L'OPUNTIA COME INTEGRATORE PER ANIMALI IN TARDA GESTAZIONE E LATTAZIONE

Ricercatori:

Gerardo Ordaz
Aureliano Juárez
Manuel López
Héctor Eduardo Martínez
Rosa Elena Pérez
Ruy Ortiz

SCRITTO DA:

Angelo Incorvaia

Titta Platamone

SCOPO DELLA RICERCA

In questo 6° numero presentiamo una ricerca condotta dall'università di Querétaro in Messico che ha esaminato l'effetto dell'integrazione con Opuntia ficus-indica sulle scrofette durante la fine della gestazione e l'allattamento. Sono state suddivise in due gruppi: il gruppo di controllo (CG), alimentato in modo convenzionale, e il gruppo sperimentale (EG), alimentato con mangime commerciale più O. ficus-indica. Risultati significativi includono una minore concentrazione di glucosio e una maggiore concentrazione di insulina nell'EG, e una minore concentrazione di trigliceridi durante la gestazione, il parto e l'allattamento nell'EG. Inoltre, le scrofette dell'EG avevano una maggiore concentrazione di HDL durante l'allattamento, un VFI più elevato e una minore perdita di peso corporeo allo svezzamento rispetto al CG.

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TITOLO:

Opuntia ficus-indica come integratore per scrofe in tarda gestazione e lattazione: effetti sui parametri biochimici e assunzione volontaria di mangime.

INTRODUZIONE:

La resistenza all'insulina (IR) è un disturbo metabolico che comporta una diminuzione della sensibilità cellulare all'insulina e predispone all'iperglicemia e alla dislipidemia (Unger et al. 2014). Tuttavia, nelle scrofe, come nella maggior parte dei mammiferi femmine, l'IR è un adattamento metabolico alla fine della gestazione e dell'allattamento che consente di indirizzare un maggiore apporto di nutrienti all'utero (per una maggiore crescita esponenziale del feto) e alla mammella (per avviare la produzione di latte). (Père e Etienne 2007, 2018). L'importanza dell'IR nelle scrofe è che ha un effetto sulla produttività della scrofa, in particolare sull'assunzione di mangime durante l'allattamento (Père e Etienne 2007; Manu et al. 2020). Poiché l'effetto dell'IR è stato osservato in una minore assunzione di mangime, durante la tarda gestazione questo effetto non è percepito, poiché, durante questo periodo, gli schemi di alimentazione si basano su un'alimentazione limitata della scrofa, in contrasto con l'alimentazione ad libitum durante la lattazione (Solà-Oriol e Gasa 2017). Inoltre, la leptina non ha alcun effetto sull'assunzione di mangime durante la gestazione poiché esiste resistenza alla leptina (iperleptinemia) per un maggiore apporto di nutrienti nell'utero (Tessier et al. 2013). Tuttavia, durante l'allattamento, le scrofe non presentano resistenza alla leptina (Cools et al. 2014). Alcuni studi mostrano che si verifica un aumento graduale della concentrazione sierica di leptina fino al terzo medio della gestazione, raggiungendo una concentrazione elevata e rimanendo elevata fino al parto nelle femmine suine (Saleri et al. 2015). È stato riferito che la profondità del grasso dorsale era positivamente associata alle concentrazioni di leptina. Tuttavia non esiste una relazione diretta tra i livelli di leptina circolante e la fertilità delle scrofe, se la leptina è coinvolta nel controllo della riproduzione, il suo ruolo è meramente permissivo. Per esempio. attraverso l'associazione che la leptina ha con la ridotta assunzione di mangime nelle scrofe in lattazione. La minore assunzione di mangime favorisce il catabolismo della scrofa e ne modifica lo stato metabolico. Ciò mette a rischio la sintesi degli ormoni coinvolti nella riproduzione: LH, FSH, IGF-I, estrogeni, ecc. (De Rensis et al. 2005; Mosnier, Etienne, et al. 2010; Solé et al. 2021).

Per le ragioni sopra descritte, dovrebbero essere ricercate strategie che massimizzino l'assunzione di mangime nelle scrofe in lattazione. È stato riportato (Serena et al. 2007; Quesnel et al. 2009; Jha e Berrocoso 2015; Li et al. 2021) che l'aggiunta di fibre alimentari alla dieta delle scrofe in gestazione promuove la salute gastrica e aumenta l'assunzione di mangime durante l'allattamento. Questo perché la fibra alimentare favorisce il profilo metabolico minimizzando la resistenza all'insulina e la dislipidemia (Serena et al. 2007; Li et al. 2021).

Nelle pecore, nei conigli, nei topi e nei maiali, la fibra alimentare di vari alimenti, tra cui Opuntia spp., è stata collegata a un miglioramento del metabolismo del glucosio e dei lipidi (Brahim et al. 2012; Halmi et al. 2013; Ordaz et al. 2017). Le concentrazioni plasmatiche più basse di glucosio, colesterolo e trigliceridi correlate al consumo di O. ficus-indica sono associate a: (i) stimolazione della secrezione di insulina e miglior riassorbimento del glucosio da parte di diversi tessuti e, (ii) modifica la biosintesi dei lipidi legandosi a acidi biliari, questo migliora il catabolismo del colesterolo (Kritchevsky et al. 1988; Fernández et al. 1992; Pari e Latha 2005; Gouws et al. 2019). Di conseguenza, la nostra ipotesi si concentra sull'effetto di O. ficus-indica sulla regolazione degli indicatori biochimici (principalmente insulina e leptina), minimizzando la resistenza all'insulina e i suoi effetti sulla produttività delle scrofe durante la tarda gestazione e la lattazione. Pertanto, questo studio mirava a valutare l'effetto dell'integrazione con O. ficus-indica sulle scrofette durante la fine della gestazione e l'allattamento, e in particolare sui loro parametri biochimici e sull'assunzione volontaria di mangime durante l'allattamento.

CONCLUSIONI:

L'IR è un processo fisiologico intrinseco delle scrofe, tuttavia negli attuali sistemi di produzione suina l'IR limita il potenziale produttivo della scrofa perché ha effetti sulla produttività della scrofa: basso apporto di mangime in lattazione, maggiore perdita di peso corporeo in lattazione, bassa produttività nella produzione successiva ciclo, minore longevità, ecc. L'assunzione di O. ficus-indica alla fine della gestazione e durante l'allattamento nelle scrofette modula favorevolmente la regolazione degli indicatori biochimici che partecipano allo sviluppo della resistenza all'insulina e della dislipidemia, che si riflette in una maggiore assunzione volontaria di cibo e minore perdita di peso corporeo allo svezzamento.

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Opuntia ficus-indica as a supplement for gilts in late gestation and lactation: effects on biochemical parameters and voluntary feed intake

Gerardo Ordaz [a], Aureliano Juárez [b], Manuel López [c], Héctor Eduardo Martínez [d], Rosa Elena Pérez [d] and Ruy Ortiz [c]

aCentro Nacional de Investigación Disciplinaria en Fisiología y Mejoramiento Animal, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Querétaro, Mexico; bInstituto de Investigaciones Agropecuarias y Forestales, Universidad Michoacana de San Nicolás de Hidalgo, Michoacán, Mexico; cFacultad de Medicina Veterinaria y Zootecnia, Universidad Michoacana de San Nicolás de Hidalgo, Michoacán, Mexico; dFacultad de Químico Farmacobiología, Universidad Michoacana de San Nicolás de Hidalgo, Michoacán, Mexico

ABSTRACT

This study evaluated the effect of *Opuntia ficus-indica* L. supplementation on gilts during late gestation and lactation, particularly on their biochemical parameters and voluntary feed intake (VFI) at lactation. Thirty-two gilts were randomly distributed into two groups: control group (CG), gilts fed conventionally and experimental group (EG), gilts fed commercial feed plus *O. ficus-indica*. Glucose concentration was lower ($P < 0.05$) in the EG. Insulin concentration was higher in the gilts that consumed *O. Ficus-indica*. Triglyceride's concentration was lower ($P < 0.05$) at gestation, farrowing and lactation in the EG. Total cholesterol was higher ($P < 0.05$) in gestation and lactation in the CG. HDL present higher concentration in lactation in the gilts that consumed *O. Ficus-indica*. LDL concentration was higher ($P < 0.05$) in gestation and lactation in the CG. Leptin concentration was higher ($P < 0.05$) at lactation in the CG. The gilts of the EG had higher VFI (22.6% more) and presented less body weight loss (3.7% less) at weaning ($P < 0.05$). These findings suggest that *O. Ficus-indica* favourably regulates the biochemical indicators involved in the development of insulin resistance, and this is reflected in the higher VFI and lesser body weight loss at weaning.

1. Introduction

Insulin resistance (IR) is a metabolic disorder that involves decreases in cellular sensitivity towards insulin and predisposes to hyperglycemia and dyslipidemia (Unger et al. 2014). However, in sows, like most female mammals IR is a metabolic adaptation at late gestation and lactation that allows to direct a higher input of nutrients to the uterus (for the higher exponential growth of the fetus) and the udder (to start milk production) (Père and Etienne 2007, 2018). The importance of IR in sows is that it has an effect on the sow's productivity, specifically on feed intake in lactation (Père and Etienne 2007; Manu et al. 2020). Because the effect of IR was observed in lower feed intake, during late gestation this effect is not perceived, since, during this period, feeding schemes are based on sow's restricted feeding, in contrast to *ad libitum* feeding at lactation (Solà-Oriol and Gasa 2017). Also, leptin has no effect on feed intake in gestation since there is resistance to leptin (hyperleptinemia) for a higher input of nutrients to the uterus (Tessier et al. 2013). However, in lactation, sows do not experience leptin resistance (Cools et al. 2014). Some studies show that there is an increase in the serum leptin concentration gradually until the middle third of the gestation, reaching a high concentration and remaining high until farrowing in swine females (Saleri et al. 2015). It was reported that backfat depths were positively associated with leptin concentrations. However, no direct relationship between levels of circulating leptin and sow fertility, if leptin is involved in the control of reproduction, its role is merely permissive. E.g. through the association that leptin has on reduced feed intake in lactating sows. The lower feed intake promotes catabolism of the sow and modifies its metabolic state. This puts at risk the synthesis of hormones involved in reproduction: LH, FSH, IGF-I, estrogens, etc. (De Rensis et al. 2005; Mosnier, Etienne, et al. 2010; Solé et al. 2021).

For the reasons described above, strategies that maximize feed intake in lactating sows should be sought. It has been reported (Serena et al. 2007; Quesnel et al. 2009; Jha and Berrocoso 2015; Li et al. 2021) that the addition of dietary fibre to the diet of gestating sows promotes gastric health and increases feed intake during lactation. This is because dietary fibre favours the metabolic profile minimizing insulin resistance and dyslipidemia (Serena et al. 2007; Li et al. 2021).

In sheep, rabbits, mice, and pigs, the dietary fibre of various foods, including *Opuntia* spp., has been linked to an improvement in glucose and lipid metabolism (Brahim et al. 2012; Halmi et al. 2013; Ordaz et al. 2017). The lower plasma concentrations of glucose, cholesterol, and triglycerides related to the consumption of *O. ficus-indica* are associated with: (i) stimulation of insulin secretion and best glucose reabsorption by different tissues and, (ii) modifies lipid biosynthesis by

binding to bile acids, this improves cholesterol catabolism (Kritchevsky et al. 1988; Fernández et al. 1992; Pari and Latha 2005; Gouws et al. 2019). Consequently, our hypothesis focuses on *O. ficus-indica* effect on the regulation of biochemical indicators (insulin and leptin mainly), minimizing resistance to insulin and its effects on sow productivity during late gestation and lactation. Hence, this study aimed to evaluate the effect of *O. ficus-indica* supplementation on gilts during late gestation and lactation, and particularly on their biochemical parameters and voluntary feed intake at lactation.

2. Materials and methods

This research was carried out at the Swine Unit of 'Posta Zootécnica' belonging to the Veterinary Medicine and Husbandry Faculty of Universidad Michoacana de San Nicolás de Hidalgo (FMVZ-UMSNH), Tarímbaro, Michoacán, México (Road; 19°46′N, 101°08′W, and altitude of 1855 m). The animals used in this research were bred in accordance with the regulations of the zoo-technical and zoo-sanitary legislation of Mexico for the humanitarian care and use of animals in research SAGARPA-SENASICA.

2.1. Animal diets and husbandry

Forty gilts were directly exposed to mature boars (eight gilts: one boar) for at least 15 min daily from 160 days of age until the last gilt had displayed pubertal estrus. Gilts that presented the second estrus at 21.0 ± 1.0 days ($n = 35$ gilts) were inseminated (182 ± 1.3 days; 137 ± 8.2 kg) with semen of boar genotype Yorkshire × Pietrain and were housed in groups ($n = 7$ gilts) in 16 m^2 pens during the 110 days of gestation. Eight gilts were removed from the investigation: five during the selection process to be inseminated (sows with a lagged reproductive cycle), one gilt due to abortion and two gilts due to problems related to lameness. Therefore, thirty-two sows were used to carry out the research. All gilts were fed 2.5 kg^{-1} of commercial feed per day (divided into two portions, at 8:00 and 15:00 h), until day 84 of gestation (Table 1). At day 85 of gestation, the gilts were housed in individual pens of 2.0 × 2.0 m^2. According to a completely random design, the animals ($n = 32$ gilts) were divided into two groups ($n = 16$ gilts·group^{-1}): control group (CG), gilts fed commercial feed only (2.5 kg·day^{-1}) and experimental group (EG), gilts fed commercial feed (2.5 kg·day^{-1}) plus *O. ficus-indica* (as a source of dietary fibre). *O. ficus-indica* (fresh base) supplementation was 1.0% with respect of the gilts' body weight; the body weight of the gilts corresponded to the stage at which the gilts were found (gestation or lactating). Immediately after farrowing, all gilts were fed *ad libitum* with a commercial diet for lactation (Table 1). The only variation in the gilts' feeding at lactation was the addition of fresh *O. ficus-indica* to the diet of EG (Table 1).

Cladodes of *O. ficus-indica* were offered to the gilts at approximately 90 days of age; their chemical composition is shown in Table 1. Cladodes were manually cut (41.0 kg per week) and stored at 4.0°C until they were fed to the gilts. For feeding, cladodes were manually fragmented into pieces of approximately 3.0 × 2.0 cm and were mixed with the commercial feed corresponding to the first meal of the day (8:00 am) procedure performed in both phases, gestation, and lactation.

For farrowing and lactation sows were lodged in cages of stainless steel with plastic slatted floors until the moment of weaning (21 d post-farrowing). During farrowing and lactation, there was artificial light between 8:00 and 15:00 h, and the environmental temperature was 20–24°C. Each cage was provided with a heat source for the piglets. Farrowing occurred naturally on day 115 ± 0.12 of gestation (day 0 of lactation). The sows at farrowing had a litter size of 10.9 ± 1.3 piglets, 9.5 ± 0.8 piglets born alive, 1.3 ± 0.2 stillbirths, and 0.1 ± 0.01 mummies. Litters were balanced by eight piglets within the first 48 h post-farrowing. Piglets that died during lactation were not replaced. During lactation, seven casualties were recorded. In the CG, three died because of crushing, and in EG, four casualties occurred (three because of crushing and one from diarrhea). The casualties caused by crushing occurred during the first week of lactation and the casualty from diarrhea occurred in the second week of lactation.

2.2. Blood sampling

At day 85, 100, and 110 of gestation and at day 1, 3, 7, 14, and 21 of lactation, eight gilts from a group^{-1} were selected for preprandial (12 h fasting) blood sampling. A 10 mL blood sample was taken from the vena jugularis between 7:00 and 7:30 (1 h before the start of the morning meal). Immediately after

Table 1. Composition of gestation and lactation diets.

Item	Control		*O. ficus-indica*	
Ingredients, g/kg	Gestation	Lactation	Gestation	Lactation
Sorghum	824.0	649.5	824.0	649.5
Soy paste	60.0	100.0	60.0	100.0
Canola paste	61.2	185.2	61.2	185.2
Orthophosphate	11.8	5.3	11.8	5.3
Calcium carbonate	14.0	12.4	14.0	12.4
Soy oil	22.0	38.5	22.0	38.5
Lysine	1.2	2.5	1.2	2.5
Metione-Cysteine	0.9	1.5	0.9	1.5
Salt	3.0	3.0	3.0	3.0
Vitamins and minerals premix[a]	2.0	2.5	2.0	2.5
Nutrient levels, %				
Metabolizable energy, MJ·kg	13.8	13.8	13.8	13.8
Crude protein	12.5	17.5	12.3	17.4
Crude fat	3.7	4.5	3.6	4.4
Fibre	3.1	4.3	3.3	4.5
Humidity	12.0	12.0	12.9	12.8
Ashes	10.0	10.0	9.9	9.9
Calcium	1.4	1.2	1.5	1.5
Phosphorus	0.64	0.67	0.63	0.66
Lysine	0.52	0.95	0.50	0.94
Methionine + cysteine	0.43	0.59	0.43	0.59
Nutrient levels of *O. ficus-indica*, %				
Metabolizable energy, Mcal·kg			2.2	
Crude protein			5.6	
Crude fat			0.2	
Fibre			28.8	
Humidity			88.6	
Ashes			24.5	
Nitrogen-free elements			40.8	
Mucilage g/300 g dry base			2.6	

[a]Contribution per kg of feed: Cu 30 mg; Fe 160 mg; Zn 160 mg; Mn 55 mg; Se 0.5; Cr 0.2 mg; Vitamin A 14.200 IU; Vitamin D$_3$ 2800 IU; Vitamin E 125 mg; Vitamin K$_3$ 5 mg; Vitamin B$_1$ 2.4 mg; Vitamin B$_2$ 8.7 mg; Vitamin B$_6$ 4.5 mg; Vitamin B$_{12}$ 0.05 mg; Pantothenic acid 35 mg; Acid folic 6 mg.

sampling, each blood sample was divided into two subsamples: 6 mL in tubes with serum cloth activator (for an analysis of glucose, triglycerides, cholesterol, HDL and LDL) and 4 mL in tubes with lithium heparin (for analysis insulin and leptin). The subsamples were stored at 4°C until centrifugation. Subsequently, the tubes were centrifuged (1000 × g for 10 min), and plasma and serum samples were stored at −20°C until further analysis.

2.3. Hormones and metabolites' analysis

Plasma concentrations of glucose, insulin, triglycerides, cholesterol, HDL, LDL, and leptin were determined. Glucose, triglycerides cholesterol, HDL, and LDL concentrations were determined using enzymatic methods adapted in a Cobas C111 Mira (Roche, Basel, Switzerland). The reagents used were as follows: GLUH2 (ref. 04 657 527 190, E.E.U.U), sensitivity was 2.0 mg·dL^{-1}, the intra- and inter-assay variation coefficient was <1.0 and <1.9% at 128.0 mg·dL^{-1}; TRIGL (ref. 04 657 594 190, E.E.U.U), sensitivity was 9.0 mg·dL^{-1}, the intra-and inter-assay variation coefficient was <8.0 and <14.0% at 600 mg·dL^{-1}; CHOL2 (ref. 04 718 917 190, E.E.U.U), sensitivity was 10.0 mg·dL^{-1}, the intra-and inter-assay variation coefficient was <10.0 and <12.0% at 300 mg·dL^{-1}; HDLC3 (ref. 05 401 488 190, E.E.U.U), sensitivity was 10.0 mg·dL^{-1}, the intra-and inter-assay variation coefficient was <10.0 and <12.0% at 100 mg·dL^{-1}; and LDL3 (ref. 07 005 806 190, E.E.U.U), sensitivity was 10.0 mg·dL^{-1}, the intra- and inter-assay variation coefficient was <8.0 and <12.0% at 120 mg·dL^{-1}. Insulin and leptin concentrations were determined using commercial ELISA kits (SIGMA-ALDRICH, St. Louis, MO, E.E.U.U). The sensitivities for each hormone were as follows: insulin, 4 μIU·mL^{-1}, the intra- and inter-assay variation coefficient was <10 and <12% at 47.5 μIU·mL^{-1} respectively, and leptin, 2 pg·mL^{-1}, the intra- and intra-assay variation coefficient was <10.0 to <12% at 400 pg·mL^{-1}.

2.4. Gilts' productive performance

The feed intake, energy balance, loss of bodyweight of the gilts and piglet development were evaluated; for feed intake, the feed supplied and rejected was weighed daily with a digital scale (Dibatec®; capacity of 40 kg and accuracy of ±5 g). The energy imbalance was obtained through the methodology established by Noblet et al. (1990). Gilts were weighed pre-farrowing (day 110 of gestation) and at weaning (day 21 of lactation) using a fixed electronic scale (STG-1500-T1500SL, OCONY®; with a capacity of 1-1500 kg). To estimate the loss in body weight at lactation, the weight of the post-farrowing gilts was estimated using the prediction equation of Mallmann et al. (2018). Piglets were weighed at birth and on days 7, 14, and 21 (weaning) of lactation.

2.5. Statistical analysis

Data were analyzed by ANOVA through repeated measurements by PROC MIXED [SAS Inst. Inc., Cary, NC, EUA] (Littell et al. 1998). The gilt represented the experimental unit in the

model. The effects of the group, day, and their interaction were evaluated in terms of gilts body weight, piglets' weight, plasma glucose, insulin, triglyceride, cholesterol, HDL, LDL, leptin, and HOMA-IR index. The model used was:

$$Y_{ijkl} = \mu + G_i + C(G)_{j(i)} + D_k + G*D_{ik} + \varepsilon_{ijkl} \quad (1)$$

where Y_{ijkl} = response variable: gilt body weight, piglets' weight, plasma glucose, insulin, triglyceride, cholesterol, HDL, LDL, leptin, and HOMA-IR index; μ = constant common in the population; G_i = fixed effects of the i-th group, with i = CG, EG; $G(G)_{j(i)}$ = random effect of the j-th gilt, nested within the i-th group, with i = CG, EG; D_k = fixed effects of the k-th day; $G*D_{ik}$ = fixed effects of the interaction of the i-th group with the k-th day; ε_{ijkl} = random effect associated with each observation ($\sim$NID = 0, σ_e^2).

The data of feed intake, intake energy, energy balance, body weight loss of the gilts and piglets weaned per gilt were evaluated through ANOVA in PROC GLM (SAS 9.4 Inst. Inc., Cary, NC, USA). The effects of the group, week, and their interaction were evaluated. The model used was:

$$Y_{ijk} = \mu + G_i + W_j + G*W_{ij} + \varepsilon_{ijk} \quad (2)$$

where Y_{ijk} = response variable: feed intake, intake energy, energy balance, body weight loss of the gilts and piglets weaned per gilt; μ = constant common in the population; G_i = fixed effects of the i-th group, with i = CG, EG; W_j = fixed effects of the j-th week of lactation; $G*W_{ij}$ = fixed effects of the interaction of the i-th group with the j-th week of lactation; ε_{ijk} = random effect associated with each observation ($\sim$NID = 0, σ^2_e).

Significant differences among groups were considered at $P < 0.05$. Normality of distribution and homogeneity of variance for residuals were tested using PROC UNIVARIATE [SAS Inst. Inc., Cary, NC, EUA]. In the case of non-normality, parameters were normalized by *log* transformation prior to analysis to generate a normal distribution.

Insulin resistance was indirectly estimated using HOMA-IR according to the equation proposed by Matthews et al. (1985):

HOMA-IR =

$$\frac{\text{prepandrial glucose,} \quad \text{mmol·L}^{-1}*\text{fastig insulin,} \quad \text{μU·mL}^{-1}\cdot}{22.5}$$

The values in tables and figures are presented as minimum squares ± SEM.

3. Results

3.1. Metabolic indicators

The effects of the supplementation with *O. ficus-indica* on the biochemical indicators of gilts were estimated per group, sampling day, and group per day interaction. According to the group per day interaction, CG showed higher ($P < 0.05$) plasma glucose concentrations on each evaluation day (Figure 1). A plasma glucose peak was found at farrowing day in both groups; however, it was lower in EG gilts ($P < 0.05$): 94.7 vs. 112.9 ± 3.4 mg·dL^{-1} of CG. Plasma insulin according to group per day interaction ($P = 0.0034$) was higher ($P < 0.05$) at farrowing day and at days 3 and 7 of
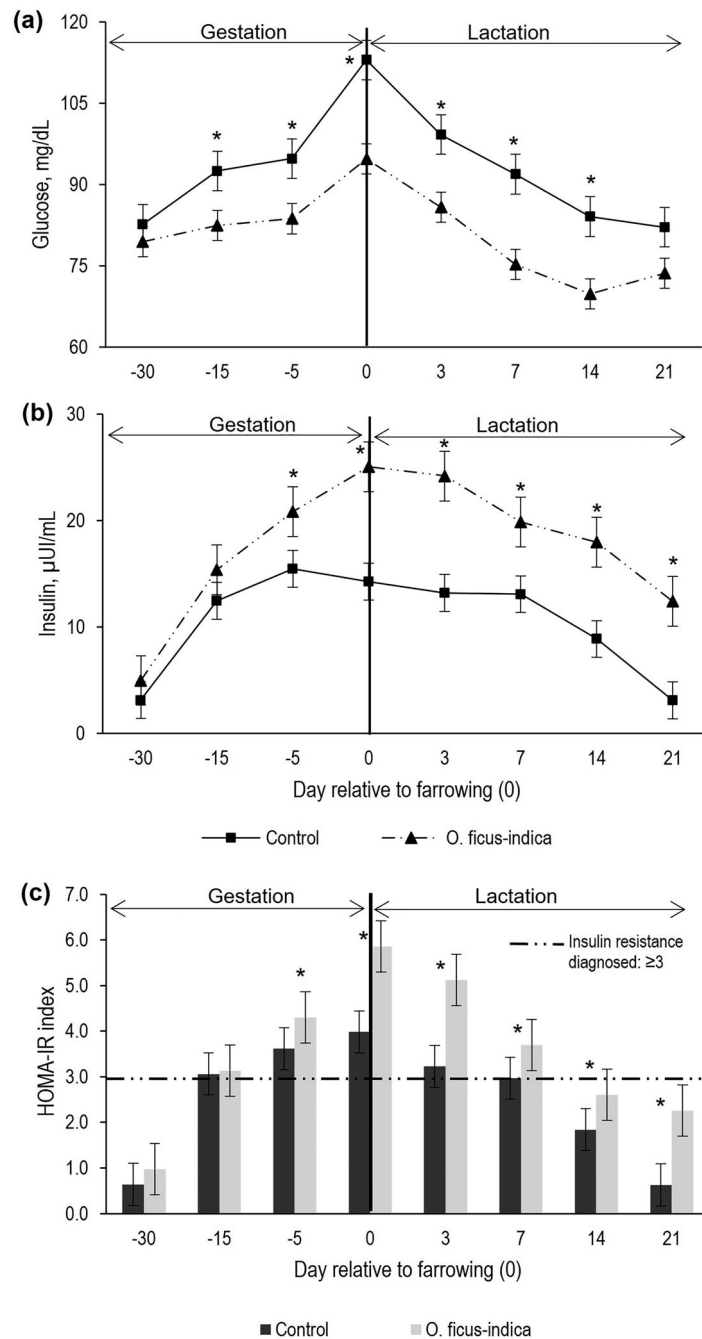
Figure 1. Plasma concentration of glucose (a), insulin (b), and HOMA-IR index (c) according to the group. Each point or bar represents the mean ± standard error of mean (SEM; $n = 16$ gilts by group). *Indicates statistically significant difference ($P < 0.05$) between groups.

lactation in both groups (Figure 1), however, EG showed higher concentration (Figure 1). HOMA-IR index was higher ($P < 0.05$) in gilts that consumed *O. ficus-indica* on each evaluated day (Figure 1). According to HOMA-IR index, both groups presented IR from day 100 of gestation at day 7 of lactation (Figure 1). However, IR degree was higher ($P < 0.05$) in EG gilts (10.8% more from day 100 of gestation to farrowing and 30.6% more in the first week of lactation) than that in CG (Figure 1).

Group per day interaction effect ($P < 0.001$) on the lipid indicators was evaluated. Plasma triglycerides were lower ($P < 0.05$) at days 100 and 110 of gestation in EG (Figure 2). At lactation, from the second week, the gilts that consumed *O. ficus-indica*

presented higher ($P < 0.05$) plasma triglycerides, a pattern that remained consistent until the end of lactation (Figure 2). Plasma total cholesterol showed a similar trend as triglycerides at gestation, that is, lower ($P < 0.05$) concentrations in EG (Figure 2). Day three post-farrowing was the only day that showed significant differences in total cholesterol between groups, with its concentration being higher ($P < 0.05$) in the CG gilts (Figure 2).

HDL in gestation (day 100 and 110) was lower ($P < 0.05$) in gilts that consumed *O. ficus-indica*. At lactation, the gilts that consumed *O. ficus-indica* (EG) showed higher plasma HDL ($P < 0.05$; Figure 2). Gilts that consumed *O. ficus-indica* presented lower ($P < 0.05$) concentration of plasma LDL in both phases
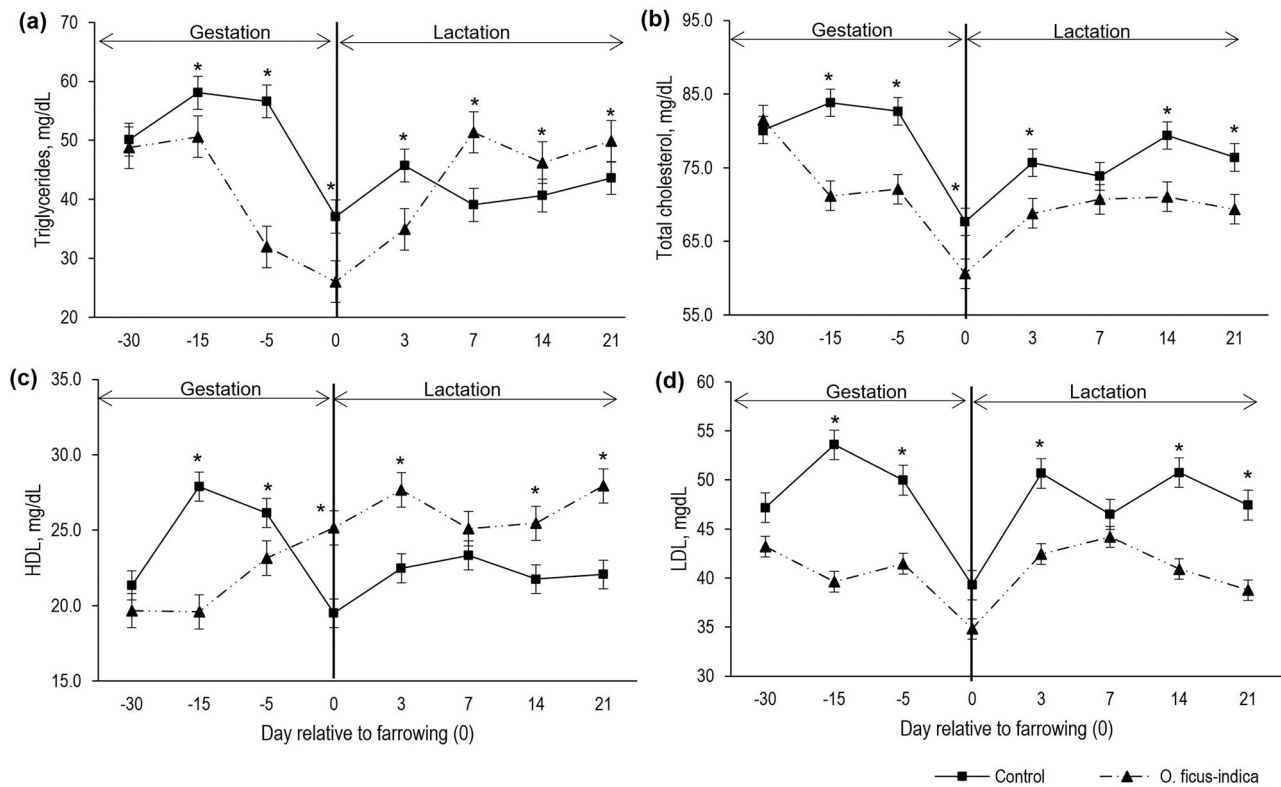
Figure 2. Plasma concentration of triglycerides (a), cholesterol (b), HDL (c), and LDL (d) according to the group. Each point represents the mean ± standard error of mean (SEM; $n = 16$ gilts by group). *Indicates statistically significant difference ($P < 0.05$) between groups.

(Figure 2). Group per day interaction effect ($P < 0.001$) on plasma leptin showed that, at gestation (day 100 and 110) plasma leptin was equal ($P > 0.05$) in both groups (Figure 3). However, at lactation, the CG gilts showed higher ($P < 0.05$) leptin concentrations on each evaluated day (Figure 3).

3.2. Gilts' performance

The effects of supplementation gilts with *O. ficus-indica* on voluntary feed intake, energy balance, loss of bodyweight and piglet development in lactation were estimated by group
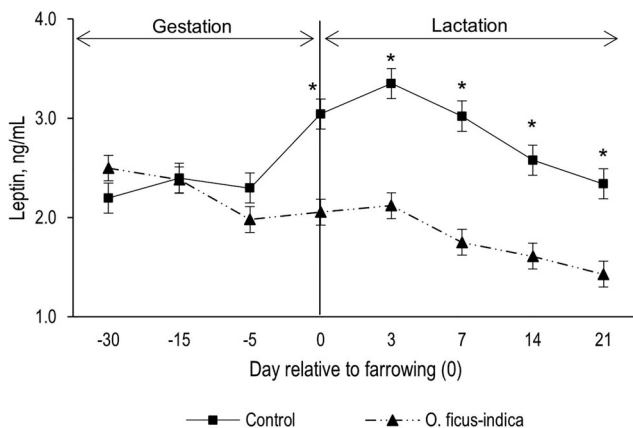

Figure 3. Plasma concentration of leptin according to the group. Each point represents the mean ± standard error of mean (SEM; $n = 16$ gilts by group). * Indicates statistically significant difference ($P < 0.05$) between groups.

($P < 0.001$), week ($P < 0.001$), and their interaction. The group per week interaction affected the daily feed intake ($P = 0.037$) and energy balance ($P = 0.012$). Commercial feed intake on an average per day at lactation was higher ($P < 0.05$) in the EG gilts: 5.4 vs. 4.2 ± 0.06 kg·day^{-1} in CG gilts (Table 2). Energy balance on average showed a similar trend as feed intake; increased energy balance in gilts that consumed *O. Ficus-indica* (0.43 ± 1.19 MJ·day^{-1}) compared with the control (-7.33 ± 1.19 MJ·day^{-1}). The loss of bodyweight in lactation was lower ($P < 0.05$) in EG gilts: 1.1 vs. $4.8 \pm 1.2\%$ in CG gilts (Table 3). Group per week interaction had a similar trend to the feed intake and energy balance, being higher in the gilts that consumed *O. ficus-indica*, in each evaluated week (Table 3). *O. ficus-indica* supplementation had no effect ($P > 0.05$) on the weight of piglets at birth and at weaning (Table 3).

4. Discussion

In sows, the gradual development of IR promotes the presence of dyslipidemia (Mosnier, Etienne, et al. 2010). IR detected at the end of gestation is accentuated at the first week of lactation because the sow physiologically requires more glucose for lactose synthesis (Pari and Latha 2007). In the presence of IR, the sow mobilizes body reserves (fat and protein) and thus increases the concentration of energy substrates (e.g. total cholesterol, triglycerides, leptin) because the sows do not yet present optimal feed intake to satisfy their nutritional requirements (Mosnier, Etienne, et al. 2010). An increase in lipid indicators was observed in CG gilts in both late gestation and lactation. The behaviour of these biochemical indicators (total

Table 2. Least squares mean for feed intake, energy intake and energy balance of sows according to the group and week of lactation.

Items	N	Week (W)	Group (G)		P-value		
			Control	O. ficus-indica	G	W	G*W
Feed intake, kg/day	32	1	3.4[a1] ± 0.09	4.5[b1] ± 0.09			
		2	4.1[a2] ± 0.09	5.5[b2] ± 0.09	0.037	<.0001	0.0001
		3	4.6[a3] ± 0.09	6.2[b3] ± 0.09			
Intake energy, MJ/day	32	1	32.4[a1] ± 0.89	44.6[b1] ± 0.89			
		2	40.2[a2] ± 0.89	54.6[b2] ± 0.89	0.028	<.0001	0.017
		3	45.3[a3] ± 0.89	61.9[b3] ± 0.89			
Energy balance, MJ/day	32	1	−5.2[a1] ± 1.23	−0.5[b1] ± 1.23			
		2	−6.1[a2] ± 1.23	1.0[b2] ± 1.23	0.012	0.008	0.021
		3	−9.7[a3] ± 1.23	−0.3[b3] ± 1.23			

Notes: [a, b] Different literals indicate statistically significant difference ($P < 0.05$) into of row. [1, 2, 3] Different numerals indicate the statistically significant difference ($P < 0.05$) into of column for each indicator, respectively.

cholesterol, triglycerides, LDL, and leptin) in CG is associated with a higher concentration of glucose at the late gestation stage and during the first week of lactation and this relationship with the feed intake at lactation. In addition to the high glucose concentration during the peripartum period, high concentrations of endogenous opioid peptides are also present during this period, essential peptides to stimulate the production of endorphins, reduce the concentrations of GnRH, FSH and LH and synthesize prolactin to start lactation (Barb et al. 1986; Farmer 2016). The higher the synthesis of prolactin and its interaction with IR, the glucose concentration increases for the formation of milk components, in this case, lactose. In addition to the effect of the opioid peptides described above, they also have action on feed intake due to their interaction with proopiomelanocortin (POMC). It has been established that POMC has several post-translational metabolic pathways, not only giving rise to β-endorphins. At the same time, it synthesizes corticotropic hormone (ACTH), hormone that participates in the inhibition of feed intake (González et al. 2006).

Quesnel et al. (2009) report that the administration of fibrous diets (>30% NDF) favours the feed intake at lactation. With respect to using O. ficus-indica as a source of dietary fibre in the present research, it has been reported in rats (Nuñez et al. 2013) that the consumption of this cactus decreases plasma glucose and increases plasma insulin. Soluble fibre in monogastric is not digested by the gastrointestinal enzymes, therefore, they modify the absorption of bile

salts, cholesterol, and glucose (Morán et al. 2012). In addition, a diet rich in soluble fibre increases the viscosity of food bolus and propitiates the absorption of energy substrates (Shapiro and Gong 2002). Haber et al. (1977) showed that, when carbohydrates are present intracellularly in plant foods, their release in the intestine is slower and glucose-insulin responses in the blood decreases.

HOMA-IR index for IR diagnoses in humans and sows is ≥ 3.0 (Matthews et al. 1985; Tan et al. 2015). The gilts that consumed O. ficus-indica had a higher HOMA-IR index with respect to the CG, this is due to the higher synthesis of insulin in the gilts of the EG. It should be noted that regardless of the highest HOMA-IR index in the EG the hyperinsulinemia is not a product of IR, it was due to the over-production of insulin by the consumption of O. ficus-indica. This behaviour is justified analysing glucose behaviour, where EG had no concomitant glucose-insulin increase. The consumption of O. ficus-indica reduced glucose concentration per direct action of insulin because this cactus stimulates insulin secretion, improves the insulin-stimulated phosphorylation of IRS-2 and Akt in the liver, and thus normalizes the excessive production of hepatic glucose (Pari and Latha 2005). O. ficus-indica can act the same way as oral antidiabetics, by shutting down the K^+/ATP channels, depolymerizing membrane and stimulating the Ca^{2+} channels for insulin secretion (Halmi et al. 2013).

Changes in glucose kinetics due to the consumption of O. ficus-indica propitiates lower catabolism (indirectly assessed in loss of bodyweight), which is conducive to less dyslipidemia because of the higher feed intake at lactation. With regard to the greater dyslipidemia found in the CG gilts, it has been reported that regardless of the sows' genotype (lean or fat), the highest degree of dyslipidemia in the CG respect to EG is mainly associated with the IR by which the sow passes during peripartum (Mosnier, Le Floc'h, et al. 2010; Torres-Rovira et al. 2011). IR cause an increase in glucose concentrations, which limits feed intake. The low feed intake favours body catabolism in the sow, therefore the release of NEFA's, this is reflected in a higher concentration of cholesterol, LDL, and leptin (Figures 2 and 3).

Increased triglycerides and HDL from the seventh-day post-farrowing at the end of lactating in EG gilts could be associated with the beginning of ovarian reactivation (Barb et al. 2008). Ovarian reactivation is characterized by an increase in reproductive hormones FSH, LH, and estrogens – hormones that are synthesized through cholesterol precursors (Barb et al.

Table 3. Least squares mean for the productive performance of the sow and piglets according to the group.

Items	N	Group (G)		P-value G
		Control	O. ficus-indica	
Gilts body weight, kg				
Day 85 of gestation	32	179.4[a] ± 1.4	183.5[a] ± 1.4	0.069
Day 110 of gestation	32	191.5[a] ± 1.4	190.5[a] ± 1.4	0.483
Post-farrowing[&]	32	181.7[a] ± 1.4	179.7[a] ± 1.4	0.421
Weaning	32	172.9[a] ± 1.4	177.6[b] ± 1.4	0.012
Body weight loss, kg	32	8.88[b] ± 0.31	2.13[b] ± 0.31	0.005
Body weight loss, %	32	4.81[a] ± 0.27	1.10[b] ± 0.27	0.001
Piglets weight, kg				
Birth	256	1.4 ± 0.12	1.5 ± 0.13	0.083
Day 7 post-farrowing	250	2.3 ± 0.18	2.4 ± 0.20	0.547
Day 14 post-farrowing	249	4.5 ± 0.23	4.4 ± 0.25	0.661
Weaning day 21 post-farrowing	249	5.9 ± 0.31	6.0 ± 0.33	0.365
Piglets weaned per gilt	249	7.7 ± 0.4	7.8 ± 0.3	0.096

Notes: [a, b] Different literals indicate statistically significant difference ($P < 0.05$) into of row. [&] Estimated according to the prediction equations established by Mallmann et al. (2018).

1991). During ovarian reactivation, the dietary fibre of *O. ficus-indica* could act favourably by its effect on non-starch polysaccharides, that when subjected to fermentation by the colon microbiota lead to a higher production of volatile fatty acids (Cani et al. 2006). Volatile fatty acids intervene on energetic contribution of the organism and can facilitate the synthesis of precursors of cholesterol (Molist et al. 2009). Volatile fatty acids that are monomers in the luminal aqueous phase are absorbed by any segment of the digestive tract, therefore have a total digestibility (Berruezo et al. 2011), and this propitiates the increase in triglycerides and HDL from the second week of lactation in EG gilts (Figure 2).

Leptin is a mediator of the regulation of the long-term energy balance, as it has an effect on the suppression of feed intake and induces weight loss (Martínez et al. 2014). Leptin resistance has been reported during the last third of gestation, however, it has no effect on feed intake (Saleri et al. 2015; Szczesna and Zieba 2015). Such behaviour was also observed in the present investigation, since no difference was found between groups in the leptin concentration at the last third of gestation. As far as the lactation phase is concerned, it has been reported (Tessier et al. 2013) that there is no resistance to leptin, since, in this phase, the loss of the intracellular signal of the function of leptin receptors. Therefore, in lactation, leptin does have an effect on food consumption. This could be observed in the feed intake of the sows, the sows from the CG had lower feed intake and higher leptin concentrations with respect to the EG (Table 2 and Figure 3).

Leptin concentration is higher in sows of Asian genotypes than in European genotypes (Guay et al. 2001). Farmer et al. (2007) report a difference in leptin concentration on the eighteenth day of lactation. The Landrace genotype showed a higher leptin concentration with respect to the Yorkshire, Duroc, and synthetic lines genotypes. This behaviour is associated with the greater thickness of dorsal fat in Landrace sows and their association ($r = 0.67$) with leptin (Estienne et al. 2000). Kolaczynski et al. (1996), established that, the increase in 10% of bodyweight results in a 300% increase in the leptin concentration; a phenomenon that is observed during the last third of gestation and propitiates lower feed intake at lactation. Quesnel et al. (2009) report that a diet rich in fibre during gestation leads to a reduction in leptin concentration and an increase in feed intake at lactation. This behaviour was also observed in the present research: the gilts that consumed *O. ficus-indica* presented a lower concentration of leptin in lactation and a greater feed intake, in addition, energy balance was lower as was the loss of bodyweight at weaning.

Finally, among the hypotheses that were had about the use of *O ficus-indica* in the feeding of pregnant and lactating sows to reduce the glucose concentration was the possible effect on the development of the piglet and the quantity and quality of the sow's milk. About it, the research group has already reported that the consumption of *O ficus-indica* does not affect the quality and quantity of the milk produced by the sow or the development of the piglet (Ortiz et al. 2017, 2020). However, there are some limitations that must be considered when interpreting the results of this study. The study was carried out in sows of hybrid genotype, it would be necessary to carry out more investigations in the genetic lines of

current hyperprolific sows which are more susceptible to a lower feed intake due to their higher energy demand to meet the requirements of a larger litter and higher milk production. It should be noted that when evaluating the energy balance in hybrid sows (with $n = 8$ piglets/litter) fed *O ficus-indica*, it was higher (-2.1 ± 3.5 MJ·day^{-1}) with respect to conventionally fed sows: -9.1 ± 2.7 MJ·day^{-1} (Ordaz et al. 2019). Reason for which, it is expected that the productive behaviour of hyperprolific sows fed with nopal as part of the diet is positive, since it would generate greater feed consumption which would reflect a better metabolic state of the animals. In addition, strategies must be sought to process and store *O ficus-indica* that facilitate its incorporation into the sow's diet without losing its properties, in order to be implemented in intensive swine production systems.

5. Conclusion

IR is an inherent physiological process of sows, however in current swine production systems IR limits the productive potential of the sow because it has effects on sow productivity: low feed intake in lactation, greater body weight loss in lactation, low productivity in the next production cycle, less longevity, etc. The intake of *O. ficus-indica* at late gestation and during lactation in gilts favourably modulates the regulation of biochemical indicators that participate in the development of insulin resistance and dyslipidemia, which is reflected in higher voluntary feed intake and less body weight loss at weaning.

Disclosure statement

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ORCID

Gerardo Ordaz http://orcid.org/0000-0003-4502-3727
Aureliano Juárez http://orcid.org/0000-0003-2372-1209
Manuel López http://orcid.org/0000-0003-2895-7384
Héctor Eduardo Martínez http://orcid.org/0000-0002-0044-9399
Rosa Elena Pérez http://orcid.org/0000-0001-6215-8653
Ruy Ortiz http://orcid.org/0000-0002-5226-5356

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