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Technical note

Productive evaluation and cost:benefit analysis of lactating sows fed a diet containing nopal (*Opuntia ficus-indica*)

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Abstract:

Postpartum sows can suffer from hypophagia, which negatively effects productive and reproductive performance. An evaluation was done of productivity, production costs and the cost:benefit ratio in lactating hybrid sows administered one of two feeding regimes (FR): 1) conventional feed (CFR); and, 2) conventional feed with added cladodes of nopal *Opuntia ficus-indica* (OFR). A total of 116 parturitions were evaluated: 58 in the CFR (n= 17 sows), and 58 in the OFR (n= 17 sows). Seven variables were recorded: blood glucose (BG); daily feed intake (FId^{-1}); body weight loss (BWL), weaning-estrus interval (WEI); repeated services percentage (RSP); non-productive days (NPD); and subsequent litter size (LS). Statistical analysis was done with the Fixed Effects Models (MIXED

SAS®) and economic evaluation with the cost-benefit analysis methodology. Compared to the CFR, sows in the OFR performed better (*P*<0.05) in terms of having lower preprandial BG (55.5 x 2.31 mg dL^{-1}), higher FId^{-1} (5.3 x 0.17 kg d^{-1}); lower BWL (6.0 %), WE (144 h), RSP (12.4 %) and NPD (36.0 d), and higher LS (11.2 piglets). Values in the WEI sows were preprandial BG (70.0 x 2.31 mg dL^{-1}); FId^{-1} (4.7 x 0.17 kg d^{-1}); BWL (11.7 %); RSP (17.1%); NPD (50.0 d); and LS (9.8 piglets). The production cost weaned $piglet^{-1}$ was \$539.02 MXN in the OFR *vs* \$590.81 MXN in the CFR, while profit sold $piglet^{-1}$ was \$216.68 MXN in the OFR *vs* \$168.88 MXN. Inclusion of nopal in the diet of lactating sows reduced blood glucose levels and increased daily feed intake, thus lowering body weight loss in this stage and generating greater sow productivity and economic efficiency.

Key words: Cladode, Piglet, Glucose, Profitability.

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A vital objective in livestock production is to minimize production costs and therefore maximize revenue per unit produced(1), but the indicators that most impact production costs must be identified if they are to be reduced(2). In swine production, the production cost from piglet to weaning has the greatest impact (≥31 %) on the cost per kilogram of pork(3). Consequently, a primary strategy for minimizing this cost is to raise sow prolificity(4). However, increasing this variable alone does not guarantee lower production costs since higher prolificity results in larger percentages of stillborn piglets(4), lower piglet weight at birth and weaning(5), and greater sow physiological fatigue when nursing larger litters(6). The latter is particularly notable in lean and hyperprolific sows(2).

During the peripartum-lactation transition period, high amounts of glucose(6) are required to support exponential growth of fetuses and mammary gland development(7,8); an insulin resistance physiological mechanism is implemented for this purpose(6). This phenomenon can cause the postpartum sow to begin lactation with a negative energy balance and to reduce her feed intake (known as hypophagia)(7,9). This in turn encourages mobilization of the sow's body reserves to meet its nutritional requirements and produce milk(8,9). Lactational hypophagia hinders sow productive efficiency(10) and therefore proves a challenge to reducing piglet-to-weaning production costs. Regulation of the metabolic hunger centers in lactating sows is crucial to augmenting feed intake and productivity(11). This effect can be triggered by increasing fiber intake through addition of ingredients such as prickly pear nopal (*Opuntia ficus-indica*) to sow feed(12-16). The present study objective was to evaluate the effect of addition of nopal (*Opuntia ficus-indica*) to the feed of lactating sows on voluntary feed intake, and its impact on productivity, production costs and the cost:benefit ratio.

The trial was done at the swine production system of the Zootechnical Post of the Faculty of Veterinary Medicine and Zootechny of the Universidad Michoacana de San Nicolás de Hidalgo (FMVZ-UMSNH), in Tarímbaro Municipality, Michoacán state, Mexico. An evaluation was done of 116 births from 34 parturition sows (Yorkshire x Landrace x Pietrain) over a 24-mo period. The sows were selected by self-replacement from the FMVZ-UMSNH's reproductive herd. Beginning at first estrus (82 ± 9.4 kg), they were monitored for three consecutive cycles to assess their reproductive viability based on estrus cyclicity (20 ± 2 d between estruses) up to time of first service (117.7 ± 12.4 kg). Serviced sows with a positive gestation diagnosis were housed as a group (n= 7) in pens (16 m^2) and given 2.0 kg commercial feed sow^{-1} day^{-1} (Table 1) during the first two thirds of gestation, and 2.5 kg sow^{-1} d^{-1} (in two portions at 0800 and 1400 h) during the final third (up to 108 d gestation). Water was freely available via an automatic drinking bottle.

One week prior to probable parturition date, the sows were randomly selected and assigned to one of two postpartum feeding regimes (FR): 1) conventional feeding regime, or CFR (n= 58 piglets from 17 sows); and, 2) the CFR plus nopal (*O. ficus-indica*), or OFR (n= 58 piglets from 17 sows). Once assigned, the sows were moved to the parturition room where they were fed a conventional diet for lactating sows at 2.5 kg sow^{-1} (Table 1). Postpartum, the sows in both groups were fed *ad libitum* during the 21 d of lactation with the designated diet. The nopal in the OFR treatment was administered on a fresh base at 1% of total feed amount (calculated based on prepartum sow body weight). Before feeding, nopal cladodes were cut into pieces (approx. 3x2 cm), immediately added at the corresponding commercial feed proportion ratio in the OFR, and fed to the sows at 0800 h.

Table 1: Feed ingredients and nutritional composition

Ingredients, g kg^{-1}	Gestation	Lactation*	
		CFR	OFR
Sorghum	824.0	649.7	649.7
Soy paste	60.0	100.0	100.0
Canola paste	61.5	185.3	185.3
Orthophosphates	11.8	5.4	5.4
Calcium carbonate	14.0	12.4	12.4
Soy oil	22.0	38.5	38.5
Lysine	1.2	2.5	2.5
Salt	4.0	4.0	4.0
Vitamin and mineral premix[a]	2.0	2.5	2.5
O. ficus-indica nutritional composition[b]			
Crude protein, %			5.6
Crude fat, %			0.2
Fiber, %			28.8
Moisture, %			88.6
Ash, %			24.5
Nitrogen free elements, %			40.8
Mucilage, g 300 g^{-1} dry base			2.6
Nutritional composition[c]			
Metabolizable energy, Mcal/kg[d]	2.3	2.3	2.3
Crude protein, %	12.5	17.5	17.4
Crude fat, %	3.7	4.5	4.4
Fiber, %	3.1	4.3	4.5
Moisture, %	12.0	12.0	12.8
Ash, %	10.0	10.0	9.9
Calcium, %[d]	0.75	0.75	0.75
Phosphorous, %[d]	0.60	0.60	0.59
Lysine, %[d]	0.52	0.95	0.94
Met-Cyst, %[d]	0.43	0.59	0.59

[*] CFR = conventional feed regime; OFR = conventional feed regime plus nopal

[a] Proportion kg^{-1} of diet: 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; folic acid 6 mg.

[b] Nopal provided only in morning in fresh base. Addition rate was 1% based on prepartum sow body weight.

[c] Nutritional composition of diet containing 1% added nopal determined after addition of nopal in a dry base.

Seven variables were evaluated per sow^{-1} FR^{-1}. Pre- and postprandial blood glucose (BG) was measured according to an established protocol[(17)]. Daily feed intake (FId^{-1}) was calculated based on the feed supplied and feed rejected sow^{-1} d^{-1}. Feed was weighed on a digital scale (Dibatec®; 40 kg capacity, 5 g accuracy). Feed rejected per sow^{-1} d^{-1} was weighed daily in the morning, before feeding. Body weight loss (BWL) was calculated by subtracting prepartum sow live weight (d 110 gestation) from sow live weight at weaning (21 d postpartum). The variables used for calculation of BWL were expressed as a percentage using the following equation:

$$BWL_{\%} = 100 - \left(\frac{Weight\ at\ weaning * 100}{Weight\ at\ postpartum}\right);$$

The weaning-estrus interval (WEI) was the time in hours from the moment of weaning to appearance of estrus. A sow's non-productive days (NPD) were estimated with the following equation:

$$NPD = 365 - [PSY * (DL + DG):$$

Where PSY= parturitions sow^{-1} year^{-1}; DL= days in lactation; DG= days of gestation;

$$PSY = 365\ /IPI.$$

Where IPI= inter-parturition interval;

$$IPI = DG + DL + WEI + RSPd$$

Where WEI= weaning-estrus interval; RSPd= repeated services percentage in days. The repeated services percentage (RSP) was estimated with the equation:

$$RSP = 100 - \left[\left(\frac{SS - SRE}{SS}\right) * 100\right];\ RSPd = \left(\frac{RSP * SS}{100}\right) * 21\ .$$

Where SS= serviced sows; SRE= sows returned to estrus. Productivity in the subsequent parturition was calculated using litter size (LS), piglet live births (LB) and weaned piglets (WP).

The data were analyzed with the fixed effects methodology (MIXED) (SAS Inst. Inc., Cary, NC, USA). Data for sow BG and FId^{-1} were analyzed with the repeated measurements methodology using sow as the object of the random effect of time (days in lactation) and three fixed effects: FR, parturition number (PN) and the nesting of PN within FR:

$$Y_{ijkl} = \mu + FR_i + C(FR)_{j(i)} + PN_k + PN(FR)_{k(i)} + \varepsilon_{ijkl}.$$

Body weight loss (BWL), WEI, RSP, NPD, LS, LB and WP were estimated using FR, PN and the nesting of PN within FR with the model:

$$Y_{ijk} = \mu + FR_i + PN_j + PN(FR)_{j(i)} + \varepsilon_{ijk}.$$

Where:

Y_{ijkl} = response variable: BG, FId^{-1};

μ = constant characterizing population;

FR_i = fixed effect of $^{i-}$th feed regime with i= CFR and OFR;

$C(G)_{j(i)}$= random effect $^{j-}$th sow, nested within $^{i-}$th feeding regime;

PN_k = fixed effect $^{k-}$th parturition number with k= 1, 2, 3 and 4; N

PN(FR)$_{k(i)}$ = fixed effect of nesting of $^{k-}$th parturition number inside $^{i-}$th feeding regime;

$\mathcal{E}_{ijklmn}$ = random error associated with each observation (~NID=0, σ^2_e).

Differences between the means were identified using the least mean square (LsMeans) method with an α= 0.05. Values in tables and text are presented as least mean square ± standard error (SE). Identification of relationships between FRs (CFR *vs* OFR) and reproductive and productive indicators was done using Pearson correlations of these indicators within each FR using the correlation procedure in the SAS® statistical program. The economic analysis was run using numerical data for the variables described for both FRs (CFR and OFR) and applying the methodology proposed by Rouco and Muñoz[18], as modified by Bobadilla *et al*[19].

Strategies have been implemented to mitigate the effects of lactational physiological hypophagia[20,21]. These have failed either because they are economically unviable or because they do not resolve the source of the problem: regulation of postpartum blood glucose (BG)[6]. In the present results pre- and postprandial BG levels in the OFR treatment were lower (P<0.05) (postprandial 63.5 to 67.5 mg dL^{-1}) than in the CFR (postprandial 75.7 to 80.3 mg dL^{-1}) (Table 2). In the CFR, it was the 1st and 4th parturition sows that exhibited the highest BG levels (P<0.05).

Table 2: Least mean squares for prepartum and weaning sow weight, blood glucose, and feed intake by feeding regime.

		General mean		Parturition number					*P*-value		
Indicator	**FR**	**Mean**	**SE**	**1**	**2**	**3**	**4**	**SE**	**FR**	**PN**	**PN(FR)**
Prepartum sow weight, kg	CFR	213.2^{1}	6.10	175.9^{a1}	201.9^{b1}	218.7^{c1}	236.2^{d1}	6.21	0.5185	<0.001	<0.001
	OFR	207.2^{1}		189.5^{a1}	195.3^{b1}	211.1^{c1}	232.9^{d1}				
Preprandial BG, mg dL^{-1}	CFR	70.0^{1}	1.27	71.5^{a1}	66.2^{b1}	66.5^{b1}	75.6^{a1}	2.31	<0.001	0.031	0.011
	OFR	55.5^{2}		53.8^{a2}	54.6^{a2}	56.0^{a2}	58.1^{a2}				
Postprandial BG, mg dL^{-1}	CFR	75.9^{1}	1.29	76.5^{a1}	80.3^{a1}	79.4^{a1}	75.7^{a1}	2.43	<0.001	0.531	0.021
	OFR	65.3^{2}		63.5^{b2}	66.0^{b2}	65.0^{b2}	67.5^{b2}				
Feed intake (commercial feed), kg	CFR	4.7^{1}	0.10	3.7^{a1}	4.7^{b1}	4.3^{c1}	4.8^{b1}	0.17	<0.001	<0.001	<0.001
	OFR	5.32		5.1^{a2}	5.2^{a2}	5.3^{a2}	5.5^{a2}				
Nopal intake FB/DB, kg	CFR	--	--	--	--	--	--	--	--	--	--
	OFR	1.7/0.20	0.03	1.3/0.15^{a}	1.7/0.20^{b}	1.8/0.21^{bc}	1.9/0.24^{c}	0.07	--	<0.001	--
Nopal rejection FB/DB, kg	CFR	--	--	--	--	--	--	--	--	--	--
	OFR	0.3/0.04	0.01	0.5/0.07	0.2/0.03	0.3/0.03	0.4/0.05	0.02	--	<0.001	--
Weaning weight sow, kg	CFR	187.0^{1}	1.13	157.8^{a1}	176.1^{b1}	1895^{c1}	213.6^{b1}	2.22	<0.001	<0.001	<0.001
	OFR	192.6^{2}		178.7^{a2}	184.5^{b2}	201.3^{b2}	213.7^{c2}				
Body weight loss, %	CFR	11.7^{1}	0.31	11.3^{a1}	12.0^{a1}	13.8^{a1}	9.8^{b1}	0.57	<0.001	0.330	<0.001
	OFR	6.0^{2}		6.5^{ab2}	5.2^{a2}	4.9^{a2}	7.4^{b2}				

FR= feeding regime; CFR= conventional feeding regime; OFR= conventional feeding regime plus nopal; PN= parturition number; BG= blood glucose; FB= fresh base; DB= dry base.

[a, b, …, e] Different letter superscripts in the same row indicate significant difference (*P*<0.05).

[1, 2] Different numerical superscripts in the same column indicate significant difference (*P*<0.05) between CFR and OFR within each indicator.

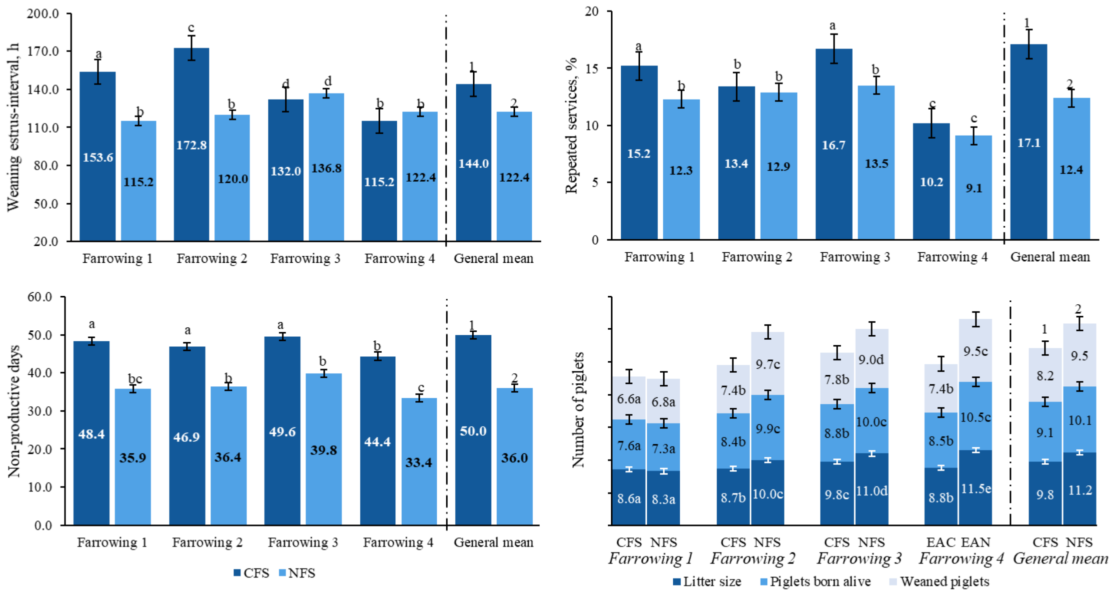
The observed decrease in BG in the OFR treatment coincides with previous research indicating that it is due to the effect (mechanical pathway) of the pectins and mucilage present in the soluble fiber of the nopal(15,22,23); these components increase feed viscosity, slowing its transit and increasing glucose absorption(22). However, the non-fermentable dietary fiber in nopal may also lead to an increase in intestinal release of the GLP-1 protein, which inhibits glucagon release, consequently slowing glucose synthesis(13,24). This protein also causes increased insulin synthesis(16,25).

Daily feed intake (FId^{-1}) was higher (11.3 %) in the OFR than the CFR (*P*<0.05) (Table 2). Parturition number (PN) did not affect FId^{-1} in the OFR (*P*>0.05) but did affect it in the CFR (*P*<0.05). The feed intake of lactating sows is mainly affected by sow age (PN) and metabolic physiology(7), both of which are difficult to manipulate(6). The lack of an effect (*P*>0.05) of PN on FId^{-1} in the OFR treatment suggests that addition of nopal to the diet of lactating sows in this treatment counteracted the negative effects of lactational hypophagia.

Body weight loss (BWL) was higher in the CFR than in the OFR (P<0.05; Table 2). Within the CFR treatment BWL was higher in third parturition sows (13.8 %) than in the other PN categories (*P*<0.05). In the OFR fourth parturition sows (7.4 %) had higher BWL than the other categories (*P*<0.05). A possible explanation for this discrepancy between treatments is that addition of nopal to the diet improved colon fermentation processes, leading to a higher concentration of volatile fatty acids (VFAs)[26,27]. This increase in VFAs can be channeled into the organism's energy expenditure thus inhibiting catabolism and BWL during lactation[27].

A BWL greater than 10 % at lactation cessation has been linked to inadequate restoration of ovarian function and reproductive failure[28]. Compared to those the CFR, sows in the OFR exhibited a number of positive responses as a result of their better BWL: improved restoration of ovarian function (*P*<0.05); fewer reproductive failures (*P*<0.05); shorter weaning-estrus intervals (WEI) (122.4 h); a lower repeated services percentage (RSP) (12.4 %); and fewer non-productive days (NPD) (36.0 d)(Figure 1).

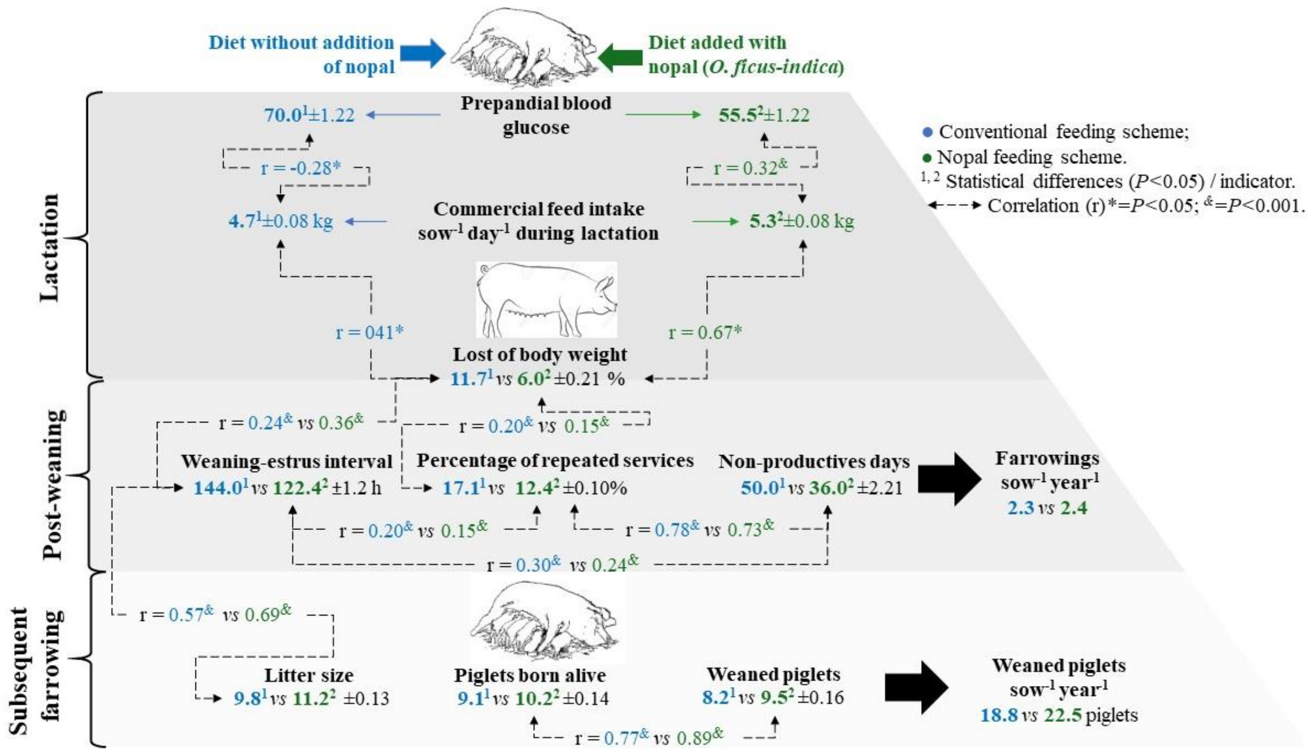
Figure 1: Least squares means for sow reproductive and productive variables by feeding regime



a, b, ..., e Different letters over columns indicate significant difference (*P*<0.05).
1, 2 Different numbers over the general mean columns indicate significant difference (*P*<0.05).

Greater efficiency in neuroendocrine regulation in sows during and after the lactation period improves post-weaning reproductive indicators, raises prolificity and productivity and reduces non-productive days[6,7]. The present results coincide with this report (Figures 1 and 2). Increased insulin synthesis caused by nopal consumption[22], also positively affected post-lactation reproductive indicators (Figure 1). This occurs because insulin influences regulation of sow reproductive processes through increased insulin synthesis and IGF-1 release, which regulate production of follicle stimulating hormone and luteinizing hormone[28].

Figure 2: Pearson correlations and conceptualization of the effect of added nopal in diets for lactating sows on productive and reproductive indicators



Litter size (piglets born live and weaned piglets) in primiparous sows did not differ ($P>0.05$) between treatments because they were given the same feed during gestation. However, in the following parturition, litter size increased ($P<0.05$) in the OFR (Figure 1).

The present results agree with a previous study indicating that addition of nopal to the diet of lactating sows has no effect on sow milk nutritional components (protein, fat and lactose) or quantity, meaning piglet development during lactation is unaffected[29].

The sow productivity analysis (Figure 1 and 2) showed that weaned piglets sow^{-1} yr^{-1} in OFR (22.5 WP sow^{-1} yr^{-1}) was higher than in CFR (18.8 WP sow^{-1} yr^{-1}). Feed still represented the largest portion of production costs in both regimes: 73.97 % in OFR and 74.42 % in CFR (Table 3). Amortization sow^{-1} was higher (4.2 %) in the OFR. This indicator is based on the tangible fixed asset (sow)[30], which exhibited variation in its use life within each FR. However, bore amortization did not differ between the treatments since its initial value and use life were similar in each FR.

Table 3: Production costs structure (MXN and %) by feed regime

	CFR		OFR	
Concept	**MXN**	**%**	**MXN**	**%**
Amortization sow^{-1}	1,672.09	1.18	1,745.02	1.12
Amortization boar	928.58	0.65	928.58	0.59
Sow feed	105,762.44	74.42	115,685.33	73.97
Boar feed	3,859.22	2.72	3,859.22	2.47
Piglet feed	6,169.53	4.34	7,458.35	4.77
Medication	16,409.81	11.55	18,668.72	11.94
Opportunity cost	7,319.74	5.15	8,055.06	5.15

CFR = conventional feeding regime; OFR = conventional feeding regime plus nopal.

In the CFR production costs (WP^{-1}) were \$590.81 MXN, which generated profits of \$168.88 MXN piglet^{-1} sold. In the OFR, production costs (WP^{-1}) were \$539.02 MXN and profits were \$216.68 MXN piglet^{-1} sold. The marginal cost was therefore higher (8.7 %) in the CFR. Based on the number of WP, the break-even point or threshold of profitability was lower in OFR (Table 4). The cost:benefit ratio indicated that for each peso invested FR^{-1} profits were 41 ¢ in OFR and 30 ¢ in CFR.

Table 4: Analysis of production costs, income and profits (MXN) per weaned piglet by feed regime

Concept	CFR	OFR	Difference
Fixed costs	168.88	121.48	-47.41
Variable costs	443.82	417.55	-26.28
Total costs	590.81	539.02	-51.60
Total income	759.51	759.51	--
Net profit	168.88	216.68	51.60
Marginal cost	318.73	349.19	23.23
Break even (Nº. weaned piglets)	149.16	137.72	-11.44
Cost/Benefit ratio	1.30	1.41	0.11

CFR= conventional feeding regime; OFR= conventional feeding regime plus nopal.

Pig feed is the item that most affects production costs, ranging from 65 to 95 % of the total[1], which coincides with the present results. Compared to the CFR sows, the higher productive efficiency (weaned piglets yr^{-1}) of the sows in the OFR generated: (i) a lower cost per weaned piglet; (ii) a reduction in production costs; and (iii) higher net revenue vs. productivity. As a result the cost:benefit ratio in the OFR was 1.41 % while that for the CFR was 1.30 %. Both figures are within reported ranges (1.04 to 2.11 %)[31,32], although a swine production system is considered profitable when its cost:benefit ratio is ≥1.15 %[18,19]. Nonetheless, numerous variables (in addition to those included in the present study) affect profitability[30,32], including sales price policies in effect at a given time, which cannot be controlled by producers, and production system structural variation, both technical and financial.

Supplementation of commercial feed with cladodes of prickly pear nopal *Opuntia ficus-indica* on a fresh basis in the diet of lactating sows had positive effects on the piglet production system. It mitigated lactational physiological hypophagia and body weight loss, and improved sow productivity by increasing the number of piglets weaned sow^{-1} yr^{-1}. These contributed to lowering production costs per weaned piglet, consequently improving system profitability.

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