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ORIGINAL ARTICLE

Effect of the addition of cactus (*O. ficus-indica*) to the lactating sows' diet on piglet development at lactation and post-weaning

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ABSTRACT

Objective: The aim was to evaluate the effect of cactus (*Opuntia ficus-indica*) to the lactating sows' diet on piglet development at lactation and post-weaning.
Materials and Methods: Twenty-four litters of hybrids sows were evaluated in this study. The sows were divided into two groups: Control (CG), sows fed conventionally and experimental (EG), sows fed with commercial fed plus cactus. Post-weaning, the piglets of both groups were monitored up to the 20 kg liveweight (LW). It was evaluated, lactation (in sows): feed intake (FI), milk production (MP), and quality (MQ) and LW of the piglet. Post-weaning (in piglets): FI, LW, and length of intestinal villi (LIV) at 0, 24 h, and 42 days post-weaning.
Results: FI sow^{-1} was higher in EG ($p < 0.05$). MP, MQ, and LW piglet^{-1} at weaning were equal ($p > 0.05$). FI piglet^{-1} in the sixth and eighth week of age was higher in EG ($p < 0.05$); at the end of weaning phase, EG presented higher LW ($p < 0.05$): 8.4% more. LIV of the jejunum were higher ($p < 0.05$) in EG at 48 h (28.8%) and 42 days post-weaning (29.9%). At day 0, post-weaning LIV of the descending portion was higher ($p < 0.05$) in CG (1,571.0 µm) versus EG (1,058.0 µm). At day 42, post-weaning LIV of the transverse portion was higher ($p < 0.05$) in EG: 23.7% higher.
Conclusion: Cactus intake in lactating sows does not affect the piglet development. However, post-weaning piglets present higher LIV in jejunum and transverse portion, aspect that improves LW.

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Introduction

The stages of lactation and weaning in pig production are crucial to the productivity of the swine industry [1,2]. Because during these stages, important physiological changes occur in the sow [3] as in piglet [4], among the most important changes are found; at lactation, lactational physiological hypophagia, which can affect milk production and piglet development [5,6] and post-weaning, the stress that piglets present due to the separation of the sow, change of accommodation, transition from a liquid diet (milk) to a solid (preinitiator), mixture of different litters, establishment of the social hierarchy, and exposure to new pathogens [7].

With regard to lactational hypophagia, post-farrowing sows have decreased in voluntary feed intake due to increased glucose concentration and insulin resistance [8,9]. It has been established [10] that, the deficit of feed intake at lactation phase affects productive and reproductive indicators of the sows, as it is milk production, weaning piglet weight, weaning sow's body weight, weaning-estrus interval, as well as fertility and prolificacy of the sows in the next reproductive cycle [9]. Aspects that have a negative impact on the productivity of production systems and increase production costs [2].

Post-weaning, piglets present changes in the gastrointestinal tract; because is until the 10th week of age when the development of the digestive enzyme system of the piglet is completed [11]. Therefore, the early change (21 days of age) of liquid feeding (milk) to solid causes reduction of the enzymatic activity and modifies the structures of the intestinal

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mucosa: reduction of the size of the intestinal villi, inflammation of the mucosa and atrophy of the enterocytes, propitiating lower digestive capacity, and decrease of the weight gain of the piglet [1,5]. Reason why, they have sought strategies that modulate the microbiota and intestinal integrity of the post-weaning piglet in a favorable way [5].

In order to counteract the effects of lactational hypophagia, the addition of cactus (*Opuntia ficus-indica*) has now been evaluated to the diet of sows at lactation [3,12], and it has been concluded that, this type of diet increase up to 28% the voluntary feed intake of sows [12], without affecting production and quality of milk neither development of weaning piglet [4]. However, it has not been established if there is a residual effect of the diet in piglets on its development at weaning stage. Since it has been determined that *O. ficus-indica* contains compounds with bacteriostatic properties (phenols and flavonoids) susceptible to modulate the intestinal microbiota [13], compounds that could prevent the colonization of pathogenic bacteria in the intestine, inflammation of this and atrophy of the intestinal villi of the piglets in the weaning stage. Hence, the addition of cactus (*O. ficus-indica*) to the lactating sows' diet on piglet development at lactation and post-weaning was evaluated.

Materials and Methods

The investigation was carried out in the Swine Sector of the Posta Zootechnical belonging to the Faculty of Veterinary Medicine and Zootechnical of the Universidad Michoacana de San Nicolas de Hidalgo (UMSNH), Michoacan, México. The animals used in this research were bred in accordance with the regulations of the legislation zootechnical and zoosanitary of Mexico for the humanitarian care and the use of animals in investigation, Secretary of Agriculture and Rural Development. In Addition, all the procedures used in this study were approved by the Animal Rights and Protection Act in the state of Michoacán of Ocampo: Volume CLXIX, Num. 58, tenth section. Chapter XII, Articles 62–64 experimentation and by the Official Mexican Norms OMN-062-ZOO-1999 and OMN-033-ZOO-1995.

Animals, diets, and housing

Twenty-four hybrid sows (Yorkshire × Landrace × Pietrain) were monitored for 4 months (six sows month^{-1}) through a completely random design. The sows were served by natural mating with hybrid boars (Duroc × Pietrain) and housed in groups (n = 8 sows) in pens of 16 m^2 for 109 days gestation, at day 110 of gestation were lodged in cages for farrowing and lactation of stainless steel with slap until the weaning (21 days post-farrowing). The farrowing and lactation area were provided with artificial light between 8:00 and 15:00 h, and the environmental temperature was maintained between 25°C and 28°C. Each farrowing and lactation cage had heat source for piglets. The farrowing was not induced, it occurred on day 115 ± 0.53 of gestation (day 0 of lactation).

At gestation all the sows received the same diet for gestating sows (Table 1); 2.5 kg day^{-1} supplied in two equal portions 8:00 and 14:00 h. When the sows entered the area of farrowing and lactation, their selection was randomized to form two groups: control (CG, n = 12 sows, three sows month^{-1}) and experimental (EG n = 12 sows, three sows month^{-1}). This procedure was carried out for 4 months in order to evaluate 24 sows, due to the installed capacity of the area: six cages for farrowing and lactation. Immediately after farrowing, all the sows were fed *ad libitum* with a conventional lactation-phase diet (Table 1). The only variation in feeding sows at lactation was the addition of 1% of cactus (*O. ficus-indica*) in fresh basis (FB) to EG diet; percentage established according to the body weight of the sow at day 110 of gestation (Table 1).

Cladodes' age of *O. ficus-indica* offered to EG sows, was approximately 90 days (chemical composition; Table 1). The cladodes were manually cut; the required amount was cut (42.0 kg average) week^{-1}. Therefore, the cladodes were stored at 4°C until they were supplied to the sows. For supply *O. ficus-indica*, the cladodes were fragmented into pieces of approximately 3 × 2 cm, and immediately thereafter add the required amount for each sow of the EG

Table 1. Nutritional composition.

Item	Gestation diet	Lactation diet	
		Control	Experimental
Metabolizable energy (MJ/kg)	9.6	9.6	9.6
Protein (%)	12.5	17.5	17.4
Crude fat (%)	3.7	4.5	4.4
Fiber (%)	3.1	4.3	4.5
Humidity (%)	12.0	12.0	12.8
Ash (%)	10.0	10.0	9.9
Calcium (%)	1.4	1.2	1.5
Phosphate (%)	0.64	0.67	0.66
Lysine, %	0.52	0.95	0.94
Methionine-Cysteine (%)	0.43	0.59	0.59
Nutrimental composition of *O ficus-indica*			
Protein (%)			5.6
Crude fat (%)			0.2
Fiber (%)			28.8
Humidity (%)			88.6
Ash (%)			24.5
Nitrogen-free elements (%)			40.8
Mucilage (g 300 g^{-1} dry basis)			2.6

at 8:00 h in conjunction with the corresponding commercial feed ration.

Experimental procedure

Lactation

At lactation, piglets were weighed and identified by means of enumerated earrings. After farrowing (24 h post-farrowing), the litters were homogenized to eight piglets littered^{-1}. All the litters received commercial feed® (Preinitiator) from the 15th day of age.

During the lactation stage, it was evaluated;

1. Voluntary feed intake (FI) daily sow^{-1}. The supplied feed and the rejected sow^{-1} day^{-1} it was weighed with a digital scale (Dibatec®; capacity of 40 kg and accuracy of ±5 gm). Feed rejection sow^{-1} day^{-1}, it was weighed daily in the morning, before feeding, in order to determine the daily FI.
2. Milk Production (MP) was estimated through the methodology proposed by Sinclair et al. [14], which consists of the weighing-suction-weighing method of each piglet on days 6, 10, and 15 of lactation. The weighing of piglets pre and post-suction was carried out with a digital scale (Dibatec®) with a capacity of 40 kg and accuracy of ±5 gm. This weighing was performed four times in each established day. In addition, it recorded the time of breastfeeding and interval between breastfeeding to determine the daily MP. With this information, the milk production sow^{-1} was estimate through the following equation:

$$\text{Milk production, kg} = W + U + D + M$$

where W = weight gain (kg); U = weight loss due to urination; D = weight loss due to defecation; and M = metabolic weight loss.

Weight loss due to urination (U) was calculated with the equation described by Klaver et al. [15] as follows:

$$U = [\text{NU} * (2.9 * W^{0.75} + 18.7)]$$

where NU = number of urinations; $W^{0.75}$ = metabolic weight.

Ten gram was considered as a defecation loss (D) according to Sinclair et al. [14]. And, the estimation for metabolic weight loss (M) was calculated using the equation described by Noblet and Etiene [16] as follows:

$$M \text{ (mg)} = 60 \text{ per kg of wheight}$$

3. Milk quality (MQ), for this, was extracted 10 ml of milk sow^{-1}, the days 3, 11, and 17 of lactation. The milk extraction was manually (milking), after administering 2 ml of Oxytocin® intramuscular route; 5 minutes post-application of oxytocin we proceeded to give the udder a massage and milking was done. Each sample was deposited in containers (capacity of 100 ml) sterilized and stored at 4°C for subsequent analysis (1 h post-milking) by the Lactoscan® equipment, which determined the content of lactose, protein, and fat.
4. Development (kg) of piglet, for this, piglets were weighed at birth at 14 and 21 days of lactation with a digital scale (Dibatec®) to later establish their average daily gain.

Post-weaning

It was monitored a total of 96 piglets from the sows of both groups (CG and EG). Piglets were selected according to age and weaning weight: 21 days of age and a weight of 5.5 ± 1.1 kg. Piglets were grouped according to the group of sows from which they came: piglets of the CG (n = 48), piglets from sows fed with conventional diet at lactation phase and piglets of the EG (n = 48), piglets from sows fed with the conventional diet plus cactus.

At weaning piglets were immediately transferred to the weaning area and confined in elevated cages (152 × 244 cm) where 12 piglets were housed^{-1} according to the corresponding group. Each cage had a stainless-steel trough (76.2 × 32.5 × 65.3 cm) with a capacity of 60 kg, and two automatic nipple-type drinkers. The ventilation and internal temperature of the weaning area (average 18°C) was controlled using curtains. Both groups offered water and feed *ad libitum,* the feed was in the form of a pellet (Preinitiator®) and was supplied according to the following phases (Table 2): Phase 1, from 4 to 10 kg; Phase II, from 10 to 15 kg, and Phase III, from 15 to 20 kg. Both groups were monitored and subjected to the same zootechnical practices at weaning phase, which lasted 6 weeks post-weaning.

The variables evaluated post-weaning were as follows:

1. Voluntary feed intake (FI); the feed supplied was weight daily with a digital scale (Rhino® with a

Table 2. Nutritional content& of the feed* for piglets in weaning phase.

Content (%)	Phase I*	Phase II*	Phase III*
Humidity	12	12	12
Protein	23	22	21
Fat	8	6	5
Crude fiber	3	3	3.50
Ash	7.50	7	6
Nitrogen free-elements	43.50	50	52.50
Phosphor	0.51	0.43	0.32
Calcium	0.85	0.80	0.55

*Feed in pellet form.
&According to the manufacturer's labels.

capacity of 300 ± 100 kg) and the reject was retracted the next day.

2. Liveweight (LW) of piglet; at weaning stage, each piglet was weighed at birth and at day 14 and 21 with a digital scale (Rhino® with a capacity of 300 ± 100 kg) in order to determine the growth curve during the weaning stage in each evaluated group.
3. Daily weight gain (DWG); it was determined by the following equation.

$$DWG = \frac{PWBW - PWEW}{7}$$

where DWG = daily weight Gain; PIBW = Piglet's weight at the beginning of the week; PWEW = Piglet's Weight at the end of the week.

4. Intestinal integrity, specifically length of intestinal villi (LIV), for this purpose, were randomly slaughtered six piglets group^{-1}: two at weaning (21 days of age); two at 23 days of age, and two at 63 days of age (20 kg of weight). The slaughter of animals was carried out in accordance with the established by the Secretariat of Agriculture and Rural Development in the Official Mexican Norm: OMN-033-ZOO-1995. Immediately after slaughter, samples from each portion of the small and large intestine were collected according to the methodology established by Yang et al. [17].

Samples obtained (n = 108; 54 group^{-1}) were washed with saline solution and fixed by immersion in formalin solution to 10% according to established by Reis et al. [18]. Forty eight hours post obtaining samples, this were processed for histological studies using the paraffin inclusion technique, the tissues were processed in a Histokinette Microm® ST 120, the cuts were made of 7 µm thick in a microtome Microm® HM 325 and later were stained with hematoxylin-eosin, three measurements were made in all the samples obtained, for the measurement an image analyzer Leica® LAS 3.5 (Germany) was used with an increase of 40× to observe the morpho metric parameters of the intestinal architecture, the length of the villus was denoted by the vertical distance from the opening of the crypt to the apex of the villi.

Statistical analysis

The data were analyzed by ANOVA using the fixed effects methodology (MIXED) [19]. The data of FI (sow and piglets), MP, QM, Piglet development in lactation, LW, DWG post-weaning, and LIV were analyzed using ANOVA for repeated measurements, with sow (lactation)/piglet (weaning) as the object of the random effect of time (lactation/weaning week) and, as fixed effects: group, week (lactation/weaning), and nesting group(week), under the following model:

$$Y_{ijkl} = \mu + G_i + S/P(G)_{j(i)} + W_k + G(W)_{ik} + \varepsilon_{ijkl}$$

where

Y_{ijkl} = Response variable: FI, MP, QP, Piglet development, LW, DWG, and LIV; µ = General Average; G_i = Fixed effect of i-th group with i = control and experimental; $S/P(G)_{j(i)}$ = Random effect of the Ith sow/piglet, nested with the i-th group with i = control and experimental; D_k = Fixed effect of the kth week of lactation/post-weaning with k = 1, 2, and 3 in lactation and k = 4, 5,..., 10 post-weaning; $G(W)_{ik}$ = Fixed effect of nesting i-th group with the k-th week of lactation/post-weaning; ε_{ijkl} = Random error associated with each observation (~Normal and Independent Distribution = 0, σ^2_e).

The estimation of milk production, at the 21 days of lactation, was through the calculation of the polynomial regression estimators (ß0, $ß_1$, and $ß_2$) for both groups, using the day of lactation as linear and quadratic effect. The differences between groups were obtained by means of the minimum square means (LsMeans) methodology [19] to α = 0.05.

Table 3. Feed intake (conventional), production, and quality sows' milk and weight of piglet in lactation phase.

Item	Group		S.E.
	Control	Experimental	
Voluntary feed intake* (kg)			
Week 1	4.0^{a1}	4.6^{a2}	0.16
Week 2	4.9^{b1}	6.0^{b2}	0.16
Week 3	5.3^{b1}	6.1^{b2}	0.17
Cactus intake fresh basis (kg)			
Week 1	--	1.9	0.04
Week 2	--	1.8	0.04
Week 3	--	2.0	0.04
Milk production and quality			
Milk production (kg)	7.2^{1}	7.4^{1}	0.19
Lactose (%)	6.6^{1}	6.6^{1}	0.07
Protein (%)	4.5^{1}	4.5^{1}	0.49
Fat (%)	8.2^{1}	7.6^{1}	0.19
Piglet' weight in lactation (kg)			
Birth	1.3^{a1}	1.4^{a1}	0.09
Day 14 of lactation	3.7^{b1}	3.7^{b1}	0.09
Day 21 of lactation	5.0^{c1}	5.1^{c1}	0.09

*In the case of the experimental group, the table only shows the conventional feed intake without considering the cactus intake;
S.E. = standard error.
Literals $^{a, b}$ indicate differences (p <0.05) within the column and indicator.
Numerals $^{1, 2}$ indicate differences (p <0.05) within row.

Results

Lactation

Group effect and nesting group (week) were found on the FI balanced sow^{-1} day^{-1} ($p < 0.0001$), without considering cactus intake from the EG sows. In this regard, the sows of EG showed higher FI sow^{-1} at the 3 weeks of evaluation ($p < 0.05$) compared to CG (Table 3). However, the increase in FI of the EG sow^{-1} did not improve MP and QM ($p > 0.05$), indicators that were equals to CG, MP: 7.2 and 7.4 ± 0.19 kg sow^{-1} day^{-1}, for CG and EG, respectively. Whit respected to QM, the lactose and protein in milk were equal in both groups: 6.6 ± 0.57 and 4.5±0.40%, respectively. The same happened with fat in milk: both equal averages ($p > 0.05$): 7.9 ± 1.6% in EG and 8.2 ± 0.19% in CG (Table 3). Results that match the LW of piglets at lactation, since it was not affected by the group ($p = 0.6533$). At weaning, the LW of piglets was: 5.5 ± 0.09 kg piglet^{-1} in both groups evaluated (Table 3).

Post-weaning

As for the weaning phase (5.5–20 kg), group effect ($p = 0.0038$) and group (week post-weaning) nesting ($p = 0.0001$) were found on FI piglet^{-1} day^{-1}. The EG piglets presented higher FI day^{-1} ($p < 0.05$) between the sixth (0403 ± 0.01 kg of feed) and eighth (0703 ± 0.01 kg of feed) week of age, compared to the FI of the piglets of the CG (Table 4). However, at the end of the weaning stage (ninth week of age), the FI dia^{-1} of piglets was equal in both groups analyzed ($p > 0.05$): 0.736 and 0.734 ± 0.01 kg of feed piglet^{-1} day^{-1} for piglets the CG and EG, respectively (Table 4). The DWG of piglets in the weaning phase was affected by the group ($p = 0.0179$) and group (week post-weaning) nesting ($p = 0.0001$). EG piglets showed higher DWG ($p < 0.05$) from the seventh week of age (0430 ± 0.02 kg piglet^{-1} day^{-1}) compared to the DWG of the CG piglets (0356 ± 0.02 kg piglet^{-1} day^{-1}) (Table 4). At the end of the weaning phase, the DWG was 0445 and 0366 ± 0.02 kg piglet^{-1} day^{-1} for the piglet the EG and CG, respectively ($p < 0.05$) (Table 4).

Finally, the LW of piglets in the weaning phase was not affected by the group ($p = 0.2475$); however, the nesting group (week post-weaning) if affect that variable ($p < 0.0001$). With regard to this latter effect, it was found that the EG piglets were the ones that showed higher LW ($p < 0.05$) in the eighth and ninth week of age (16.3 and 19.4 ± 0.42 kg piglet^{-1}, respectively), this compared with the LW observed in the CG piglets (15.1 and 17.8 ± 0.42 kg in the eighth and ninth week, respectively). This implied that CG piglets required one more week to complete the weaning stage (Fig. 1).

As regards the LIV of piglets, no group effect was found ($p > 0.05$) in any portion of the small intestine (duodenum, jejunum, and ileum) or large intestine (cecum, transverse, and descending) evaluated. As for the nesting group (week post-weaning) effect was found in the portions: duodenum ($p = 0.0001$), jejunum ($p = 0.0027$), cecum ($p = 0.0072$), transverse ($p = 0.0001$), and descending ($p = 0.0094$), but this was not the case in ileum ($p = 0.4862$).

In relation to the LIV of the small intestine (Fig. 2), it was observed that at weaning (21 days of age) the piglets of both evaluated groups showed equal ($p > 0.05$) in the averages of the LIV in each segment of the evaluated intestine. However, higher LIV was observed ($p < 005$) in the ileum (2387.3 and 2412.4 ± 165.6 µm for CG and EG piglets, respectively) in comparison with the rest of the evaluated segments of the small intestine. However, at 48 h post-weaning (23 days of piglet age) LIV of the jejunum of the piglets of the CG presented lower ($p < 0.05$) length (1074.2±156.3 µm) compared to the LIV of the jejunum of the piglets of the EG (1509.4 ± 156.3 µm), maintaining this trend up to the 42 days of piglets age (Fig. 2). As for the LIV of the ileum, these decreased to 42 days of age ($p < 0.05$), compared to the weaning day (21 days) and 48 h post-weaning, in both groups evaluated (Fig. 2).

With regard to the LIV of the large intestine, it was found that these, at weaning time, were different ($p < 0.05$) in the descending portion (Fig. 3): greater LIV in the piglets of the CG (1,570.6 ± 187.0 µm) compared with the LIV (1,057.7 ± 187.0 µm) of the piglets of the EG ($p < 0.05$), whereas the LIV of the transverse portion of the large intestine to 48 h post-weaning (1,428.2 ± 200.1 µm), increased

Table 4. Voluntary feed intake, weight gain, and live weight of the piglets during weaning phase.

Item (kg)	Post-birth week	Group		S.E.
		CGP	EGP	
Voluntary feed intake day^{-1}	4	0.098^{a1}	0.086^{a1}	0.01
	5	0.233^{b1}	0.243^{b1}	0.01
	6	0.372^{c1}	0.403^{c2}	0.01
	7	0.457^{d1}	0.532^{d2}	0.01
	8	0.611^{e1}	0.703^{e2}	0.01
	9	0.736^{f1}	0.734^{f1}	0.01
Feed intake average		0.418^{1}	0.450^{2}	0.007
Daily weight gain	4	0.068^{a1}	0.052^{a1}	0.02
	5	0.224^{b1}	0.234^{b1}	0.02
	6	0.296^{c1}	0.336^{c1}	0.02
	7	0.356^{d1}	0.430^{d2}	0.02
	8	0.442^{e1}	0.530^{e2}	0.02
	9	0.366^{f1}	0.445^{f2}	0.02
Weight gain average		0.292^{1}	0.333^{2}	0.01

CGP = piglets from mothers of the control group; EGP = piglets from mothers of the experimental group; S.E. = standard error.
Literals $^{a, b}$ indicate differences (p <0.05) within the column and indicator.
Numerals $^{1, 2}$ indicate differences (p <0.05) within row.

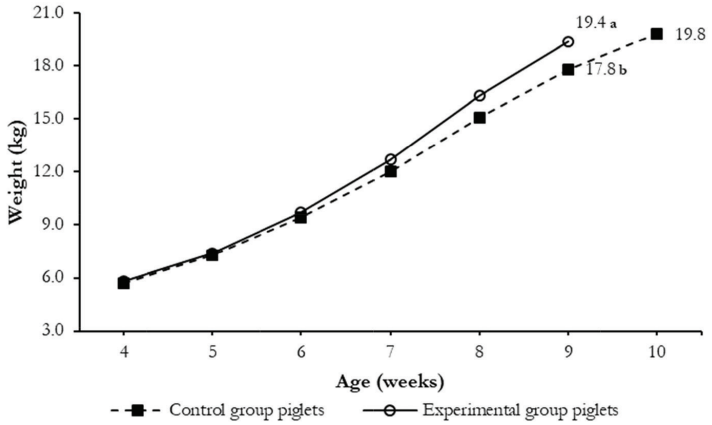

Figure 1. Growth (kg) of piglets in the weaning phase (5–20 kg). Literals a, b indicate differences (p <0.05) within week of evaluation.

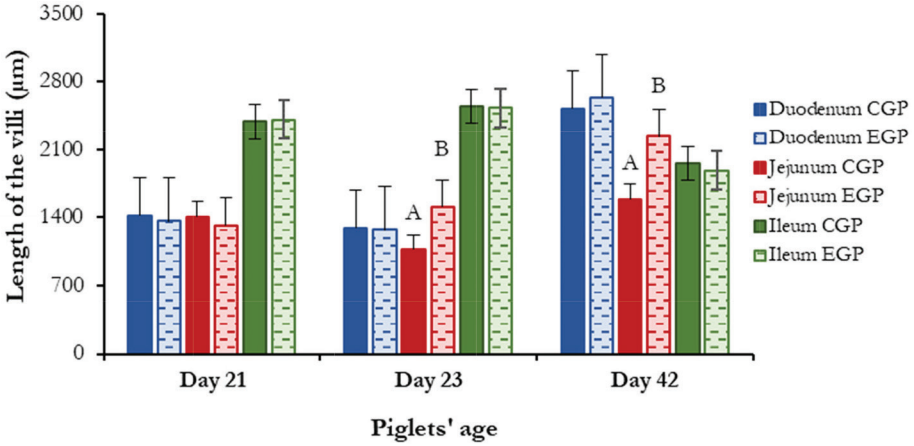

Figure 2. Length (µm) of the intestinal villi (small intestine portion) of the piglets in stage of the 5 to 20 kg live weight. CGP = piglets from mothers of the control group; EGP = piglets from mothers of the experimental group. Literals [A, B] indicate differences (p <0.05) within days of age and between portion of the intestine.

(p < 0.05) in the piglets of the CG with respect to the weaning day (1,105.7 ± 200.8 µm). Aspect that did not happen with the piglets of EG: at weaning (21 days of age), the LIV of the transverse portion of the large intestine was of 913.1 ± 200.8 µm and 48 h post-weaning was of 838.1 ± 200.1 µm (Fig. 3). However, at 42 days of age it was found that, in the EG piglets the LIV of the transverse portion of the large intestine (2,506.8 ± 200.8 µm) was higher (p < 0.05) with respect to the LIV of the piglets of the CG (1,926.7 ± 200.8 µm) (Fig. 3).

Discussion

The use of genetically improved pigs in swine production systems is aimed at increasing system' productivity (higher growth rate) and improving product quality (carcass leanness) [10]. However, the current genetic lines used in pig production, especially those specializing in growth rate, have shown problems in reproductive efficiency, since, in the genetic lines specialized for leanness is exacerbated the phenomenon known as lactational physiological hypophagia [8]. Condition that causes a decrease in the feed intake of sows at the first week of lactation [9]. In this sense, the results on the feed intake of sows at the lactation phase (Table 3) agree with that described by the researchers mentioned above, specifically with the results of the CG (Table 3).

In the case of the voluntary feed intake of the EG sows at lactation phase (Table 3), this agrees with the results obtained by Ortiz et al. [12], who report more voluntary

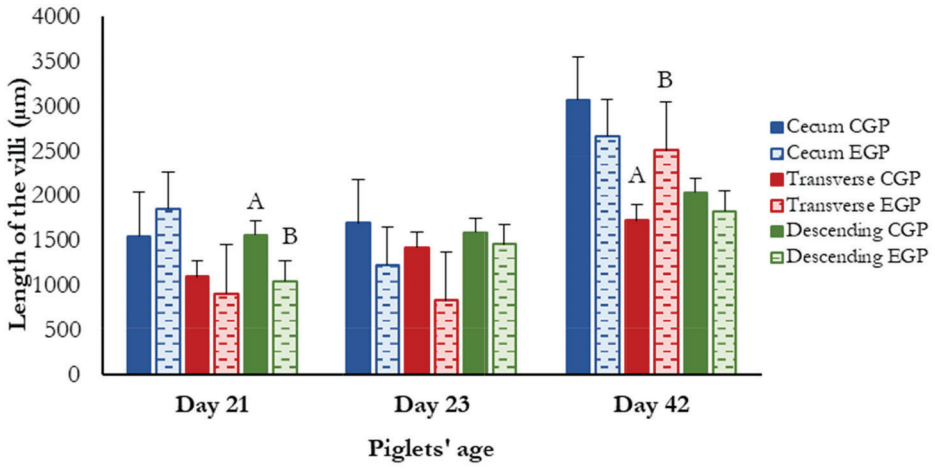

Figure 3. Length (µm) of the intestinal villi (large intestine portion) of the piglets in stage of the 5 to 20 kg live weight. CGP = piglets from mothers of the control group; EGP = piglets from mothers of the experimental group. Literals $^{A, B}$ indicate differences (p <0.05) within days of age and between portion of the intestine.

feed intake ($p < 0.05$) in sows that received a diet supplemented with cactus: 4.5, 6.8, and 7.2 kg sow^{-1} in the first, second, and third week of lactation, respectively; Results similar to those found in this research (Table 3). This increase in the voluntary feed intake of sows in lactation phase could be explained through the hypoglycemic effect caused by the ingestion of cactus [20]; since the decrease in blood glucose reactivates the appetite regulating centers, especially in the first week of lactation [3,21]. The reduction in the concentration of glucose of lactating sows caused by the ingestion of cactus may be associated with the content of Ca^{+2} (52.1 g kg^{-1} of fresh basis) containing the cactus [20], which has been associated with the regulation of blood glucose by stimulating the secretion of insulin [22]. Also, the non-fermentable dietary fiber can stimulate the restoration of orexigenic pathways [21], since fiber stimulates the release of glucagon-like peptide (GLP-1), a peptide that participates in the release of insulin and the inhibition of hepatic production of glucose [23].

Results of voluntary feed intake of EG sows (Table 3) confirm reported by Ortiz et al. [12]: cactus intake mitigates the effects of lactational physiological hypophagia in sows. However, the increase in the feed intake in the EG was not reflected in the milk production of the sows (Table 3). Aspect that had already been observed in other research studies around the effect of diets for sows in lactation phase added with cactus [4]. Lovise et al. [24] report that the additional feed intake by the sows in lactation phase is reflected in less loss of body weight at lactation but not in an increase in milk production. However, if changes in the diet for lactating sows have been reported to affect milk production and quality [25].

About changes in the milk production and quality in sows when adding cactus to the diet, no effect was found ($p > 0.05$) on these indicators (Table 3). Lee et al. [26] report average milk production of 8.5 kg sow^{-1} day^{-1} in lactations of 21 days, value higher than that of the sows analyzed in this investigation (Tables 3). The lower milk production in the sows of both groups analyzed, possibly due to genetic aspects; this, without discarding the environmental aspects, such as breastfeeding intensity, sow age, or udder development [8,25,27]. In relation to milk quality, the diet for lactating sows added with cactus not propitious changes on the concentration of fat, protein, and lactose (Table 3), this independently that has been reported that the ingestion of cactus affects the blood glucose and cholesterol concentration, decreasing them [28,29], behavior that could affect the amount of fat in milk, which did not occur: the amount of fat present in the milk of the sows in both groups was similar (Table 3). As for protein and lactose in milk, these were not affected either. In addition, the nutritional values of the milk of the sows of both evaluated groups agree with the values reported by other researchers [30,31].

Ortiz et al. [4] establish that the production and quality of the milk of the sows under a diet added with cactus does not affect the development of the piglet at the lactation phase. Aspect that could be confirmed in this investigation by not finding differences ($p > 0.05$) in the liveweight of the piglet at 21 days of age, between the two groups (Table 3). Vadmand et al. [32] report that piglet growth at the lactation phase is contingent on the quantity and quality of the milk consumed. Aspect that confirms that the diet of the sows added with cactus does not modify the production

nor the quality of the milk of these; therefore, it does not alter the development of piglets.

For aspects of the evaluation of piglet growth post-weaning, it had been hypothesized that the piglets of the EG; piglets from sows fed a cactus-supplemented diet could benefit from the secondary metabolites of cactus [33] present in the sows' milk. Since these metabolites have prebiotic properties that modify the composition or activity of gastrointestinal microbiota, which would benefit the health of the host [34] and this is reflected in greater production of short chain fatty acids [35]. Short chain fatty acids (acetate, propionate, and butyrate) play an important role in the morphology of the gastrointestinal tract of the pig; because it increases the length of the intestinal villi and the depth of the intestinal crypts [11] modification that is reflected in higher nutrient absorption [36]. Acetate is also oxidized by skeletal and cardiac muscle cells [37], it can be used as an energy source. In this sense, the EG piglets could have faced the post-weaning stress more successfully than the piglets of the CG by having more integrity of the intestinal villi. Aspect that would explain the best behavior ($p < 0.05$) in the growth of these piglets from the sixth week after birth (Table 4 and Fig. 1).

Pluske [38] it establishes the existence of intestinal changes induced by weaning, which are observed in two successive periods: (i) transitional period (dependent of the anorexia) and (ii) restoration of intestinal functions; during the transitional period the decrease of the absorbent surface occurs, modification in the function of the epithelial barrier, adaptation of digestive enzymes, imbalance of the microbiota and triggering of the local inflammatory response, said structural, and functional gaps begin to normalize from 7 days post-weaning and it is until the third week post-weaning when all the intestinal functionality is reestablished. In this sense, the piglets of EG, from the third week post-weaning, showed better behavior in the feed intake and weight gain, with respect to the piglets of the CG (Table 4). In addition, the results on the feed intake post-weaning of the groups of piglets evaluated (Table 4) agree within found the reported by Perez et al. [5] and Mesonero et al. [39], who observed daily average intake of 0.557 and 0.400 kg, respectively.

According to the preceding paragraph, the EG piglets could have a better period of adaptation, possibly to a change in their microbiota, since piglets from sows that consumed cactus, whose contents of non-starch polysaccharides cannot be degraded by digestive enzymes and are absorbed into the large intestine, which generates changes toward a beneficial microbiota and, where the main products of this microbiota are short chain fatty acids (lactate, acetate, propionate, and butyrate) [35]. In this situation, Mori et al. [40] established that these changes may occur in the microbiota of the sow's digestive system and can be transferred to the piglet in the lactation phase. In addition, the greater LIV found in the piglets of EG at 23 and 42 days of age (Figs. 2 and 3) justifies the best productive performance of the piglets of EG post-weaning (Fig. 1).

Hedemann et al. [41] establish that the addition of soluble fiber to the diet of pigs provokes an increase in the viscosity of the intestinal content and increase in the LIV, suggesting positive correlation between the viscosity and LIV. With the inclusion of wheat straw (100 g kg^{-1}), higher depth of the crypts of the jejunum and ileum has been reported and the cell division was faster [42]. The increase in cell proliferation of crypts induced by fiber can be explained by the trophic effect of short chain fatty acids, especially butyrate, since the effect of short chain fatty acids is not limited to the colon as it had stipulated This fatty acid also stimulates cell proliferation and the LIV of the small intestine. Therefore, the cactus intake by the EG sows could lead to greater fermentation due to the content of structural carbohydrates containing (73%), which generated higher synthesis of short-chain fatty acids that in turn were transmitted to the piglet by the milk, which was reflected in higher ($p < 0.05$) LIV (Figs. 2 and 3). This better expression of the LIV is a useful criterion for estimating the digestive capacity of the intestine tract; because it shows a higher contact surface for higher absorption of nutrients [43].

The growth of the LIV observed in the piglets of EG suggests higher integrity or health of the intestine that in turn may have also caused improvement in the intestinal microbiota of the pig by eliminating bacteria potentially pathogens and decrease the inflation of the intestinal mucosa, since, the secondary metabolites of cactus have antimicrobial properties, antioxidant and anti-inflammatory effect attributed mainly to the polyphenols present in the cactus [44].

Conclusion

The addition of cactus to the lactating sow's diet increases the voluntary feed intake without affecting the production or quality of milk, which ensures the development of the lactating piglet. In addition, post-weaning piglets present a higher rate of growth possibly due to the changes in the villi of the jejunum and the transverse large intestine, suggesting that the secondary metabolites of the cactus may be present in the milk of the sows and these improve gastrointestinal health.

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Conflict of interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

All authors have reviewed and approved the final manuscript submission.

References

[1] Zindove TJ, Dzomba EF, Kanengoni AT, Chimonyo M. Effects of within-litter birth weight variation of piglets in performance at 3 weeks of age and at weaning in a Large White x Landrace sow herd. Livest Sci 2013; 155:348–354; https://doi.org/10.1016/j.livsci.2013.04.013

[2] Solà-Oriol D, Gasa J. Feeding strategies in pig production: Sows and their piglets. Anim Feed Sci Technol 2017; 233:34–52; https://doi.org/10.1016/j.anifeedsci.2016.07.018

[3] Ordaz OG, Juárez CA, Pérez SER, Román BRM, Ortiz RR. Effect of spineless cactus intake (*Opuntia ficus-indica*) on blood glucose levels in lactating sows and its impact on feed intake, body weight loss, and weaning-estrus interval. Trop Anim Health Prod 2017; 49:1025–33; https://doi.org/10.1007/s11250-017-1295-7

[4] Ortiz RR, Orozco GA, Val AD, Portillo ML, Pérez SER. Efecto de la adición de nopal (*Opuntia ficus-indica*) a la dieta de cerdas lactantes sobre la producción y calidad de la leche. Rev Electrónica Nova Sci 2017; 9(1):290-312; https://doi.org/10.21640/ns.v9i18.765

[5] Pérez RES, López RM, Bautista GEC, García VA, Róman BRM, Ortiz RR. Efecto del suero de leche como complemento de la dieta sobre el crecimiento de las vellosidades intestinales y el peso de lechones en la etapa de 6 a 20 kg. Rev Cient 2014; 24(4):319–24. Available via https://www.redalyc.org/html/959/95931404009/ (Accessed 25 February 2019)

[6] Ordaz OG, Juarez CA, Pérez SER, Martínez FHE, Esquivel CJ, Ortiz RR. Effect of lactating sows' diet supplemented with cactus (*Opuntia ficus-indica*) on feed intake and reproductive and productive post-weaning performances. Trop Anim Health Prod 2018; 50:1671–82; https://doi.org/10.1007/s11250-018-1611-x

[7] Campbell, JM, Crenshaw JD, Polo J. The biological stress of early weaned piglets. J Anim Sci and Biotechnol 2013; 4:19:1–6; https://doi.org/10.1186/2049-1891-4-19

[8] Quesnel H, Meunier-Salaün MC, Hamard A, Guillemet R, Etienne M, Farmer C, et al. Dietary fiber for pregnant sows: influence on sow physiology and performance during lactation. J Anim Sci 2009; 87:532–43; https://doi.org/10.2527/jas.2008-1231

[9] Cools A, Maes D, Decaluwé R, Buyse J, Van kempen TA, Janssens GP. Peripartum changes inorexigenic and anorexigenic hormones in relation to back fat thickness and feedind strategy of sows. Domest Anim Endocrinol 2014; 45:22–7; https://doi.org/10.1016/j.domaniend.2013.04.003

[10] Kim SW, Weaver AC, Shen YB, Zhao Y. Improving efficiency of sow productivity: nutrition and health. J Anim Sci Biotechnol 2013; 4(26):1–8; https://doi.org/10.1186/2049-1891-4-26

[11] Molist F, Gómez de Segura A, Gasa J, Hermes RG, Manzanilla EG, Anguita M, et al. Effects of the insoluble and soluble dietary fibre on the physicochemical properties of digesta and the microbial activity in early weaned piglets. Anim Feed Sci Technol 2009; 149:346–53; https://doi.org/10.1016/j.anifeedsci.2008.06.015

[12] Ortiz RR, Ordaz OG, Andrade HEO, Saucedo PA Pérez SRE. El nopal (*O. ficus-indica*) como complemento de la dieta de cerdas lactantes sobre los niveles de glucosa sanguínea y consumo de alimento durante la fase de lactancia. XIII Simposium-Taller nacional y VI Internacional, Monterrey Nuevo León, México, 9 y 10 Octubre 2014.

[13] Sánchez E, Davila-Aviña J, Castillo SL, Heredia N, Vázquez-Alvarado R, García S. Antibacterial and antioxidant activities in extracts of fully grown cladodes of 8 cultivars of cactus pear. J Food Sci 2014; 79;M659–64; https://doi.org/10.1111/1750-3841.12416

[14] Sinclair AG, Shaw JM, Edwards SA, Hoste S, McCartney A. The effect of dietary protein level on milk yield and composition and piglet growth and composition of Meishan synthetic and European White breeds of sow. Anim Sci 1999; 68:701–08; https://doi.org/10.1017/S1357729800050724

[15] Klaver J, Van-Kempen GJM, de-Lange PGB, Verstegen MWA, Boer H. Milk composition and dally yield of different milk components as affected by sow condition and lactation/feeding régimen. J Anim Sci 1981; 52(5):1091–7; https://doi.org/10.2527/jas1981.5251091x

[16] Noblet J, Etienne M. Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets. J Anim Sci 1986; 63:1888–96; https://doi.org/10.2527/jas1986.6361888x

[17] Yang YX, Kim YG, Lohakare YD, Yun JH, Lee JK, Kwon MS, et al. Comparative efficacy of different soy protein sources on growth performance, nutrient digestibility and intestinal morphology in weaned pigs. Asian-Aust J Anim Sci 2007; 20(5):775–83; https://doi.org/10.5713/ajas.2007.775

[18] Reis STC, Guerrero MJC, Aguilera BA, Mariscal LG. Efecto de diferentes cereales sobre la morfología intestinal de lechones recién destetados. Tec Pec Méx 2005; 43:309–21. Available via https://cienciaspecuarias.inifap.gob.mx/index.php/Pecuarias/article/view/1370/1365 (Accessed 25 February 2019)

[19] SAS. SAS/STAT user's guide, version, 9.4. SAS Institute Inc., Cary, NC, 2012.

[20] Deldicque L, Van KP, Ramaekers M, Pischel I, Sievers H, Hespel P. Additive insulinogenic action of *Opuntia ficus-indica* cladode and fruit skin extract and leucine after exercise in healthy males. J Int Soc of Sports Nutr 2013; 10(45):1–6; https://doi.org/10.1186/1550-2783-10-45

[21] González MEH, Ambrosio KGM, Sánchez SE. Regulación neuroendócrina del hambre, la saciedad y mantenimiento del balance energético. Artemisa 2006; 8(3):191–200. Available via http://www.medigraphic.com/pdfs/invsal/isg-2006/isg063i.pdf (Accessed 01 March 2019).

[22] Pari L, Latha M. Antidiabetic effect of Scoparia dulcis: effect on lipid peroxidation in streptozotocin diabetes. Gen Physiol Biophys 2005; 24:13–26. Available via http://www.gpb.sav.sk/2005_01_13.pdf (Accessed 01 March 2019)

[23] Nuñez MAL, Paredes OL, Reynoso RC. Functional and hypoglycemic properties of nopal cladodes (*O. ficus-indica*) at different maturity stages using in vitro and in vivo test. J Agric Food Chem 2013; 61:10981–6; https://doi.org/10.1021/jf403834x

[24] Lovise ST, Helen AG, Petter NK, Hetland H, Framstad T. Pea starch meal as a substitute for cereal grain in diets for lactating sows: the effect on sow and litter performance. Livest Sci 2013; 157:210–7; https://doi.org/10.1021/jf403834x

[25] Farmer C. Nutritional impact on mammary development in pigs: a review. J Anim Sci 2018; 96(9):3748–56; https://doi.org/10.1093/jas/sky243

[26] Lee SH, Joo YK, Lee JW, Ha YJ, Yeo JM, Kim WY. Dietary conjugated linoleica cid (CLA) increases milk yield without losing body weight in lactating sows. J Anim Sci Biotechnol 2014; 56:11; https://doi.org/10.1186/2055-0391-56-11

[27] Farmer C. Altering prolactin concentrations in sows. Domest Anim Endocrinol 2016; 56:S155–64; https://doi.org/10.1016/j.domaniend.2015.11.005

[28] Shane-McWhorter, L. Dietary supplements for diabetes: an evaluation of commonly used products. Diabetes Spectrum 2009; 22:206–13; https://doi.org/10.2337/diaspect.22.4.206

[29] Pérez SER, Ordaz OG, Juárez CA, Ortiz RR. Efecto del consumo de nopal en cerdos post-destete sobre el crecimiento de vellosidades intestinales y su repercusión en su desarrollo. Reunión Nacional de Investigación Pecuaria Memoria, Año 3, 2018, vol. 1(1), pp 393–5. Available via http://reunionpecuaria2018.inifap.gob.mx/RNIP/_MEMORIAS/2017.pdf (Accessed 01 March 2019).

[30] Foisnet A, Farmer C, David C, Quesnel H. Relationships between colostrum production by primiparous sows and sow physiology around parturition. J Anim Sci 2010; 88:1672–83; https://doi.org/10.2527/jas.2009-2562

[31] Hansen A, Strathe A, Kebreab E, France J, Theil P. Predicting milk yield and composition in lactating sows: a Bayesian approach. J Anim Sci 2012; 90(7):2285–98; https://doi.org/10.2527/jas.2011-4788

[32] Vadmand CN, Krogh U, Hansen CF, Theil PK. Impact of sow and litter characteristics on colostrum yield, time for onset of lactatión, and milk yield of sow. J Anim Sci 2015; 93:2488–500; https://doi.org/10.2527/jas.2014-8659

[33] El-Mostafa K, El-Kharrassi Y, Badreddine A, Andreoletti P, Vamecq J, Saïd M, et al. Nopal Cactus (*Opuntia ficus-indica*) as a source of bioactive compounds for nutrition, health and disease. Molecules 2014; 19:14879–901; https://doi.org/10.3390/molecules190914879

[34] Heo JM, Opapeju FO, Pluske JR, Kim JC, Hampson DJ Nyachoti CM. Gastrointestinal health and function in weaned pigs: a review of feeding strategies to control post-weaning diarrhoea without using in-feed antimicrobial compounds. J Anim Phys Anim Nutr 2012; 97:207–37; https://doi.org/10.1111/j.1439-0396.2012.01284.x

[35] Lindberg JE. Fiber effects in nutrition and gut health in pigs. J Anim Sci Biotechnol 2014; 5(15):2–7; https://doi.org/10.1186/2049-1891-5-15

[36] Chen H, Mao XB, Che LQ, Yu B, He J, Yu J, et al. Impact of fiber types on gut microbiota, gut envioronment and gut function in fattening pigs. Anim Feed Sci Technol 2014; 195:101–11; https://doi.org/10.1016/j.anifeedsci.2014.06.002

[37] Zjilstra RT, Jha R, Woodward AD, Fouhse J, Kempen TATG. Starch and fiber properties affect their kinectics of digestión and thereby digestive physiology in pigs. J Anim Sci 2012; 90:49–58; https://doi.org/10.1186/2049-1891-5-15

[38] John F. Patience, Springer Link, Pluske JR. Physiology of feed efficiency in the pig: emphasis on the gastrointestinal tract and specific dietary examples. In: Feed efficiency in swine, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 239–57, 2012; https://doi.org/10.3920/978-90-8686-756-1_12

[39] Mesonero JAE, Van Der Horst Y, Carr J, Maes D. Implementing drinking water feed additive strategies in post-weaning piglets, antibiotic reduction and performance impacts: case study. Porcine Health Manag 2016; 2(25):1–8; https://doi.org/10.1186/s40813-016-0043-0

[40] Mori K, Ito T, Miyamoto H, Ozawa M, Wada S, Kumagai Y, et al. Oral administration of multispecies microbial supplements to sows influences the composition of gut microbiota and fecal organic acids in their post-weaned piglets. J Biosci Bioeng 2011; 112(2):145–50; https://doi.org/10.1016/j.jbiosc.2011.04.009

[41] Hedemann MS, Eskildsen M, Laerke HN, Pedersen C, Lindberg JE, Laurinen P, et al. Intestinal morphology and enzymatic activity in newly weaned pigs fed contrasting fiber concentrations and fiber properties. J Anim Sci 2006; 84:1375–86; https://doi.org/10.2527/2006.8461375x

[42] Jin L, Reynolds LP, Redmer DA, Caton JS, Crenshaw JD. Effects of dietary fiber on intestinal growth, cell proliferation, and morphology in growing pigs. J Anim Sci 1994; 72:2270–8; https://doi.org/10.2527/1994.7292270x

[43] Knud EBK, Mette SH, Nygaard HL. The role of carbohydrates in intestinal health of pigs. Anim Feed Sci Technol 2012; 173:41–53; https://doi.org/10.2527/1994.7292270x

[44] Guevara FT, Jimenez IHugo, Reyes EML, Mortensen AG, Laursen BB, Lin LW, et al. Proximate composition, phenolic acids, and flavonoids characterization of commercial and wild nopal (Opuntia spp.). J Food Compos Anal 2010; 23(6):525–32; https://doi.org/10.1016/j.jfca.2009.12.003