Grazed barley for dairy cows in small-scale systems in the highlands of Mexico

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ABSTRACT
Small-grain cereals with characteristics of hardiness of, such as barley have been evaluated as conserved forage for cows in small-scale dairy systems (SSDDs); but barley may also be grazed due to its regrowth capability after defoliation. The objective was to assess grazing of barley at 59 (B59), 66 (B66) and 73 (B73) days after seeding with milking cows in SSDSs. Twelve Holstein cows were grouped in a randomised 3 x 3 Latin Square design, replicated four times, with 14-day experimental periods. Measurements of animal variables and collection of feed and milk samples took place over the 4 final days of each period. A partial cost analysis was performed including only feeding expenses. The mean net forage accumulation during the experiment was 97.1 kg DM d⁻¹. The botanical composition was affected by secondary vegetation (Mexican aster and wild radish, among others), where barley content was higher in B73 than in B66 and B59 pastures. The contents of dry matter (189–414 g kg⁻¹), neutral detergent fibre (NDF; 456–585 g kg⁻¹ DM), acid detergent fibre (ADF; 181–265 g kg⁻¹ DM) and crude protein (CP; 86–158 g kg⁻¹ DM) showed significant (p < 0.05) interactions among periods and pastures. Milk yield (MY) was 6.5% higher for treatment B66 (18.7 kg) in relation to B59 (17.5 kg), with intermediate values for B73 (18.1 kg). Feeding cost per kg milk was significantly lower in treatments B66 than B59 (p < .05), increasing the profit margins. It is concluded that grazed barley is a viable forage option for SSDSs. Initiating grazing of barley at 66 days post-sowing had a better cow performance than grazing at 59 d, with higher margins over feeding costs. The three treatments proved economically viable, with income/feeding costs ratios above 3.00.

HIGHLIGHTS
- Feeding strategies with small grain cereals (barley) represent a feeding alternative for small-scale dairy farmers.
- The implementation of barley grazing in small-scale milk production systems is an option given the low rainfall.
- Barley, as a short cycle crop, allows dairy farmers to obtain good quality forage to feed their cows.

Introduction
Extreme temperatures, erratic and changing rainfall patterns due to climate change affect livestock and agricultural activities; additionally, there are wide variations in crop yields from one year to the next (Pecchioni et al. 2014) and thereby, in nutrient availability in forages (Rojas-Downing et al. 2017). The livestock sector faces a context where it has to compete for the available resources (land, water, energy, among others), and is constantly questioned as regards to its environmental footprint (de Vries and de Boer 2010). However, livestock activities are able to produce high-quality proteins from forages, as in milk or meat for human intake (Broderick 2018).

In developing countries, having a herd may be considered a replaceable asset or savings capable to improve livelihoods and reduce poverty (Herrero et al. 2013), as shown in Mexico where small-scale dairy production enabled farming families to overcome poverty (Espinoza-Ortega et al. 2007).

Small-scale agriculture in developing countries, such as Mexico comprises the majority of farmers...
(FAO—Food and Agriculture Organization 2019). In the case of dairy production, it contributes to the optimal use of their limited resources (Arriaga-Jordán et al. 2002). Small-scale dairy systems (SSDSs) have potential for their development by means of reducing the use of external inputs particularly bought concentrates, which increase production costs that lead to a decrease in their sustainability (Hemme 2007; Fadul-Pacheco et al. 2013; Prospero-Bernal et al. 2017). Increasing the reliance on farm-grown forage resources improves their profitability and sustainability (Prospero-Bernal et al. 2017). Grazing cultivated pastures under irrigation have proven as a viable feeding strategy in these systems (Prospero-Bernal et al. 2017), but current restrictions on the availability of irrigation water are limiting this option. Small-grain cereals may be an option for SSDSs.

The use of small-grain cereals silage such as barley, triticale, and oat to feed dairy cows was shown appropriate for SSDS as sole forage or combined with maize silage and grazing (Guadarrama-Estrada et al. 2007; Burbano-Munoz et al. 2018; Gómez-Miranda et al. 2020; González-Alcántara et al. 2020).

Barley is capable of regrowing after defoliation while in vegetative state, increasing its herbage yield, which may be utilised by grazing, as an extra harvest for forage or else, to produce grain (Royo et al. 1997), demonstrating a greater resistance to drought than wheat and triticale, in addition to completing their phenological development processes in less time (Miranda-Domínguez et al. 2016).

Since there is little information on grazing barley as a first defoliation in the literature, the objective of this study is to evaluate barley on various post-sowing dates at the initiation of grazing as main forage source for lactating cows in SSDS.

Materials and methods

Study area

The experimental work was developed under a participatory livestock research approach (Conroy 2005), through an on-farm experiment with two collaborating farmers who shared their land and cows for the experiment. Their farms are located in the municipality of Aculco, in the central highlands Mexico on 20°10' N and 99°48' W, at an altitude of 2400 m; a subhumid temperate climate with 800 mm of rainfall in summer (May–October), a marked dry season (November–April); and an annual mean temperature between 5.7 and 22.2 °C with a mean of 13.2 °C

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Experimental design and animals

The on-farm experiment was from 24 July to 3 September 2020, when the pastures were 59, 66 and 73 d post-seeding identified as B59, B66, B73, when mean sward height was 28 ± 9.28, 43 ± 10.34 and 59 ± 13.01 cm, which was in a phenological state of Z25, Z30 and Z32 according to the Zadoks scale respectively, at the beginning of the experiment.

Twelve primiparous and multiparous Holstein cows with mean live weight (LW) of 455 ± 19.8 kg, and milk yields (MYs) of 17.8 ± 2.1 kg⁻¹ cow⁻¹ d⁻¹, were selected and grouped in 4 groups of three cows each according to days in milk, and similar number of calvings.

Experimental design was a 3 × 3 Latin square replicated four times (Kaps and Lambersen 2004), as follows: square A: early lactation (11.3 ± 0.66 d in milk, number of calvings 3.6 ± 0.33); square B: mid lactation (80 ± 10 d in milk, number of calvings 1); square C: late lactation higher yielders (325 ± 10 d in milk, number of calvings 4 ± 1.73); and square D: late lactation lower yielders (180 ± 10 d in milk, number of calvings 1) with 14-d experimental periods (10 d for treatment adaptation and 4 for sampling) following Pérez-Ramírez et al. (2012).

On the basis of the pre-experimental mean LW of the cows, an intake of 13.5 ± 5 kg DM cow⁻¹ d⁻¹ was estimated, with a fixed intake of 4.5 kg DM of a compound commercial concentrate (crude protein [CP] 18%, fat 2%, fibre 20%, nitrogen-free extract 30%, moisture 12%, ash 18%, calcium 4.5% and phosphorus 0.45%) composed of ground and rolled grains and their by-products, cotton seed, oilseed meals, rumen undegradable fat, molasses, citrus pulp, NNP, common salt, ionophore; minerals: calcium, phosphorus, zinc, cobalt; selenium, and iodine of citrus, vitamins: A, D and E according to the manufacturer’s label. The amount and type of concentrate were decided by the participating farmers from their usual practice.

Cows grazed for 6 h a day in 14-d experimental periods, rotating on the three pasture treatments in days of grazing initiation after sowing: B59 = pasture of 59 d, B66 = pasture of 66 d and B73 = pasture of 73.

Animal variables

Cows were hand-milked twice a day at 6:00 and 17:00 h. MY was recorded using a clock spring scale
with 20 kg capacity in each milking during the four final days of each experimental period. Mean daily MY per period was used in analyses. A milk sample was taken in each milking, and an aliquot taken considering the yields per milking, to determine milk fat, protein and lactose contents with an ultrasonic milk analyser (Lactoscan), pH determined with pH probe (OAKTON, Fairfax County, VA), and to determine milk urea nitrogen (MUN), following the methodology described by Chaney and Marbach (1962).

LW was recorded for two consecutive days with an electronic weighing scale with capacity for 1000 kg (Gallager W210), and body condition score (BCS) estimated on a 1–5 scale according to Bewley et al. (2010); recorded at the end of each experimental period.

Dry matter intake was estimated from energy requirements as described by Macoon et al. (2003), taking requirements for maintenance, lactation, LW changes, estimating the requirements per activity using the formula 28 J·kg BW^{-1}·m^{-1}·h^{-1} (AFRC 1993) and walking to the pastures into account 5020.8 J·h^{-1}·BW^{0.75} (Macoon et al. 2003).

Crops

Sowing was carried out in May 2020 under rainfed conditions. Three hectares were broadcast sown with barley (Hordeum vulgare cv Jennifer) at a rate of 140 kg/ha with a 7-d delay for each hectare with a view to starting the grazing at various sward heights as described above. Fertilisation rate at sowing was 43–60–40 kg·ha^{-1} N–P–K; followed by 60 kg N·ha^{-1} applied at 21 d after sowing.

Set-stocked grazing was for 6 h in the barley pastures at a stocking rate of 4 cow·ha^{-1}. Net herbage accumulation (NHA) was estimated following Hoogendoorn et al. (2016). Each treatment pasture was nominally subdivided in two as sampling units, with three 0.25 m^{2} (0.5 m × 0.5 m) exclusion cages per subdivision (six cages per treatment), cutting within a 0.16 m^{2} metal frame (0.4 m × 0.4 m) outside and inside the cages at the beginning and end of each experimental period. Sward height was recorded with a measurement tape from the base of the stem to the last leaf or spikelet depending on the stage (Miranda-Domínguez et al. 2016; Wilson-García et al. 2017).

Due to the climatic conditions, a variety of weeds were found in the pasture, in traditional barley crops for grain and preserved forage, weeds are controlled by agrochemicals that leave noxious residues in plants, soil and environment (Aamir Iqbal et al. 2020). Since the objective of this study is the evaluation of grazing barley in the early stages of growth, the application of available herbicides had withdrawal time restrictions between 15 and 60 d post-application, which would delay grazing (Ikley et al. 2021).

The botanical composition of the pastures was determined from samples on day 11 of each experimental period (first day of each measurement period). Five 0.16 m^{2} squares (0.4 m × 0.4 m) per pasture treatment were cut, manually separating the plants as: barley, Mexican aster (Cosmos bipinnatus), wild radish (Raphanus raphanistrum) locally called ‘mustard’, several gramineae grouped as grass, as well as diverse unidentified weeds and total dead tissue (Sanderson et al. 2005; Dubieux et al. 2016); and results expressed in percentage (%) per group by pasture. Using this information, the herbage accumulation of each species in the pastures was estimated in kg DM·ha^{-1}·d^{-1}; by multiplying the proportion of each plant group by the NHA of each pasture.

Chemical composition of feeds

Two hand-plucked pasture samples simulating grazing were taken were taken during the last 4 d of each experimental period for chemical analyses (Dubieux et al. 2016). Samples were dried at 55 °C for 48 h to determine dry matter content. Determination of organic matter (OM), CP, neutral detergent fibre (NDF), acid detergent fibre (ADF) and in vitro OM digestibility (IVOMD), followed standard procedures described by Celis-Alvarez et al. (2016).

Estimated metabolisable energy (eME) was calculated using the formula described by the Agricultural and Food Research Council (AFRC 1993) utilising DMOD (digestible OM in the dry matter): eME (MJ·kg DM) = 0.0157 * DMOD g·kg OM.

Economic analysis

Feeding costs and profit margins were calculated using the partial budgeting methodology (Harper et al. 2013), using feeding costs and incomes from milk sales. The total costs of pasture were divided into the yield of DM per pasture, and pasture feeding costs calculated on the basis of estimated pasture intake per cow (following Macoon et al. 2003) during the experimental periods.

Statistical analyses

Treatments were randomly assigned in squares A and C, whilst squares B and D mirrored the sequence of
short experimental periods in cross-over designs. Cross-over experiments are well accepted and validated in the scientific literature. Experiments with a small number of cows are also well accepted and validated in the scientific literature. Cows in on-farm experiments exclude larger experiments with a larger number of cows. Experiments with a small number of cows are also well accepted and validated in the scientific literature.

Pasture variables in terms of NHA, sward height, botanical composition and chemical composition of feeds were analysed with a randomised split plot experimental design with the following model:

\[ Y_{ijkl} = \mu + R_i + X_j + E_{ij} + P_{k} + (TX \times P)_{jk} + e_{ijklm} \]

where \( Y_{ijkl} \) is the response variable; \( \mu \) is the general mean; \( R_i \) is the effect from replicates, \( i = 1, 2, 3; \( X_j \) is the pasture effect (main plot), \( j = B73, B66, B59; E_{ij} \) is the residual error of the main plot; \( P_k \) is experimental period effect (split plot) \( k = 1, 2, 3; \) \( TX \times P \) is the effect of the interaction between pastures and experimental periods; \( e_{ijklm} \) is residual error.

Tukey’s test was applied to compare means when significant differences at \( p \leq 0.05 \) were detected.

### Results

#### Forage yields

Forage DM yield at the beginning of the experiment was 2.33 DM t ha\(^{-1}\) for B73, 2.08 DM t ha\(^{-1}\) for B66, and 1.99 DM t ha\(^{-1}\) for B59, with a height of 59, 43 and 28 cm for B73, B66 and B59, respectively. Forage in pastures increased gradually in relation to experimental period \( p < 0.01 \); however, sward height did not show differences \( p > 0.05 \) with a mean of 74 cm (Table 1).

Pastures had a NHA of 1360 kg DM-ha-period\(^{-1}\) with a mean availability of 97.1 kg DM-ha\(^{-1}\) ha/d, with no differences among treatments \( p > 0.05 \). In terms of experimental periods, P2 had 1900 kg DM/ha being 46 and 41% higher than NHA for P1 and P3, respectively (Table 1).

There were significant differences in net barley accumulation \( p < 0.001 \) where pasture B73 presented 62 and 83% more than B66 and B59, respectively. A significant difference \( p < 0.05 \) among periods were observed, with a significant increase in barley during P2, 46% regarding P1 and 55% in relation to P3.

The interaction between pastures and periods was significant \( p < 0.05 \) for Cosmos bipinnatus, being pasture B66*P2 with higher presence and B73*P2 the interaction with the least presence of Mexican aster.
Regarding the presence of the 'grass' component in the barley pastures, in B66 was 44 and 59% significantly higher \((p < .01)\) as compared with B73 and B59, respectively. The presence of *Raphanus raphanistrum* in B73 decreased as periods progressed, whilst for pasture B66 it was inverse, where its presence increased up to P3. Moreover, it was virtually absent in pasture B59\(^*\)/C3\(^*\)P1; and later increased during B59\(^*\)/C3\(^*\)P2 and decreased in during B59\(^*\)/C3\(^*\)P3 (Table 2).

### Chemical composition of feeds

Chemical composition had a statistically significant interaction of pastures by period \((p < .0001)\) in DM, OM, NDF, ADF and CP contents. Table 3 shows that pastures B73 and B66 started with similar DM and OM contents, though B73 had a more perceptible increment in relation to B66, while NDF and ADF had similar values during the three periods, which decreased in the third period, and was lower in B59 over the same period.

CP content was higher in P1 for the three pastures as compared to P2 and P3; where B59 had the highest CP contents for the three periods. Digestibility and energy content of the pastures did not show significant differences \((p > .05)\).

### Animal variables

The results for animal variables are shown in Table 4. There were significant differences among treatments \((p < .05)\), where B66 had the higher MY and B59 the lowest, with B73 intermediate. MYs in B66 were 6.5% higher than B59.

Milk fat, protein, lactose and MUN contents did not show any statistical difference \((p > .05)\). No differences were observed in LW (mean 465 ± 00 kg) nor in BCS (mean 2.6) \((p > .05)\). DM intake was also not different among treatments \((p > .05)\).
Economic analysis

Table 5 shows results for the economic analysis. Feeding costs were no different between treatments \((p > .05)\).

Feeding costs per kg of milk were significantly lower in treatment B66, 10% less in relation to B59 and treatment B73 showed no differences with the other two treatments. These results correspond to the highest MY in B66 which was 7% higher than B59.
Increased MY and lower feeding costs per kg milk in B66 resulted in 10% higher margins over feeding costs in total, per kg milk and per cow/day, with a significantly higher income/feeding costs ratios for B66 compared to B59. B73 showed intermediate values for economic variables between B66 and B59.

**Discussion**

Growing barley in Mexico has traditionally focussed on the grain harvest for the beer industry, although given the advantages of barley due to its hardiness, adaptability and nutritional quality, is now being investigated as a valuable forage source for ruminants.

In an analysis of forage barley growth, Wilson-García et al. (2017) found primary growth forage yields of 500–1200 (kg DM ha⁻¹), 800–1500 (kg DM ha⁻¹) and 1000–2000 (kg DM ha⁻¹) at 56, 63 and 70 days after sowing, which are similar to the reports of this study at the beginning of grazing with a mean of 2133 kg DM ha⁻¹.

Adding to the above, climate conditions during the rainy season (Arriaga-Jordán et al. 2001), mainly in their vegetative state. Gutiérrez et al. (2008) mentioned that some of these weeds, such as Cosmos bipinnatus may reach up to 10% CP, so they are used as alternative forages in these systems, so that no herbicides were used in this study.

Reports on the chemical composition of cereal crops showed significant differences attributed to the various seeding dates (Flores-Nájera et al. 2016). In any case, as in this study, the barley crops were grazed, defoliation and regrowth allowed the contents of NDF and ADF in the forage to be lower to literature reports, such as 586–609 g/kg DM, 389–401 g/kg DM for NDF and ADF (Baron et al. 2012, Hundal et al. 2014), though similar to the results of Sadeghpour et al. (2013) of 526 and 309 g/kg DM of NDF and ADF, respectively.

Since CP is one of the components that define forage quality (Lithourgidis et al. 2006), it was observed that pastures B73 and B66 were within the CP range reported in the literature from 80 to 111 g/kg DM (Juskiw et al. 2000; Baron et al. 2012). However, pasture B59, where grazing initiated at an earlier development stage, had a higher CP content, comparable with reports by Hundal et al. (2014) (136 g/kg DM); therefore, the available forage had greater cellular and lower cell wall contents given the continual defoliation of pastures from that earlier initiation of grazing.

The digestibility of pastures was in line to reports by Baron et al. (2012) (697–726 g/kg DM) but lower

**Table 4. Animal variables.**

| Value | B73 | B66 | B59 | SEM | p Value |
|-------|-----|-----|-----|-----|---------|
| Milk yield (kg) | 18.1<sup>ab</sup> | 17.5<sup>a</sup> | 17.5<sup>b</sup> | 0.117 | .017 |
| Milk fat (g/kg) | 33.7 | 33.3 | 33.1 | 0.060 | .688 |
| Protein (g/kg) | 28.7 | 28.7 | 28.7 | 0.027 | .518 |
| Lactose (g/kg) | 43.1 | 43.4 | 43.0 | 0.024 | .453 |
| pH | 6.8 | 6.8 | 6.8 | 0.004 | .582 |
| MUN (mg/dL) | 11.8 | 11.8 | 12.0 | 0.029 | .054 |
| Live weight (kg) | 464.2 | 468.1 | 464.5 | 0.415 | .220 |
| Body condition score (1–5) | 2.6 | 2.6 | 2.6 | 0.006 | .524 |
| DMI CC (kg DM cow⁻¹ d⁻¹) | 4.4 | 4.4 | 4.4 | 0.000 | – |
| DMI pasture (kg DM cow⁻¹ d⁻¹) | 7.8 | 6.5 | 6.8 | 0.134 | .104 |
| Total intake of DM (kg DM/cow⁻¹ d⁻¹) | 12.3 | 10.9 | 11.3 | 0.134 | .104 |

**Table 5. Economic analysis of treatments during experimental periods (USD$).**

| Value | B73 | B66 | B59 | SEM | p Value |
|-------|-----|-----|-----|-----|---------|
| Feeding costs | | | | | |
| Commercial concentrate (USD$) | 20.90 | 20.90 | 20.90 | 0.000 | – |
| Pasture (USD$) | 2.99 | 2.47 | 2.62 | 0.051 | .105 |
| Total feeding costs (USD$) | 23.90 | 23.38 | 23.53 | 0.051 | .105 |
| Incomes | | | | | |
| Total milk yield (kg) | 252.45<sup>ab</sup> | 262.62<sup>a</sup> | 245.62<sup>b</sup> | 1.646 | .017 |
| Feeding costs (USD/kg milk) | 0.1083<sup>ab</sup> | 0.0991<sup>a</sup> | 0.1091<sup>b</sup> | 0.001 | .019 |
| Selling price (USD/SQ/kg milk) | 0.32 | 0.32 | 0.32 | 0.000 | – |
| Income from milk sales (USD$) | 79.88<sup>ab</sup> | 83.09<sup>a</sup> | 77.71<sup>b</sup> | 0.520 | .107 |
| Total margin over feed costs (USD$) | 55.98<sup>ab</sup> | 59.71<sup>a</sup> | 54.18<sup>b</sup> | 0.542 | .014 |
| Margin over kg milk (USD$/kg) | 0.2071<sup>ab</sup> | 0.2158<sup>a</sup> | 0.2058<sup>b</sup> | 0.001 | .038 |
| Margin over feed costs (USD cow⁻¹ d⁻¹) | 4.00<sup>ab</sup> | 4.26<sup>a</sup> | 3.87<sup>b</sup> | 0.038 | .014 |
| Income/feeding cost ratio | 3.34<sup>ab</sup> | 3.54<sup>a</sup> | 3.29<sup>b</sup> | 0.025 | .018 |

B73: pasture grazing 73, d; B66: pasture grazing 66, d; B59: pasture grazing 59, d; DMI: dry matter intake; CC: commercial concentrate; ns: p > .05; SEM: standard error of the mean; USD$: American dollars
than results by Hundal et al. (2014) (796–807 g/kg·DM). Furthermore, eME content was 32% higher than reports in the literature for forage barley (6.92–7.13 MJ/kg·DM), reaching values of 10.0 MJ/kg·DM.

Cow performance was in line with findings by Burbano-Muñoz et al. (2018) in diets based on small-grain cereals with a mean MY of 18.6 kg/d; and higher than reports by Plata-Reyes et al. (2020) of 15.0 kg/d for diets on grazing pastures. The nutritional quality of the investigated barley pastures allowed higher MYs than other reports in these small-scale production systems (Fadul-Pacheco et al. 2013; Prospero-Bernal et al. 2017).

Treatment B66 had the higher MYs, despite the apparent lower nutritional value of this pastures compared to B59; with treatment B73 with intermediate MYs between the other two treatments. The values for milk fat, protein and lactose contents were no different between treatments (p > .05) and were within the parameters defined in the Official Mexican Standard for Class C milk.

Milk protein content was below of the mean content reported for these systems (Prospero-Bernal et al. 2017). Jenkins and McGuire (2006) mentioned that the depression of proteins in milk may be an indirect effect of lower energy intakes in diets with a high forage component.

MUN content is usually an indicator of protein concentration in diets and of the energy/protein balance (Spek et al. 2013). Kohn et al. (2002) defined that MUN values between 8.5 and 11.5 mg/dL account for an efficient use of proteins, being slightly higher in the present experiment with mean values of 11.9 mg/dL but indicating an efficient use of diet protein in balance with the metabolisable energy supply.

Although total dry matter intake was not different between treatments, since B73 and B66 produced higher MYs, which implies that the quality of the forage consumed in treatments B73 and B66, although not statistically different, was sufficient to produce a greater quantity of milk than in treatment B59. This led to lower feeding costs per kg milk, which turned into a larger profit margin over feeding costs per kg milk and per cow/day. Obtained results were similar to reports by Celis-Alvarez et al. (2016), but higher than to reports by Burbano-Muñoz et al. (2018).

Conclusions

It is concluded that grazed barley is a viable forage option where the forage had an adequate nutritional quality to sustain MYs in SSDSs. It was also shown that despite the invasion by secondary vegetation, grazed barley pastures can be a forage alternative without the need to use agrochemicals for their control.

Initiating grazing of barley at 66 d post-sowing had a better cow performance than grazing at 59 d post-sowing, producing a higher MY that was noticed in the margins over feeding costs and in the income/feeding costs ratio. Also, initiating grazing at 73 d post-sowing showed intermediate cow performance between grazing in B66 and B59, so that it may be an option. The three treatments proved economically viable, with income/feeding costs ratios above 3.00.

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Ethical statement

The management of cows over the experiment as well as fieldwork with the collaborating farmers followed methods and practices accepted by Universidad Autónoma del Estado de México. The collaborating farmers actively participated in the experiment, had knowledge of the objectives, were duly informed and consulted and their decisions were respected at all times. The experiment was undertaken on one of the farmer’s farmland, with cows from the other farmer’s herd and under his management conditions, and provided a signed letter of consent for their participation in the research.

Disclosure statement

No potential conflict of interest was reported by the authors. The authors alone are responsible for the content and writing of this article.

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Data availability

Data are available with the corresponding author at: (Flopezg@Uaemex.Mx) upon reasonable request.

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