LA INCLUSIÓN DE MAÍZ EN LA DIETA DE CABRAS EN PASTOREO EXTENSIVO DURANTE LA GESTACIÓN TARDÍA, INCREMENTA LA PRODUCCIÓN DE CALOSTRO Y MEJORA LA INTERACCION TEMPRANA MADRE-CRÍA

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TESIS

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TESIS

POR

SANTIAGO RAMÍREZ VERA

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DEDICATORIA

Esta Tesis va dedicada especialmente a DIOS padre todopoderoso, a Jesús Hijo de DIOS y a la Virgen María.

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RESUMEN

El objetivo general de este trabajo fue investigar si la inclusión[1] de un alimento alto en energía, como el maíz, en la dieta de cabras en pastoreo extensivo durante los últimos 12 días de gestación, incrementa la producción de calostro y mejora la vinculación temprana madre-cría. Para lograr este objetivo se diseñaron tres estudios. Para los estudios 1 y 2, veinte días antes de la fecha promedio del parto las cabras fueron asignadas a 2 grupos experimentales estandarizados de acuerdo a su peso y condición corporal. Durante el día, ambos grupos fueron mantenidos en condiciones de pastoreo extensivo y retornaban a su corral en las noches. Las cabras asignadas al grupo control, no recibieron ningún sustituto nutricional durante toda la gestación (grupo control). Las hembras gestantes asignadas al grupo al que se le incluyó maíz, recibieron diariamente durante los últimos 12 ± 1.0 días de gestación 0.6 kg de maíz rolado/hembra como parte de la dieta alimenticia (grupo maíz).

En el primer estudio, se investigó si la inclusión de maíz en la dieta durante los últimos 12 días de gestación permitía mejorar la producción de calostro y la actividad motriz del recién nacido. La producción de calostro durante las primeras 10 h postparto fue mayor en las cabras del grupo maíz (1,102 ± 144 g) comparado con las cabras control (405 ± 50 g, P = 0.002). En las cabras del grupo maíz la concentración de glucosa en sangre al parto (160 ± 13 mg/dL) fue mayor que en las cabras control (115 ± 12 mg/dL, P = 0.037). En las cabras del

[1] En la presente tesis, el término “inclusión de maíz en la dieta” se refiere al ofrecimiento de maíz antes de que los animales salieran al pastoreo durante los últimos 12 días de gestación, en donde dicho alimento formó parte de la dieta total consumida. Se ha demostrado en animales en pastoreo que el consumir un alimento alto en energía antes del pastoreo reduce el tiempo del mismo y por consecuencia reduce la cantidad de forraje que consume, por lo cual, el alimento proporcionado es parte de la dieta (Short et al., 1996; Shauer et al., 2005).

grupo maíz se observó una disminución en las concentraciones de progesterona plasmática en el día 3 antes del parto, mientras que en las cabras control esta disminución ocurrió un día antes del parto ($P \leq 0.008$). Las crías nacidas del grupo maíz emitieron mayor frecuencia de balidos bajos que las crías del grupo control ($P = 0.015$). La frecuencia y duración en la búsqueda de la ubre, así como la frecuencia de amamantamiento fueron mayores en las crías del grupo maíz que en las crías control ($P \leq 0.015$). Además, la duración del trabajo de parto fue más prolongado en las hembras control ($P = 0.001$) y en este grupo, un mayor porcentaje de hembras presentaron partos anormales (33.3%, $P = 0.036$) que las cabras del grupo maíz (9.0%). En este primer estudio se concluye que la inclusión de maíz en la dieta del pastoreo extensivo durante los últimos 12 días de gestación incrementa la producción de calostro y mejora la vitalidad del recién nacido.

En el segundo estudio se investigó si la inclusión de maíz en la dieta de pastoreo extensivo durante los últimos 12 días de gestación mejoraba la conducta materna al parto y fortalecía la formación del vínculo selectivo madre-cría a 3 h postparto. La conducta materna (10 hembras/grupo) fue evaluada con la ayuda de video-grabaciones durante los primeros 60 min postparto. Las cabras del grupo maíz mostraron una mayor frecuencia en el consumo de fluido amniótico, de membranas amnióticas y además realizaron más invitaciones al amamantamiento a sus crías que las hembras control ($P \leq 0.047$). La

selectividad materna[2] fue evaluada a 3 h postparto (control; n = 37 y maíz; n = 44) mediante dos presentaciones separadas de la cría propia y una ajena durante 5 min. Las cabras del grupo maíz mostraron mayor número de conductas de aceptación (balidos bajos, aceptaciones a la ubre y tiempo de amamantamiento), para la cría propia que las cabras control ($P \leq 0.03$). Por lo contrario, las madres control mostraron mayor número de conductas de rechazo (balidos altos, rechazos a la ubre y conductas agresivas), para la cría propia que las hembras del grupo maíz ($P \leq 0.005$). En el grupo maíz, a las 3 h postparto, existió mayor proporción de cabras maternales (41/44, 93%) que en el grupo control (29/37, 78%, $P = 0.048$). Asimismo, se encontró que fue mayor la proporción de cabras selectivas en el grupo maíz (36/41, 88%), que en el grupo control (15/29, 52%, $P = 0.001$). En este segundo estudio se concluye que en cabras, la inclusión de maíz en la dieta de pastoreo extensivo durante los últimos 12 días de gestación mejora la conducta materna al parto y permite el adecuado establecimiento de la selectividad materna a 3 h postparto.

En un tercer estudio se investigó si una suplementación[3] con o la inclusión de maíz en la dieta durante las últimas 2 semanas de gestación mejoraba la capacidad de reconocimiento mutuo madre-cría en cabras subnutridas de

[2] En la presente tesis el término “selectividad materna” se refiere a la capacidad de la madre para reconocer a corta distancia (valiéndose del sentido del olfato) a su progenie y aceptarla exclusivamente al amamantamiento así como rechazar activamente a crías ajenas.

[3] En esta tesis el término “suplementación” se refiere a proporcionar un alimento adicional a la dieta de cada individuo; es decir, en la presente tesis, para completar los requerimientos nutricionales en los animales a los que experimentalmente se les restringió su nutrición durante la gestación, fueron suplementados con maíz durante los últimos 15 días de gestación, así este alimento formó parte adicional a la dieta (Short *et al.,* 1996; Shauer *et al*., 2005).

manera experimental (Exp. 1) y en cabras bajo condiciones de pastoreo extensivo (Exp. 2). En el Exp. 1, se utilizó un grupo de hembras alimentadas con el 100% de sus requerimientos nutricionales (control, n = 19), un segundo grupo de hembras subnutridas experimentalmente (subnutridas, n = 17) alimentadas con sólo el 70% de sus requerimientos nutricionales (a partir del día 75 de gestación hasta el parto) y un tercer grupo de hembras subnutridas como el anterior, pero que además fue suplementado con 0.6 kg de maíz rolado durante los últimos 15 días de gestación (suplementado, n = 21). En el Exp. 2, se utilizaron 2 grupos de cabras en pastoreo: el primer grupo de cabras sólo fue alimentado con el forraje disponible en las áreas de pastoreo sin ningún alimento adicional (pastoreo, n = 37); un segundo grupo de cabras que se mantuvo en pastoreo, además se le incluyó diariamente 0.6 kg de maíz/cabra durante los últimos 12 días de gestación (maíz, n = 44). La capacidad de reconocimiento no olfativo en las cabras fue evaluada mediante una prueba de elección doble a las 8 h (Exp. 1) y a 4 h postparto (Exp. 2). Las cabras subnutridas y pastoreo no mostraron diferencia significativa en el tiempo invertido cerca de la cría propia y de la ajena. Mientras que las cabras control, suplementado y maíz invirtieron más tiempo cerca de la cría propia que de la ajena. Las cabras pastoreo invierten más tiempo mirando a la cría ajena que las cabras maíz. La capacidad de reconocimiento de la madre por su cría fue evaluada mediante una prueba de elección doble a las 12 h de vida (Exp. 1) y a las 8 h (Exp. 2). Las crías nacidas del grupo subnutridas y pastoreo no mostraron preferencia significativa por la madre propia, mientras que las crías nacidas del grupo control, suplementado y maíz mostraron una clara

preferencia por su madre durante dicha prueba. Las crías nacidas de cabras pastoreo invirtieron más tiempo mirando a la madre ajena que las crías nacidas de cabras maíz. En este tercer estudio, se concluye que suplementar con o incluir maíz en la dieta durante las últimas dos semanas de gestación mejora la capacidad de reconocimiento mutuo madre-cría en cabras subnutridas experimentalmente y en aquellas cabras mantenidas en pastoreo semiárido extensivo.

De manera general, con estos resultados se puede concluir que en las cabras mantenidas en pastoreo semiárido extensivo, la inclusión de maíz en la dieta durante los últimos 12 días de gestación incrementa la producción de calostro y mejora la vinculación temprana madre-cría.

ABSTRACT

The overall objective of this thesis was to investigate if inclusion[1] of maize, a high-starch feed in the diet of semi-arid grazing goats during the last 12 days of pregnancy could increase the colostrum yield and improves the early mother-young bond. To reach such objective 3 studies were designed. In studies 1 and 2, twenty days before mean date of parturition grazing goats were assigned to one of the 2 experimental groups conformed according to their initial body weight and condition score. During the day, both groups were fed only with natural vegetation from grazing areas and during night animals returned to their respective corral. During whole gestation, goats assigned to the control group did not receive any nutritional supplement (control group). Each goat assigned to the maize group, received 0.6 kg of flaked maize/day during the last 12 days of pregnancy (maize group).

In the first study was investigated if the inclusion of maize to the diet during the last 12 d of gestation improves colostrum yield and neonatal behavior in does under grazing semi-arid rangeland. In the maize does the total colostrum yield/10 h was greater (1,102 ± 144 g) than in control does (405 ± 50 g, P = 0.002). In addition in the maize does the concentration of glucose in the blood at parturition (160 ± 13 mg/dL) was greater than in control does (115 ± 12 mg/dL, P = 0.037). In maize does a significant decrease in plasma progesterone

[1] In this thesis, the term "inclusion of maize in the diet" refers to the offer of maize to the animals just before grazing during the last 12 days of pregnancy, where the maize was part of the total diet consumed. It has been showed that in grazing animals the consumption of a feed high-energy as maize before starts grazing reduces grazing time and therefore reduces the feed intake in the rangeland, so offered maize was a part of the total diet (Short et al., 1996; Shauer et al., 2005).

concentrations occurred 3 d before parturition, whereas it decrease occurred 1 d before parturition in control does (P ≤ 0.008). Kids born from maize does shown greater (P ≤ 0.015) frequency of low-pitched bleats, frequency and duration of teat seeking and a greater frequency suckling activity (P< 0.001) than in kids from control does. Furthermore, duration of parturition was longer (P = 0.001) and had greater numbers fetal malpresentation (33.3%, P = 0.036) in control does than in maize does (9.0%). In this first study, it was concluded that inclusion of maize in the diet of grazing goats under semi-arid rangeland during the last 12 d of gestation improved colostrum yield and neonatal activity.

In the second study we asses if maize inclusion in the grazing diet of goats during the last 12 d of gestation improves maternal behaviour at birth and strength the exclusive mother-kid bond at 3 h after birth. Mother-kid interactions (10 mothers and their single kid/group) were recorded during the first 60 min after kid´s expulsion. The frequencies of the amniotic fluid consumption, amniotic membranes consumption and invitations to suckling to their kids were greater in maize goats than in the controls (P ≤ 0.047). The maternal selectivity[2] was evaluated at 3 h postpartum (control; n = 37 y maize; n = 44) through 2 successive 5-min presentations of mother with their own kid and an alien. Maize goats show higher number of acceptation behaviors (low-pitched bleats, udder acceptations and time of suckling) towards the own kid than the control goats (P ≤ 0.03). In contrast, control goats shown greater number of rejection behaviors

[2] In present thesis, the term "maternal selectivity" refers to the ability of the mother to recognize at short distance (using the sense of smell) their progeny and exclusively accept it at suckling as well as actively to reject any alien kid that try to suckle.

(high-pitched bleats, udder rejection and of aggressive behavior) for their kid than maize goats ($P \leq 0.005$). At 3 h postpartum, the proportion of maternal goats was greater ($P = 0.048$) in the maize goats (41/44, 93%) that in the control does (29/37, 78%). From this maternal mothers in each group the 88% of the goats from maize group were selective at 3 h postpartum (36/41), while only the 52% of the mothers of control goats did (15/29, $P = 0.001$). The conclusion of the second study was that maize inclusion in the grazing diet of goats during the last 12 days of gestation improves the maternal behavior at birth and strength the exclusive mother-kid bond at 3 h after birth.

The third study was for investigated if a supplementation[3] with maize or including maize in the diet during the last two weeks before birth improves the capacity of goat-kid mutual recognition either in experimental malnourished (Exp. 1) or under natural extensive grazing conditions (Exp. 2). In Exp. 1, three groups of goats were used: a first group where goats received their 100% of their nutritional requirements (control, n = 19), a second group goats that were fed with their 100% of their nutritional requirements until day 75 of gestation, but during the last 75 days were fed only with their 70% of energy and protein requirements (underfed, n = 17), a third group of goats that were underfed as previous group but in addition, during the last 15 days of pregnancy every animal receive 0.6 kg/day of crush maize (supplemented, n = 21). In Exp. 2, 37

[3]In this thesis, the term "supplementation" refers to providing additional feed to the diet of the animals, in other words in the present thesis, to complete the nutritional requirements in experimentally underfed animals during pregnancy, they were supplemented with maize during the last 15 days of pregnancy, which feed formed an additional feed to the diet (Short et al., 1996; Shauer et al., 2005).

grazing goats under natural extensive management (grazing group) and other 44 under the same grazing conditions but that during the last 12 ± 1.0 day of gestation each female included in his diet 0.6 kg/day of corn (maize group) were used. The non-olfactory recognition was assessed in goats in a two-choice test at 8 h (Exp. 1) and at 4 h postpartum (Exp. 2). Either underfed or grazing goats did not shown significant difference in the time spent near to the own or the alien kids. While control, supplemented and maize goats spent more time near to the own kid than near to the alien kid during the test, grazing goats spent more time looking toward the alien kid than maize goats. In kids, preference for their mother was assessed in a two-choice test at 12 h in Exp. 1 and at 8 h postpartum in Exp. 2. Either kids from underfed or grazing groups did not show significant preference for the own dam, while kids from control, supplemented and maize groups shown clear preferences for their mother during the test. Kids from grazing group spent more time looking toward the alien mother than in kids from maize group. In this third study, it was concluded that maize suplementation or including maize in the diet during the last two week of pregnancy improve the capacity of mother-young mutual recognition in either experimentally underfed or in natural grazing goats.

As a whole, the results obtained from this thesis indicate that in goats kept under semi-arid extensive grazing, the inclusion of maize in the grazing diet during the last 12 days of gestation increases colostrum yield and improves the early goat-kid interaction.

TABLA DE CONTENIDO

1. INTRODUCCIÓN

En los mamíferos, la sobrevivencia de la progenie representa un elemento determinante para el éxito reproductivo de los padres (Blache *et al*., 2008). La nutrición es uno de los factores que más afecta al ciclo reproductivo en sus diferentes fases (Martin *et al*., 2004a, b). Los efectos de la nutrición sobre el ciclo reproductivo son asociados a un incremento en la demanda de nutrientes durante la gametogénesis, durante el desarrollo y crecimiento fetal y durante la lactancia (Blache *et al.,* 2000, 2008). Sin embargo, la mayor demanda de nutrientes se presenta durante la gestación tardía y la lactancia; así, al no cubrirse dicha demanda nutricional en estas fases, ello repercute en problemas de la madre y de la cría (Rhind *et al.,* 2001; Capper *et al.,* 2007). En caprinos y ovinos, una subnutrición durante la gestación tardía afecta el peso de la cría al nacimiento, retrasa y disminuye la producción de calostro disponible para las crías al nacimiento (Robinson, 1983; Rhind *et al.,* 2001; Sormunen-Cristian *et al.,* 2001). Sin embargo, en ovejas una restricción del 50% en los requerimientos nutricionales durante los primeros 100 días de gestación no afectó el peso de la cría al nacimiento (Simitzis *et al.,* 2009). Por el contrario, en ovejas de la raza Santa Inés, una restricción nutricional del 60% de sus requerimiento a partir del día 100 de gestación hasta el parto, tuvieron crías con menor peso al nacimiento (2.9 kg) que las ovejas alimentadas a libre acceso (3.8 kg; Geraseev *et al.,* 2006). En ovejas mantenidas en pastoreo parieron

crías de menor peso al parto (4.0 kg), que a las que además se les proporcionó un complemento nutricional del día 91 al 140 de gestación (4.5 kg; Frutos *et al.,* 1998). Lo anterior muy posiblemente debido a que las hembras movilizan más reservas corporales durante la gestación tardía, lo cual se debe a que del 70 al 90% del crecimiento fetal ocurre en este periodo de la gestación (Robinson, 1990; Frutos *et al.,* 1998; Sormunen-Cristian *et al.,* 2001).

En ovejas y cabras, una subnutrición durante las últimas 2 semanas de gestación disminuye el desarrollo de la ubre y retrasa el inicio de la lactogénesis II, disminuyendo así la cantidad de calostro al parto (Mellor, 1987; Robinson, 1990). Sin embargo, en ovejas mantenidas en pastoreo extensivo, una suplementación energética con maíz durante los últimos 8 días de gestación duplicó la producción de calostro, comparadas con aquellas alimentadas con una dieta que sólo cubrió sus requerimientos (814 vs. 1,175 g, respectivamente; Banchero *et al.,* 2004b; 2007).

En general, se ha demostrado que la nutrición durante la gestación repercute de manera importante sobre el peso de la cría y esto a su vez está relacionado directamente con la vitalidad de las mismas después del nacimiento (Nowak y Poindron*,* 2006). Asimismo, los efectos de la nutrición de la madre durante la gestación, sobre la vitalidad de la cría y sobre la producción de calostro afectan también las relaciones madre-cría. Por ejemplo, en las ovejas nulíparas, a las que se les redujo la dieta a un 35% sus requerimientos nutricionales durante los últimos 4 meses de gestación se perturbó el comportamiento de sus corderos posiblemente debido al reducido peso corporal de los mismos (Dwyer *et al.,* 2003). Además, en este último estudio, las madres subnutridas mostraron

menores interacciones con sus corderos que las madres que fueron bien alimentadas durante la gestación.

Con relación a los efectos de la subnutrición durante la gestación sobre la disminuida cantidad de calostro al parto, en otros estudios se ha demostrado que aquellas crías, que de manera experimental, no se les permitió consumir calostro durante las primeras 6 h de vida presentaban dificultades para discriminar a su madre de una ajena a 24 h post-nacimiento (Nowak *et al.,* 1997; Goursaud y Nowak, 1999).

Las cabras de regiones semiáridas por lo general son mantenidas en condiciones extensivas, en donde ellas están expuestas a variaciones en la calidad y en la disponibilidad del forraje durante todo el año. Esto provoca que en ciertas épocas exista deficiencia de nutrientes en la vegetación disponible y por ello, los animales no cubren sus requerimientos nutricionales (Ramírez *et al.,* 1991; Juárez-Reyes *et al.,* 2004; Cerrillo *et al.,* 2006). Esta subnutrición podría coincidir con el estado gestante de las hembras y profundizar más los efectos de la subnutrición sobre la conducta de la madre y de la cría, así como con un retraso y disminución en la producción de calostro. En particular, en el subtrópico mexicano, las cabras son explotadas en su mayoría bajo un manejo extensivo y la mayoría de los partos ocurren de noviembre a febrero, es decir, durante la estación seca (que se presenta de octubre a mayo, Sáenz-Escárcega *et al.,* 1991), cuando la disponibilidad de alimento para el pastoreo es limitada. Sin embargo, hasta hoy no se conoce si al incluir en la dieta un alimento alto en energía como el maíz en animales en pastoreo, al final de la gestación, pueda tener efectos fisiológicos y conductuales sobre la madre y sus crías.

Considerando los puntos anteriores, el objetivo general del presente trabajo fue investigar si la inclusión de maíz en la dieta de cabras en pastoreo extensivo, durante los últimos 12 días de gestación, influye sobre la producción de calostro y en la interacción temprana madre-cría.

2. REVISIÓN DE LITERATURA

2.1 Calostro

El calostro es la primera secreción de la glándula mamaria alrededor del parto y cumple diversas funciones, entre ellas constituye la única fuente nutritiva del recién nacido durante los primeros días de vida (Neville, 2001; Senger, 2003; Trott *et al.,* 2011). Normalmente el calostro se produce y acumula en la ubre aproximadamente desde 3 días antes del parto y hasta las 24 h después de este. Posteriormente, el calostro se diluye como leche y esta transición es marcada por una disminución en el contenido de inmunoglobulinas y sodio, así como por un incremento en la concentración de lactosa y potasio (Mellor, 1990). En cabras de la raza Majorera, el calostro contiene aproximadamente 8% de grasa, 9.5% proteína y 4% de lactosa; estas concentraciones son mayores en el calostro de ovejas (13%, 11.8% y 3.3%, respectivamente, Argüello *et al.,* 2006; Anifantakis, 1986; Park *et al.,* 2007). El calostro transfiere anticuerpos, enzimas, hormonas, factores de crecimiento y neuropéptidos de la madre a la cría antes de que produzca su propia inmunidad y la absorción intestinal de inmunoglobulinas cesa a las 24 h de vida (Hall *et al.,* 1992; Pattinson *et al.,* 1995). Por lo cual, la ingesta insuficiente de calostro en los primeras horas después del nacimiento es el segundo factor que afecta la sobrevivencia de la cría (Nowak y Poindron, 2006).

2.1.1 Síntesis del calostro

En la síntesis del calostro o la lactogénesis se advierten dos procesos que ocurren durante el periodo preparto y durante el parto (Trott *et al.,* 2011). El primero relacionado con el desarrollo de la glándula mamaria (lactogénesis I), y el otro se establece con el inicio de la síntesis y secreción láctea (lactogénesis II; Mellor, 1987; Neville, 2002).

Lactogénesis I es el primer proceso que involucra la diferenciación de la glándula mamaria. Así, en este proceso ocurre el desarrollo de la estructura lóbulo-alveolar la cual representa el 90% de la masa celular de la glándula mamaria (en ovejas inicia del día 95 a 100 de gestación, Senger, 2003). En dicho evento, la progesterona y los estrógenos tienen un papel de mayor importancia para el desarrollo de la glándula mamaria (Martinet y Houdebine, 1999). La progesterona contribuye a la multiplicación de células epiteliales de la glándula mamaria (Martinet y Houdebine, 1999). Lo estrógenos en sinergia con la prolactina (PRL) actúan en la proliferación de las células epiteliales de la glándula mamaria; la aplicación de estas hormonas por separado reduce hasta un 50% dicha proliferación (Trott *et al*., 2011). En ovejas tratadas con estrógenos y con un inhibidor de la PRL, se observó que ocurrió un mayor desarrollo de la glándula mamaria en animales tratados sólo con estrógenos. Lo anterior indica la importancia de la PRL en este proceso de desarrollo (Martinet y Houdebine, 1999). Además, en rumiantes la aplicación de estrógenos y progesterona durante 10 a 20 días permite el desarrollo de la glándula mamaria seguido de la secreción de leche en hembras vírgenes o no preñadas (Head *et al.,* 1975).

Lactogénesis II es el segundo proceso el cual involucra la síntesis y secreción láctea, antes y después del parto (Neville, 2001, 2002). Así, la disminución en la síntesis y secreción de progesterona al final de la gestación es la principal señal que dispara el inicio de la lactogénesis II (Delouis, 1978; Neville, 2001; Foisnet *et al.,* 2010). Un retraso en la caída de la progesterona prolonga el inicio de la lactogénesis II y reduce la producción de calostro (Mellor *et al.,* 1987; Robinson, 1990; Banchero *et al.,* 2006). Una concentración alta de progesterona sanguínea inhibe la síntesis láctea a través de dos mecanismos; primero, reduciendo la secreción de PRL y segundo, la progesterona tiene un efecto directo sobre la glándula mamaria al inhibir la síntesis de la enzima lactosa sintetasa, la cual, es importante en la síntesis de lactosa (Mellor, 1987; Leong *et al.,* 1990). Además, la concentración de lactosa es el determinante osmótico principal del volumen de leche (Shennan y Peaker, 2000). Sin embargo, la concentración de lactosa está influenciada por la disponibilidad de glucosa sanguínea, principal precursor en la síntesis de lactosa (Bell y Bauman, 1997).

2.2 Factores que influyen en la producción de calostro

2.2.1 Tamaño de camada

La cantidad de calostro acumulado en la ubre antes del parto, y la producción después del parto, depende del tamaño de la camada (Nowak y Poindron, 2006). Ovejas con partos dobles produjeron 20% más calostro que las que tenían partos sencillo (2,873 vs. 2,358 g; Al-Sabbagh, 2008). Sin embargo, en ovejas que producen más calostro, debido a mayor tamaño de camada, la producción se retrasa en comparación con las ovejas que paren una sola cría

(Alexander y Davies, 1959; Geenty, 1986; Hall *et al.,* 1990). Dicho retraso en la producción de calostro podría implicar menor disponibilidad de calostro al parto (Alexander y Davies, 1959; Geenty, 1986; McNeill *et al.,* 1998). Este retraso es atribuido a que las madres que paren más de una cría presentan una mayor concentración de progesterona, que las hembras que paren crías únicas (McNeill *et al.,* 1998). En cabras de la raza Majorera las características físicas-químicas del calostro no son afectadas por el tamaño de camada o el número de lactancias (Argüello *et al.,* 2006).

2.2.2 Raza

Las ovejas de razas productoras de carne se ha observado que producen menos calostro que aquellas razas para producción de leche (Robinson *et al.,* 2002). Las ovejas Merino producen una cantidad similar de calostro que las ovejas de la raza Ideal bajo condiciones de pastoreo (1297 vs. 1104 g, respectivamente). Sin embargo, las ovejas de la raza Corriedale mantenidas en estabulación, la producción de calostro fue menor (852 g) que las razas mencionadas anteriormente (Banchero, 2007). Las ovejas de la raza Scottish Blackface producen menos calostro que las de la raza Suffolk durante las primeras 18 h postparto en madres con una cría (1,805 *vs.* 2,340 g, respectivamente) y en madres con dos crías (2,080 *vs.* 2,835 g, respectivamente; Mellor, 1990). Sin embargo, el contenido de grasa es mayor en las ovejas Blackface comparado con ovejas de la raza Suffolk (16.5 *vs.* 13.3 %, respectivamente; Dwyer y Morgan, 2006). Estos últimos autores no

encontraron un efecto de la raza sobre el porcentaje de proteínas y de inmunoglobulinas en el calostro.

2.2.3 Nutrición y condición corporal

La adecuada nutrición de las hembras durante la gestación tardía es de gran importancia para el desarrollo y crecimiento fetal, así como para el desarrollo de la glándula mamaria. La nutrición durante la gestación se relaciona de manera importante con el inicio de la lactogénesis II al parto (Robinson, 1990). Por ejemplo, en ovejas y cabras, una subnutrición durante las últimas 2 semanas de gestación disminuye el desarrollo de la ubre y retrasa el inicio de la síntesis láctea y como consecuencia disminuye la producción de calostro al parto (Mellor, 1987; Robinson, 1990). Ovejas con una buena condición corporal (entre 2.5 a 3.5 puntos) producen mayor cantidad de calostro que hembras con una condición < 2.5 puntos (Thomas *et al.,* 1988). Una desnutrición ligera del 10% en ovejas durante la gestación tardía no afectó la producción de calostro al parto (Hashemi *et al.,* 2008). Caso contrario, cuando la desnutrición fue del 30% durante la segunda mitad de gestación, ello redujo la producción de calostro al parto, comparado con ovejas alimentadas con el 110% de sus requerimientos nutritivos (Banchero *et al.,* 2006).

Como se mencionó anteriormente, los efectos de una subnutrición sobre el inicio de la lactogénesis II y la disminución en la producción de calostro, se debe a 2 mecanismos; primero por un retraso en la caída de las concentraciones de progesterona y segundo por la disminuida disponibilidad de sustrato nutricional al final de la gestación (Robinson, 1990). En el primer

mecanismo, se ha observado en ovejas, que las hembras con buena nutrición, la disminución en las concentraciones de progesterona ocurre 5 días antes del parto, por el contrario, en ovejas una subnutrición retrasa la disminución en las concentraciones de progesterona plasmática hasta un día antes del parto, retrasando así el inicio de la síntesis de calostro (Mellor *et al.,* 1987; Robinson, 1990; Banchero *et al.,* 2006). Además, las concentraciones elevadas de progesterona inhiben la síntesis de la lactosa sintetasa, enzima importante para la síntesis de lactosa (Leong *et al.,* 1990).

El segundo mecanismo por el cual una subnutrición afecta la síntesis de calostro, es la disponibilidad de sustratos, en su mayoría la glucosa, que es el principalmente utilizado para la síntesis de lactosa (Bell y Bauman, 1997; Shennan y Peaker, 2000). Cabras altas productoras de leche utilizan entre 65 a 85% de glucosa sanguínea y ello se correlaciona con la producción de leche. Por ejemplo, en cabras, una infusión de glucosa en la arteria de la glándula mamaria incrementa un 87% la síntesis de lactosa y por consecuencia hay un incremento de 62% en la producción de leche (Linzell, 1967). Al parto, la concentración de glucosa sanguínea se incrementa y disminuye en pocas horas. Sin embargo, en ovejas subnutridas dicha concentración de glucosa es menor que en hembras bien alimentadas (Bell y Bauman, 1997; Banchero *et al.,* 2006). Esta baja concentración de glucosa contribuye a una disminución en la síntesis de lactosa y por ende reduce la producción de calostro (Mellor *et al.,* 1987; Mellor, 1987; Banchero *et al.,* 2006).

2.3 Estrategias nutricionales para incrementar la producción de calostro

El 30% de las ovejas bien alimentadas no producen suficiente calostro para los corderos mellizos; el 10% no producen suficiente calostro para su cordero único (McNeill *et al.,* 1998). La deficiente producción de calostro puede incrementarse en animales mal alimentados, y en particular, en aquellos que son mantenidos en condiciones extensivas donde hay variaciones importantes en la disponibilidad y calidad de los pastos naturales (Banchero *et al.,* 2007). En estas condiciones de producción es necesaria una suplementación alimenticia estratégica para cubrir las demandas energéticas y proteicas durante la gestación tardía. Por lo que en ovejas, una suplementación durante la última semana de gestación revierte los efectos producidos por una subnutrición sobre el inicio de la síntesis de calostro y sobre su producción al parto (Mellor *et al.,* 1987; Banchero *et al.,* 2004 a,b).

2.3.1 Influencia de la suplementación proteínica preparto sobre la producción de calostro

En ovejas alimentadas con el 100% de sus requerimiento de proteína cruda (PC) y 10.5 megajoules (MJ) de energía metabólica (EM) para mantenimiento producen más calostro a 12, 24 y 48 h postparto que aquellas hembras alimentadas con una dieta que contiene el 140% de sus requerimiento en PC y 10.5 MJ de EM, a partir del día 85 de gestación hasta el parto (Ocak *et al.,* 2005). Asimismo, en ovejas alimentadas con una dieta alta en PC durante las últimas 6 semanas de gestación, no afectó la producción de calostro durante las primeras 18 h después del parto (Annett *et al.,* 2005). Ovejas suplementadas

durante los últimos 8 días de gestación con 37% de PC y 13.8 MJ EM/Kg de materia seca (MS) tienen un producción de calostro de 830 g, a las 10 h postparto, similar a la producción obtenida en ovejas alimentadas con 14% de proteína y 9.3 MJ ME/Kg MS (Banchero *et al.,* 2004b). Sin embargo, en ovejas alimentadas con una dieta baja en proteína (9.6%) y alta en energía (13.6 MJ ME/Kg MS), la producción de calostro es mayor (Banchero *et al.,* 2004ab). Los estudios antes mencionados confirman la correlación negativa de la suplementación preparto con proteína sobre la producción de calostro.

2.3.2 Influencia de la suplementación energética preparto sobre la producción de calostro

En ovejas una suplementación con maíz, alimento alto en energía, durante los últimos 8 días de gestación incrementó la producción de calostro al parto, comparado con aquellas hembras alimentadas en condiciones de pastoreo extensivo y que no recibieron dicho suplemento (206 *vs.* 635 g, respectivamente; Banchero *et al.,* 2007, 2009). Además, en las ovejas suplementadas durante ese periodo, la producción de calostro fue mayor durante las primeras 10 h postparto que las no suplementadas (Banchero *et al.,* 2004b; 2007). De la misma manera, la suplementación energética con maíz durante los últimos 8 días de gestación incrementó la producción de calostro tanto en hembras que paren crías únicas (control; 475 *vs.* suplementado; 730 g) o gemelas (control; 631 *vs.* suplementado; 1,259 g), durante las primeras 10 h postparto (Banchero *et al.,* 2004a; 2007). Los estudios previamente mencionados confirma la importancia de una suplementación energética

durante la gestación tardía para una mayor producción de calostro durante las primeras 10 h postparto.

2.3.3 Efectos fisiológicos y metabólicos de la suplementación energética preparto

En ovejas subnutridas, cuando se les proporciona una suplementación energética durante los últimos días de gestación, la disminución en la concentración de progesterona en plasma es más rápida que en las hembras que no reciben dicha suplementación (Mellor *et al.,* 1987; Banchero *et al.,* 2004ab). Además, la suplementación preparto con maíz incrementó las concentraciones de glucosa en el periparto. Esto es, el maíz proporciona mayor cantidad de almidón para la formación de glucosa, la cual es utilizada para la síntesis de lactosa que finalmente se traduce en una mayor producción de calostro (Banchero *et al.,* 2004ab). Estos hallazgos demuestran la importancia de la energía durante la gestación tardía y su efecto sobre el inicio de la secreción y sobre la producción de calostro.

2.4 Conducta materna temprana en pequeños rumiantes

La conducta maternal consiste en la expresión de una serie de patrones desplegados al final de la gestación, durante y después del parto, con el objetivo de proveer alimento, calor, protección y estímulos sensoriales y sociales necesarios para el buen desarrollo de la cría. Dicho cuidado intenso del neonato, es un evento crítico para su posterior sobrevivencia (Poindron, 2001; Melo y Fleming, 2006).

Las ovejas y cabras gestantes poco antes del parto tienden a aislarse del resto del rebaño (Allan *et al.,* 1991; Lidfors *et al.,* 1994). El objetivo de dicho aislamiento es el de seleccionar el sitio para parir (Lickliter, 1985; Dwyer, 2009). Esto permite proteger al neonato de los depredadores y del robo por otras hembras parturientas. Asimismo, se sabe que este aislamiento permite una mayor interacción entre la madre y su cría, además de facilitar el rápido acceso a la ubre (Poindron *et al.,* 1998; Nowak *et al.,* 2000; Poindron *et al.,* 2007ab). Conforme se acerca el parto, las hembras muestran signos de inquietud (se postran y se levantan continuamente y patalean el suelo), emiten más vocalizaciones y son intolerantes a sus compañeras (Hersher *et al.,* 1963; Das y Tomer, 1997; Poindron, 2001). En presencia de alguna cría ajena, las hembras pueden mostrar una conducta materna completa desde 4 h antes del parto (Poindron, 2001; González-Stagnaro y Madrid-Bury, 2004).

Al parto, después de la expulsión del producto, la hembra limpia y consume mediante lamidos parte de los fluidos amnióticos y membranas que se adhieren a la cría (Lickliter, 1985; Ramírez *et al.,* 1998). Se ha reportado que la finalidad de la limpieza es secar a la cría (mover membranas las cuales podrían sofocar a la cría) y disminuir la hipotermia (Nowak y Poindron, 2006). Posteriormente, la madre con los miembros posteriores le proporciona pataleos leves a la cría para estimularla a que se levante y orientarla a la ubre para que se amamante (Nowak *et al.*, 2007; Dwyer, 2009). Asimismo, en este tiempo, las hembras muestran un mayor número de balidos bajos emitidos con la boca cerrada. Estos balidos orientan al recién nacido hacia la madre, dichos balidos son emitidos exclusivamente sólo en la presencia de la cría, los cuales tienen un

efecto de calma (Sèbe *et al*., 2007, 2008). Asimismo, las hembras muestran una alta respuesta a las llamadas vocales de su cría (González-Mariscal y Poindron, 2002). La comunicación vocal madre-cría es un componente importante para una temprana interacción y posteriormente para un reconocimiento acústico a distancia entre ellos (Vince, 1993; Searby y Jouventin, 2003). La separación madre-cría resulta en un incremento en la emisión de balidos altos emitidos con la boca abierta y una mayor actividad motriz, las cuales cesan cuando se reúne con sus crías (Poindron *et al.,* 1993; Nowak *et al*., 2011).

Así, el consumo de fluidos o de membranas amnióticas y una temprana interacción madre-cría facilita el desarrollo de un vínculo exclusivo madre-cría, el cual se caracteriza por amamantar sólo a su cría y rechazar a cualquier cría ajena que intente amamantarse (Nowak *et al.,* 2000; Nowak *et al.,* 2007; Poindron *et al.,* 2010).

2.5 Mecanismos de reconocimiento mutuo madre-cría

En ovejas y cabras, las relaciones madre-cría se caracterizan por un contacto estrecho entre la madre y sus crías, que a su vez dependen de una habilidad de reconocimiento inter-individual, y que es crítico para la sobrevivencia de las crías. Este reconocimiento mutuo madre-cría es determinado por diferentes mecanismos sensoriales de acuerdo al rango de distancia en que se encuentren, y en el caso de la crías a la edad de la misma. Así, el reconocimiento a corta distancia de la cría por su madre, se refiere a una capacidad de discriminación por contacto directo y en el cual las señales olfativas lo determinan y condicionan la aceptación o rechazo de la cría.

Asimismo, se ha demostrado que la madre debe desarrollar dicha habilidad en virtud de que tanto en ovejas como en cabras, el olor de las crías no difunde a más allá de 50 cm (Alexander y Shillito, 1977a; Alexander, 1978; Poindron *et al*., 2003). Este mecanismo de reconocimiento mediado por el olfato, se refiere a la selectividad materna anteriormente descrita (Keller *et al.,* 2003). Por el contrario, en el caso también de la madre, el reconocimiento a distancia es aquel en el que ella no puede discriminar a su cría de una ajena mediante el olor y por lo tanto hace uso de señales como las auditivas y/o las visuales (Terrazas *et al*., 1999; Ferreira *et al*., 2000; Terrazas *et al*., 2003; Sébe *et al*., 2007).

2.5.1 Reconocimiento madre-cría a distancias cortas

El despliegue adecuado de la conducta materna al parto permite la formación en pocas horas de un vínculo exclusivo con sus crías. Este vínculo restringe el cuidado materno exclusivamente sólo para su progenie y rechazar activamente cualquier cría ajena (selectividad materna; Poindron *et al.,* 1984; Lévy *et al.,* 1995; Poindron *et al.,* 2007b). La formación de este vínculo depende principalmente de memorizar el olor individual de cada cría momentos después del parto (memoria olfativa; Brennan y Kendrick, 2006). Por ejemplo, en ovejas y cabras, una supresión de la percepción olfativa (mediante una anosmia) al parto conduce a la aceptación de cualquier cría al amamantamiento (madres no selectivas; Bouissou, 1968; Poindron, 1976ab; Romeyer *et al.,* 1994). Este tipo de discriminación olfativa es limitada a distancias muy cortas, principalmente para la aceptación al amamantamiento (Poindron y Carrick, 1976; Alexander,

1978; Poindron y Le Neindre, 1980). En cabras y ovejas, se ha demostrado que dicho reconocimiento olfativo debe realizarse a distancias menores de un metro, ya que a una distancia mayor se perturba el reconocimiento olfativo (Alexander, 1978; Poindron *et al.,* 2003). Sin embargo, se ha encontrado que en las madres a las que se les realizó una anosmia un mes antes del parto, mostraron una preferencia por su cría en el primer día postparto durante una prueba de reconocimiento (Ferreira *et al.,* 2000; Poindron *et al.,* 2003). Asimismo, se ha observado que la vista también juega un papel en la aceptación de la cría a la ubre. Algunas ovejas anósmicas rechazan corderos ajenos si éstos son muy diferentes en el color de la cara con la de su propio cordero (Alexander y Shillito, 1977a,b). Además, las ovejas intactas pueden rechazar el amamantamiento a su propio cordero si el pelaje de la cara es pintado de otro color. Esto último, demuestra que otras señales sensoriales también están involucradas en el reconocimiento de las cría por su madre a distancias cortas. Se ha reportado que para una adecuada formación del vínculo selectivo se requiere que la madre y su cría interaccionen durante las primeras 4 h postparto. Cuando el recién nacido es removido antes del contacto con la madre, ésta rechazará a su cría a 4 h después de haberlas separado (Poindron y Le Neindre, 1980). Sin embargo, en cabras y ovejas, un periodo de contacto de tan solo 30 min postparto es suficiente para que la mitad de las madres sean selectivas (Klopfer *et al.,* 1964; Keller *et al.,* 2003). Ello demuestra la existencia de un periodo sensible importante para el establecimiento del vínculo materno-filial y la selectividad materna (González-Mariscal y Poindron, 2002, Poindron *et al.,* 2007a).

2.5.1.1 El periodo sensible y su relación sobre la vinculación materno-filial

En ovejas cabras y vacas, el periodo sensible es generalmente considerado una periodo de transición entre la activación de la conducta materna al parto y finaliza con la formación de un vinculo exclusivo entre la madre y sus crías (Poindron *et al.,* 2001, 2007b; Nowak *et al*., 2011). En ovejas y cabras, este periodo es un factor crítico para el desarrollo y mantenimiento del cuidado materno (Poindron *et al*., 1993). El mantenimiento de la motivación materna depende de la inmediata interacción madre-cría al parto (Poindron *et al.,* 2007a,b). Si a la madre no se le permite el contacto con su cría al parto, la motivación materna de cuidar a sus crías desaparece (González-Mariscal y Poindron, 2002). En estas especies, una separación de 4 h iniciando al parto, el 50% de las madres rechazan a sus crías. Si esta separación es de 12 h, el rechazó a sus crías se incrementa en el 75% de las madres (Poindron y Le Neindre, 1980; Poindron *et al*., 2001, 2007b). Caso contrario, un mayor porcentaje de cabras aceptan a su cría si esta separación es después de un contacto previo después del parto.

La interacción madre-cría al parto es gran importancia para el desarrollo del vínculo selectivo madre-cría (Poindron *et al*., 2007a,b). Al parto, el 21% de las madres están selectivas; a 8 h postparto y después de 30 min de interacción madre-cría el 61% están selectivas (Keller *et al*., 2003; Poindron *et al*., 2007b). Mientras que hembras a las cuales se les restringe dicha interacción por 1 h después del parto, el 64% fallan en la formación del vínculo selectivo a 12 h

postparto contra el 9% de las hembras que se les permitió el contacto con sus crías en ese tiempo (Poindron *et al*., 2007b). En ovejas y cabras, una interacción madre-cría de 4 h sin disturbio después del parto, permite la formación del vínculo exclusivo en más del 90 % de las hembras (Bordi *et al*., 1994; Keller *et al*., 2003; Otal *et al*., 2009; Terrazas *et al.*, 2009). Este contacto durante el periodo sensible permite a la madre identificar el olor individual, el cual es de gran importancia para la formación del vínculo madre-cría y posteriormente facilitar el reconocimiento de la misma (Otal *et al*., 2009; Poindron *et al*., 2010).

2.5.2 Reconocimiento madre-cría a distancia (reconocimiento no olfativo)

En cabras se ha demostrado que las madres pueden reconocer a distancia a su cría sin la ayuda de las señales olfativas (Terrazas *et al*., 2003; Poindron *et al.,* 2003). De hecho, varios estudios en ovejas y cabras muestran que las madres tienen la capacidad de reconocer a su cría a distancias mayores de 1 m sólo con la ayuda visual y acústica (Alexander, 1978; Terrazas *et al.,* 1999; Poindron *et al.,* 2003). En ovejas, este reconocimiento no olfatorio se ha reportado que ocurre ya desde las 8 h postparto (Terrazas *et al.,* 1999) o antes (Keller *et al*., 2003) y a distancias de 10 m de su cría (Poindron y Carrick, 1976). En cabras, la anósmia antes del parto no impidió el reconocimiento de su cabrito en una prueba de elección doble a distancia (Poindron *et al.,* 2003). Es decir, cabras anósmicas invierten un mayor tiempo cerca de su propia cría que las madres intactas. Asimismo, en cabras ha sido comprobado que son capaces de

discriminar entre su cría y una ajena, tan sólo por las señales acústicas a 48 horas postparto (Terrazas *et al*., 2003). Por lo que tanto en ovejas como en cabras evaluadas mediante una prueba de elección doble, sin la ayuda del señales olfatorias muestran una preferencia por su crías a 6 y 4 h postparto (Keller *et al.,* 2003; Poindron *et al.,* 2003). Además, recientemente se ha demostrado que las ovejas tienen la capacidad de reconocer a sus corderos sólo con la ayuda de las vocalizaciones emitida por los mismos a 24 h postparto (Sèbe *et al.,* 2007). Estos hallazgos muestran la importancia que tienen las señales visuales y auditivas emitidas por la cría en el reconocimiento por su madre a distancias mayores a 1 m.

2.5.3 Reconocimiento de la madre por su cría

Los corderos son capaces de identificar a su madre de una ajena entre 12 y 24 h después del nacimiento, mientras que en cabritos se ha reportado que esta habilidad ocurre también a 12 h de vida (Poindron *et al.,* 1993; Terrazas *et al.,* 2002; Poindron *et al*., 2007c; Terrazas *et al.,* 2009). Los estudios realizados tanto en cabritos (Poindron *et al*., 2007c), como en corderos (Terrazas *et al*., 2002), demostraron que la cría basa su elección en el reconocimiento de una conducta general que muestran las madres durante la prueba, en la cual se hace uso de señales visuales, auditivas y olfativas. De esta manera la cría prefiere y es atraída por una conducta materna de aceptación con el despliegue de balidos bajos y menor actividad motriz; mientras que evitan o rechazan a madres que muestra conductas de agitación, como balidos altos, amenazas y alta actividad motriz (Terrazas *et al.,* 2002). A 12 h de vida las crías pueden

discriminar a su madre en un corral que permita un contacto estrecho (< 50 cm de distancia entre ellos) y después de 3 días de edad a algunos metros de distancia (Nowak, 1990a,b; Nowak *et al.,* 2000). En ambos proceso de reconocimiento sólo se involucra la percepción acústica y visual de las señales emitidas por la madre (Nowak, 1991; Terrazas *et al.,* 2002). En corderos, la capacidad de reconocer a su madre sólo con la ayuda de sus vocalizaciones reproducidas con la ayuda de bocinas ocurre hasta las 48 h después del nacimiento (Sèbe *et al.,* 2007, 2008). A edades mayores, Ruíz-Miranda (1992, 1993), sugirió que los cabritos de 2 a 4 meses de edad utilizan el color del pelaje para distinguir a su madre de otras al buscarla dentro del rebaño.

2.5.3.1 Importancia de los primeros amamantamientos sobre el reconocimiento de la madre por su cría

El reconocimiento y preferencia hacia la madre depende de los primeros amamantamientos al nacimiento (Nowak *et al.,* 2007). Por ejemplo, corderos a los cuales se les permite el amamantamiento durante las primeras 6 h tienen una mayor preferencia por sus madres que a madres ajenas que los corderos a los que se les restringió el amamantamiento durante los primeras 6 h después del nacimiento (Nowak *et al.,* 1997, 2011). Además, los corderos que logran un consumo temprano de calostro tienen una mejor capacidad para reconocer a su madre a 24 h después de nacer que los que no lo consumen (Goursaud y Nowak, 1999; Val-Laillet *et al.,* 2004). Esto demuestra la importancia de la disponibilidad e ingestión de calostro al nacimiento para mejorar la interacción madre-cría y posteriormente para un reconocimiento temprano.

2.6 Factores que influyen sobre la relación madre-cría

2.6.1 Experiencia materna

La capacidad de la madre en desplegar una adecuada conducta materna al parto es influenciada por la experiencia. Esto es muy palpable en ovejas primerizas, en donde hasta el 50% de la hembras muestran una perturbación en el despliegue de la conducta al parto (Poindron, 2005). Es decir, el porcentaje de hembras que aceptan amamantar a su cría es mayor en ovejas con experiencia que en aquellas sin partos previos. Asimismo, las hembras primerizas muestran más conductas agresivas hacia su cría que las hembras multíparas (Dwyer y Lawrence, 2000). Los corderos de madres inexpertas muestran un retardo en la respuesta para amamantarse (Dwyer, 2003). En casos extremos, las ovejas primíparas no despliegan una conducta materna y abandonan a sus crías, lo cual conlleva a la muerte del recién nacido (Dwyer y Lawrence, 1998). Sin embargo, después de 2 h postparto, las madres multíparas y primíparas muestran en promedio la misma cantidad de balidos bajos maternales y de conductas de limpieza (O´Connor *et al.,* 1992; Dwyer y Lawrence, 2000). Esto indica que la experiencia maternal es adquirida mediante los primeros contactos de la madre con su cría durante las primeras horas después del parto, formándose así una “memoria maternal”. Por consiguiente se ha demostrado que una hora de interacción previa con su cría es suficiente para que la madre muestre una buena conducta materna 10 h después de separarlas (Dwyer y Lawrence, 1998; Lee *et al.,* 1999; Poindron, 2005). Por su parte, la experiencia materna también perturba la capacidad de la madre para

reconocer a su cordero a distancia, de esta manera se observó que las hembras primíparas no fueron capaces de discriminar a su cordero de uno ajeno a las 6 h postparto, mientras que las multíparas sí lo hicieron (Keller *et al*., 2003).

2.6.2 Influencia de la vitalidad y peso de la cría al nacimiento sobre la relación madre-cría

La conducta del neonato es de gran importancia para la formación del vínculo selectivo, es decir, que la madre amamante exclusivamente a su propia cría y rechace cualquier otra cría ajena. La conducta de la cría al nacimiento es afectada por diversos factores como el cuidado materno, el peso de la cría al nacimiento y el vigor de la misma (Klopfer y Klopfer, 1977; Dwyer *et al.,* 2003). Sin embargo, la vitalidad de la cría también se ve afectada por factores como la duración del parto y el estado nutricional de la madre. Los corderos poco vigorosos al nacimiento, debido a una deficiente nutrición de sus madres durante la gestación, tardan más tiempo para levantarse después de nacidos y en buscar la ubre para amamantarse. Por el contrario, en crías vigorosas, dichas latencias fueron más cortas (Dwyer *et al.,* 1996, 2003; Mathenson *et al.,* 2011). Como se mencionó anteriormente, un proceso de parto prolongado reduce la vitalidad del cordero al nacimiento e incrementa la latencia en la conducta de búsqueda de la ubre y en el amamantamiento (Dutra y Banchero, 2011). Resultados similares se han observado en becerros nacidos de vacas que presentan dificultad al parto los cuales mostraron un vigor reducido durante las primeras 3 h de vida (Barrier *et al.,* 2011). En ovinos, este efecto puede ser

corregido cuando se proporciona un suplemento energético 14 días antes del parto, el cual incrementa el peso y el vigor en crías (simples o dobles; Murphy, 1999) al nacimiento. Esto podría explicarse por una mayor disponibilidad energética en las crías, y de este modo, muestran un mejor desempeño conductual de la cría al nacimiento. Los efectos de una adecuada vitalidad de la cría y de un peso adecuado a su nacimiento tienen repercusiones importantes sobre el cuidado materno que la cría reciba al nacimiento. En efecto, Klopfer y Klopfer (1977) reportaron en cabras que las crías más vigorosas tienen un mejor cuidado de sus madres que las crías menos vigorosas. A su vez, lo anterior puede mejorar la interacción mutua y ello resultar en la formación temprana del vinculo madre-cría (Nowak *et al.,* 1997; Nowak y Poindron, 2006; Poindron *et al.,* 2007a,b).

2.6.3 Efecto de la nutrición sobre la interacción madre-cría

Una mala nutrición durante la gestación prolonga el inicio de la interacción oveja-cordero al parto; además, las madres subnutridas durante la gestación mostraron más conductas agresivas hacia su cría e invirtieron mayor tiempo comiendo que atendiendo su cría en la primera hora postparto (Thompson y Thompson, 1949). Asimismo, en ovejas primíparas una subnutrición moderada durante la gestación (proporcionando sólo el 65% de sus requerimientos) provocó que las madres lamieran menos a sus corderos que las ovejas alimentadas con el 100% de sus requerimientos (Dwyer *et al.,* 2003). Además, dicha restricción nutricional en las madres gestantes provocó una disminución en el peso del cordero al nacimiento, los cuales, como fue mencionado

anteriormente, fueron más lentos para incorporase y mostraron menos actividad de amamantamiento que los corderos provenientes de madres bien nutridas (Dwyer *et al.,* 2003).

En animales en pastoreo, se reportó que las ovejas mantenidas en campos con una adecuada disponibilidad de forraje durante la gestación tardía emiten mayor número de balidos maternales a 12 h postparto que las madres mantenidas en campos con pobre disponibilidad de forraje durante la gestación tardía (Corner *et al.,* 2010). El mismo efecto se observó en sus crías, de modo que aquellas provenientes de ovejas mantenidas en campos con mayor disponibilidad de forraje tuvieron mayor frecuencia de emisión de balidos bajos (señal de calma; Nowak *et al*., 2011) que las crías de madres mantenidas en campos con menor disponibilidad de forraje (Corner *et al.,* 2010). También, se ha encontrado en cabras que cuando sólo se les proporciona el 70% de sus requerimientos nutricionales (de energía y proteína), durante la segunda mitad de gestación las hembras limpian menos tiempo a su cría. El efecto es más marcado en los cabritos nacidos de madres subnutridas, los cuales muestran una mayor latencia para levantarse, buscar y alcanzar la ubre que crías nacidas de madres bien alimentados (Robledo, 2005; Terrazas *et al.,* 2009).

3. PLANTEAMIENTO DEL PROBLEMA

Está bien determinado que la formación de un vínculo exclusivo de la madre con sus crías es un elemento esencial de la conducta maternal en cabras. La expresión de una conducta materna adecuada después del parto depende, en mucho, de la participación propia de la madre y también del desempeño de las crías. Primero, la madre deberá mostrar un interés completo hacia su cría, a la cual dirigirá los cuidados maternos. Segundo, durante este proceso es muy importante la vitalidad y el comportamiento que la cría despliegue una vez que nace, lo cual podría depender a su vez de su peso al nacer. Es decir, que las crías se levanten lo más pronto posible después de nacer, que busquen activamente el acceso a la ubre y que logre amamantarse. Mientras que la mayoría de los estudios sobre las características y factores que afectan la conducta maternal en los pequeños rumiantes han sido realizados en animales bien nutridos experimentalmente, poco se ha estudiado sobre las características de la conducta materna en animales subnutridos al ser mantenidos en pastoreo natural.

En cabras y ovejas, diversos factores internos y externos influyen sobre el establecimiento y la expresión adecuada de la conducta materna. Entre los cuales están involucrados la conducta del neonato, la temprana ingestión de calostro, la experiencia materna, el temperamento materno, y la nutrición de las madres durante la gestación (Dwyer, 2008). En efecto, se conoce que una subnutrición inducida durante la gestación afectó adversamente la producción de calostro y la conducta de las madres y de sus crías en comparación con los

animales bien nutridos. Sin embargo, una suplementación con maíz durante los últimos 8 días de gestación incrementó la disponibilidad de calostro al parto.

Las cabras de regiones subtropicales, como las localizadas en el norte de México que son mantenidas bajo condiciones de pastoreo semiárido, están sometidas a través del año, a variaciones estacionales en la disponibilidad y en la calidad del forraje (Sáenz-Escárcega *et al.,* 1991). Por lo general, se ha reportado que bajo esas condiciones de producción los animales no cubren el 100% sus requerimientos nutricionales (Ramírez *et al.,* 1991). En ocasiones, la reducción de la cantidad y calidad del pastoreo en los agostaderos semi-áridos coincide con el periodo de mayor demanda nutricional de las cabras durante estados tardíos de la gestación. Es decir, cuando ocurre hasta el 90% del crecimiento y desarrollo fetal, el desarrollo de la glándula mamaria y la posterior producción de calostro, lo cual generalmente se presenta durante los últimos 45 días de gestación (Robinson, 1990; Rhind *et al.,* 2001). En el norte subtropical de México el 80% de los partos de las cabras ocurre entre noviembre y febrero, durante la estación seca, cuando la disponibilidad de forraje es limitada. Esto último se asocia con una disminución considerable en el estado metabólico de las hembras parturientas.

Considerando lo anterior, en la presente tesis se postula que en las cabras mantenidas en pastoreo extensivo, como las descritas anteriormente, la inclusión de maíz en la dieta, alimento alto en energía, incremente la disponibilidad de calostro para la cría al nacimiento. Entre otras hipótesis, es probable que dicha inclusión mejore la conducta de la madre y de las crías después del nacimiento.

Por ello, el objetivo general de la presente tesis es investigar si la inclusión de maíz, alimento alto en energía, en la dieta de cabras en pastoreo extensivo durante los últimos 12 días de gestación, incrementa la producción de calostro y mejora la vinculación temprana madre-cría.

4. OBJETIVOS DEL PROYECTO DE TESIS

Objetivo general

Investigar si la inclusión de maíz, alimento alto en energía, en la dieta de cabras en pastoreo semiárido extensivo durante los últimos 12 días de gestación incrementa la producción de calostro y mejora la vinculación temprana madre-cría.

Objetivos específicos

Experimento 1

Determinar en cabras si la inclusión de maíz en la dieta de pastoreo semiárido, durante los últimos 12 días de gestación incrementa la producción de calostro y mejora el comportamiento de la cría al nacimiento.

Experimento 2

Investigar en cabras si la inclusión de maíz en la dieta de pastoreo semiárido durante los últimos 12 días de gestación mejora la conducta materna al parto y fortalece la formación del vínculo selectivo madre-cría a 3 h postparto.

Experimento 3

Determinar si la suplementación con o la inclusión de maíz en la dieta durante las últimas 2 semanas de gestación mejora la capacidad de reconocimiento mutuo madre-cría en cabras subnutridas de manera experimental y en cabras mantenidas en pastoreo extensivo natural.

5. HIPÓTESIS DE TRABAJO

Hipótesis experimento 1

En cabras bajo pastoreo semiárido, la inclusión de maíz en la dieta, durante los últimos 12 días de gestación incrementa la producción de calostro y mejora el comportamiento de la cría al nacimiento.

Hipótesis experimento 2

En cabras, la inclusión de maíz en la dieta de pastoreo semiárido durante los últimos 12 días de gestación mejora la conducta materna al parto y fortalece la formación del vínculo selectivo madre-cría a 3 h postparto.

Hipótesis experimento 3

En cabras, la suplementación con o la inclusión de maíz en la dieta durante las últimas 2 semanas de gestación mejora la capacidad de reconocimiento mutuo madre-cría en cabras subnutridas de manera experimental y en cabras mantenidas en pastoreo semiárido extensivo.

6. ARTÍCULOS CIENTÍFICOS OBTENIDOS DEL PROYECTO DE TESIS

Artículo 1. **S. Ramírez-Vera,** A. Terrazas, J. A. Delgadillo, N. Serafín, J. A. Flores, J. M. Elizundia and H. Hernández. Feeding corn during the last 12 days of gestation improved colostrum production and neonatal activity in goats grazing subtropical semi-arid rangeland. J. Anim. Sci. (2012), doi:10.2527/jas.2011-4306.

Artículo 2. **S. Ramírez-Vera,** A. Terrazas, J.A. Delgadillo, J.A. Flores, J. Vielma, G. Duarte, G. Fitz-Rodríguez, I.G. Fernández, N. Serafín and H. Hernández. Inclusion of maize in the grazing diet of goats during the last 12 days of gestation reinforces the expression of maternal behaviour and selectivity during the sensitive period. Livest. Sci. (sometido).

Artículo 3. **S. Ramírez-Vera,** H. Hernández, J. A. Delgadillo, R. Santiago, D. Merino-Lima, J. A. Flores, H. Sánchez, J. Vielma, G. Duarte and A. Terrazas. Supplementation with maize during late gestation improves mutual recognition in goats and kids underfed either experimentally or under natural extensive grazing conditions.

ARTÍCULO 1

Feeding corn during the last 12 days of gestation improved colostrum production and neonatal activity in goats grazing subtropical semi-arid rangeland

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Feeding corn during the last 12 days of gestation improved colostrum production and neonatal activity in goats grazing subtropical semi-arid rangeland[7,8]

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ABSTRACT. The objectives were to investigate if partial substitution 20 of a grazing diet with a supplemental high-starch feed during the last 12 d of gestation improved colostrum yield and neonatal activity in does grazing semi-arid rangeland. For the first objective, 25 pregnant does were randomly assigned to 1 of 2 treatments: (1) grazing only (control; n = 11), and (2) grazing plus 0.6 kg/d of supplemental corn (as fed), a high starch feed, during the last 12 ± 1.0 d before parturition (SC; n = 14). Colostrum was collected at parturition and again at 1, 3, 6, and 10 h postpartum for yield and composition. In all goats, blood concentrations of glucose and plasma progesterone were determined. Total colostrum yield/10 h was greater (P = 0.002) in the SC does (1,102 ± 144 g) than in control does (405 ± 50 g). From 6 to 10 h postpartum, contents of colostrum protein and solids not fat were lower (P ≤ 0.012) whereas lactose contents were greater (P = 0.035) in the SC does than in control does. Concentration of glucose in the blood at parturition was greater (P = 0.037) in the SC does (160 ± 13 mg/dL) than in control does (115 ± 12 mg/dL). A significant decrease in plasma progesterone concentrations occurred 1 d before parturition in control does, whereas the decrease occurred 3 d before parturition in SC does. For the second objective, 20 does (10 per group) and their single kids were randomly assigned to the same treatments as above for evaluation of dietary treatment on neonatal activity. Kid activity was assessed using videos recorded during the first 90 min after birth. Frequency of low-pitched bleats was greater (P< 0.001) in kids of SC does than in kids of controls. Frequencies and durations of teat seeking from 30 to 90 min after birth and of suckling activity were greater (P ≤ 0.015) in kids of SC does than in kids of controls. Duration of parturition was longer (P = 0.001) in control does (58 ± 10.2 min) than in SC does (21 ± 2.8 min). Finally, percentage of fetal malpresentation was greater (P = 0.036) in control does (33.3%) than in SC does (9.0%). We conclude that partial substitution of the grazing diet with a high-starch feed, corn, during the last 12 d of gestation improved colostrum yield and neonatal activity in goats grazing subtropical semi-arid rangeland.

Key words: colostrum, energy, gestation, goat, neonatal activity, parturition

INTRODUCTION

Ewes and does kept under poor grazing conditions mobilized body reserves during the last 6 wk of gestation due to fast fetal growth and colostrum yield (Hussain et al., 1996; Meyer et al., 2011). Poor nutrition may reduce the survival rate of neonates by reducing colostrum availability, which is critical for optimal health and bonding of the newborn (Nowak et al., 1997). In ewes, poor feeding during gestation delays lactogenesis, because of a slow prepartum decline of plasma progesterone (Mellor et al., 1987). On the contrary, a high-energy supplement during late gestation hastened this progesterone decline and increased colostrum availability for the lamb (Hall et al., 1992; Banchero et al., 2007). Poor gestational nutrition also affects neonatal behavior at birth. For example, in nulliparous ewes, reducing daily nutritional supply to 35% of requirements during the last 4 mo of pregnancy impaired neonatal behavior by reducing the lamb's birth weight (Dwyer et al., 2003); low-birth-weight lambs were slower to stand than heavier lambs and suckled less frequently. Similar results have been observed in newborn kids from underfed goats (Terrazas et al., 2009).

Eighty percent of goats in the world inhabit subtropical semi-arid regions (Knights and Garcia, 1997), in which availability of good quantity and quality forage is limited throughout the year (Ramírez et al., 1991). In these regions, 80% of parturitions occur between November and February, during the dry season, when feed availability is limited.

MATERIALS AND METHODS

Location and Grazing Conditions

Animals were cared for in accordance with guidelines outlined by an Institutional Animal Care and Use Committee (IACUC).

Studies were conducted in the Comarca Lagunera region in the northern part of subtropical Mexico (25° 36´N). This region possesses a semi-arid climate where the mean annual rainfall is about 266 mm (range: 163 to 504 mm) from June to September. The dry season is characterized by a dramatic decrease of food available for grazing,

with a shortage of pasture lasting from October to May (Sáenz-Escárcega et al., 1991). In this region, does are bred under natural conditions, eating only the available natural pasture. Animals graze daily from 0900 to 1800 h, and during the night they are sheltered in pens. The vegetative species available in grazed areas in this region consist mainly of shrubs (*Prosopis glandulosa, Acacia farneciana, Atriplex acantocarpa, Agave scabra, and Mimosa biuncifera*), herbaceous plants (*Heliantus ciliaris, Salsola kali, and Solanum elaeagnilolium*), and grasses (*Sorghum halepense, Chloris virgata, Setaria verticillata, Eragrostis pectinacea, Bouteloua curtipendula, Aristida purpurea, and Bouteloua barbata*). Throughout the year, the composition of goat diets in the Comarca Lagunera region was made up of around 82% shrubs, 12% herbaceous plants, and 6% grasses (Ramírez et al., 1991). A study by Juárez-Reyes et al. (2004) in this region reported that pregnant goats maintained under semi-arid grazing conditions consumed, on average, 1.2 kg/d DM and 2.1 Mcal/d of ME DM from this diet, which does not meet their maintenance and production nutritional requirements.

Animals, Experimental Treatments, and Peripartum Management

Multiparous does (n = 45) 3- to 4-yr-old were used. Does were mated in May by means of the "male effect" technique as described by Delgadillo et al. (2006). Twenty days before the mean expected date of delivery, does were assigned to 2 treatment groups balancing for their initial BW (50.2 ± 1.9 kg; mean ± SEM), BCS (1.9 ± 0.07 points), and body mass index (BMI; 9.6 ± 0.3 points). During the day, both groups of does were maintained under the same outdoors grazing conditions and returned to their pen at night (1 pen per group). Treatments were: (1) grazing only (control), and (2) grazing plus 0.6 kg/d of supplemental corn, a high-starch feed, during the last 12 ± 1.0 d before parturition (SC). The control does (n = 21) did not receive any additional feed. Pregnant does assigned to the SC group (n = 24) received daily 0.6 kg of flaked corn/doe (as-fed basis) on average during the last 12 ± 1.0 d of gestation. Corn was offered individually to each doe using small buckets in 2 parts, 0.3 kg in the morning before grazing and 0.3 kg in the afternoon when the animals returned to their pens. Previous studies have shown that goats consumed an average 135 g of CP/kg DM and 2.1 Mcal/d of ME (Juárez-Reyes et al., 2004; Cerrillo et al., 2006). Offered corn substituted a part

of the grazing diet giving 87.3 g of CP/kg DM and 3.06 Mcal of ME/kg DM. In the pens, does of both groups had free access to clean fresh water and mineral blocks, which were provided in 25-kg blocks (Cebú, Salinas del Rey, Torreón, México) and containing at least 17% P, 3% Mg, 5% Ca, and 75% NaCl, as recommended by NRC (2007). In the morning, when females were taken out to graze, those showing clear signs of imminent parturition (i.e. restlessness, frequent vocalizations, isolation from the conspecifics, abdominal straining, presence of birth fluids or hooves of kid) were placed in pens together with other does, regardless of their experimental group. From this time, does that kidded were kept in a common pen and daily fed alfalfa hay (1.0 kg/doe), which provided 50% of their nutritional requirement (170.0 g of CP/kg DM and 1.9 Mcal of ME/kg DM), and had ad libitum access to water.

Colostrum Production, Blood Glucose, and Plasma Progesterone

Eleven and 14 does were randomly selected from the control and SC treatment groups, respectively, to determine the effect of dietary treatment on colostrum production and composition, and prepartum blood glucose and plasma progesterone concentrations. Does were monitored 24 h/d to know the exact time of parturition. Quantity of colostrum was measured in one half of the udder (i.e., "collection half") immediately after a doe finished kidding and at 1, 3, 6, and 10 h postpartum. For each collection, 5 IU of oxytocin (Oxilac, Proquivet, Guadalajara, México) was administered intravenously to ensure colostrum ejection and recovery of any residual colostrum remaining after milking. The collection half was completely hand-milked, colostrum was weighed, and a 20-mL sample of colostrum was kept on ice and transported to the laboratory for analysis of fat, protein, lactose, solids not fat, and percentage of solids, using a Milkoscan 6000 (Foss Electric, Hillerød, Denmark). To prevent suckling of the collection half, the teat was covered with tape so that kids were prevented to access this half for the first 10 h postpartum. We ensured that the kids suckled the available colostrum from the other half of the udder. When the collection period ended, kids were allowed ad libitum access to both halves of the udder. Furthermore, we took every precaution to not disrupt bonding of the kid to the doe during colostrum sampling.

Glucose concentration in does was measured in blood samples obtained by jugular venipuncture at 0700 h on d -21, -14 pretreatment, and during treatment period (i.e. just before the substitution with corn) on d -7, -6, -5,-4, -3, -2, -1 before birth, at birth and at 1, 2, 4, and 8 h postpartum. Glucose was immediately measured using a single drop of whole blood with a blood glucose meter and sensor electrodes as previously described in ewes (Banchero et al., 2004a; Accu Chek Sensor Comfort, Roche, Mexico). The accuracy of the procedure was of 95%, and the correlation with a glucose assay in plasma was 0.994.

Plasma progesterone was measured from blood samples (5 mL) obtained by jugular venipuncture using heparinized plastic tubes (30 μL; Inhepar Pisa, Guadalajara, Mexico) at d -7, -6, -5,-4, -3, -2, -1 before parturition, at parturition, and at 1 and 18 h postpartum. Samples were centrifuged at 2,147 × g for 10 min at 4°C and plasma was stored at -20°C until analysis. Concentrations of progesterone in plasma were determined by solid-phase RIA (Coat-A-Count progesterone kit, Siemens, Los Angeles, CA, USA; Abraham, 1981), with an intra-assay coefficient of variation of 1.04%, and sensitivity of the assay was 0.02 ng/mL.

Neonatal Activity

The remaining does from each treatment group (n = 10 per group), which were not used for determining colostrum production, were used to determine the effect of dietary treatment on activity of their neonate. Does had given birth to a single kid. When a doe was displaying signs of imminent parturition (i.e. restlessness, frequent vocalizations, isolation from the conspecifics, abdominal straining, presence of birth fluids or hooves of kid), it was gently moved to an individual pen of 2 m^2 , located at least 50 m from the rest of flock. Doe-kid interactions were recorded during the first 90 min after the expulsion of the kid, using a Sony camcorder (model V-8, Japan) placed on a tripod outside of the individual pen. Activities of the subjects were described aloud by an observer and this description was recorded by the camcorder to facilitate later analysis of the video-recordings in the laboratory. Video recordings were analyzed using the Observer Video-Pro software (version 4.0; Noldus, The Netherlands). The 90 min

recording of the doe-kid interactions were analyzed in 3 consecutive 30-min periods from birth of the kid to 90 min postpartum.

Latency, frequency and/or duration of the following activities of the kids were measured: low-pitched bleats = emission of bleats by the kid with mouth closed; teat seeking = extension of the head, and muzzle in contact with the body of the mother as it tried to reach the udder; sucking activity = sucking the teat of the mother for more than 5 s without interrupting.

Assistance at kidding, BW, BCS, and BMI

Assistance and Duration of Kidding. All does and kids in each treatment group were used to determine the effect of dietary treatment on instances of birthing assistance and duration of kidding. At delivery, does were observed and, in case of dystocia, they were assisted. Does were allowed to give birth and care for their newborn kids without human intervention for 1 h after rupture of the water-bag or the appearance of some part of the kid (usually the hooves). However, kidding assistance was provided if the does had failed to progress after this time. When intervention was necessary, it was kept to a minimum and mainly involved correcting malpresentation of the kid. After intervention, the doe was left undisturbed for the birth process to proceed. Assistance at delivery was scored as without assistance (presentation correct and doe delivered unaided) or manual assistance (malpresentation necessitating assistance). Duration of labor was also recorded and was defined as the time elapsed between the appearance of fluids and the expulsion of the kid.

Body Weight, BCS, and BMI. All does and kids in each treatment group were included to determine the effect of dietary treatment on BW, BCS, and BMI. Kids were weighed just after birth. For does, BW, BCS and BMI were measured every 20 d during the first 4 mo of gestation, and every week during the last month up to parturition. Does and kids were weighed on a mobile scale with a 200-kg capacity and a precision of 0.05 kg. The BCS was determined using the method previously described for this specie by Walkden-Brown et al. (1997), which considers a scale point from 1 (very lean) to 4 (fat). Finally, the BMI was calculated by means of the procedure described by Tanaka et al. (2002) as follows:

BMI = [BW, kg / withers height, m / body length, m × 10]

Statistical Analyses

All statistical analyses were performed using the software SYSTAT 13 (Chicago IL). Two series of statistical analyses were computed separately to compare the changes in BW, BMI, blood glucose concentrations: one was performed taking into account data collected before the start of feeding corn, to test for a possible grouping effect; in the other series of analyses, only data collected during treatment was considered, to test for the effect of dietary treatment. In each period, an ANOVA (GLM procedure of SYSTAT) with treatment in the model statement was used. Plasma progesterone concentrations and colostrum production were analyzed using the same procedure. Separate individual independent t-tests with Bonferroni adjustments were also performed to compare groups at each time point. The weights of the kids were compared between the 2 groups using this same procedure. All dependent variables were included as repeated measures. Because of the ordinal nature of the data for BCS, this variable was analyzed for a week effect within each group using the Friedman test, whereas the Mann-Whitney U test was used for comparison between the 2 groups at a given time. Statistical analyses of individual activity parameters of kids were analyzed with nonparametric tests (two-tailed) because of the lack of normality of the data. Frequency of kids activities at birth in the control and the SC groups were analyzed by means of Fisher exact test considering a random distribution. Data concerning assistance and duration of kidding were analyzed using the Chi-square (χ^2) and the t test for independent data, respectively. Exact values of P are indicated in the text and the level of statistical significance was set at $P \leq 0.05$.

Effect of Dietary Treatment on Colostrum Yield, Blood Glucose, and Plasma Progesterone

Ten does from the control group kidded 10 single kids and 1 kidded twin kids, whereas in goats from the SC does, these values were 12 and 2, respectively.

Colostrum Yield. At kidding, the amount of colostrum accumulated in one collection half was greater in SC does than in control does ($P = 0.002$; Figure 1). Similarly, colostrum yield during the subsequent first 10 h was greater in SC does than in control does ($P \leq 0.025$; Figure 1). Thus, total colostrum yield during the first 10 h postpartum was greater in SC does than in control does ($P < 0.001$; Figure 1).

Colostrum Constituents. The percentages of fat in the colostrum at kidding and during the first 10 h post-kidding did not differ between SC and control does ($P \geq 0.183$; Table 1). The percentage of protein in colostrum was greater ($P \leq 0.012$; Table 1) for the control does than for the SC does from 3 h postpartum onwards. This was also the case for content of solids not fat in colostrum ($P \leq 0.017$; Table 1). At 6 and 10 h after kidding, lactose content in colostrum was greater in SC does than in control does ($P = 0.035$; Table 1). The percentage of total solids of colostrum was greater only at 10 h post-kidding in control does compared with SC does ($P = 0.005$; Table 1).

Peripartum Blood Glucose Concentrations. Blood glucose concentrations did not differ between groups before dietary treatment ($P = 0.524$) and no pretreatment time effect was observed ($P = 0.924$). Similarly, no interaction pretreatment time × group was found ($P = 0.650$). However, at d 7, 5, and 4 pre-kidding, blood glucose concentrations were greater in SC does than in control does ($P \leq 0.045$; Figure 2). At kidding, as well as 1 and 2 h post-kidding, glucose concentrations were greater in SC does than in control does ($P \leq 0.037$). In both groups, glucose concentration in blood increased at birth and decreased after (time effect, $P < 0.001$; Figure 2).

Peripartum Concentrations of Plasma Progesterone. Plasma progesterone concentrations in control does were greater at d -6, -4 and -3 before parturition than in SC does ($P \leq 0.036$; Figure 3). Similarly, at kidding and at 1 h post-kidding, plasma progesterone concentrations were greater in control does than in SC does ($P \leq 0.019$). Compared with d -7, the concentrations of plasma progesterone were significantly lower already at d -3 in SC does, whereas in control does a decrease was not found until d -1 pre-kidding ($P = 0.008$ and $P = 0.001$, respectively; Figure 3).

Effect of Dietary Treatment on Neonatal Activity

Does from the control group gave birth to 5 male kids and 5 female kids, whereas in goats from the SC group, these values were 4 and 6, respectively.

Emission of Low-pitched Bleats. The latency of emission of low-pitched bleats did not differ between kids born from SC does and those born from control does ($P = 0.226$; Figure 4). In contrast, the number of low-pitched bleats emitted was greater in kids born from SC does than in those born from control does during the first 90 min after birth ($P < 0.001$; Figure 4).

Teat Seeking. The time from birth to teat seeking did not differ ($P = 0.29$) between kids of the 2 treatment groups (Table 2). During the first 2 periods after birth, the frequency of teat seeking was greater in kids born from SC does than in kids born from control does ($P \leq 0.004$). In addition, the mean duration of this activity tended to be greater during the period of 30 to 60 min after birth in kids born from SC does than in kids born from control does ($P = 0.06$; Table 2). Similarly, during the last period, duration of teat seeking was greater in kids born from SC does than in kids born from control does ($P = 0.034$; Table 2). Values for frequency and duration of this activity also varied between the observation periods (time effect, $P < 0.001$).

Sucking Activity. Latency to display sucking activity did not differ between both groups of kids ($P = 0.131$). However, from 30 to 90 min after birth, kids born from SC does sucked more frequently and for longer than kids born from control does ($P \leq 0.011$ and $P \leq 0.015$, respectively; Table 2). Duration but not frequency of this activity varied between the observation periods (time effect, $P < 0.01$).

Effect of Dietary Treatment on Assistance at kidding, BW, BCS, and BMI

Assistance and Duration of Kidding. The duration of the parturition process was longer in the control does than in the SC does (58 ± 10.2 vs. 21 ± 2.8 min, respectively; $P = 0.001$). A greater percentage (33.3%, 7/21) of the kids born from control does were malpresented than of kids born from SC does (9.0%, 2/22; $P = 0.036$).

Body Weight, BCS, BMI and Kids Birth Weight. In both groups, BW, BCS and BMI varied throughout the pretreatment period (time effect, $P < 0.001$) whereas no time × group interaction was found ($P \geq 0.161$). Besides, BW did not differ throughout the

pretreatment period between the 2 groups. Body mass index at parturition tended to be greater in the SC does than in control does ($P = 0.06$; Figure 5). On the other hand, BCS of SC does at parturition was greater than in control does ($P = 0.001$; Figure 5). However, during the feeding corn period, time had an effect on BW, BCS and BMI ($P < 0.001$) and an interaction time × group was found for the 3 variables ($P \leq 0.007$; Figure 5). In both groups, BW and BMI increased before parturition and decreased at that time, whereas BCS decreased ($P < 0.001$) during the pretreatment and dietary treatment periods until birth. Birth weights of the kids were pooled and no difference was found between the 2 groups (controls: 3.2 ± 0.08 kg; n = 22; SC group: 3.3 ± 0.06 kg; n = 26; $P = 0.21$).

DISCUSSION

Our hypothesis that partial substitution of grazing diet with supplemental corn during the last 12 d of gestation increases goat colostrum production and improves the newborn kid's activity was supported by the present study. Our results show for the first time in goats maintained under semi-arid natural grazing rangeland, the strong beneficial effects of substituting a portion of the grazing diet with supplemental high-starch feed during late gestation on the dams' lactogenesis and corporal state. Furthermore, this feeding strategy during late gestation significantly improved the activity of the neonates.

Increased colostrum yield that we found in the present study in SC does at parturition and during the first 10 h postpartum, is congruent with recent reports in ewes. In these reports, supplementation with corn or barley during the last 8 d of gestation increased the quantity of colostrum available at parturition (Banchero et al., 2004a,b, 2007, 2009). In the ewe, the starch provided by corn is a source of energy that contributes to increase blood glucose; this, in turn, increases lactose synthesis, and thus, colostrum yields (Hodgson et al., 1991; Landau et al., 1999; Banchero et al., 2006, 2007). Greater blood glucose concentrations observed in our corn-fed goats suggested that the same mechanism occurred in the goat to increase colostrum yield. Interestingly, in our study we also found that feeding supplemental corn prepartum also increased the concentration of lactose in colostrum, indicating that partial substitution of the grazing

diet with a high-starch feed had a beneficial effect on colostrum quality in the goat as reported in ewes (Banchero et al., 2004a).

However, a greater availability of glucose for colostrum synthesis is not the only mechanism by which greater dietary energy increased colostrum yield. Another consequence of greater energy in late pregnancy is to facilitate the decrease of plasma progesterone concentrations at the end of pregnancy, which explains why this decrease occurred earlier in SC than in control does. This is in agreement with previous reports in the ewe (Mellor et al., 1987; Hall et al., 1992). This early decrease of progesterone is important, because when progesterone decrease is delayed, it also results in delaying the onset of colostrogenesis (Hall et al., 1990; O´Doherty and Crosby, 1996). Prepartum decrease in circulating concentrations of plasma progesterone is considered to be the lactogenic trigger in many species, including humans (Kuhn, 1969; Delouis, 1978; Neville, 2001; Foisnet et al., 2010). Thus, the faster decrease in plasma progesterone concentrations observed in our SC does compared with control does may explain the greater quantity of colostrum available to the neonate in the first hours postpartum. To our knowledge, it is the first time that the relations between blood glucose, plasma progesterone concentrations, and colostrum yield are associated with the level of energy just before parturition in goats grazing poor-quality pasture.

In our study, improvement of kids' activity at birth by increased maternal dietary energy, confirmed recent results in goats that received 100% of their nutritional requirements during gestation (Terrazas et al., 2009). In this latter study, newborn kids born from well-fed goats were faster to stand, to search for the udder and to reach it than kids born from experimentally underfed goats, which were fed 30% below their nutritional requirements for energy and protein (Terrazas et al., 2009).

In addition, the greater frequency of low-pitched bleats observed in newborn kids from SC does than in control does agrees also with observations made in lambs by Corner et al. (2010). These authors found that lambs born from ewes having an adequate pasture (sward height of 4 cm) during gestation emitted more low-pitched bleats than lambs born from ewes maintained on pasture with a lower sward height (2 cm), suggesting a reduced vigor of these latter lambs. Therefore in our study, a greater frequency of vocalization in kids from SC does suggested that greater maternal dietary

energy resulted in an increased vigor of kids. Furthermore, this increase in vocalizations appeared partly independent from the increase in colostrum yield and quality because it was present before the kids started to suck. Similarly, the elevated frequency and duration of teat-seeking activity and of the sucking activity recorded in kids born from SC does were another indication of the greater vitality of these kids during the early mother-young interactions, as suggested also in newborn lambs (Dwyer et al., 2003). However, whereas these authors suggested that poor behavior of lambs from undernourished mothers was due to a decrease in birth weight, in our study, the birth weights of kids did not differ between the control does and SC does. Therefore, our results suggested that energy status had a direct effect on the neonate activity in the goat. Together, greater vocal activity and vigor displayed by newborn kids could result in greater attractiveness for their mother, thus reinforcing the display of their maternal care towards these more active neonates, as proposed by Klopfer and Klopfer (1977).

As a whole, neonatal activity, including bleating, successful attempts to suck, maintenance of close contact with dam, are behavioral stimuli, which contribute to the establishment and maintenance of the dam-offspring bond and are also associated with newborn survival (Vince, 1993; Nowak, 1996; Sèbe et al., 2007, 2008). Greater maternal dietary energy, provided prepartum, reduced the frequency of assistance at kidding and shortened the duration of labor. The precise mechanism by which adequate nutrition during pregnancy facilitates the parturition process is not totally understood. It has been suggested that restricted uterine growth and volume of amniotic fluid in underfed mothers would reduce fetal movements and consequently would lengthen parturition (Dwyer et al., 1996). Furthermore, parturition process represents an important metabolic demand for the mother (Neilson et al., 2003), and therefore, non-feeding corn mothers may not have sufficient energy to cope with this physiological process. In addition, regardless of the mechanism responsible for the greater percentage of malpresentation found in underfed females, this could be a further cause for the differences of activity observed between control kids and kids from SC mothers. Indeed, recent studies have shown that fetal malpresentation and prolonged parturition may impair neonatal activity, mainly reducing lamb vitality as evidenced by low udder-seeking and suckling activities (Dwyer et al., 1996, 2003; Dutra and Banchero, 2011).

Additional effects of feeding corn to pregnant goats were found in the present study. For example, BCS and BMI did not decline drastically at parturition in SC does, contrary to control does. These effects could be related to a lower mobilization of body reserves; perhaps, corn supplied part of the elevated energetic demands in this final stage of gestation (Frutos et al., 1998; Banchero et al., 2004a). To conclude, our results underline the interest of providing more energy to late-pregnant goats maintained under grazing management in semi-arid rangeland. Partial substitution of the grazing diet with a high-starch feed in late gestation is likely to increase the chances of survival of kids. In fact, this increased colostrum yield and improved neonatal suckling activity are determinant for the establishment of a strong mother-young bond, including the development of a preferential attachment with the mother which facilitates to discriminate her from other dams (Nowak et al., 1997, 2007; Goursaud and Nowak, 1999).

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Figure captions

Figure 1. Effects of not feeding or feeding supplemental corn (0.6 kg/doe; as fed) to grazing does during the last 12 ± 1.0 d of pregnancy on colostrum (mean ± SEM) accumulated at parturition in one teat and secreted from parturition to 1, 1 to 3, 3 to 6 and 6 to10 h after parturition. Closed bars indicate responses of does fed corn (n = 14) and open bars indicate responses of does not fed corn (n = 11) whereas grazing under semi-arid conditions. Differences between groups at each time point are indicated by asterisks (* $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$).

Figure 2. Effects of not feeding or feeding supplemental corn (0.6 kg/doe; as fed) to grazing does during the last 12 ± 1.0 d of pregnancy on concentrations of glucose in blood (mean ± SEM) at birth and during the early postpartum period. Closed circles indicate responses of does fed corn (n = 14) and open circles indicate responses of does not fed corn (n = 11) whereas grazing under semi-arid conditions. Differences between groups at each time point are indicated by asterisks (* $P < 0.05$ and ** $P < 0.01$).

Figure 3. Effects of not feeding or feeding supplemental corn (0.6 kg/doe; as fed) to grazing does during the last 12 ± 1.0 d of pregnancy on peripartum concentrations of plasma progesterone (mean ± SEM). Closed circles indicate responses of does fed corn (n = 14) and open circles indicate responses of does not fed corn (n = 11) whereas grazing under semi-arid conditions. Open and filled arrows indicate a significant decline in plasma progesterone concentrations in relation to d -7 before birth in not feeding or

feeding supplemental corn does, respectively. Differences between groups at time each point are indicated by asterisks (* $P < 0.05$ and ** $P < 0.01$).

Figure 4. Distribution of the number and mean latency (± SEM) to emit low-pitched bleats in kids born from not feeding or from feeding supplemental corn (0.6 kg/doe; as fed) goats during the last 12 ± 1.0 d of pregnancy. Closed bars indicate responses in kids from does fed corn (n = 10) and open bars indicate responses in kids from does not fed corn (n = 10) whereas grazing under semi-arid conditions. Distribution is relative to the total number of low-pitched bleats during the three periods after birth. Differences between groups are indicated by asterisks (*** $P< 0.001$). a vs. b denotes differences in the frequency of this behavior between observation periods in control kids.

Figure 5. Mean (± SEM) BW, BMI (Body Mass Index) and BCS during pregnancy and at parturition in not feeding or feeding supplemental corn (0.6 kg/doe; as fed) goats during the last 12 ± 1.0 d of pregnancy. Closed circles indicate responses of does fed corn (n = 25) and open circles indicate responses of does not fed corn (n = 21) whereas grazing under semi-arid conditions. The filled bar indicates the last 12 ± 1.0 d of pregnancy when feeding supplemental corn was provided to grazing does. Differences between groups are indicated by asterisks ($P < 0.001$ and $P = 0.06$).

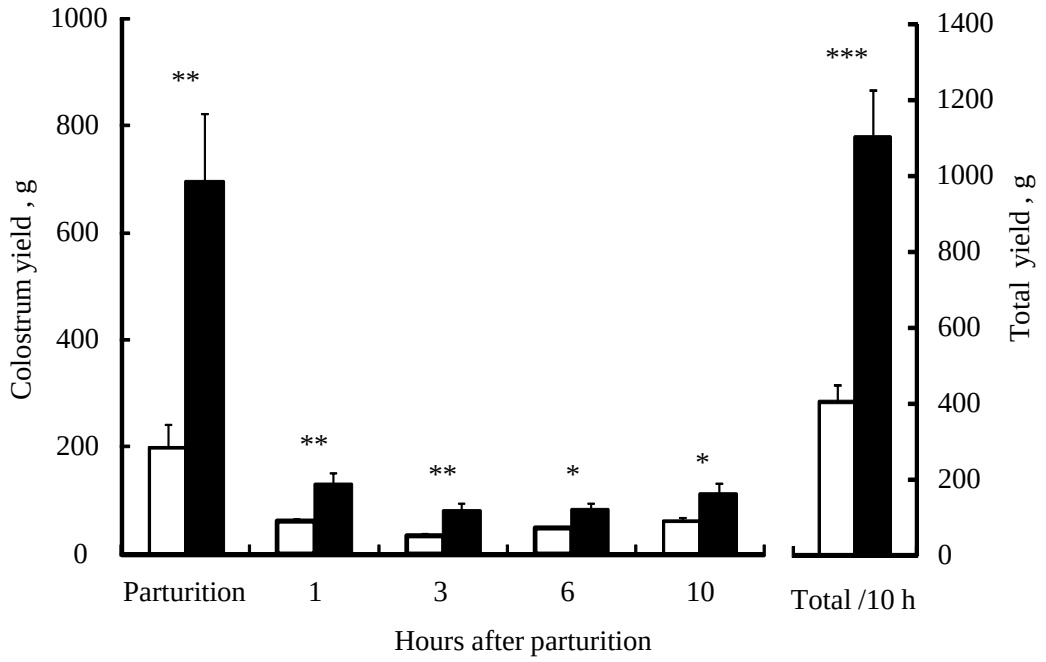


Figure 1. Ramírez-Vera et al.

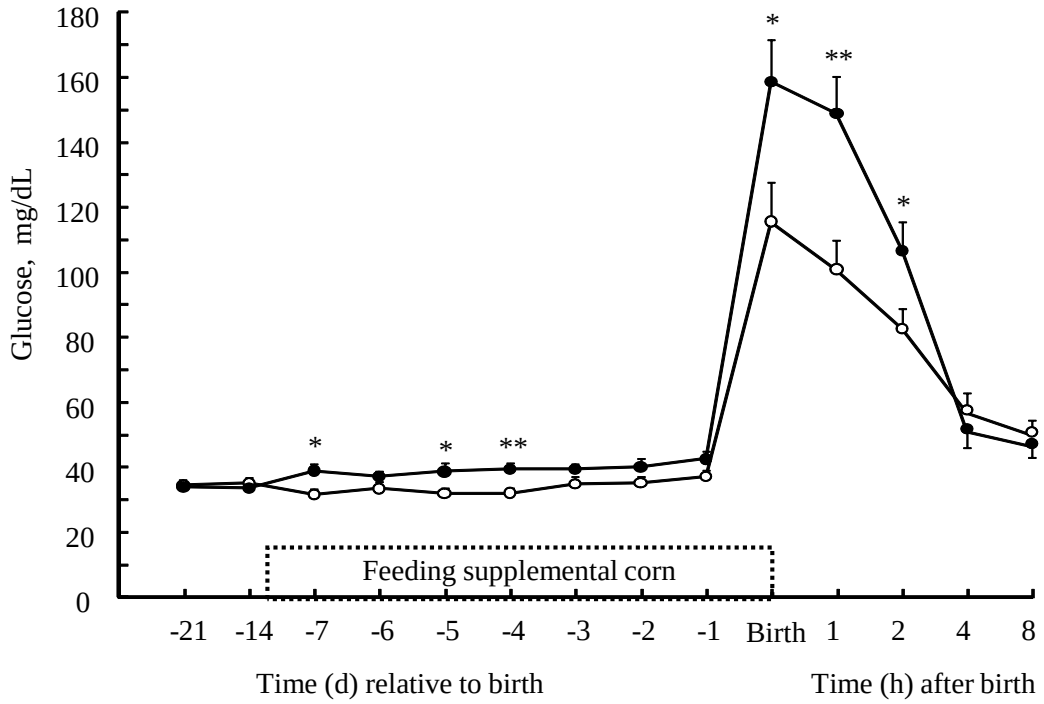
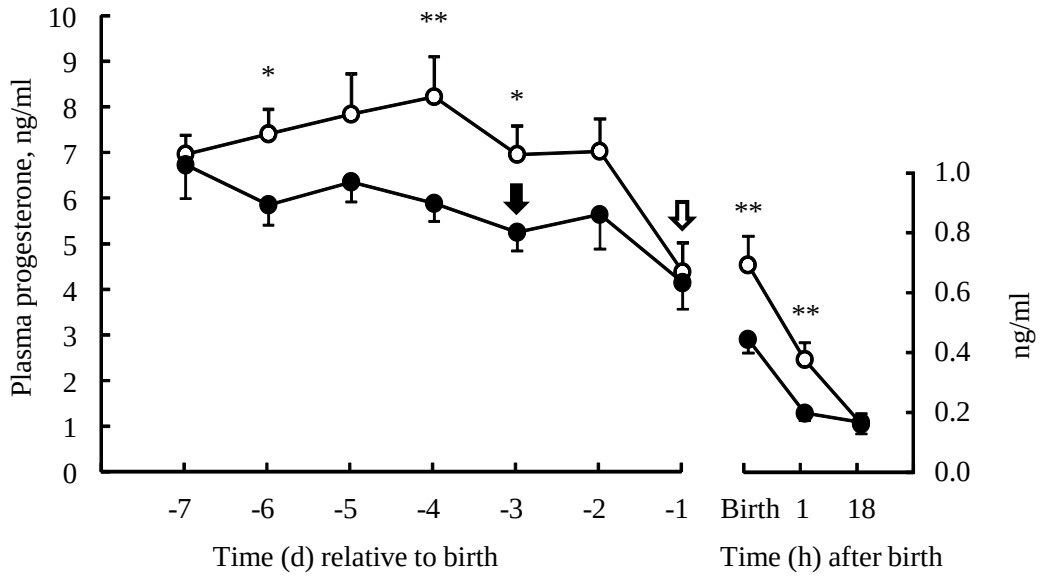


Figure 2. Ramírez-Vera et al.


Plasma progesterone, ng/ml
10
9
8
7
6
5
4
3
2
1
0
*
**
*
**
**
1.0
0.8
0.6
0.4
0.2
0.0
ng/ml
-7
-6
-5
-4
-3
-2
-1
Birth
1
18
Time (d) relative to birth
Time (h) after birth

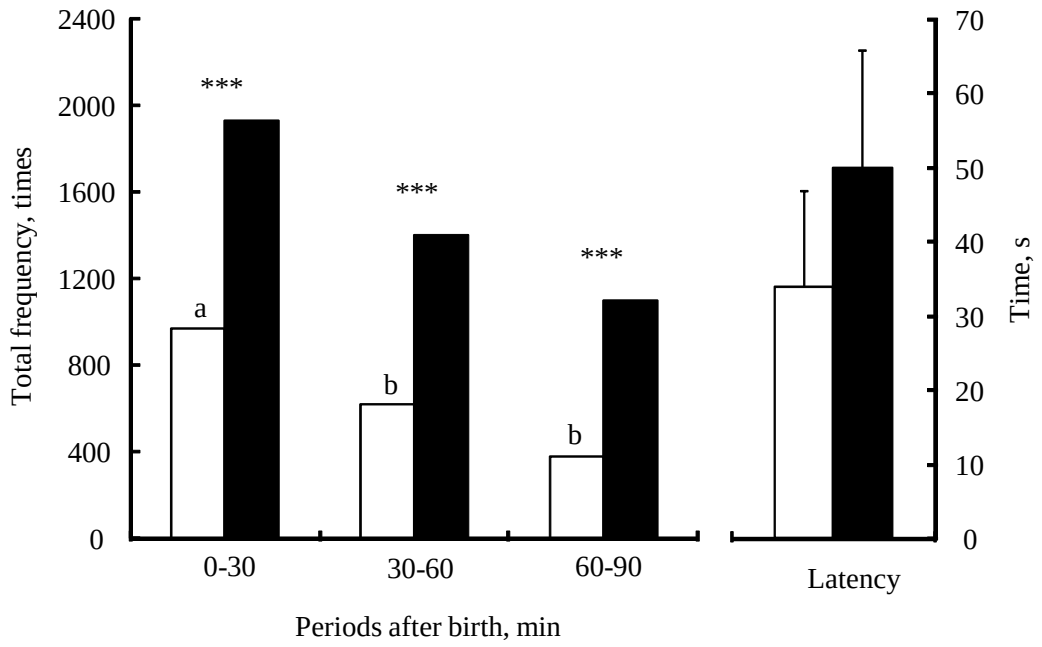


Figure 4. Ramírez-Vera et al.

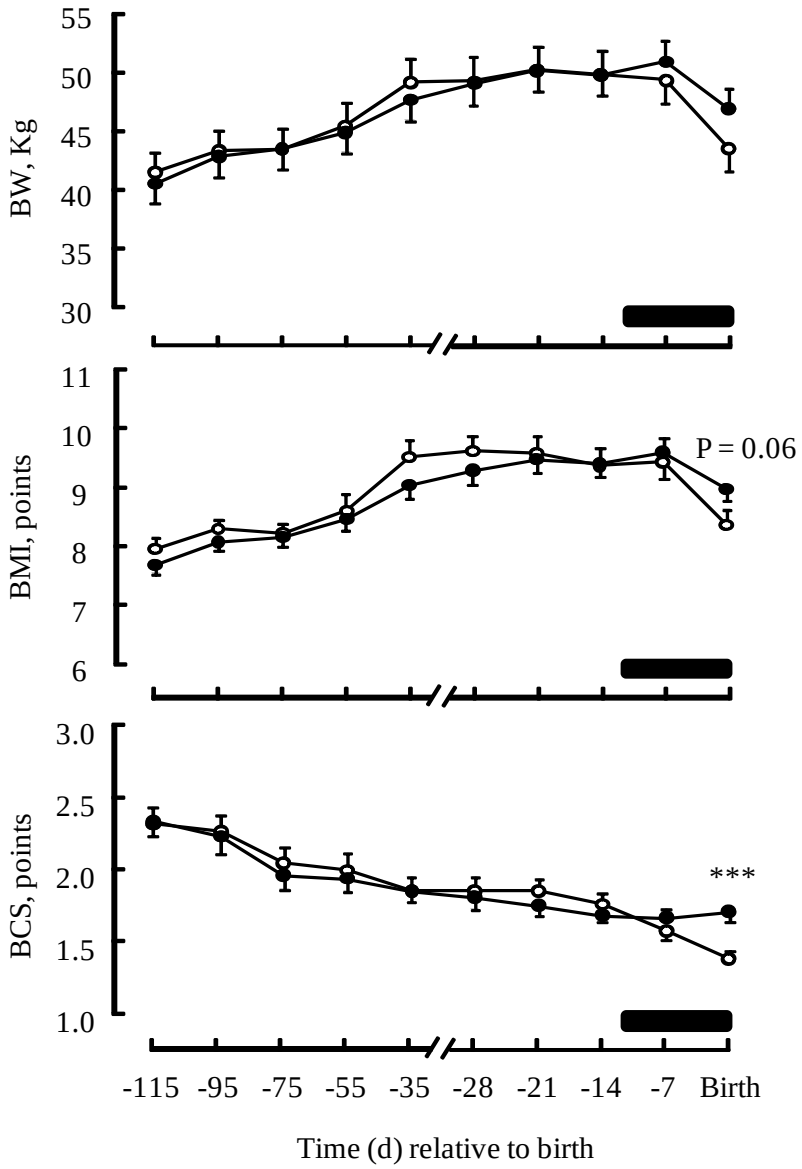


Figure 5. Ramírez-Vera et al.

Table 1. Mean colostrum constituents (± SEM) at different postpartum times in goats maintained under extensive grazing management without (control, n = 11) or with 0.6 kg of flaked supplemental corn/day (as fed) during the last 12 ± 1.0 d of pregnancy (SC, n = 14).

%	Hour (s) after birth	Control	SC	*P*-value [1]
Fat	At birth	6.8 ± 0.5	5.8 ± 0.5	0.183
	1	8.4 ± 0.9	10.0 ± 1.2	0.308
	3	7.8 ± 0.8	8.0 ± 0.6	0.913
	6	7.1 ± 0.5	6.8 ± 0.5	0.636
	10	6.2 ± 0.3	5.8 ± 0.3	0.311
Protein	At birth	12.4 ± 0.5	11.7 ± 1.0	0.603
	1	11.0 ± 0.6	10.0 ± 0.8	0.343
	3	10.6 ± 0.9	7.5 ± 0.7	0.012
	6	8.3 ± 0.8	5.7 ± 0.4	0.006
	10	7.0 ± 0.8	4.6 ± 0.2	0.002
Lactose	At birth	3.5 ± 0.2	3.8 ± 0.3	0.487
	1	2.9 ± 0.4	3.5 ± 0.3	0.277
	3	3.5 ± 0.3	4.1 ± 0.2	0.107
	6	3.7 ± 0.3	4.3 ± 0.1	0.035
	10	3.9 ± 0.2	4.4 ± 0.1	0.035
Solids not fat	At birth	15.5 ± 0.5	15.1 ± 1.0	0.722
	1	13.8 ± 0.6	13.6 ± 0.9	0.842
	3	13.9 ± 0.6	11.7 ± 0.6	0.017
	6	12.1 ± 0.6	10.3 ± 0.4	0.012
	10	11.1 ± 0.5	9.5 ± 0.1	0.002
Solids	At birth	21.5 ± 0.6	20.1 ± 1.3	0.367
	1	21.8 ± 1.3	23.2 ± 1.8	0.543
	3	21.2 ± 1.0	19.5 ± 1.0	0.230
	6	18.9 ± 0.8	17.0 ± 0.7	0.089
	10	17.2 ± 0.6	15.3 ± 0.3	0.005

[1]P-value refers to comparisons between groups.

Table 2. Mean latency, duration (± SEM) and total frequencies for activity displayed in the first 90 min after birth by kids born from does maintained either under extensive grazing management without (control, n = 10) or with 0.6 kg of flaked corn/day (as fed) during the last 12 ± 1.0 d of pregnancy (SC, n = 10).

		Kid activity					
		Teat Seeking			Sucking		
	Periods after birth, min	Control	SC	*P*-value [1]	Control	SC	*P*-value [1]
Latency, min		18 ± 4	14 ± 4	0.290	39 ± 8	26 ± 5	0.131
Frequency, times	0-30	156[ab]	159[a]	0.905	7[a]	20[a]	0.068
	30-60	285[a]	392[b]	0.004	27[a]	60[a]	0.011
	60-90	170[b]	383[ab]	< 0.001	11[a]	38[a]	0.005
Duration, s	0-30	346 ± 106[ab]	312 ± 116[a]	0.649	38 ± 19[a]	64 ± 28[a]	0.383
	30-60	498 ± 99[a]	755 ± 80[b]	0.060	59 ± 29[a]	188 ± 36[b]	0.015
	60-90	230 ± 68[b]	565 ± 109[ab]	0.034	22 ± 10[a]	105 ± 29[ab]	0.006

[a-b]Within the same column, means that values without a common superscript differ (P < 0.05).
[1]P-value refers to comparisons between groups.

ARTÍCULO 2

Inclusion of maize in the grazing diet of goats during the last 12 days of gestation reinforces the expression of maternal behaviour and selectivity during the sensitive period

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Inclusion of maize in the grazing diet of goats during the last 12 days of gestation reinforces the expression of maternal behaviour and selectivity during the sensitive period

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ABSTRACT

The objectives of this study were to investigate if partial substitution of a grazing diet with maize during the last 12 d of gestation in goats bred under semi-arid grazing conditions improves maternal behaviour and reinforces the exclusive mother–kid bond at 3 h after birth. For the first objective, 20 pregnant goats and their single kids were randomly assigned to 1 of 2 treatments (10 per group): (1) only grazing (control group); and (2) grazing plus 0.6 kg/d of supplemental maize, a high-starch feed, during the last 12 ± 1.0 d before parturition (maize group). Frequency of amniotic fluid consumption was higher and latency was lower in the maize group than in the control group ($P \leq 0.049$). Frequency of amniotic membrane consumption and invitations to suckling were higher in the maize group than in the control group during the first 30 min after birth ($P \leq 0.046$). Duration of invitations to suckling tended to be higher in the maize group than in the control group ($P = 0.07$). For the second objective, 81 pregnant goats were randomly assigned to the same treatments as above to evaluate the effect of dietary treatment on maternal selectivity at 3 h postpartum. During the maternal selectivity test (5 min), frequency of low-pitched bleats and udder acceptances to their own kids was higher in the maize group than in the control group ($P \leq 0.03$). The control goats emitted more low-pitched bleats and tended to showed more udder acceptances to alien kids than the maize group ($P \leq 0.06$); emission frequency of low-pitched bleats and high-pitched bleats towards their own and alien kids did not differ in the control goats ($P \geq 0.22$). The number of udder rejections and aggressive behaviours towards their own kids were greater in the control goats than in the maize group goats ($P \leq 0.005$). At 3 h postpartum, 93% of the goats fed maize were maternal, whereas only 78% of the control goats were maternal ($P = 0.048$). Of the maternal mothers in each group, 88% of the goats in the maize group were selective at 3 h postpartum (36/41), whereas only 52% of the goats in the control group were selective (15/29, $P = 0.001$). We concluded that feeding supplemental maize during the last 12 days of gestation to goats maintained under semi-arid grazing conditions improves maternal behaviour at birth and significantly reinforces maternal selectivity at 3 h postpartum, which may increase the survival of kids during the first days after birth.

Keywords: goat, late gestation, high-starch feed, maternal behaviour, maternal selectivity.

1. Introduction

Ewe and goat mothers show a sensitive period after parturition, during which time maternal–filial bonding occurs (Poindron et al., 2007a, 2007b). This maternal–filial bond is commonly called 'maternal selectivity', and once established, mothers tend to accept only their own young and actively reject alien young. Literature clearly shows that for an adequate mother–young bond to be consolidated, at least 4 h of previous mother–young interaction is necessary during the sensitive period (Terrazas et al., 2009; Bordi et al., 1994). A greater proportion of goats accept alien kids at 2 h than at 4 h postpartum, and aggressive behaviour towards alien kids increases according to hours of time after birth and is higher at 4 h than at 2 h (Bordi et al., 1994). In ewes, 80% have already established maternal selectivity at 4 h postpartum, and they reject any alien kid that tries to suckle under undisturbed conditions (Keller et al., 2003; Otal et al., 2009). However, the adequate display of maternal care (maternal behaviour) and the development of maternal selectivity can be modified by factors such as consumption of amniotic fluid, early mother–young contact, and nutrition of the mothers during gestation. Nulliparous ewes that received only 65% of their nutritional requirements during the last 4 months of pregnancy spent less time licking and were more aggressive towards their lambs at birth than adequately fed ewes (Dwyer et al., 2003).

Most studies on the characteristics of maternal behaviour and maternal selectivity in ewes and goats have been conducted under controlled experimental conditions. Research on animals maintained under natural grazing conditions is limited, even though 80% of goats in the world inhabit subtropical, semi-arid regions (Knights and Garcia, 1997). The subtropical, semi-arid area of northern Mexico, for example, supports 2 million goats (SAGARPA, 2007). In this region, the rainfall season lasts from June to September. The dry season occurs from October to May, and during that time, food availability in natural grazing areas decreases dramatically (Sáenz-Escárcega et al., 1991; Ramírez et al., 1991). In goats from this region, about 80% of parturitions occur between November and February, during the dry season; therefore, pregnant animals could suffer from

undernutrition, which could have important consequences for both mothers and newborns. In semi-arid northern Mexico, kid mortality rates can reach up to 25% because of factors related to the undernutrition of goats during late gestation (Mellado et al., 1991).

Therefore, we investigated if partial substitution of the grazing diet with a high-starch feed, maize, during late gestation may have a beneficial effect on early mother–young interaction. Our hypothesis was that during the first 3 h after birth, during the sensitive period and selective maternal behaviour development, partial substitution of the grazing diet with maize during late gestation may improve the expression of the maternal behaviour and the maternal selectivity after 2 h of mother-young interaction.

2. Materials and methods

2.1. Location and grazing conditions

The study was conducted in the Comarca Lagunera region in subtropical northern Mexico (25° 36´N, 103° 27'W). This region has a semi-arid climate with a mean annual rainfall of approximately 266 mm from June to September. The dry season is characterized by a dramatic decrease in food availability for goats under natural grazing conditions, with a shortage of pasture from October to May (Sáenz-Escárcega et al., 1991). In this region, some animals graze daily in the natural available pasture from 0900 to 1300 h and from 1600 to 1800 h. Throughout the year, goat diets in the grazing areas are composed of about 82% shrubs, 12% herbaceous plants, and 6% grasses (Ramírez et al., 1991).

2.2. Animals, experimental groups, and peripartum management

Multiparous pregnant goats (n = 81) 3 to 4 years old were used. Twenty days before the mean expected date of delivery, goats were assigned to 1 of the 2 treatment groups balanced for initial body weight (BW) and body condition score (BCS). Pregnant goats assigned to the control group (n = 37, BW 54.0 ± 2.2 kg, and BCS 2.1 ± 0.1 points) received no additional feed. Pregnant goats assigned to the maize group (n = 44, BW 55.3 ± 1.8 kg, and BCS 2.1 ± 0.1 points) received a daily average of 0.6 kg of flaked maize/goat, a high-starch feed (as fed), during the last 12 ± 1.0 d of gestation.

Maize was offered individually to each doe in 2 rations, 1 in the morning and 1 in the afternoon (50% each time). Previous studies have shown that animals from grazing areas consumed an average of 135 g crude protein (CP)/kg dry matter (DM) and 2.1 Mcal/d metabolizable energy (ME) (Juárez-Reyes et al., 2004; Cerrillo et al., 2006). Maize substituted a part of the grazing diet provided 87.3 g CP/kg DM and 3.06 Mcal ME/kg DM. During the day, experimental animals were maintained under the same outdoor grazing conditions and were returned to their pens at night together with the rest of the herd. In the pens, goats in both groups were provided free access to fresh drinking water and mineral blocks (25 kg/block; Cebú, Salinas del Rey, Torreón, México).

2.3. Maternal behaviour at parturition

To determine the effect of dietary treatment on maternal behaviour during the first hour postpartum, only 10 mothers and their single kids per group were used. When a doe displayed signs of imminent parturition, she was gently moved to an individual 2-m2 pen located at least 50 m from the rest of the herd. Mother–kid interactions were recorded during the first 60 min after expulsion of the kid using a Sony camcorder, Handycam V8 (Sony corporation, Tokyo, Japan) placed on a tripod outside of the individual pen. Observer Video-Pro software, version 4.0 (Noldus Information Technology, Wageningen, The Netherlands) was used to analyze the video recordings in the laboratory.

The time elapsed from expulsion of the kid to performance of any behaviour for the first time was defined as latency and was calculated for the entire 60-min observation period. In ewes, the consumption of amniotic fluid and only 30 min of early mother–young interaction has been shown to promote the development of early selective bonding under undisturbed conditions (Poindron et al., 2007a); therefore, we analyzed the frequency and duration of behaviours in 2 consecutive 30-min periods after birth. Separate analysis also provided information about how quickly mothers exhibited the typical components of maternal care. Thus, latency, frequency, and/or duration of the following maternal behaviours at parturition were measured: (1) amniotic fluid consumption (when the mother consumes amniotic liquid on the ground after rupture of the water bag), (2) amniotic membrane consumption (when the mother consumes

amniotic membrane tissue adhered to her body or on the ground), and (3) invitations to suckling (when the mother scratches the body of her kid to raise it and begin suckling).

2.4. Maternal selectivity test at 3 h postpartum

Maternal selectivity at the udder at 3 h postpartum was performed in all goats used (control group, n = 37; maize group, n = 44). After 2 h of mother–kid interaction, kids were separated 1 h before the test. The mother was placed in the test corral (2 m2) 5 min before onset of the test to habituate her to the pen and avoid the effects of novelty. The selectivity test consisted of 2 successive 5-min presentations; mothers were exposed to their own kids and to alien kids of the same age and similar physical aspect (colour and size). These exposures to their own and alien kids were randomized throughout the tests. The following behaviours in the mothers were measured: (1) number of low-pitched bleats (LPB), (2) number of udder acceptances (UA), (3) nursing duration (ND), (4) number of high-pitched bleats (HPB), (5) number of udder rejections (UR), and (6) number of aggressive behaviours (threats and head butts; AgB). The first 3 behaviours are indicative of acceptance of the kids, and the last 3 behaviours are indicative of rejection of the kids.

2.4.1. Proportion of maternal and non-maternal goats at 3 h postpartum

Each mother was classified individually as maternal or non-maternal using the following qualitative criteria (Poindron et al., 2010).

A mother was classified as maternal or accepting her own kid (1) if she nursed her kid and did not display any aggressive behaviour during the test; or (2) if, in the absence of nursing and any aggressive behaviour, she displayed more acceptance behaviours than rejection behaviours. If the mother emitted more low-pitched bleats than high-pitched bleats (ratio LPB/(LPB + HPB) $\geq$ 0.5), this was considered acceptance behaviour.

A mother was classified as non-maternal or rejecting her own kid (1) if she displayed some aggressive behaviour and no nursing during the test; or (2) if, in the absence of these 2 behaviours, she displayed more rejection behaviours than acceptance behaviours. If the mother emitted fewer low-pitched bleats than high-pitched bleats

(ratio LPB/(LPB + HPB) < 0.5), this was considered rejection behaviour. If there were as many acceptance behaviours as rejection behaviours, acceptance of the own kid was considered as ambiguous.

2.4.2. Proportion of selective mothers in each group

The following criteria were used to classify maternal goats as selective or non-selective. A mother was classified as non-selective if she nursed the alien kid for more than 5 s without interruption and without displaying any aggressive behaviour during the entire test. A doe was classified as ambivalent if she nursed the alien kid for more than 5 s without interruption but also showed aggressive behaviour during the test. In all other instances, mothers were classified as selective.

2.4.3. Maternal acceptance and rejection index for each kid (their own or alien) in each group

A maternal preference index for each kid was computed in the following manner. First, each variable to be included in the index was standardized. Values for their own kid and the alien kid were included in a single standardization process using SYSTAT 13 software (Systat Software, Inc., Chicago, IL, USA). Then, an acceptance index for their own kid and the alien kid was computed by summing the standardized values of acceptance behaviours (LPB + UA + ND). A rejection index for their own kid and the alien kid was also computed using the same procedure but with the rejection behaviours (HPB + UR + AgB).

2.5. Blood glucose concentrations and BCS

Blood glucose concentration in goats (control group, n = 11; maize group, n = 17) was measured at 0700 h on day 14 during pre-treatment and on day 6 pre-kidding, at parturition, and at 2 and 4 h postpartum during dietary treatment. A single drop of whole blood was collected, and blood glucose concentration was determined using a blood glucose meter, as previously described for ewes (Banchero et al., 2004; Accu Chek Sensor Comfort, Roche, Mexico). BCS was determined at 14 and 7 d before the expected mean date of delivery by palpation of the spinous and lateral processes and the

musculature of the lumbar region of the spine, according to the method described by Walkden-Brown et al. (1997).

2.6. Statistical analyses

All statistical analyses were performed using SYSTAT 13 software. Frequency of behaviours at parturition between the control and the maize groups were analyzed using Fisher's exact test, considering a random distribution. Variables from the maternal selectivity test and acceptance and rejection indices were analyzed between groups using the Mann–Whitney U test. The proportion of maternal and non-maternal mothers was compared between the 2 groups by using the chi-square test. The proportion of selective or non-selective mothers was compared using the same procedure. Because the BCS data are ordinal, this variable was analyzed for a weak effect within each group using the Friedman test, whereas the Mann–Whitney U test was used for comparison of the 2 groups at a given time. Blood glucose concentrations during treatment were analyzed using the GLM procedure in SYSTAT with treatment in the model statement. Exact P values are indicated in the text, and the level of statistical significance was set at $P \leq 0.05$.

3. Results

3.1. Effect of dietary treatment on maternal behaviour at parturition

Latency to amniotic fluid consumption was higher in goats in the control group than in goats in the maize group (31.3 ± 7.2 and 14.0 ± 5.1 min, respectively; P = 0.049). Frequency of amniotic fluid consumption was higher in the maize group than in the control group during the first 30 min postpartum (P = 0.01; Fig. 1). However, from 30 to 60 min, amniotic fluid consumption did not differ between groups (P = 0.9). In addition, duration of amniotic fluid consumption did not differ between the control group and the maize group during the 2 periods ($P \geq 0.09$).

Latency to amniotic membrane consumption did not differ between the control group and the maize group (43.4 ± 6.5 and 41.6 ± 6.7 min, respectively; P = 0.9). During the first 30 min of observation, frequency of amniotic membrane consumption was higher in the maize group than in the control group (P = 0.046; Fig. 1), but from 30 to 60

min, frequency did not differ between the 2 groups (P = 0.3). In addition, duration of amniotic membrane consumption did not differ between the control group and the maize group during the 2 periods ($P \geq 0.6$).

Latency of invitations to suckling did not differ between mothers in the control group (46.1 ± 6.6 min) and mothers in the maize group (33.5 ± 7.5 min; P = 0.29). Frequency for this behaviour was higher in the maize group than in the control group during the first 30 min (P = 0.01; Fig. 1), but from 30 to 60 min, frequency did not differ between groups (P = 1.0; Fig. 1). Duration of invitations to suckling tended to be higher in the maize group than in the control group during the first 30 min of observation (P = 0.07; Fig. 1), but from 30 to 60 min, duration did not differ between the control group and the maize group (P = 0.9).

3.2. Effect of treatment on maternal selectivity at 3 h postpartum

3.2.1. Acceptance behaviours (Fig. 2). The number of LPB emitted by mothers towards their own kids was higher in the maize group than in the control group (P = 0.03). In contrast, the number of LPB emitted by mothers towards alien kids was higher in the control group than in the maize group (P = 0.01). Mothers in the maize group emitted a higher number of LPB towards their own kids than to alien kids (P = 0.001) whereas no differences were found between the number of LPB emitted by mothers in the control group towards their own kids and to alien kids (P = 0.22). The number of UA towards their own kids was higher in the maize group than in the control group (P = 0.02) whereas the number of UA towards alien kids tended to be higher in the control group than in the maize group (P = 0.06). Comparisons within the same group showed that the number of UA was higher towards their own kids than towards alien kids in both groups (P = 0.0001). Furthermore, ND for their own kids and for alien kids did not differ in goats in the control group and in the maize group ($P \geq 0.1$). Comparisons within the same group showed that in the 2 groups, ND was higher for their own kids than for alien kids (P = 0.0001).

3.2.2. Rejection behaviours (Fig. 2). In mothers from control group, the number of emitted HPB did not differ between their own kids and alien kids (P = 0.4), whereas in

mothers in the maize group, the number of HPB was higher towards alien kids than towards their own kids (P = 0.006). The number of UR towards their own kids was greater in the control group than in the maize group (P = 0.0001), whereas the number of UR towards alien kids did not differ between the 2 groups (P = 0.17). Comparisons within the same group showed that the number of UR was greater towards alien kids than towards their own kids in both groups ($P \leq 0.005$). The number of AgB towards their own kids was higher in mothers in the control group than in mothers in the maize group (P = 0.005), whereas the number of AgB towards alien kids did not differ between the 2 groups (P = 0.6). However, comparisons within the same group showed that in the 2 groups, the number of AgB was higher towards alien kids than towards their own kids (P = 0.001).

3.3. Proportion of maternal and non-maternal goats at 3 h postpartum and for maternal goats as selective or non-selective in each group

The proportion of mothers that accepted their own kids (maternal) at 3 h postpartum was higher in the maize group than in the control group (41/44 and 29/37, respectively; P = 0.048). The proportion of goats that rejected their own kids (non-maternal) was higher in the control group (6/44; P = 0.05) than in the maize group (1/44), and only 2 mothers in each group were ambiguous. Furthermore, at 3 h postpartum, 88% of the goats in the maize group were selective mothers (36/41), and only the 52% of the goats in the control group were selective mothers (15/29; P = 0.001).

3.4. Maternal acceptance and rejection index for each kid (their own or alien) in each group

The acceptance index for their own kids was higher in mothers in the maize group than in mothers in the control group (0.560 ± 352 and −0.666 ± 0.307, respectively; P = 0.02), whereas the acceptance index for alien kids was higher in the control group than in the maize group (0.465 ± 0.451 and −0.391 ± 0.268, respectively; P = 0.01). In contrast, the rejection index for their own kids was higher in the control group than in the maize group (0.743 ± 0.510 and −0.625 ± 0.157, respectively; P =

0.002), and the rejection index for alien kids was higher in goats in the maize group than in goats in the control group (0.429 ± 0.330 and −0.510 ± 0.246, respectively; P = 0.04).

3.5. *Effect of dietary treatment on BCS and peripartum blood glucose concentrations*

Blood glucose concentrations were higher (P ≤ 0.016; Table 1) at parturition in mothers in the maize group than in mothers in the control group. In both groups, glucose concentrations in blood increased at parturition and decreased later (time effect, P < 0.001; Table 1). The BCS before parturition did not differ between the control group and the maize group; in contrast, at parturition, BCS was higher in the maize group than in the control group (P = 0.01; Table 1).

4. Discussion

Our hypothesis that including maize in the diet of grazing goats during the last 12 d of gestation improves maternal behaviour and reinforces maternal selectivity at 3 h postpartum was supported by the results of the present study. During the initial 30 min of mother–young interactions, mothers in the maize group displayed a higher frequency and duration of behaviours characteristics of this species' intensive maternal care towards their kids. In addition, at 3 h postpartum the number of maternal mothers was higher in the maize group than in the control group. Finally, feeding with pre-partum supplemental maize made mothers more selective at 3 h postpartum, as shown by the higher proportion of selective mothers in the maize group than in the control group, regardless of only 2 h of previous contact between mothers and kids. Our results show for the first time that under natural, semi-arid grazing conditions, goat mothers show some degree of weakness in attachment to their young and that an energetic feed as maize reinforces this behavioural process at birth.

The results of this study emphasize and confirm that the initial 30 min of intensive mother–young interaction is determinant for the consolidation of a strong maternal selective bond. Higher amniotic fluid or membrane consumption displayed by mothers in the maize group during this initial 30 min may have accounted for improved maternal behaviour and selectivity. Poindron et al. (2010) recently showed that removal of amniotic fluids from the lamb through washing impaired maternal responsiveness and

decreased the proportion of mothers forming an exclusive bond with their young. This fluid likely has chemosensory information that facilitates exclusive bonding and, thus, prevents the acceptance of alien lambs (Otal et al., 2009; Poindron et al., 2010). In ewes under controlled nutrition and after 8–12 h of total separation, the proportion of selective mothers after only 15 min of contact with their young was intermediate between the proportion found in ewes tested either at birth (21%) or after 30 min of contact (61%; Poindron et al., 2007a). Although delaying contact did not impair maternal care towards their own lambs, 64% of ewes deprived of their lambs during the first hour failed to develop maternal selectivity at 12 h compared to 9% of ewes in contact with their lambs from birth (Alexander et al., 1986). Thus, in parturient goats under poor grazing conditions, the inclusion of maize in the diet facilitates the early formation of maternal selectivity through high amniotic fluid or membrane consumption and by intense maternal care.

As described in the results, the intensity of maternal behaviours during the first 30 min was higher in mothers in the maize group than in mothers in the control group. After this first 30-min period, only invitations to suckling were higher in mothers in the maize group than in mothers in the control group. Our results coincide with previous findings in undernourished ewes during the last 4 months of pregnancy, which showed that the ewes were less attached to and showed more aggressive behaviour towards their lambs at birth than adequately fed ewes during pregnancy (Dwyer et al., 2003). Improvement in the maternal behaviour in mothers in the maize group of this study may be partially due to the level of neonatal activity displayed by their kids. In fact, feeding maize during late pregnancy in goats that graze extensively improved neonatal activity (high frequency for udder seeking, sucking, and LPB emission) after birth (Ramírez-Vera et al., 2012). This improved kid behaviour could result in greater attractiveness for their mothers, thus reinforcing the display of maternal care towards these more active neonates, as proposed by Klopfer and Klopfer (1977).

However, improved early mother–young interaction and suckling-related stimulations cannot be excluded as considerations for the establishment of this strong mother–young bond. For example, in lambs, delay in the first suckling prevents normal development of

a preferential relationship with their mothers (Nowak et al., 1997; Val-Laillet et al., 2004). Early ingestion of colostrum triggers mechanisms that facilitate the establishment of this bonding process (Goursaud and Nowak, 1999).

Adequate energetic status as evidenced by higher blood glucose concentrations and increased BCS at birth in mothers in the maize group may also improve maternal behaviour. In fact, underfed ewes were slow to tend to their lambs due to the exhaustion of labour and, possibly, the associated lack of available energy to cope with this physiological process (Thompson and Thompson, 1949; Neilson et al., 2003). Adequate maternal behaviour at birth and the formation of a strong bond with their neonates are important constraints for the increased survival of kids.

5. Conclusion

In grazing goats maintained under extensive semi-arid conditions, feeding supplemental maize during late gestation reinforces the expression of maternal motivation. Our study results showed improvement of maternal behaviour at birth and a significant reinforcement in maternal selectivity behaviour at 3 h postpartum in mothers in the maize group. These findings may lead to increased survival potential of kids in herds managed in extensive semi-arid regions, where availability and quality of pastures vary throughout the year.

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Figure captions

Fig. 1. Total frequency and mean duration (± SEM) for behaviours displayed in 2 consecutive 30-min periods after birth, by mothers maintained either under extensive grazing management without (□, control, n = 10) or with daily 0.6 kg of flaked supplemental maize /doe during the last 12 ± 1.0 days of pregnancy (■, maize, n = 10). Differences between groups (*P < 0.05, **P < 0.01).

Fig.2. Mean (± SEM) of LPB (low-pitched bleats), UA (udder acceptations) and ND (nursing duration), acceptance behaviours and HPB (high-pitched bleats), UR (udder rejections) and AgB (aggressive behaviours) rejection behaviours in the selectivity test, at 3 h postpartum in mothers maintained either under extensive grazing management without (□, control, n = 37) or with daily 0.6 kg of flaked supplemental maize /doe during the last 12 ± 1.0 days of pregnancy (■, maize, n = 44). Differences between groups (*P < 0.05, **P < 0.01). a vs. b; A vs. B denotes differences in this behaviour between the own and alien kids.

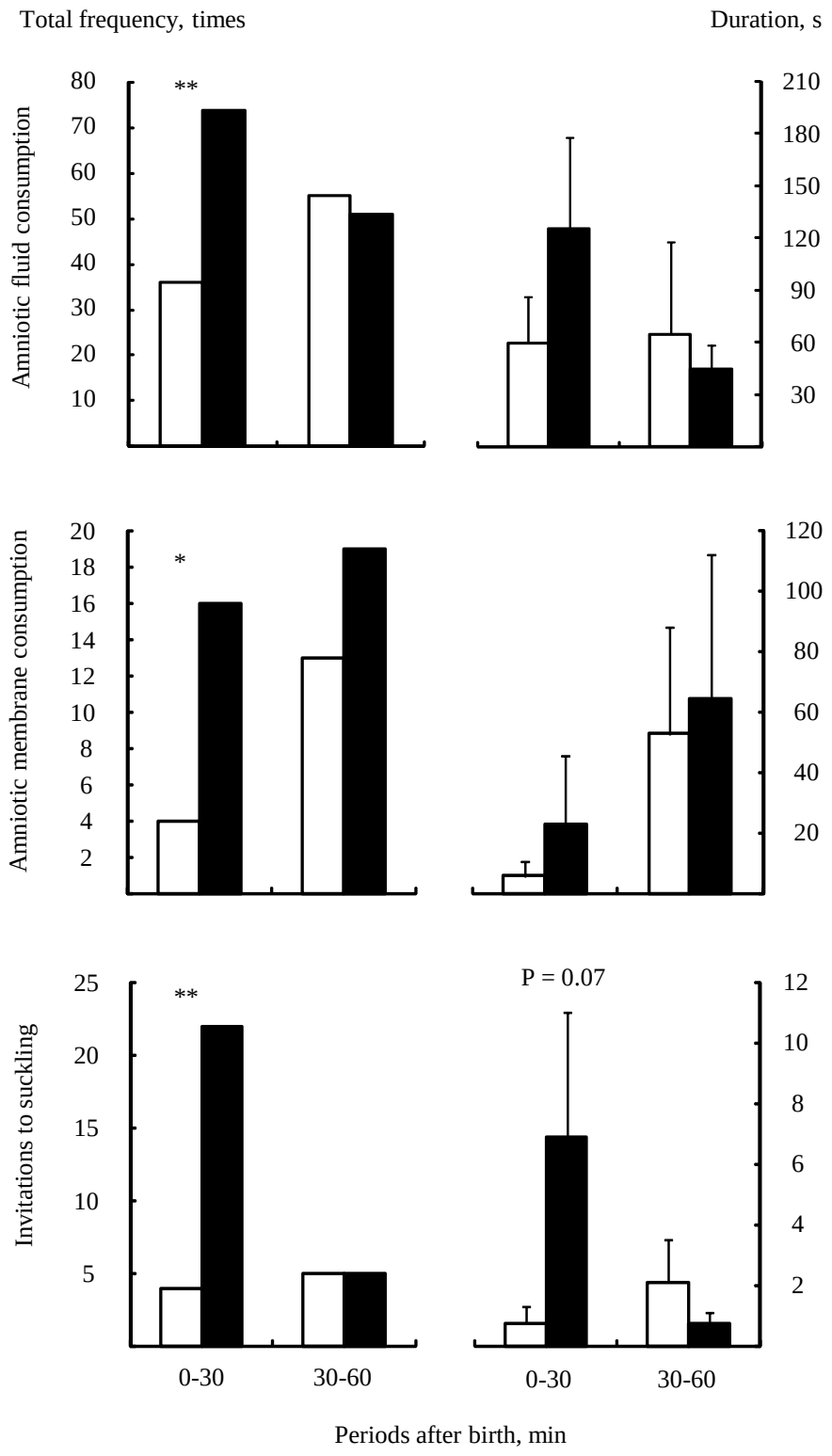

Fig. 1. Ramírez-Vera et al.

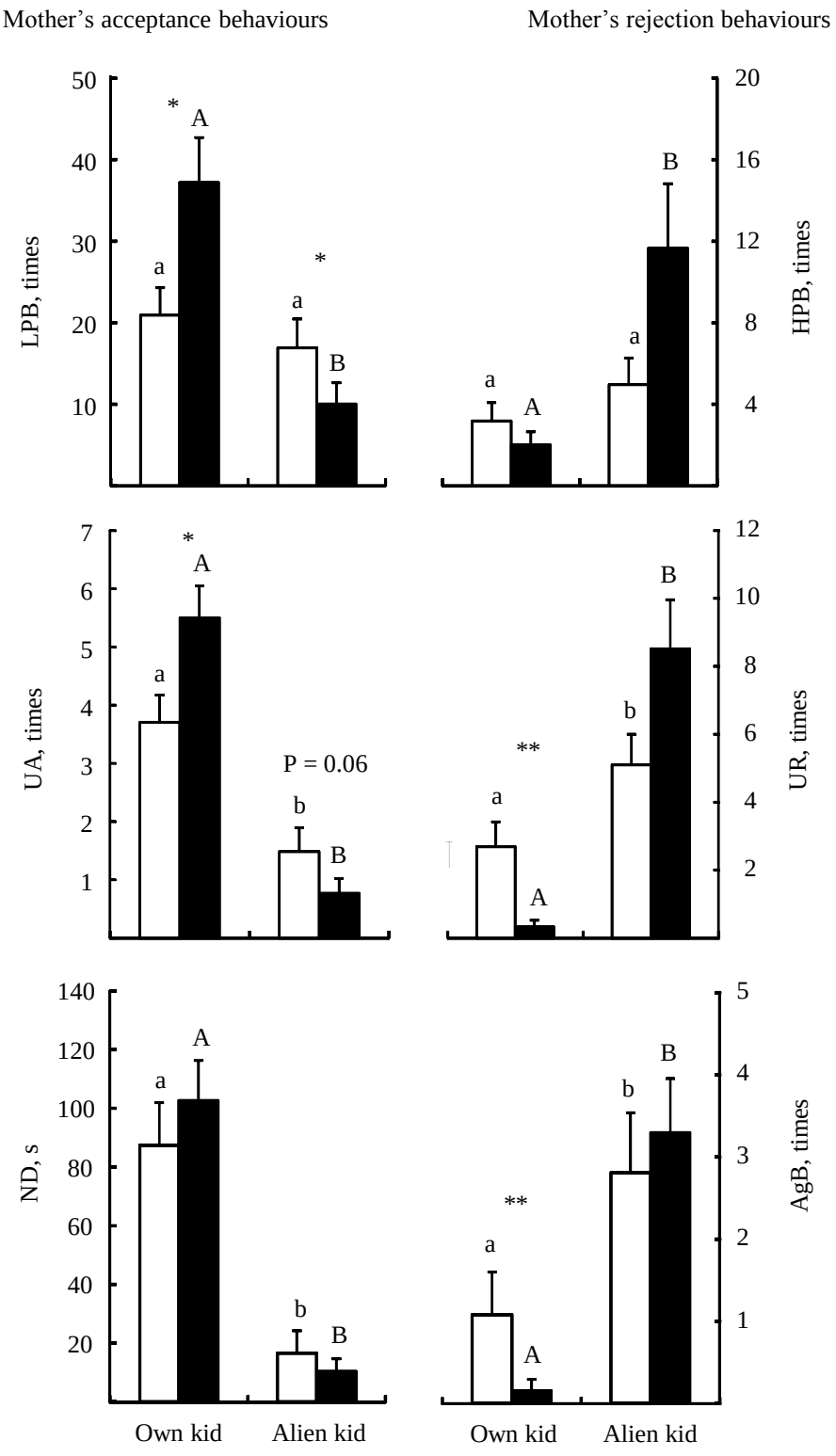

Fig. 2. Ramírez-Vera et al.

Table 1. Effects of including daily supplemental maize (0.6 kg/doe) in grazing diet during the last 12 ± 1.0 days before parturition on concentrations of glucose in blood (mean ± SEM) at birth and during the early postpartum period and BCS in goats maintained under semi-arid grazing conditions (maize group). Another group of goats was fed only with the vegetation available from grazing areas (control group).

	Days prepartum			Hours postpartum	
	14	7	Parturition	2	4
Blood glucose (mg/dL)					
Control, n = 11	27 ± 2[a]	25 ± 3[a]	80 ± 8[a]	56 ± 5[a]	49 ± 6[a]
Maize, n = 17	27 ± 1[a]	34 ± 2[b]	139 ± 9[b]	80 ± 7[b]	53 ± 5[a]
BCS (points)					
Control, n = 37	2.1 ± 0.07[a]	1.9 ± 0.08[a]	1.6 ± 0.05[a]		
Maize, n = 44	2.1 ± 0.07[a]	2.1 ± 0.07[a]	1.9 ± 0.06[b]		

[ab]refers to comparisons between groups ($P < 0.05$).

ARTÍCULO 3

Supplementation with maize during late gestation improves mutual recognition in goats and kids underfed either experimentally or under natural extensive grazing conditions

Supplementation with maize during late gestation improves mutual recognition in goats and kids underfed either experimentally or under natural extensive grazing conditions

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Abstract

We investigated whether maize supplementation with or maize inclusion in the diet during the late gestation improves mother-young mutual recognition in underfed goats and their kids in two separate experiments carried out sequentially. In Exp. 1 nutrition was controlled experimentally in 3 groups; 19 goats (CON) were fed with their physiological requirements during pregnancy, 17 goats were underfed (UF) and 21 goats were underfed and supplemented with maize (maize). [goats and their kids (n=21, n = 19 and n=21, respectively) were used]. In Exp. 2, two groups of goats grazing poor pasture under extensive management were used; 37 goats (grazing, n = 37) only grazed the available pasture, while other 44 grazing plus supplemental maize, feed during the last 12 ± 1.0 days before parturition (SUP, n = 44) together with their kids. Non-olfactory recognition of the kids was assessed in dam at 8 h (Exp 1) and 4 h postpartum (Exp. 2) by a two-choice test, while in kids preference for the mother was assessed at 12 h (Exp 1) and 8 h after birth (Exp. 2). Either UF or grazing goats did not show significant difference in the time spent between the own and alien kids. In contrast, CON, maize and SUP goats did so. The time spent looking toward the own kid was higher than to the alien in the 5 groups from both experiments. However, in Exp. 1 the time looking toward the own kid was lower in UF goats, but did not differ from the maize group. In Exp. 2 the time looking toward the alien kid was higher in grazing than in SUP goats. Mothers visit more frequently their own than to the alien kid in the 5 groups assessed. Neither kids from UF nor grazing groups did not show a clear preference for the own dam, while kids from CON, maize and SUP did so. In conclusion, the addition with or inclusion of maize to the diet during the last two week of gestation improves the mother-young mutual recognition in either experimentally underfed or in extensive grazing goats.

Key words: Goat; maize; underfed; grazing; pregnancy; learning; survival; goat kids; *Capra hircus*.

Introduction

Maternal behavior is a natural response in mammal species to guarantee the offspring's survival[1]. The Goat is one of the specie that develops a selective relationship with their progeny and that give birth to precocial newborns[2]. In the mothers the olfactory recognition of its kid is evident from the first 2 h after birth[3], while distal young recognition through the visual and/or acoustic cues is evident up to 8 h after birth[4]. In the case of the kids, they are able to recognize their mother from an alien one at 8 h after birth[5].

Goat production especially in developing countries suffers prolonged periods of malnutrition that some time coincides with gestation[6,7]. Fed manipulation during gestation as supplementation, complementation or addition of some nutritional substrates is viable techniques with low price that could help to improve the corporal condition of the dams during postpartum period. For example in underfed ewes or in grazing does giving maize in the diet during last days of pregnancy the quantity and quality of colostrums is increased together with other productive parameters[8,9]. While in lambs some studies had been demonstrated that the ability to discriminate their mother from an alien one at 24 h of age depends on the first nutritive successful suckling episodes[10]. In this way when the lamb is not able to suckle in good manner during first 6 hours of age, its ability to discriminate its mother from an alien one is impaired during a double choice test at 24 or 48 h of age[11]. In addition in lambs had been observed that the presence of the fluids and especially those with high nutritive contents as colostrum, in the gastrointestinal tract facilitate the development of filial attachment, independently of the suckling behavior[12]. In sheep there are evidences that nutritional supplementation at the end of pregnancy, could improves the maternal behavior and the ability of the rearing in Merino ewes, including an increase in colostrum yield[13,14]. An experimental malnutrition in goats during the second half of pregnancy induces a poor expression of maternal behavior and low locomotors behavior in the kids during the first hour after birth. In addition, the mother – young mutual recognition is impaired[15]. In comparison in goats under natural grazing condition, in which the availability of the nutritive forage is limited during some periods of the year, the inclusion of maize in the diet during the last days of pregnancy improves the colostrum production and the viability of the kids[9].

Our hypothesis was that including maize in the diet during the last two weeks of pregnancy to either experimentally underfed or under natural extensive grazing conditions goats, will improves the mother-young mutual recognition during the first day after birth. In order to prove this hypothesis two experiments were performed. In one experiment three experimental groups of goat and their kids were tested in a double choice test: control, underfed and underfed + 15 days of maize supplementation. In the other experiment two groups of goats and their kids maintained under natural extensive grazing condition only and grazing + last 12 days of gestation of feeding supplemental maize were tested for the ability of mutual mother-young recognition.

Materials and Methods

Exp. 1

Animals and experimental groups

Sixty multiparous Alpine dairy goats of 3 to 5 years old were used. The reproduction was synchronized with a hormonal treatment similar as described by Terrazas *et al*.[15]. The pregnant state was obtained by ultrasonography diagnosis. The body weight of the does were taking into account to conform the following three groups. The animals were assigned to one of the next three groups, according to their feed management:

1) Control group (CON): nineteen goats (Kids: 4 single-bearing,10 twins-bearing, 4 triplets-bearing and 1 quadruplets-bearing) were fed 100% of their nutritional requirements according their physiological condition[16].
2) Underfed group (UF): seventeen goats (Kids: 3 singles-bearing, 4 twins-bearing, 7 triplets-bearing and 3 quadruplets-bearing), the females were fed during the last 75 days of pregnancy, only with their 70% of energy and protein requirements.
3) Underfed + Maize (maize): twenty one goats (Kids: 2 singles-bearing, 9 twins-bearing, 8 triplets-bearing and 2 quadruplets-bearing), this group receive the same diet than the UF group, but during the last 15 days of pregnancy every animal receive 0.6 kg/day of crushed maize.

In CON group, the composition of the diet was as follows: 43.16% of chaffed maize straw, 33% of worn-out flour maize, 19.8% alfalfa hay, 2.2% of soybean meal and 1.9%

of minerals. This represented 2.083 Mcal/kg EM with 11.2% crude protein. In the UF group, the females received the same type and amount of feed as the CON group until week 11 of gestation, Thereafter energy and protein were limited to 70% of requirements until parturition. To achieve this, the diet was modified as follows: 73% chaffed maize straw, 25% alfalfa hay, 2% minerals and free access to water, resulting in a diet of 1.72 Mcal/kg with 7.2% crude protein. Therefore, UF goats received the same quantity of dry matter as CON goats, but the nutritive value of the food was 30% lower in energy and protein contain in the diet. From parturition onwards, all animals in both nutritional groups were fed according to the full requirements of their reproductive state. Each group was kept indoors in a rectangular 7 x 15 m pen.

Variables and their measures

Behavioral measures

Two-choice preference test at 8 h postpartum in the mothers

Goats were submitted to a test of two-choice between their own and an alien of same age and similar physical aspect (colors and size) at 8 h postpartum (19 CON, 17 UF and 21 maize), in which choice relied only on visual and acoustic cues[4]. Testing conditions were the same as those described in a previous study[15]. Briefly, the testing area was a triangular enclosure (10 x 10 x 10 m), delimited by 1-m high, solid-metal barriers [see Terrazas et al.[15]]; a kid was placed in two of the three corners and the mother was released from the third corner. Two experimenters recorded the following parameters over 5 min: (a) latency to reach a contact zone, (b) identity of the first kid reached, (c) total time spent in each contact zone near of a kid, (d) number of maternal visits to each contact zone and (e) total time spent looking towards each kid, regardless of the position of the goat in the testing area. Looking towards was defined as the rear-front axis of the goat's head being directly oriented towards a kid.

Two-choice test at 12 h postpartum in kids

As for the mothers, three separate groups of kids born from control (CON, n = 21: 4 singles, 11 twins and 6 triplets), underfed (UF, n = 19: 3 singles, 6 twins, 7 triplets

and 3 quadruplets) and maize (n = 21: 1 single, 6 twins and 14 triplets) goats were tested at 12 h after birth.

The tests were carried out in a roofed building adjacent to the holding pens of the pregnant and postparturient animals. Kids were tested in a rectangular area and pen conditions were similar as described by Terrazas *et al.*[15]. The test lasted 5 min and the time was monitored with a stopwatch. During the test, the following variables were recorded on a preformatted sheet: (a) latency to reach a mother, (b) identity of mother (own or alien) that the kid reached first, (c) time spent in each contact zone, (d) number of kid's visits to the each contact zone and (e) the time spent looking towards each dam, regardless of the position of the kid in the testing area.

Non behavioral measures

Live body weight

Goats of each group were weighed on days 72, 89, 110 y 131 of pregnancy, at parturition and at days 15, 30 and 45 postpartum. Kids were weighed at birth and at days 15 and 30 of age.

Assistance at delivery

When an half of hour had been pass after the exposure of the some part of the kid´s body, and no immediate evolution was observed or when a dystocia or mal-presentation of the kid occurred, then a human assistant was conducted. The exploration of the mother and the assistance was carried with the help of sterile hand glove with natural lubricant. The assistant was done for personal with obstetric experience. The proportion of assistance at delivery was recorded when does had failed to progress of parturition and intervention was necessary.

Kid´s mortality

The mortality of the kids was recorded during the first 45 days after birth, including those kids that dead at birth.

Exp. 2

The objective of this experiment was to determine whether inclusion of maize in the diet during last 12 days of gestation can improve the mutual mother-young recognition in natural grazing goats under semi-arid conditions.

Extensive grazing conditions

The study was conducted in the Comarca Lagunera region in the subtropical northern México (26°N). This region possesses a semi-arid climate where the mean annual rainfall is about 266 mm (range: 163 to 504 mm) from June to September. The dry season is characterized by a dramatic decrease of food availability for animals which lasts from October to May[17]. In this region, goats are under natural grazing conditions, eating only the available natural vegetation. 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. Throughout the year in the Comarca Lagunera region, the composition of goat diets is made up of on average 82% shrubs, 12% herbaceous plants, and 6% grasses[18]. According to available studies in this region, pregnant goats maintained under semi-arid grazing conditions consume, on average, 1.2 kg/d DM and 2.1 Mcal/d of ME DM from this diet[19], which does not meet their maintenance and production nutritional requirements.

Animals and experimental groups

Multiparous goats (n = 81) 3 to 4 years old were used, which sexual activity were synchronized with a hormonal treatment similar as described in Exp. 1. Twenty one days previous to mean expected date of delivery during the month of november, the goats were homogenized to one of the two groups considering their BW and BCS before initial dietary treatment. Pregnant does from the grazing group (grazing, n = 37, BW 54.1 ± 2.2 kg and BCS, 2.1 ± 0.07 points), continued maintained under natural extensive management, in which the animals were taken out daily to graze the available natural vegetation until parturition and they do not received any feed supplementation. Pregnant does from the supplemented group (SUP, n = 44, BW 55.3 ± 1.8 kg and BCS, 2.1 ± 0.07

points) were also maintained under natural extensive management as the grazing group, but during the last 12 ± 0.5 days of pregnancy females received a inclusion of maize in grazing diet 0.6 kg of flaked maize/female per day. Maize was offered individually to each goat using small buckets in two parts (0.3 kg in the morning before going out for grazing and 0.3 kg in the afternoon when the animals returned to their pens). Offered maize substituted a part of grazing diet giving 87.3 g of CP/kg DM and 3.06 Mcal of ME/kg DM. In the pens, all does had free access to clean, fresh water and mineral blocks, 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[16]. In the morning, when females were taken out to graze, those showing clear signs of imminent parturition (i.e. restlessness, frequent vocalizations, isolation from the conspecifics, abdominal straining, presence of birth fluids or hooves of kid) were placed in pens together with others females in similar conditions, regardless of their experimental group. In this pen the does, received 1.2 kg of feed-mixture made of 75% alfalfa and 25% grass hay, that provided 82.1 g of CP/kg DM and 1.98 Mcal of ME/kg DM. At delivery, all does were observed with the aim to assist them in the case if it was necessary. The mean (± SEM) date of parturition was November 6 ± 3.0 days. Once that parturition takes place, mothers and kids remained together in the pen (except when the tests were performed in which kids were separated by one hour before each test to stimulate in both dams and kids their seeking behavior during the test). After culminate the test dams and kids were returned to a pens where had free interaction with other females of similar conditions, regardless near of rest of flock .

Variables and their measures

Behavioral measures

Two-choice preference test at 4 h postpartum in the mothers

Due to that in a previous studies in ewes[20] and in Exp. 1 in does it was demonstrated that mothers were able to recognize their own offspring as early as 6-8 h postpartum, then in the present we tested if mother-young recognition can be achieved even more earlier. So, we performed the test at 4 h after delivery. The corral test and the procedures

were the same as described in experiment I. In all dams from the present experiment the same behavioral variables reported in Exp. 1 was measured.

Two-choice test at 8 h postpartum in the kids

As in the mothers, in the present study we tested if kids develop an earlier ability to recognize their mothers at 8 h after birth. Only one kid per mother was used to perform this test, which were selected of according high size and/or high weight from each mother. Thus, 37 kids from the grazing group (15 singles, 16 twins and 6 triplets) and 44 kids of the SUP group (17, 19 and 8, respectively) were tested. The corral test and the procedures were the same as described in experiment 1. During the test which lasted 5 min the same behavioral variables reported in Exp. 1 were measured and recorded on a preformatted sheet. Additionally, proportion of kids actives was determined, take as kid active, when this reach a contact zone near either mothers during the test.

Non behavioral measures

BW, BCS of the does. BW and BCS were measured at 35, 28, 21, 14, 7 days before the expected mean date of delivery and at parturition (after the placental expulsion). Females were weighed on a mobile scale with a 200-kg capacity and a precision of 0.05 kg. The BCS was determined using the method previously described for this specie by Walkden-Brown *et al*.[21], which considers a point scale from 1 (very lean) to 4 (fat).

Kid's body weight. All kids were weighed at birth, but only 15 kids in each group were continue weighed until the first 12 days of life due to practical reasons and the general management of the flock. Kids were weighed in the afternoon before of reuniting with their mothers.

Statistical analyses

In both experiments the statistical analyses from all behavioral parameters were carried out by nonparametric tests (two tailed) because of the lack of normality of the data. Intragroup comparisons were analyzed by the Wilcoxon signed-ranks test. Intergroup comparisons were analyzed by the Kruskal Wallis and Mann–Whitney *U* - tests. To evaluate the proportion of kids or goats that were reached in first order during the test,

the Pearson Chi-square probability test was used. The proportion of kid´s mortality and the assistance at delivery in Exp 1 were analyzed using this same procedure. BW and BCS in mothers and kids were analyzed by Student *t* test and/or ANOVA for repeated measures with time as a within factor and group as between factor. All tests were performed with the statistical package SYSTAT, version 13.0 (Chicago, IL), and exact values of P are indicated in the text and the level of statistical significance was set at $P \leq 0.05$.

Ethical note

Experimental procedures were approved by a local Institutional Committee for the Care of Experimental Animals (Faculty of Medicine and Veterinary, UNAM). Furthermore, experimental procedures were in accordance with the guidelines for the ethical use of animals in applied ethologic studies[22].

Results

Exp.1

Two-choice preference test at 8 h postpartum in the mothers

The time spent looking toward the own kid was higher in CON than in UF goats ($P = 0.04$, Fig. 1), and tended to be higher compared with maize group ($P = 0.06$). While the time spent near the alien kid tended to be higher for UF than for CON goats ($P = 0.06$, Fig. 1). Non-significant differences were found between in the rest of variables measured during the test ($P > 0.05$). When comparing was within same group we found that either CON or maize goats spent longer time near their own than to the alien kid ($P \leq 0.001$, Figure 1). While UF goats did not differ between the time spent the own and to the alien kids ($P = 0.2$). In the time spent looking toward the kids, the three groups of dams spent more time looking toward the own than to the alien kid ($P \leq 0.02$, Fig. 1). Finally, frequency to visits the kids was higher for the own than to the alien kids in the three group ($P \leq 0.03$, Figure 1). The latency to reach the contact zone did no differ between groups (CON: 15 ± 3 s, UF: 26 ± 6 s and maize: 26 ± 7 s, $P > 0.05$). Proportion of dams that reach for the first time the own kid did not differ between groups (CON: 14/19, UF: 9/17, maize: 11/21; $P > 0.05$).

INSERT FIGURES 1 ABOUT HERE

Two-choice tests in kids at 12 h after birth

The latency to reach a mother differed between groups (P = 0.01). Kids from CON group were faster to reach the contact zone of the mothers than kids from maize group (145 ± 23 *v.* 213 ± 21 s, respectively P = 0.04) and those from UF group (236 ± 21 s, P = 0.006). The proportion of kid reaching first their own mother compared to the alien mother did not differ between CON, UF and maize groups (10/21, 5/21, and 8/19, respectively P > 0.05). When comparing the proportion of kids that reach the contact zone of the mothers, this proportion was higher in CON kids compared to UF group (18/21 *v.* 11/19, respectively P = 0.04) and a tendency be higher in those from maize groups (13/21, P = 0.07). Non-significant difference was found between maize and UF group (13/21 *v.* 11/19 respectively P = 0.7).

The time spent by the kids near to the own mother differ between groups (P = 0.01). Kids from CON group spent more time near the own mother compared to kids from maize group (P = 0.03) and those from UF group (P = 0.004, see Figure 2). Non-significant differences were found between UF and maize group (P = 0.3). The time spent near the alien mother did not differ between groups (P > 0.05, see Fig. 2). When comparing within groups, kids from CON group spent more time near to the own than to the alien mother (P = 0.007, see Fig. 2), and this was similar in kids from maize group (P = 0.03). While kids from UF group did not differ in the time spent between near to the own versus to the alien mother (P = 0.3, see Fig. 2).

In the time looking toward the own dam kids from CON group spent more time than UF group (P = 0.03, see Fig. 2). Non-significant differences were found in this time between CON and maize groups (P > 0.05, see Fig. 2) and between maize and UF group (P > 0.05 see Fig. 2). The time spent looking toward alien mother did not differ between groups (P > 0.05).

When comparing within group only kids from maize group spent more time looking toward the own than to the alien dam (P = 0.02).

The number of visits to the own mother differ between groups (P = 0.03). CON kids visit more frequently the own mother compared to those of UF group (P = 0.009, see Figure 2). Non-significant differences were found between CON and maize groups (P > 0.05, see Fig. 2). Non-significant differences were found between maize versus UF group (P > 0.05, see Fig. 2). Nonetheless, when comparisons where made within group, kids from CON group visited more frequently the own than the alien mother (P = 0.03, see Fig. 2). Neither kids from maize or from UF group showed significant differences in the visits to the own versus to the alien mother (P > 0.05, see Fig. 2).

INSERT FIGURES 2 ABOUT HERE

BW of the does and kids

Mothers: BW on days 72, 89 and 110 of pregnancy did not differ between CON and UF goats. While in day 131 of pregnancy CON goats were significantly heavier than UF goats (62 ± 2 *v.* 57 ± 1.33 kg, respectively P = 0.05). Immediately after birth, BW differ between groups (P = 0.01), CON goats weigh more than maize (56.9 ± 2.1 *v.* 50.2 ± 1.3 kg, P < 0.05) and than UF goats (49.2 ± 2.1 kg, P < 0.05). Non-significant differences were found between groups in the BW on day 15, 30 and 45 after birth (P > 0.05). At birth a significant differences in the BW of kids was observed between groups (P = 0.01). CON kids were heavier than kids of UF group (3.5 ± 0.1 *v.* 3.0 ± 0.1 kg, P < 0.05) and those from maize group (3.0 ± 0.09, kg, P < 0.05) while these two latter groups did not differ significantly. Non-significant differences were found in live BW of kids between groups on days 15, 30 and 45 after birth (P > 0.05, data not show).

Assistance at delivery

The proportion of the kids that need assistance during birth was higher for goats from UF group compared to those of the CON group (16/29 *v.* 3/23, respectively P = 0.002) and those from maize group (7/32, P = 0.007). While this variable did not differs between goats from CON and maize group (P = 0.4).

Kid´s mortality

The mortality from the birth until the 45 days of age was higher for kids from UF group compared to CON kids (40% *v.* 12 %, P > 0.05), and those from maize group (18%, P < 0.05). Non-significant differences were found between mortality observed in kids from CON and maize groups (P > 0.5).

Exp.2

Two-choice preference test at 4 h postpartum in the mothers

Latency to reach a contact zone and identity of the first kid reached. Latency to reach a contact zone did no differ between grazing and SUP goats (35 ± 6 s *v*. 27 ± 4 s, *P* = 0.2). Moreover, proportion of mothers that reach first their own kid during the test was not different between goats from grazing group (62%, 23/37) and goats from SUP group (59%, 26/44, *P* = 0.8).

Total time spent in the contact zone near each kid. Goats from SUP group spent more time in the contact zone near the own kid than the grazing goats (*P* = 0.046, see Fig. 3). However, the time spent in the contact zone near the alien kid did not differ between the goats of the two group (P = 0.1, see Fig. 3). However, when this time was compared within the same group, goats from SUP group spent more time in the contact zone near to their own kid than near to the alien kid (P = 0.0001). In contrast, spent time in the contact zone near of their own kid versus near to the alien kid in goats from grazing group did not differ (P = 0.08).

Number of maternal visits to the contact zone (Fig. 3). Number of maternal visits to the contact zone near to their own kid was more frequent in goats from SUP group than goats from grazing group (P = 0.05). On the contrary, number of maternal visits near to the alien kid did not differ between mothers of both groups (P = 0.7). However, comparisons within the same group, indicated that the frequency of maternal visits to the own kid were higher than to the alien (grazing group: P = 0.03 and SUP group: P = 0.001).

Total time spent looking toward each kid, regardless of the position of the mother in the testing area (Fig. 3). Time spent looking toward the own kid did not differ between the two groups (P = 0.6). However, mothers from the grazing group, spent more time looking the alien kid than mothers from the SUP group (P = 0.001). Comparison within the same group, showed that mothers from both groups spent more time looking toward the own than toward the alien kid (grazing: P = 0.02 and SUP; P = 0.0001).

INSERT FIGURE 3 ABOUT HERE

Two-choice test at 8 h after born in the kids

Proportion of kids that reached a contact zone. Proportion of active kids during the test, and therefore that perform some preference by a given mother was significantly higher (*P* = 0.02) in kids from SUP group (75%, 33/44) than in kids from grazing group (51%, 19/37).

Because this, in the next variables, the statistical analyses considered only those kids that performed an election (grazing group, n = 19 and SUP group, n = 33).

Latency to reach a contact zone and the first mother reached. Latency to reach a contact zone did not differ between kids from grazing group (127 ± 20 s) and kids from SUP group (113 ± 15 s; *P* = 0.5). Also, there was a tendency for the proportion of kids that reached first their own dam was higher in kids from SUP group than in kid from grazing group (grazing: 63%, 12/19 and SUP: 85%, 28/33; *P* = 0.07).

Time spent in each contact zone (Fig. 4). The time spent by kids in the contact zone near a give mother (own or alien) during the test did not differ between kids born from the two groups (P ≥ 0.1. When this time was compared within group, kids born from SUP group spent more time near their own mother than near the alien mother (*P* = 0.0001). In contrast, in kids from grazing group this time did-not differ between the two mothers (P = 0.1).

Number of kid's visits to a contact zone (Fig. 4). Neither the number of visits to the own nor to the alien mother differ in both groups (P = 0.2 and *P* = 0.3, respectively). Nonetheless, when comparisons were made within the same group, kids born from SUP group visited more frequently the contact zone near their own mother than near the alien (*P* = 0.0001). In contrast, the frequency to visits to the own versus alien mothers did not differ in kids from grazing group (*P* = 0.1).

Time spent looking towards each dam, regardless of the position of the kid in the testing area (Fig. 4). The time looking toward the own mother did not differ significantly between kids born from grazing group and the kids from SUP group (*P* = 0.1). While, kids born from grazing group spent more time looking toward alien dam than the kids born from SUP does (P = 0.007). When comparisons where made within the same group, kids born from SUP mothers spent more time (P = 0.0001) looking toward their own mother than the alien, whereas in kids born from grazing does this time was not different between the two mothers (P = 0.3).

INSERT FIGURE 4 ABOUT HERE

BW and BCS of the females

BW during the last 21 days of gestation did no differ (P ≥ 0.5) between the goats of grazing group and SUP group, whereas at parturition it was higher in the mothers from SUP group than in goats from grazing group (P = 0.049). Mean BCS of the females decreased in both groups from day 115 of pregnancy until parturition (*P* = 0.001; Fig. 5) and no differences between groups were detected (*P* ≥ 0.1; Fig. 5). However, at parturition BCS was higher (*P* = 0.001) in SUP females than in grazing mothers.

INSERT FIGURE 5 ABOUT HERE

BW of the kids from birth to 12 days age

At birth, kids born from SUP goats were significantly heavier than the kids born from grazing goats (P = 0.003; n = 79 and n = 65, respectively). After birth there was a group

x time interaction on the weight of kids (P = 0.001; n = 15 in both groups). BW increased from birth to 12 days age in both groups; however, kids from the grazing group were significantly lighter than kids from the SUP group during the first 12 days of life ($P \leq 0.01$ in each point; Fig. 6).

INSERT FIGURE 6 ABOUT HERE

Discussion

In Exp. 1, malnutrition during gestation impairs the ability of the mother and the kids to recognize each other. Likewise, results from Exp. 2, indicates that under semiarid grazing conditions dams and offspring shown spontaneously similar repercussions in their ability to mutual recognition. In both experiments the negative effect was evident on the ability of the kid to recognize their mothers.

When assessed our hypothesis we find that in both experiments the maize supplementation either during the last 15 or 12 days of gestation undoubtedly improved the mother-young abilities to recognize each other, however the effects were stronger in animals under natural grazing conditions. Furthermore, results from Exp. 1 emphasizes that maize supplementation decreased the mortality rate of the kids during the first 45 days of age, decrease the events of birth assistant whereas in Exp. 2 an important finding was that a short term supplementation with maize increases the weight of the kids born from multiple litter.

Influences of maize supplementation on mutual mother-young recognition

In the 2 experiments, comparison within group shown that CON and SUP dams performed a best choice toward the own kids to say by the greater time spent near to these kids. This effect was more pronounced in the two-choice test performed in the kids. Thus, kids from CON and maize groups spent more time near to their mother than UF and grazing kids. These better performances on the mutual mother-young recognition due to the maize supplementation can be explained by several aspects: first, an early and intense mother-young interaction has been previously observed at parturition in dams that were well-nourished than in dams that were malnourished during gestation[23,15]. For example, lambs and kids born from malnourished dams were

slower to stand and suckled less frequently than lambs and kids from well-nourished dams during the first 90 minutes after birth[23,15]. Recently, in extensive grazing goats it has been showed that maize supplementation during the last 12 days of gestation increased the behavioral activity of the kids at birth[9]. Also, in the present the proportion of kids that does not had a choice by a given mother was greater in UF and grazing groups than in CON and SUP groups. As the general activity of the young made it more attractive for the mother[24], is possible that this better performance observed in CON and supplemented animals could help to establish an early and strong reinforcement of the selective bonding. This hypothesis could be supported by the fact that underfed ewes shown a poor maternal behavior due to it the low activity and vitality of their weak offspring[25]. In the same way, it was demonstrated that in underfed ewes the sonographic characteristic of the lambs high pitch bleats' recorded during the first two day of life were different and not normal than those of lambs born from well-nourished ewes[26]. This effect of mother malnutrition on offspring vocalization's impaired in turn the mother-young mutual recognition. Additionally, the greater live weight of the kids at birth from CON and supplemented groups also increases the general activity and therefore the attractiveness of the young by its mother[24, 27, 28]. Therefore, is possible that this reinforcement of the selective bonding at parturition in turn could improve the postpartum mutual recognition. Second, it is possible that CON and supplemented dams yielded more colostrum and it in turn facilitated the mother-young mutual recognition. For example, first suckling events had a crucial role on mother preference of the new born lambs[11]. In contrast to suckled lambs, those that are deprived of suckling for either 2, 4 or 6 h after birth, do not display a preference for their mother at 24 h[11]. Additionally, previous studies showed that lambs receiving colostrum spent significantly more time near their mother than lambs deprived from early colostrum consumption[29,30]. Since in the sheep and in goats maize supplementation during late gestation increases the colostrum yield, it greater availability of colostrum at birth for the offspring possibly improves the early preference for their own mothers[9,31,32].

Whit respect to kid´s recognition test by the mothers made at 8 h (Exp. 1) and to 4 h (Exp. 2) postpartum, the results indicates this ability take place as early as 4 h postpartum. In fact, at 4 h postpartum, dams spent similar time near their kids as dams

tested at 8 h postpartum. This same early recognition was observed in the mother recognition test performed by the kids at 12 h (Exp. I) and at 8 h (Exp. II) after birth. Then, maize supplementation had an early facilitator role on mother-young recognition as it had on mother-young relationships at birth[9].

Influences of maize supplementation on kid's BW, mortality rate and assistance at delivery

BW of kids born from UF and grazing does from this study was lower than kids born from CON and those from supplemented groups. There was a relationship between BW of the kids and the mortality rate which was lower in CON and maize groups than in UF group. It is coincident with previous reports in ewes in which nutritional supplementation during mid or late pregnancy reduces lamb mortality by increasing the birth weight of the lambs, possibility for an increase the possibilities of survival of newborn[33,34]. Additionally, in previous studies[15,23], the greater weight of the offspring at birth was due to the well nutrition received by the females during the whole gestation. It is very surprising that only with 12 d of inclusion of maize in the diet to our extensive grazing goats that gave birth to multiple kids was enough to increase the body weight of kids. This effect of maize on the body weight at birth was not observed in lambs when mothers were supplemented only during the last 8 days of pregnancy[32,35]. This discrepancy could be attributed possibly to the low nutritional degree which was maintained our extensive grazing goats compared with mentioned studies. In fact, in undernourished ewes (given only 70% from well-nourished) from day 80 of pregnancy until parturition the birth weight of the lambs were not different between groups[8].

The causes of the greater frequency of assistance at delivery registered in UF goats compared with CON and maize goats are not totally understood, however this finding is comparable with those in sheep, in which lambs born to low-intake mothers had a higher incidence of malpresentation than high-intake mothers, and tended to require greater assistance at delivery, despite their lower birth-weight[23]. This finding is comparable with those reported in goat under grazing conditions, in which they report more frequency of birth delivery assistance for non supplemented grazing than in supplemented goats at the end of pregnancy[9]. It has been suggested that diminished

fetal movements in the uterus by the maternal undernutrition in the first third of gestation[36], in turn by restricted uterine growth and low volume of amniotic consequently would lengthen parturition[23, 37]. Furthermore, frequency of lamb's movements considerably increases at the end of gestation which is associated to the fetus presentation at delivery[38-40]. However, as parturition represents an important metabolic demand[41], therefore, underfed females may not have sufficient energy to cope with this physiological process. Indeed, recent studies have shown that fetal malpresentation and prolonged parturition may impair neonatal activity, mainly reducing lamb vitality during first hours of life[23, 37, 42].

Maize inclusion in the grazing diet during the last 12 days of gestation had additional effects on corporal state of the females. For example, BW and BCS recorded in SUP does did not decline drastically at parturition, compared with grazing goats. This abrupt decline in BW and BCS could be related to an increase in energetic demands during the last 45 days of pregnancy by the fetal grown, developmental udder and colostrum production[43-45]. However, in both species goats and ewes a maize supplementation during late gestation could slight the mobilization of body reserves, because the maize to cover in part, some of the elevated nutritional demands at final stages of gestation[31,46,47].

As a whole, our present results underline the importance to provide with an adequate nutrition or additional energetic supplementation during late gestation in underfed goats in order to improve the mother-young mutual abilities for an early recognition each other. That is very outstanding from this study is the fact that it improvement of mutual recognition due adequate nutrition or fed supplemental increased the chances of the kid's survival.

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Figure captions

Fig. 1. Mean time (± SEM) spent in the contact zone near each kid, mean time spent looking toward each kid and mean number of maternal visits to each kid obtained in a two-choice test performed at 8 h postpartum in dams from in CON (n = 19), UF (n = 17) and maize (n = 21) . Comparison between kids, own (□) and alien (■) kid (* $P < 0.05$, ** $P < 0.01$,and *** $P < 0.01$ and Wilcoxon test). a-b different literal on each bar denotes significant variations through between groups (Mann-Whitney *U* test).

Fig. 2. Mean time (± SEM) spent in the contact zone near each mother, mean time spent looking toward each mother and mean number of kid visits to each mother obtained in a two-choice test performed at 12 h postpartum in kids from in CON (n = 19), UF (n = 17) and maize (n = 21) . Comparison between mother own (□) and alien (■) (* $P < 0.05$, ** $P < 0.01$ and *** $P < 0.01$, Wilcoxon test). a, b different literal on each bar denotes significant variations through between groups (Mann-Whitney *U* test).

Fig. 3. Mean time (± SEM) spent in the contact zone near each kid, total time spent looking towards each kid and mean number of maternal visits to each kid obtained in a two-choice test performed at 4 h postpartum in dams from in grazing goats (n = 37) and SUP goats (n = 44). Comparisons where made within group between kid own (□) and alien (■;* $P < 0.05$, ** $P < 0.01$ and *** $P < 0.01$), and ab different literal on each bar denotes significant variations through groups.

Fig. 4. Mean time (± SEM) spent in the contact zone near each mother, total time spent looking toward each mother and mean number of maternal visits to each mother obtained in a two-choice test performed at 8 h of life in kids born from grazing (n = 37), and SUP (n = 44) goats. Comparisons where made within group between mother own (□) and alien (■, * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.01$), and ab different literal on each bar denotes significant variations between groups.

Fig. 5. Mean (± SEM) body weight (BW) and body condition score (BCS) of goats during pregnancy and partum in grazing (○, n = 37), and SUP (●, n = 44) goats. Filled bar indicates the last 12 days of pregnancy when maize was provided to supplemented goats. Asterisks (* $P < 0.05$, ** $P < 0.01$ and *** $P < 0.01$) significant difference between groups.

Fig. 6. Mean (± SEM) body weight at birt of kids born from grazing (○, n = 65), and SUP goats (●, n = 79) and but only 15 kids in each group were continue weighed until the first 12 days of life. Asterisks (* $P < 0.05$, ** $P < 0.01$ and *** $P < 0.01$) significant difference between groups.

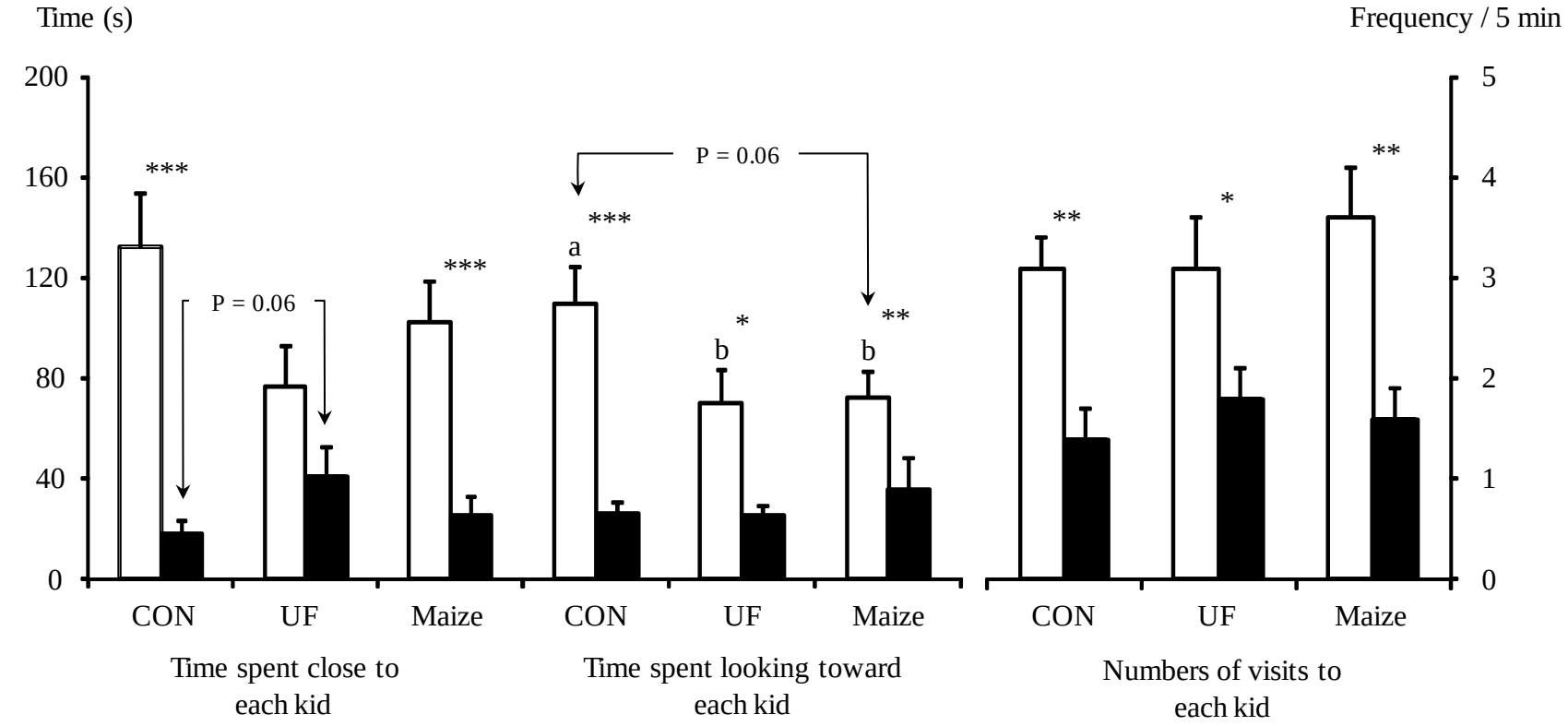
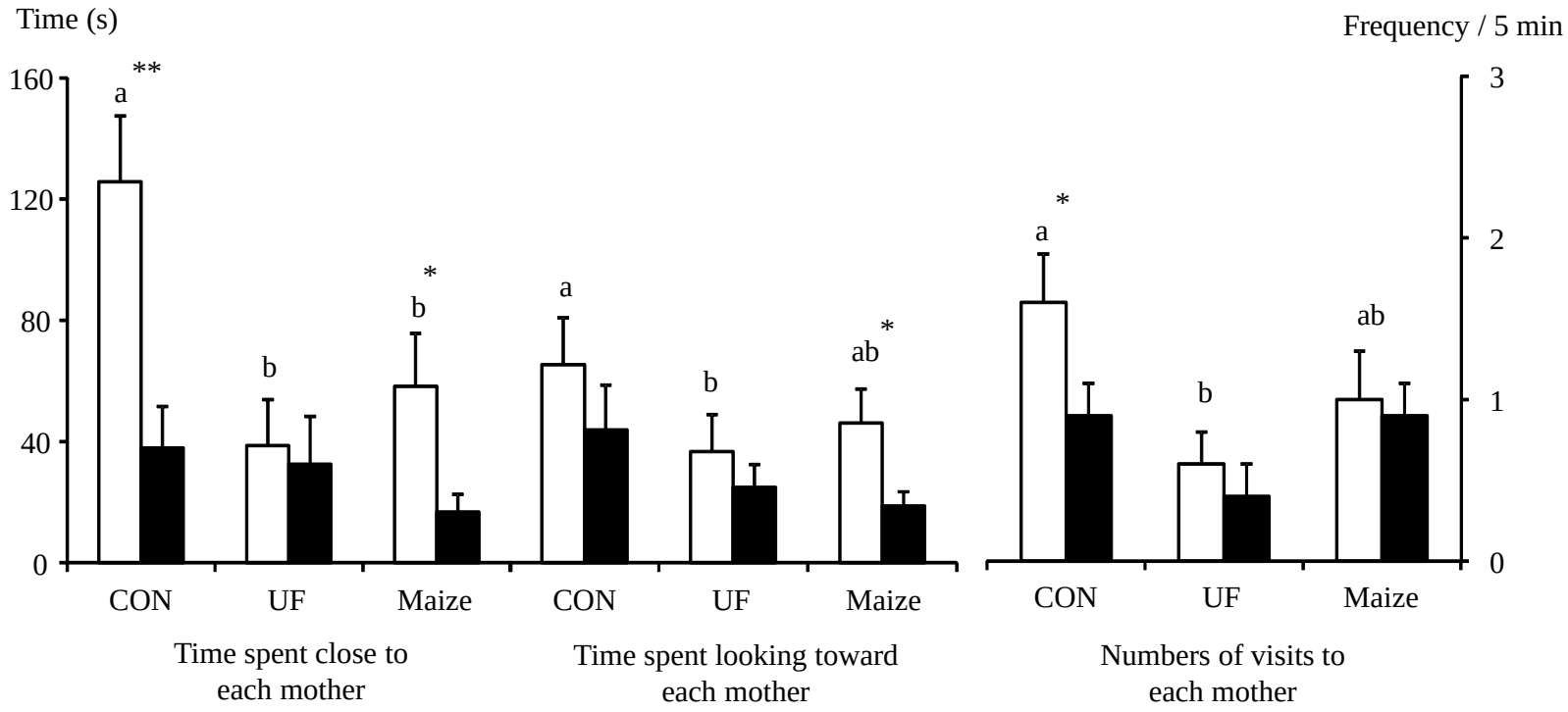


Figure 1. Ramirez-Vera *et al*.,



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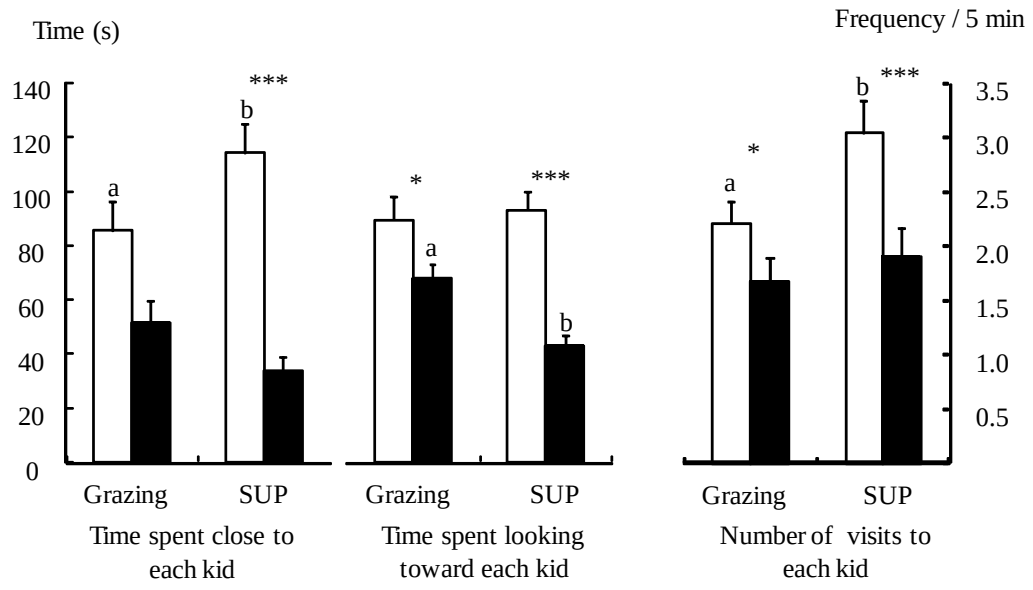

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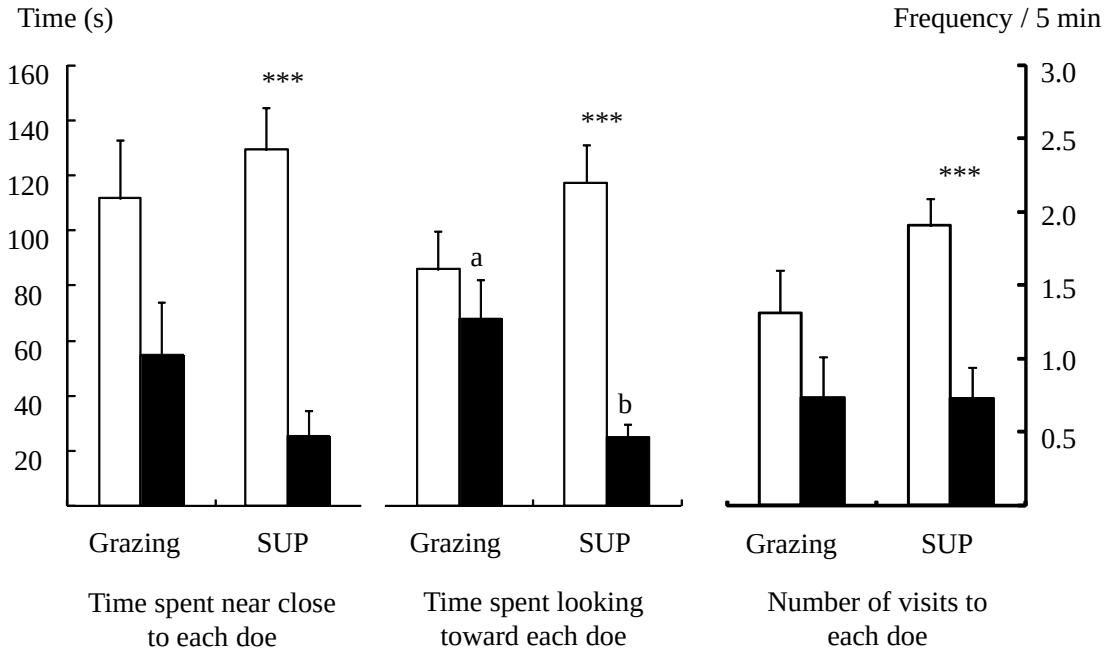

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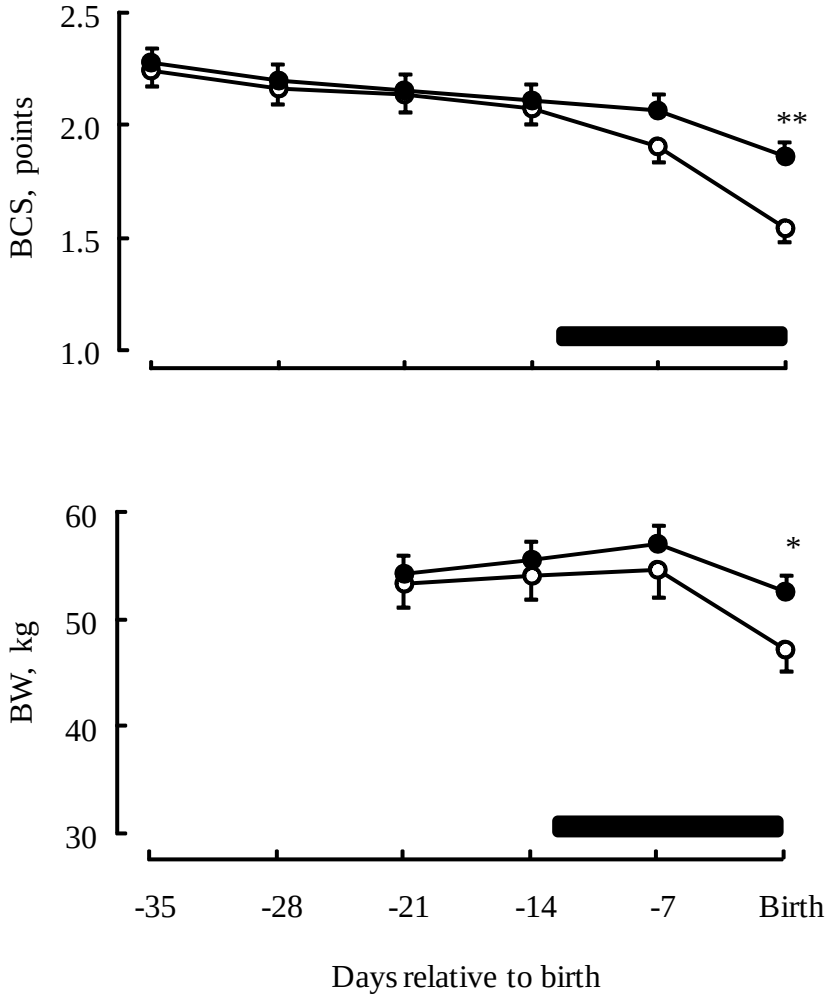

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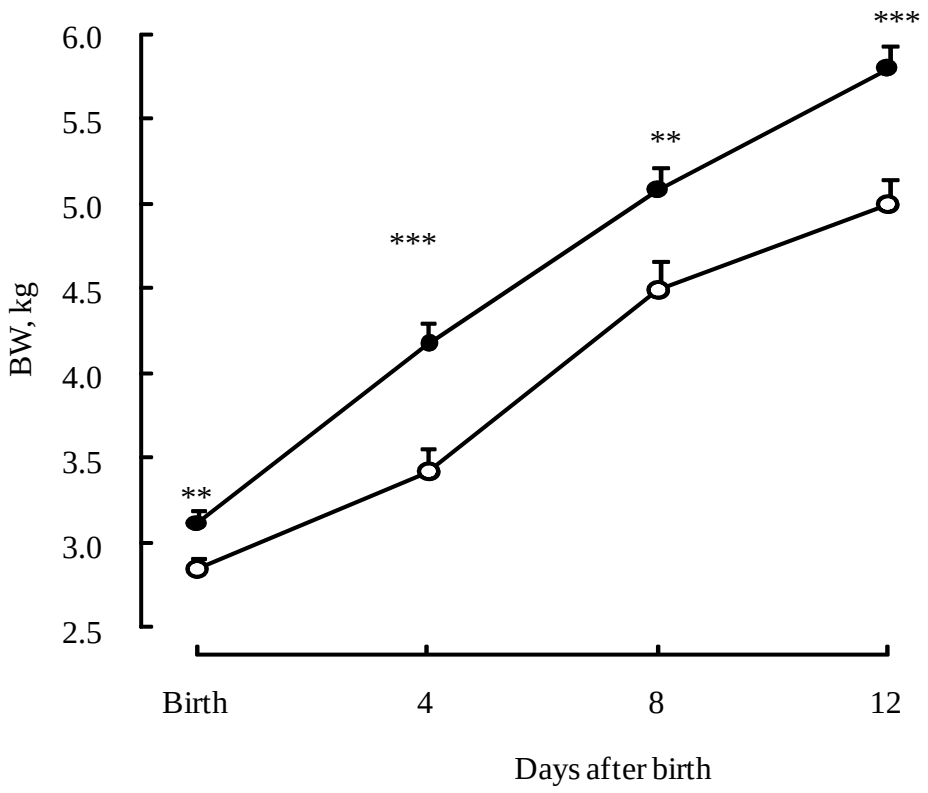

Figure 6. Ramirez-Vera *et al*.,

7. CONCLUSIONES Y PERSPECTIVAS

Los resultados de la presente tesis permiten concluir que en cabras mantenidas en las áreas de pastoreo semiárido, como lo es el subtrópico mexicano (26°N), en las que la cantidad y calidad de la vegetación que consumen los animales fluctúa a través del año, la inclusión de maíz en la dieta durante los últimos 12 días de gestación incrementa la producción de calostro y mejora la vinculación madre-cría durante las primeras horas después del parto.

Influencia de la mayor disponibilidad de calostro al nacimiento debido a la inclusión de maíz en la dieta sobre la sobrevivencia de la cría

La mayor cantidad de calostro obtenido en las madres a las que se les incluyó maíz antes del parto confirma resultados previos obtenidos en ovejas gestantes en pastoreo y extiende el hallazgo en las hembras de la especie caprina mantenidas en pastoreo extensivo semiárido. Los resultados de esta tesis muestran por vez primera que las cabras mantenidas en pastoreo semiárido, a las que no se les incluye un alimento alto en energía en la dieta preparto, producen una cantidad de calostro muy reducida. Probablemente, esa poca producción de calostro al parto es, en gran parte, una causa de la mortalidad neonatal en esta especie, la cual puede alcanzar tasas de hasta 27% en las explotaciones caprinas del norte de México. Las consecuencias pueden complicarse aún más cuando la madre ha parido 2 crías, en las que en muchos

casos no existe suficiente calostro para ambas. En efecto, está bien documentado que la nula o reducida ingestión de calostro es una causa importante, que disminuye las posibilidades de sobrevivencia del recién nacido (Mellor y Stafford, 2004). Por ejemplo, el mantenimiento de la temperatura corporal de la cría antes de la ingestión de calostro, se atribuye a una movilización en las reservas de grasa y a un incremento en la actividad muscular de la misma. Sin embargo, la disponibilidad de calostro al nacimiento es el segundo factor importante para la obtención energética usada en la generación de calor y así en el control de la temperatura (Alexander, 1974; Val-Laillet *et al.,* 2004). En cuanto a la influencia de la disponibilidad de calostro sobre la relación madre-cría, en corderos se ha reportado que aquellos, a los que se les restringe el amamantamiento durante las primeras 6 h post-nacimiento, no tienen una preferencia por sus madres en una prueba de reconocimiento a 24 h de vida (Nowak *et al.,* 1997, 2007). Al contrario, a los corderos que se les permite un consumo temprano de calostro muestran una mayor habilidad para reconocer a su madre a 24 h de vida (Goursaud y Nowak, 1999; Nowak *et al.,* 2011).

Efecto de la inclusión de maíz en la dieta sobre la interacción temprana madre-cría

Los resultados de la presente tesis indican que no sólo la mayor disponibilidad de calostro promueve una mejor relación madre-cría. La inclusión de maíz además influyó sobre la actividad de la cría después de nacer, a decir por la mayor frecuencia en la búsqueda de la ubre y la mayor actividad del

amamantamiento en los primeros momentos de vida. De hecho, es importante subrayar que antes del consumo de calostro las crías provenientes de las madres a las que se les incluyó maíz en la dieta mostraron una mayor frecuencia de balidos bajos, indicativos de un estado de “calma” (Nowak *et al.,* 2011), lo que ocurrió en menor frecuencia en las crías de madres que no se les ofreció maíz. Además, en el artículo 2, se demostró que la inclusión de maíz mejoró la conducta materna en los primeros 30 min postparto (mayor consumo de membranas amnióticas y mayores invitaciones al amamantamiento). Asimismo, la inclusión de maíz en la dieta fortaleció el establecimiento de la selectividad maternal, es decir, que la madre dirigió los cuidados maternos sólo a su progenie y rechazó activamente a las crías ajenas. Lo anterior puede explicarse en parte al hecho de que en el presente estudio, las madres que recibieron maíz mostraron un mayor consumo de fluidos amnióticos. Recientemente se demostró en ovejas que el consumo de estos fluidos por la madre es determinante para establecer sólidamente la selectividad maternal (Poindron *et al.,* 2010; Otal *et al.,* 2009). Adicionalmente, en el artículo 2 se muestra por vez primera en cabras en pastoreo que con 2 h de interacción madre-cría un 52% de ellas han establecido el vínculo selectivo y que esta proporción se incrementa a un 88% cuando se le incluye en la dieta un alimento energético como el maíz durante los últimos 12 días antes del parto. Este hallazgo de mejorar y reforzar el vínculo madre-cría mediante la nutrición durante la gestación nunca habían sido descrito en la literatura sobre la conducta materna temprana en cabras. Es importante señalar que la mejoría en la conducta materna de las madres a las que se les incluyó maíz en la dieta

ocurrió principalmente en los primeros 30 min de interacción con sus crías. Lo anterior indica que el despliegue intenso de los cuidados maternales se presentó más rápido en esos animales que en aquellos alimentados sólo con el pastoreo.

Efecto de la inclusión y la suplementación con maíz, alimento alto en energía, en la dieta sobre la capacidad de reconocimiento mutuo madre-cría

De los resultados obtenidos en el tercer estudio, se concluye que la suplementación o la adición de maíz en la dieta de las cabras durante las últimas 2 semanas de gestación indudablemente mejoró la capacidad de reconocimiento mutuo madre-cría. Es decir, que la madre tenga la habilidad de reconocer a su cría a distancia, ya desde 4 h postparto y que la cría muestre una preferencia por su madre desde las 8 h de vida. Este efecto nutricional sobre el reconocimiento temprano madre-cría no se conocía en la literatura sobre conducta materna en pequeños rumiantes. Lo anterior está relacionado de manera general a los efectos de la adición del maíz en la dieta sobre la mayor producción de calostro, la mejoría en la conducta materna y de la actividad de la cría al nacer y al establecimiento de la fuerte selectividad maternal descritos en los 2 primeros estudios. Sin embargo, como se observó en este tercer estudio, las crías provenientes de madres a las que se les incluyó maíz en su dieta preparto tuvieron un mayor peso al nacer que las crías de madres alimentadas sólo con el pastoreo. Esto último difirió a lo obtenido en estudio 1, en el cual no existió diferencia en el peso al nacer entre cabras

alimentadas sólo con el pastoreo y en aquellas que se les incluyó maíz. La discrepancia en el peso al nacimiento puede explicarse por el hecho de que en el primer estudio se utilizaron madres con sólo una cría; en cambio, en este último estudio 3 se investigó el efecto de la inclusión de maíz en la dieta preparto en cabras con camadas múltiples. Por lo cual, en el estudio 3, se sugiere que posiblemente el mayor peso de la cría al nacimiento mejoró la actividad general de la misma. Esto es confirmado con el hecho de que una mayor proporción (75%) de crías nacidas de madres a las cuales se les incluyó maíz en la dieta preparto tuvieron la habilidad para elegir a una madre, mientras que en las crías de cabras alimentadas sólo con el pastoreo sólo el 51% eligieron a una madre.

Finalmente, los resultados de este tercer estudio enfatizan que la suplementación preparto con maíz disminuyó de manera importante la tasa de mortalidad de los cabritos durante los primero 45 días de vida. Este resultado era de esperarse, pues los efectos benéficos de la inclusión de maíz sobre la producción de calostro, la mayor actividad de la cría al nacer, el mayor despliegue de conductas típicas del cuidado materno, el fortalecimiento de la selectividad maternal, así como el mayor peso de las crías, son todos ellos aspectos importantes que influyen sobre una mayor viabilidad de las crías en los primeros días de vida.

Influencia de la inclusión de maíz en la dieta de pastoreo sobre el estado corporal de las hembras parturientas

Otro efecto observado debido a la inclusión de maíz en la dieta en cabras en pastoreo extensivo es que la condición corporal al parto no disminuyó de manera considerable como en las hembras a las que no se les incluyó maíz. Es conocido que en animales subnutridos la condición corporal al parto disminuye considerablemente debido a una mayor movilización de reservas corporales por la gran demanda de nutrientes utilizados en el crecimiento fetal, el desarrollo de la glándula mamaria y la producción de calostro durante la gestación tardía. Así, este ligero decremento en la condición corporal de las madres a las que se les incluyó maíz en la dieta posiblemente se debió a que el maíz aportó una parte de la demanda energética y es probable que estas hembras movilizaran pocas reservas corporales en comparación con las hembras que sólo fueron alimentadas con el pastoreo.

De este modo, se puede concluir que la inclusión de un alimento alto en energía, como el maíz en la dieta preparto de cabras en pastoreo mejora fuertemente la producción de calostro y la relación madre-cría en los primeros momentos después del nacimiento. Habría que investigar si la inclusión de otras fuentes de energía en la dieta de las cabras mantenidas extensivamente que estén disponible en la región, de menor costo y no tóxicas, pueden tener el mismo efecto que el maíz. Además, resta por confirmar estos efectos de la inclusión de un alimento energético en la dieta de pastoreo antes del parto pero utilizando sólo animales con camadas múltiples, en los cuales posiblemente los resultados se observarían con mayor impacto. Asimismo, sería importante

investigar si la suplementación o inclusión de maíz a corto plazo en estados más tempranos de la gestación pueda resultar en mayor peso de la cría al nacer, lo cual tendría un valor adicional que beneficie a los productores al vender crías más pesadas en un tiempo más corto. Otro punto que es importante confirmar es el efecto que podría tener la adición del maíz en la dieta de pastoreo preparto pero alimentando a las hembras gestantes de manera grupal. Lo anterior implica por un lado, una reducción en el trabajo que se realiza cuando se alimentan individualmente como lo fue en los trabajos descritos en esta tesis y por otro lado, poder evaluar la interacción sobre la nutrición y la jerarquía que tienen las hembras dentro del rebaño sobre la producción de calostro y la vinculación madre-cría.

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