *et al*., 1983). Currently, in goats, there are few studies that investigate the effect of the exposure to a long-day photoperiod on daily weight gain of offspring during suckling phase. A study by Mejía (2007) was conducted when goat kids were born during autumn (decreasing days) and were nursed by their mothers until the first month postpartum. In their study, goat kids exposed together with its mothers to artificial long days had greater weaning weight than goat kids under natural days. However, from this study it was not clear if the long days had a direct effect on the kid's weight or if it was due by the increased milk yield of their mothers. Therefore, we hypothesized that artificial long days increase the weight of the goat kids at weaning when born in autumn independently if they are reared or not by its mother. The objectives of the present experiment were to determine whether exposure of goat kids born in autumn to artificial long days alters their weight at weaning when they are reared or not by its mother.

Materials and Methods

Location

The procedures used in this experiment were in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

The present study was carried out in Region Laguna in the state of Coahuila, Mexico (Latitude, 26° 23' N; Longitude, 104° 47' W). In this region, the photoperiod varied from 10 h 19 min of light in the winter solstice to 13 h 41 min in the summer solstice (Delgadillo *et al*., 1999).

General conditions of the study

Sixty-six Creole goat kids obtained from a commercial flock of 150 animals were used in the present experiment. The phenotypic characteristics of these animals have been previously reported by Delgadillo *et al*. (1999). To obtain parturitions during the autumn season, the goats were exposed to the sexually active males in June to stimulate ovulations by the so-called male effect (Delgadillo *et al*., 2002; Bedos *et al*., 2010). The mean date of birth (± SEM) for all the kids was on September 30 ± 0.3 days. The females were kept daily under extensive grazing conditions between 10:00 and 18:00 h. At night, they were housed in open pens, where had free access to water and mineral salts, which were provided in 25-kg blocks (Cebú, Salinas del Rey, Torreón, México) containing at least 17% P, 3% Mg, 5% Ca, and 75% NaCl, as recommended by NRC (2007).

Experimental design

During the first 3 days of age, 66 kids were nursed by their mothers and maintained under natural photoperiod conditions. On fourth day of age, kids were allocated to one of four treatments, balanced for birth date, birth weight, and sex (Table 1). A first group of goat kids, was daily nursed by its mothers from 18:00 h to 9:00 h and maintained under natural photoperiod (natural control group; n=17). A second group of goat kids was managed as the first group but the kids were exposed to artificial long days(natural treated group n=19).In the third group, the goat kids, were weaned from their mothers at d 4 of age and fed artificially using natural milk. In this group, goat kids were maintained under natural photoperiod (artificial control group n=15). Finally, a fourth group of kids was managed as the third group but the kids were exposed to artificial long days (artificial treated group; n=15).

Table 1. Initial measurements (mean ± SEM) considered in the kids to conform the four experimental groups.

Groups	n	Sex		Body weight at birth (kg)	Birth date
		M	F		
Natural control	17	12	5	3.1 ± 0.1	Sep-29 ± 0.4 days
Natural treated	19	12	7	3.1 ± 0.1	Oct-01 ± 0.4 days
Artificial control	15	7	8	3.0 ± 0.1	Sep-30 ± 0.3 days
Artificial treated	15	8	7	3.0 ± 0.3	Sep-29 ± 0.3 days

M= male; F= female

Artificial suckling. From d 4 to 28 of age, kids from artificial control and artificial treated groups were fed twice daily (0700 and 1900 h), using the milk obtained from the others females that were not included in the study. Daily, milk was provided in a graduated plastic container (capacity 10 L) equipped with teats. In each meal, milk was provided free access up to satisfy hungry of each kid. Milk intake of kids was determined each 3 days (Table 2.).

Photoperiodic treatment. In groups of treated kids (natural or artificial), to provide the photoperiod of long days, pens were equipped with daylight-type lamps that emitted a minimum luminous intensity of 400 lx at the eye level of the kids. Lights were on from 0600 to 0900 and from 1700 to 2200, to extend the duration of the natural day and obtain a total of 16 h light/d. In addition to the distance of 15 m separating the control and light-treated pens, a curtain made of opaque material was placed around the light-treated pens to avoid any perception of light at night by the control groups.

Measurements

Body weight of kids. Body weight of all kids was determined twice a week, from birth up to d 28. Kids were weighed on a mobile scale with a 40-kg capacity and a precision of 10 g. ***Mean daily weight gain.*** The mean daily weight gain (MDWG) in the four groups of kids was calculated as follows:

MDWG = (weaning weight – birth weight)/ 28 days.

Blood glucose measurement. The blood glucose concentrations were determined on fourteen kids from each experimental group at d 6, 10, 13, 17, 20, 24 and 27 after born. A blood drop was obtained by jugular venipuncture and placed on a reactive strip. The blood will be absorbed by the strip and evaluated by means of the test Biosensor-glucose monoxides. For this, it is used a glucometer One Touch Ultra2 with a reading range from 20 to 600 mg of glucose /dL of blood.

Milk composition. In groups of kids reared by its mother (control and treated) a sample of milk (20 mL) was obtained from each mother at d 10, 15 and 20 of lactation. The samples were collected in plastic sterile tubes kept on ice and transported to the laboratory for the determination of fat, protein, and lactose using a Milkoscan Expert Automatic 2964 (Scope Electric, Regensburg, Germany). In the case of groups of kids artificially reared, a sample of milk (20 mL) offered to the kids was obtained.

Statistical analyses

Changes in body weight of kids were analyzed using the MIXED MODELS procedure of SYSTAT 13 (Chicago, IL). The procedure included the fixed effects of the photoperiodic treatment (2 levels: natural and artificial, the error term being kids within treatment), suckling type (2 levels: natural suckling and artificial suckling and age days (the residual error being the error term), their interactions, the random effects of kids and residual. The same statistic procedure was utilized for variables: components in milk (fat, protein and lactose), and blood glucose concentrations. The individual kid was the experimental unit. All dependent variables were included as repeated measures. Mean daily gain was analyzed using a two-way ANOVA to test the effects of photoperiodic treatment and rearing type. Data were presented as means ± SEM, and the results were considered significant when $P \leq 0.05$.

Results

Body weight

At born, mean body weight did not differs between the four groups of kids (P > 0.05). However, at weaning, mean body weight was greater (P< 0.01) in the treated groups (artificial, 6.9 ± 0.2 kg and natural, 8.2 ± 0.2 kg) than in the control groups (artificial, 6.2 ± 0.2 kg and natural, 7.6 ± 0.3 kg). Goats kids fed under natural suckling (control and treated) had more (P<0.001) weight at weaning (7.6 ± 0.3 kg and 8.2 ± 0.2 kg, respectively) than kids fed under artificial suckling (control, 6.2 ± 0.2 kg and treated, 6.9 0.2 kg). No interaction was detected between the photoperiod regimen and suckling type (P > 0.05). In all groups, body weight changed during time of experiment (P<0.001; Figure 1), and these changes were different between goats kids fed under artificial and natural suckling, resulting in a significant suckling type x time interaction ($P<0.001$). No interaction was detected between photoperiod regimen and time on this variable ($P>0.05$ Figure 1).

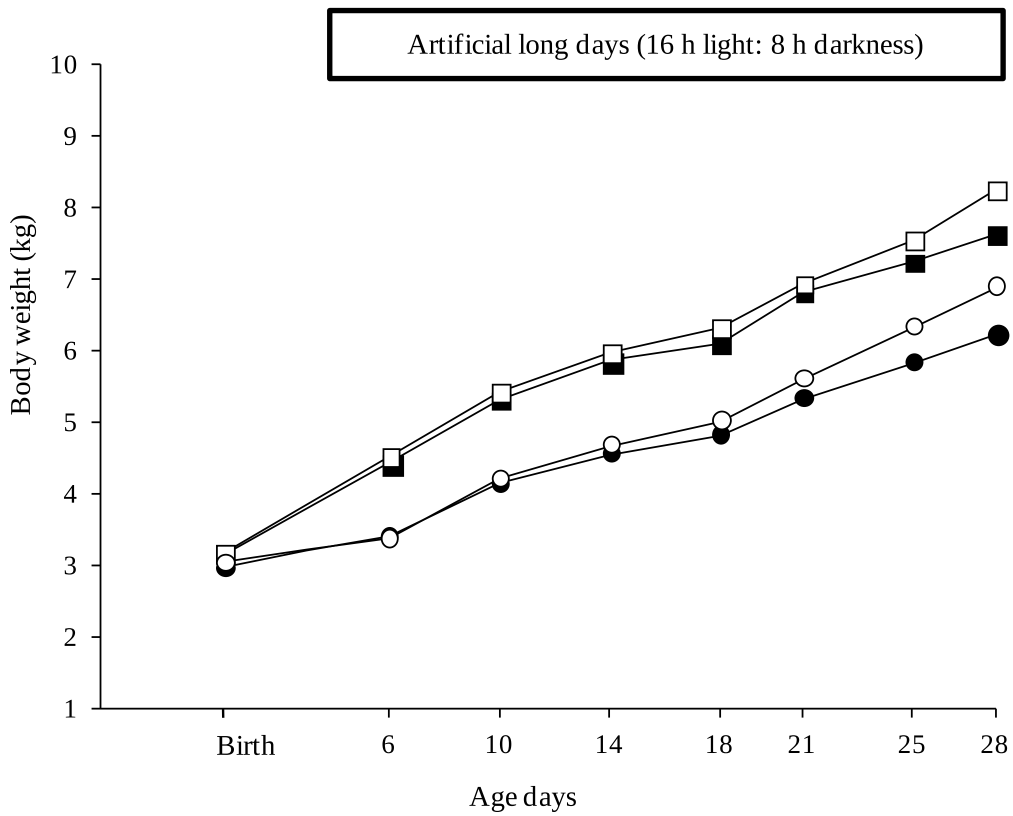

Figure 1. Mean body weight of kid fed under natural suckling and exposed at d 4 of age to an artificial long-day photoperiod (□, n =19) or maintained under a natural photoperiod (■, n = 17). Other 2 groups of kids were separated their mother at d 4 of age and fed under artificial suckling exposed to an artificial long-day photoperiod(○, n = 15) or maintained under natural photoperiod (●, n = 15).

Mean daily weight gain

Mean daily weight gain was greater (P<0.01) in treated groups (effect of photoperiod; artificial, 137 g/d and natural, 182 g /d) than in control groups (artificial, 116 g/d and natural 160 g/d; Figure 2). Kids fed under natural suckling (treated and control), gained more weight (effect suckling type; 182 g/d and 160 g/d, respectively) than kids fed under artificial suckling (137 g/d, 116 g/d, respectively; P < 0.001). No interaction was detected between photoperiod regimen and suckling type on this variable (P < 0.05).

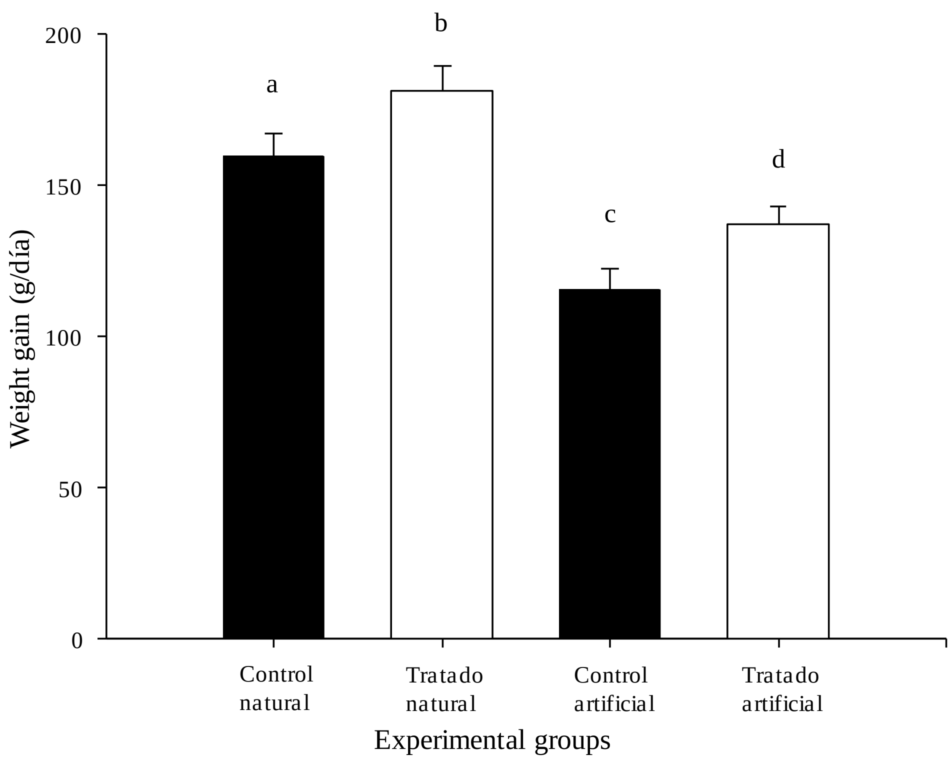

Figure 2. Mean body weight gain estimate from birth up to weaning in the four groups of study. Differences between groups in each of the periods are indicate by a letter (P<0.001).

Blood glucose concentrations

Blood glucose concentrations were greater (P < 0.05; Figure 3) in the treated groups (effect of photoperiod) with natural (98.9 ± 2.1 mg/dL) or artificial (105.1± 2.3 mg/dL) suckling than in the control groups with natural (93.4 ± 1.9) or artificial (89.6 ± 2.7 mg /dL) suckling. There was not an effect of the suckling type on glucose concentrations (P > 0.05). However, an interaction was found between photoperiod and suckling type (P <0.001), resulting in greater concentration of glucose for natural treated group (Figure 3). In all groups, glucose concentrations varied over time (P<0.001), and this changes were different between treated and control groups, resulting in an interaction photoperiod x time (P<0.01). Also, this changes were different between artificial and natural groups, resulting an interaction suckling type x time (P<0.001).

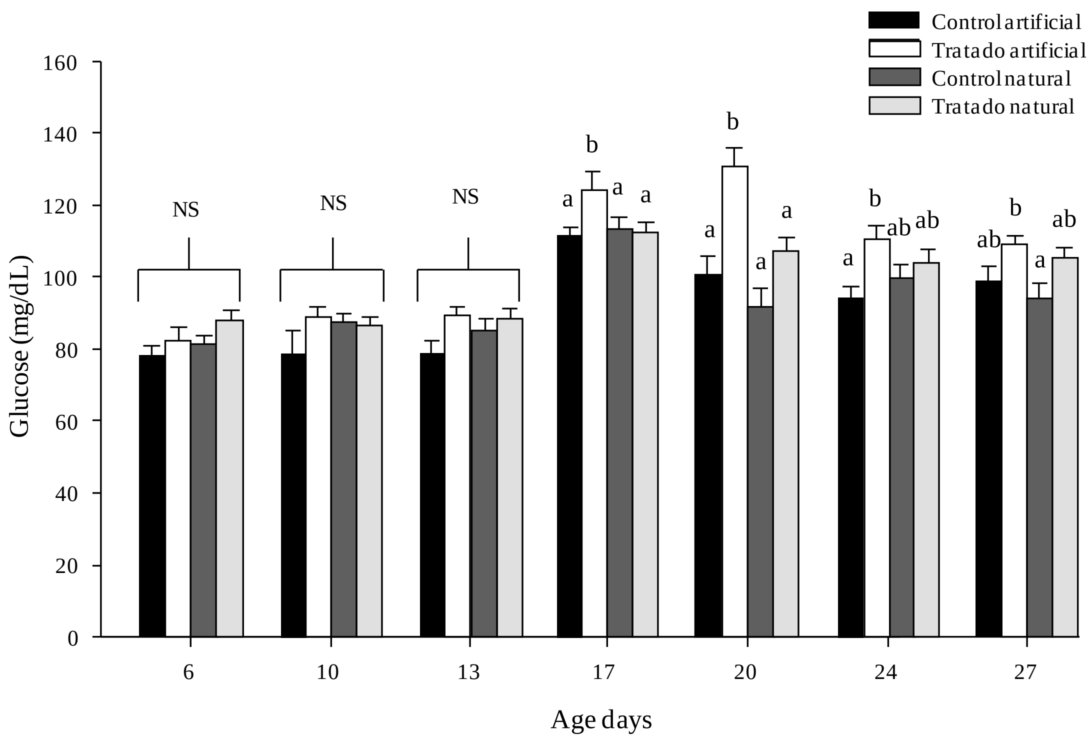

Figure 3. Mean blood glucose concentrations in the four groups of study. Differences between groups in each of the periods are indicate by a letter (P<0.05). NS=non-significant (P>0.05).

Milk composition

Mean percentage of fat, protein and lactose contents in milk ingested by goat kids were not different between groups (P > 0.05). Thus, mean percentage of fat, protein and lactose was 4.5, 3.2 y 4.8, respectively (Table 2).

Table 2. Estimated mean milk intake of kids fed under artificial suckling exposed to natural or artificial photoperiod.

Groups		**Measurement days**							
		4	7	10	13	16	19	22	25
Artificial control	g/d	220	330	520	755	950	1250	1550	1750
Artificial treated	g/d	210	355	560	800	1100	1450	1750	1950

Discussion

The results obtained in the present study shown that kids exposed to an artificial long-day photoperiod gained more weight at the weaning than kids maintained under natural decreasing photoperiod independently if kids were fed under natural or artificial suckling.

Previously, it was reported that in subtropical goat kids born in autumn kept with their mothers during the first days 30 of lactation and exposed to artificial long-day photoperiod gained more weight at weaning than kids maintained under natural decreasing photoperiod (Mejia, 2007). However, in this study, which was realized in this same region of the present, was not possible to identify whether body weight gain in kids submitted to long days was due to the treatment photoperiodic or to the high milk yield of the mothers.

Therefore, in the present to determine the influence of artificial long days on body weight, kids were separated of their dams at fourth day of age and were fed under artificial suckling. Daily, each kid was fed to free access using goat natural milk with similar contents chemicals (fat, protein and lactose) and under these conditions, kids submitted to an artificial long-day photoperiod gained more weight at the weaning than kids maintained under natural photoperiod. This finding shows for the first time the stimulatory effect of a long-day photoperiod on body weight gain during the first month of life in subtropical goat independently if they are reared by its mother or artificially. In ruminants, there are not studies reported in the literature on such stimulatory effect of artificial long days on body growth of offspring during suckling phase. Nevertheless, effectiveness of this treatment on body weight gain in heifers and lambs has been assessed during prepubertal period and under different feeding planes. In these experimental conditions, heifers and lambs submitted to artificial long days gains more body weight to the end the study that those maintained under natural photoperiod (Forbes *et al*., 1975; Peters *et al*., 1978).

The body weight at weaning from kids maintained with their dams and exposed to long days, totally coincide with results obtained by Mejía, (2007) in this same bred. The mechanism by which artificial long days increases body weight gain in these species, is still unknown. However, is likely that weight gain induced by long days in local kids is associated to an increased plasma IGF-I concentrations, since this hormone, tended to increases in heifers during artificial long days (Spicer *et al*., 2007). In fact, exposure heifers to a long-day photoperiod stimulated body growth and carcass protein accretion in comparison to those maintained under a short-day photoperiod (Zinn *et al*., 1986).

In our study, the kids maintained under natural suckling exposed to natural or artificial days gained more weight at the weaning than the kids maintained under artificial suckling exposed to natural or long days, which is consistent whit results reported in other bred of kids under different suckling regimens (Arguello *et al*., 2004).

In the current study, milk intake by kids was not the decisive factor on weight gain obtained in kids submitted to long days. In fact, in groups fed under artificial suckling, milk intake during study period was similar between both groups. Likewise, milk composition (fat, protein and lactose) ingested by kids during study period were not different between groups therefore we state that this variable did not influence in a significant way the growth of the kids. As has been reported in lambs, it is likely that the metabolism of kids exposed to long days is more efficient in converting feed into body mass than the kids maintained under natural photoperiod (Forbes *et al*., 1979). This is based on the fact that glucose concentrations in our study were greater in kids exposed to long days than in kids maintained under natural photoperiod, independently of the type of rearing. In mature ewes, it is well established that photoperiodic treatment induces changes in appetite, with higher voluntary fed intake in long days and lower in short days and these changes are associated to an increased glucose concentrations compared with ewes maintained under short days, indicative of an anabolic state (Archer *et al*., 2005). In our study, high glucose concentrations observed in groups submitted to long days reflect such increase in anabolic state, and thus having a greater body weight than goat kid under natural decreasing photoperiod, which were less heavy. In fact, recently it was reported that heavier goat kids had greater plasma glucose concentrations than lighter ones (Laporte-Broux *et al*., 2011).

It is concluded that kids exposed to an artificial long-day photoperiod gained weight faster at the weaning than kids maintained under natural photoperiod independently if kids are fed under natural or artificial suckling.

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CAPITULO 6

CONCLUSIONES Y PERSPECTIVAS

El estudio de la influencia de los días largos artificiales sobre la producción de leche en las cabras subtropicales ordeñadas una o dos veces al día, indica que bajo estas latitudes, la producción de leche resultó ser mayor en las cabras sometidas a días largos artificiales que en las cabras mantenidas bajo fotoperiodo natural. Este resultado demuestra que muy probablemente la lactancia puede ser modulada por el fotoperiodo, como sucede con el patrón de reproducción estacional mostrado en estos animales: días cortos, estimulan la actividad sexual, días largos, la inhiben. Entonces es probable que así como los animales utilizan el fotoperiodo para predecir el momento oportuno para reproducirse, posiblemente también esta señal informa que existen momentos adecuados para eficientar la lactancia. Además, combinando la exposición a los días largos artificiales con la doble ordeña, la producción de leche se incrementó aún más sin afectar sus componentes. Ello claramente muestra que estos animales locales del norte de México mantienen todavía su capacidad para responder a la estimulación de los días largos, a pesar del hecho de que su producción láctea posiblemente haya llegado a su máximo potencial por la doble ordeña diaria. Estos resultados confirman lo previamente reportado en vacas y ovejas de latitudes templadas, en cuyas especies, los días largos incrementaron la producción de leche. No obstante, en el presente trabajo, a diferencia con los estudios previos, las crías permanecieron con sus madres durante el primer mes postparto. Durante esta fase, se sabe que el estímulo de la glándula mamaria ejercido mediante el amamantamiento de la cría, induce un incremento de la producción de leche, comparado con aquellas hembras que no amamantan a sus crías. Por lo tanto, sería interesante estudiar en estas cabras, si separando las crías desde el nacimiento, los días largos incrementan la producción de leche en esta parte inicial de la lactancia, sin tener una influencia de la cría. Posiblemente, habría que compararse también con un tratamiento de luz que inicie un mes antes del parto. Además, como se pudo observar en los resultados, el incremento en la producción de leche de las cabras sometidas a días largos, se presentó solo durante la fase temprana de ordeño, es decir únicamente durante los primeros 100 días de tratamiento en las hembras ordeñadas una o dos veces al día. Este hecho, junto con el conocimiento de que en cabras se presenta un estado refractario de la PRL a los días largos sería de esperarse una disminución en la producción láctea, sin descartar que también otras hormonas lactogénicas como la GH, IGF-I y las hormonas tiroideas muestren un estado refractario. Por lo que se sugiere que en estas condiciones el tratamiento de los días largos cuando los partos ocurren en el otoño solamente sea durante los primeros 100 días de la lactancia.

Además, desde un punto de vista práctico sería interesante investigar, si las hembras responden favorablemente a un esquema de dos periodos suplementarios cortos de luz. Este consiste en proporcionar un primer periodo de 7 horas luz (3 h de luz artificial antes del alba y el resto luz natural), seguido de un segundo periodo de 2 h de luz artificial proporcionada de 16 a 17 horas después del alba. Este esquema, ha sido ampliamente estudiado en cabras localizadas en latitudes templadas para inducir la actividad sexual de las hembras durante el periodo de inactividad sexual y produce los mismos resultados que el obtenido con un esquema de 16 horas luz. Este esquema de periodos cortos de luz, permitirá reducir el gasto de energía eléctrica e incrementará el ingreso para el productor.

El estudio de los días largos artificiales sobre la producción de leche en las cabras manejadas bajo condiciones extensivas, demuestra que las cabras responden favorablemente al tratamiento de días largos, solamente si estas reciben una complementación nutricional a partir de los 30 días después del parto. Estos resultados, demuestran por primera vez el efecto de los días largos artificiales sobre la producción de leche en las cabras manejadas bajo condiciones de pastoreo extensivo. De este estudio, queda claro que el estado nutricional de las hembras sometidas a un fotoperiodo de días largos artificiales, es un factor importante que modifica de manera considerable la respuesta de las hembras en la producción de leche. Considerando la importancia de este factor en la lactancia, sería interesante seguir investigado los diferentes periodos de complementación, así como el tipo de complemento usado durante la fase de lactancia en combinación con el fotoperiodo de días largos. Estos experimentos nos permitirán identificar el tiempo óptimo durante el cual los días largos pueden actuar de manera significativa sobre la producción de leche en las cabras explotadas bajo condiciones de pastoreo extensivo.

La exposición prolongada a un fotoperiodo de días largos artificiales en cabras lactantes induce el establecimiento de un estado refractario y así, el reinicio de la actividad ovárica postparto. De este estudio, se puede concluir que una mayor proporción de hembras lactantes (69 %) reinician su actividad ovárica postparto después de percibir 150 días largos continuos, comparado con un 12 % de las hembras mantenidas bajo fotoperiodo natural. Este resultado deja claro que la fase de lactancia de las hembras no influye en el establecimiento del estado refractario, ya que en ovejas y cabras no lactantes previamente expuestas a un fotoperiodo de días cortos, seguido de un tratamiento de días largos continuos, la actividad sexual inició a los 150 días de tratamiento, lo cual es similar al tiempo en que requirieron las cabras lactantes del presente estudio. La importancia de seguir estudiando la influencia de los días largos sobre el reinicio de la actividad ovárica postparto en cabras lactantes páridas en el otoño, da la oportunidad de que las hembras presenten actividad ovulatoria en un período considerado como anestro estacional. Para los productores resulta benéfico este hecho debido a la oportunidad de obtener partos fuera de la estación natural.

Sin embargo, en el grupo de cabras mantenidas en el fotoperiodo natural no se puede descartar que la producción de leche, la cual fue mayor que en estudios previos en esta misma región, influyó sobre el reinicio de la ovulación postparto. A este respecto, existe evidencia en vacas que la duración del anestro postparto es más prolongado en vacas alta productoras, que en aquellas bajas productoras. En esta especie, está bien documentado que la baja fertilidad que se presenta al inicio de la lactancia se debe a que las hembras entran en un estado energético negativo, provocado por la alta demanda de nutrientes que la glándula mamaria requiere para producir leche. Si esto es aplicable también en cabras altas productoras entonces resulta interesante seguir estudiando las interacciones entre el fotoperiodo, la producción láctea, la nutrición y la actividad sexual postparto en estos animales

El estudio de la influencia de los días largos artificiales sobre el peso de los cabritos, muestra por vez primera resultados interesantes que permiten dar continuidad a esta hipótesis de trabajo. Ciertamente, el peso corporal de los cabritos nacidos en el otoño y expuestos a un fotoperiodo de días largos resultó ser más alto que el obtenido en cabritos mantenidos bajo fotoperiodo de días cortos naturales, independientemente, si los cabritos son amamantados por sus madres o de manera artificial. Sin embargo, de manera general, el peso corporal de las crías amamantadas por sus madres fue 1.3 kg más alto que el obtenido en los cabritos amamantados de manera artificial. Con respecto a este punto, cabe mencionar que los cabritos criados de manera artificial, fueron alimentados usando leche natural de las cabras que no fueron tratadas con los días largos. Por lo que surge la posibilidad de que si esas crías se les hubieran proporcionado la leche de sus madres tratadas con días largos, entonces tuvieran un peso también similar al de las crías amamantadas por sus madres. En efecto se sabe en algunas especies, las crías de madres cuya leche con alto contenido de factores de crecimiento presentan un mejor crecimiento que las madres cuya leche su contenido de estos factores es menor. Esto último, junto con un posible efecto directo de los días largos sobre el metabolismo de las crías, resulta en mayores pesos al destete. Al mismo tiempo, resulta interesante evaluar diferentes fórmulas lácteas en combinación con el fotoperiodo de días largos, para obtener una óptima ganancia de peso similar a la observada en las crías amamantadas por sus madres.

En su totalidad, los presentes resultados muestran evidencias de que el fotoperiodo de días largos artificiales en las cabras subtropicales paridas en el otoño tiene repercusiones importantes en su fisiología lactacional y sobre la actividad sexual postparto. Además esta señal fotoperiódica influye de manera importante sobre el peso de las crías caprinas nacidas en esa época.

CAPITULO 7

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