Journal MVZ Cordoba
2022; september-december. 27(3):e2676.
https://doi.org/10.21897/rmvz.2676

Original

Estimation of the welfare of dairy cattle in the tropics using environmental conditioning criteria

Ma. Teresa Kido-Cruz[1]; César Julio Martínez-Castro[1]*; Tania Zúñiga-Marroquín[1]; Julián Cotera-Rivera[1].

[1]Universidad del Papaloapan, Instituto de Agroingeniería. Loma Bonita, Oaxaca, México.
*Correspondence: c_julios4@hotmail.com

Received: February 2022; Accepted: August 2022; Published: September 2022.

ABSTRACT

Objective. To estimate the animal welfare of cattle through environmental conditioning criteria in dairy production units (PU) in Loma Bonita, Oaxaca, Mexico. **Materials and methods.** The sample consisted of 23 PU, using convenience sampling. The evaluated PU represent 57% of the universe of cattle farms supplying the collection center of the Seguridad Alimentaria Mexicana (SEGALMEX). To obtain the data, interviews were conducted, samples were taken in the field, and photos and videos were taken for record and reference. Fourteen indicators were evaluated covering three environmental criteria of animal welfare: 1) Prolonged absence of hunger; 2) Prolonged absence of thirst; and 3) Location, construction and equipment. This allowed the animal welfare of each PU to be classified into four categories: Excellent, Good, Acceptable and Not classified. To estimate cattle welfare, three steps were followed: 1) Evaluation of criteria related to environmental conditioning; 2) Standardization of values; and 3) Integration of values per criterion. **Results.** The cattle welfare of the evaluated PU was Excellent (17%); Good (43%); Acceptable (34%) and Not acceptable (6%). **Conclusions.** Animal welfare in the PU of Loma Bonita, Oaxaca ranges from good to acceptable. Of the 14 welfare indicators analyzed, 11 of them show values higher than 20%, and are therefore considered critical. Of the 14 welfare indicators analyzed, 11 of them show values higher than 20%, so they are considered critical. 95% of the PU show problems in terms of waiting time for cattle before milking and 60% do not have the appropriate width of the exit aisle of the milking parlor.

Keywords: Body condition; dual-purpose cattle; indicators; farm installations; milking; tropical region (*Source: CAB*).

RESUMEN

Objetivo. Estimar el bienestar animal del ganado bovino, mediante criterios de acondicionamiento ambiental en unidades de producción (UP) lechera de Loma Bonita, Oaxaca, México. **Materiales y métodos.** La muestra fue de 23 UP, empleándose el muestreo por conveniencia. Las UP evaluadas representan el 57% del universo de explotaciones bovinas que abastecen al centro de acopio del

How to cite (Vancouver).
Kido-Cruz MT, Martínez-Castro CJ, Zúñiga-Marroquín T, Cotera-Rivera J. Estimation of the welfare of dairy cattle in the tropics using environmental conditioning criteria. Rev MVZ Cordoba. 2022; 27(3):e2676. https://doi.org/10.21897/rmvz.2676

ISSNL: 0122-0268

organismo de Seguridad Alimentaria Mexicana (SEGALMEX). Para obtener los datos se aplicaron entrevistas, toma de muestras en campo, así como fotos y videos para constancia y referencia. Se evaluaron 14 indicadores que cubrieron tres criterios ambientales del bienestar animal: 1) Ausencia prolongada de hambre; 2) Ausencia prolongada de sed y 3) Emplazamiento, construcción y equipamiento. Esto permitió clasificar el bienestar animal de cada UP en cuatro categorías: Excelente, Buena, Aceptable y No aceptable. Para estimar el bienestar del ganado bovino, se siguieron tres pasos: 1) Evaluación de los criterios relacionados con el acondicionamiento ambiental; 2) Estandarización de los valores; y 3) Integración de valores por criterio. **Resultados.** El bienestar del ganado bovino de las UP evaluadas fueron Excelente (17%); Bueno (43%); Aceptable (34%) y No aceptable (6%). **Conclusiones.** El bienestar animal en las UP de Loma Bonita, Oaxaca va de bueno a aceptable. De los 14 indicadores de bienestar analizados, 11 de ellos presentan valores superiores al 20%, por lo que se consideran como críticos. Destaca el 95% de las UP que presentan problemas en cuanto al tiempo de espera del ganado antes de ser ordeñado y el 60% que no cuenta con el ancho apropiado del pasillo de salida de la sala de ordeño.

Palabras clave: Condición corporal; ganado de doble propósito; indicadores; instalaciones de la finca; ordeño; región tropical (*Fuente: CAB*).

INTRODUCTION

Concern for the welfare of cattle has recently begun to deepen. However, scientific research on this topic in countries such as Mexico is still scarce. The welfare of cattle relies on providing humane treatment and optimal conditions for the management of the animals, thus preventing situations that affect their behavior or health or cause pain or suffering. However, the pressure exerted by population growth has caused farmers to focus on meeting the demand for meat and dairy products, prioritizing productivity at the expense of the needs of the animals (1).

Bovine welfare goes beyond the ethics or compassion that can be had for the suffering of animals by establishing a scientific basis of the negative impact that is generated when welfare is not addressed; therefore, welfare should be considered an essential aspect of breeding and all other activities involved in bovine management (2). Research on the subject of bovine welfare plays a key role in achieving better conditions for livestock.

In Loma Bonita, Oaxaca, Mexico, dual-purpose cattle farming is the main livestock production system. Ranchers are concerned about their production methods, seeking to make the activity profitable. However, the systems do not always have favorable environmental conditions for the animals. This is often due to the lack of knowledge among the operators about the negative consequences that a lack of well-being can have on the economic benefits of cattle farming (3). The absence of welfare in each stage of the animal exploitation process negatively impacts the safety and quality of the products, increase costs and reduces productivity (4,5,6).

Although various proposals for indicators to measure animal welfare can be found in previous literature reviews (2,6,7), few studies have measured the welfare of cattle in Mexico, and this topic is considered an emerging theme in this country. The application of the Welfare Quality® protocol in dairy cattle ranches in the state of Hidalgo (1) and the evaluation of animal welfare during slaughter in TIF establishments in the northwest region (8) are examples of the application of such indicators.

Finally, the lack of research highlights that in Mexico, there is currently no federal law governing animal welfare from breeding to slaughter; hence, it is important to generate evaluations that make opportunities for improvement and the development of public policies that prevent or minimize problematic situations that put the feeding, health, housing or behavior of cattle at risk visible to livestock farmers. In addition, research on this topic will contribute to reducing costs for producers and creating safer and better quality products for consumers.

Thus, the objective of the present study was to estimate bovine welfare through environmental conditioning criteria in dairy production units in Loma Bonita, Oaxaca, Mexico, to allow producers to achieve greater competitiveness and adapt their current practices. Trends in the global consumer market of agricultural products, for which safety and quality requirements are established and the conditions in which animals are raised and slaughtered are monitored, are considered (3).

MATERIALS AND METHODS

Location and sample size. This research was performed in the tropical municipality of Loma Bonita, Oaxaca, Mexico, where the dual-purpose bovine system is predominant. Livestock production units (PUs) were chosen, with a focus on milk production. Information was obtained from 23 PUs. The sample size represents 57% of the set of cattle farms that supply the Mexican Food Security Agency (SEGALMEX) collection center. Nonprobabilistic sampling was performed for convenience. A veterinarian associated with the Local Livestock Association and assigned to the area was involved in the study and served as a liaison with the dairy farmers.

Another important criterion in the choice of PUs was permission from the owners to conduct interviews; this was a necessary aspect of the study since the stay at each ranch was long. Photos and videos were taken for records and reference. The evaluation and diagnosis of the PUs was carried out from October 2019 to April 2020.

Estimation of animal welfare. A large number of elements can be considered in animal welfare estimates; therefore, it was necessary to select the ways in which these elements were measured. This process is often complicated and can involve making value judgments to achieve the most explicit measurements possible. To estimate animal welfare in the present study, a bottom-up approach was followed; this approach consists of integrating the specific indicators used into the diagnostic criteria to form a general evaluation of welfare (9,10). The assessment was limited to evaluating some environmental criteria that can affect the welfare of cattle within PUs.

Four steps were taken to determine the welfare of the cattle. Step 1: The indicators were measured. Step 2: The values were standardized. Step 3: The values were integrated to form criteria. Step 4: Animal welfare was classified (10). For each step, specific data collection and analysis methods were used (11).

Step 1. Measurement of the evaluated indicators. Fourteen indicators of well-being were evaluated with various measurement methods and scales. The indicators covered three environmental factors: a) adequate nutrition (two criteria); b) adequate hydration (two criteria); and c) location, construction and equipment (ten criteria: five associated with the characteristics of the holding pens and hygiene of the cows and five associated with the characteristics of the milking parlor and handling of the cows).

a) Measurement of the indicators of adequate nutrition

1. Body condition. This indicator was measured by visual appreciation of the body reserves of the cow; manual palpation was not used to prevent inducing stress. Four regions were evaluated: 1) tail, 2) loin, 3) vertebra and 4) C/C/C (bone condition, each with three levels) (12). The scale used to measure the C/C/C indicator ranged from 1 to 3, with 1 corresponding to the worst condition and 3 corresponding to the best condition that could be found in a PU (Table 1) (13).

Based on the body condition data, an indicator was calculated from the number of cows that obtained each score on the scale. An indicator was obtained for each of the 23 PUs and for each condition (CP1, skinny; CP2, normal; and CP3, fat) (1,14), using the following formulas, whose variables are defined in table 1.

$$CP1 = \left(\sum CP_i + \sum VD_i + \sum EAD_i + \sum HV_i\right)/4$$
$$CP2 = \left(\sum SC_i + \sum PTA_i + \sum EPD_i + \sum HPV_i\right)/4$$
$$CP3 = \left(\sum CTG_i + \sum TAE_i + \sum END_i + \sum HI_i\right)/4$$

Table 1. Regions and conditions of cattle assessed to measure body condition.

Region	Condition		
	CP1 (Thin)	**CP2 (Normal)**	**CP3 (Fat)**
1. Tail	Deep cavity (DC)	Without Cavity (WC)	Cavity with fatty tissue (CFT)
2. Loin	Visible depression (VD)	Presence of adipose tissue (PAT)	Exaggerated adipose tissue (EAT)
3. Vertebra	Distinguishable Apophysis extremes (DE)	Poorly distinguishable extremities (PDE)	Indistinguishable extremities (NDE)
4. C/C/C (bone condition)	Visible bones (VB)	Low bone visibility (LBV)	Nonvisible bones (NB)

Source: Elaboration of work by previous authors (8).

2. Food sufficiency. In the study region, all the systems use rotational or continuous grazing; thus, this indicator was determined using a decision tree, considering whether the type of grazing was rotational or continuous, whether a supplement or food supplement was provided and whether mineral salt was provided to the animals (15).

b) Measurement of the indicators of adequate hydration

1. Sufficient supply of water. This indicator was measured based on the dimensions of the waterers located in each PU. Two factors were assessed: the number of cows and the amount of water they consume on average per day. These factors determine the size of the drinkers, so that each cow can have access at least ten centimeters of water trough. Three levels were assigned to the findings: 1) adequate space: ≥ 10 cm/cow; 2) moderate space: <10 but ≥ 8 cm/cow; and 3) limited space: <8 cm/cow (16).

2. Water quality. This indicator was determined by measuring the pH and the presence of silt in the water. For both factors, the measurement scale included three levels. For pH, the measurement scale was as follows: 1) adequate: values ranging from 6.5 to 8.5; 2) moderately problematic, 5.5 to 6.4 or from 8.6 to 9.0; and 3) very problematic, <5.5 or >9.0. The presence of silt was evaluated by visual inspection. The levels of the measurement scale were as follows: 1) adequate, ponds without silt (SL); 2) moderate, ponds with a light silt layer (CL); and 3) severe, ponds with a thick silt layer (GC) (17,18).

c) Measurement of location, construction and equipment criteria.

Holding pens should be used prior to milking parlors; their grouping areas are designed and organized to prevent stress due to overcrowding, possible injuries and lameness. These areas should be kept clean and disinfected to prevent the spread of bacteria, viruses and fungi and thus diseases (Table 2).

Specifically, the degree of cleanliness of the cows was evaluated by inspection of the integrity of the extremities, ventral and dorsal regions, hindquarters and udders of the cows. The following value judgments were used to assess cleanliness: a) a clean cow in its totality or with minimal spattering and b) a cow with sludge or manure stains greater than the palm of the hand in any of the areas mentioned (1). The quantitative evaluation was performed by determining the percentages of the cows that were clean and dirty (dirty cows/clean cows * 100), and the results were classified as a moderate to severe problem (Table 2).

Table 2. Indicators of the characteristics of the holding pens and milking parlors.

Characteristics	Indicator	Adequate	Moderately problematic	Very problematic
Holding pen and cow hygiene	1. Width of the entrance door adjusted according to the number of cows	3 m for <100 cows or 5 m for >100 cos	2-3 m for < 100 cows or 4-5 m for > 100 cows	2 m for <100 cows or 4 m for > 100 cows
	2. Area per cow	> 1.4 m/cow	1-1.4 m/cow	< 1 m/cow
	3. Drainage	Applicable	---	Not applicable
	4. Striped	Horizontal	Vertical	No stripes
	5. Cleanliness of the cow	Clean	Dirty	Very dirty
Milking parlor and cow handling	1. Waiting time*	45 min/lot	45-60 min/lot	>60 min/lot
	2. Exit corridor width**	80-90 cm	70-80 cm	< 70 cm
	3. Cleaning the nipple***	Complete protocol	Incomplete protocol	No cleaning
	4. Premilking stimulation****	Complete protocol	Incomplete protocol	No stimulation
	5. Cleaning the parlor*****	Complete protocol	Incomplete protocol	No cleaning

Source: Prepared by different authors (16,19,20,21,22).
*The waiting time should not be longer than 45 minutes per batch to prevent the premature release of oxytocin and early milk letdown. Long wait times can also cause foot problems and stress + (21). ** The recommended width is 80 to 90 centimeters if the exit corridor is straight and 130 to 160 centimeters if it requires turns. Cows tend to be scared when they do not know what awaits them at the end of a passageway, so an adequate opening can reduce stress and allow more fluid circulation (14). *** A protocol for cleaning and disinfecting the nipple should always be followed to prevent the entry of pathogens into the milk. The following protocol is recommended: apply a teat cleaner, wait 30 seconds, clean and dry the udder with a paper or cloth towel (do not reuse the towels) (20). **** The udder should be stimulated for between 10 and 20 seconds. The following protocol should be followed: using clean disposable gloves, pour two or three jets from each teat into a jug (do not pour the milk on the floor), and examine the milk to detect clots, discoloration or other inconsistencies. Discard the test milk (22). ***** Proper hygiene should be maintained in the milking parlor due to the risk of pathogens entering the milk. The parlor should be cleaned at each milking (16).

With respect to the characteristics of the milking parlor and management of the cows, the milking parlor is composed of a set of zones and their corresponding equipment grouped in specific areas. The design of the milking facilities influences the efficiency of activity and the productivity of the milkers (23). The factors that can affect cows and be evaluated when designing, constructing and managing milking parlors are innumerable, and their repercussions on animal welfare can range from changes in behavior (e.g., fear or nervous behavior) to health problems due to diseases such as mastitis. The indicators evaluated in this study for this set of factors are shown in Table 2.

Step 2. Standardization of values. Because the measures of the indicators of the environmental criteria for cattle are very diverse, they were standardized with a series of mathematical approaches, which are useful for unifying criteria, and thus were suitable for a single evaluation by livestock production unit (LPU) (6). The quantitative approaches used were the weighted mean (using the formula presented below) (24) and L spline (cubic segmental interpolation). Spline functions are cubic equations that model the behavior of curves made by data, allowing one to smoothly and continuously join a series of points using cubic polynomials between each pair of data (25). The sum is represented by the abstract form of the formula.

$$Weighted\ mean = \sum_{i=1}^{N} x_i P_{x_i} = x_1 P_{x_1} + x_2 P_{x_2} + x_3 P_{x3} + \cdots + x_n P_{x_n}$$

Each L spline acquires the following shape (26):

$P(y)=ay^3+by^2+cy+d$

When dealing with this type of polynomial, four variables are considered for each interval (a, b, c, and d), and a new condition is set for each point common to two intervals, with respect to the second derivative: ab) the parts of the function apply to pieces P and pass through that point. That is, the two $P_n(y)$ that surround the f(y) to be approximated are equal to f(y) at each of these points; c) the derivative at a point is always consistent for both sides of the defined function; and d) the second derivative at a point is always consistent for both sides of the piecewise-defined function that passes through that common point.

For body condition, the percentage of cows classified as very skinny (CP1) was obtained, and the L-spline function was applied. The l value was determined from:

$l=100-\%\ CP_1$

Once the value of l was obtained, the general formula was applied, which for the case of the entire system is:

$x=0 + 0.2216596254*53 + -0.0027707453 *53^2 + 0.0000592709 * 53^3$
$x = 56.9$

Step 3. Integration of values by criterion. To integrate the values by criterion, the Choquet integral, also known as monotonic expectancy, was used. By adding different criteria weighted according to their importance, the criteria become a powerful multicriteria decision tool (27). The Choquet integral is an aggregate function defined with respect to a fuzzy measure. A fuzzy measure is an established function that acts in the domain of all possible combinations of a set of criteria. The complexity is therefore the exponential value of 2^n subsets, where n is the number of criteria. Formally, we have N={1,2…n} as a general dysfunctional measure that is a function of $v:2^N \rightarrow [0,1]$, which is a monotonic function ($v(A) \leq v(B)$ when $A \subset B$) and satisfies $v(\oslash)=0$ y $v(N)=1$. Given that subset $A \subseteq N$ can be considered a group of criteria, v (A) can represent the importance or weight of this group because the smallest fuzzy measure is given by $m*(E) = \{1$ if A = B; 0 otherwise$\}$, and the largest fuzzy measure is given by $m*(E) = \{0$ if $A = \oslash$; 1 otherwise$\}$. Therefore, the Choquet integral allows assigning importance to all possible groups of criteria, giving greater flexibility to their aggregation.

Given a group of criteria ($r_1, r_2, \ldots, r_n$) and a fuzzy variable (v), the Choquet integral will be given by:

$$C_v(r) = \sum_{i=1}^{n} [r_i - r_{i-1}]\, v(H_i)$$

where $x_0 = 0$ and $H_i = \{i, \ldots, n\}$ are the subsets of indices of the components n - i + 1 greater than x.

To calculate the integral, the following conditions are presented, where C represents the criterion,

P is the principle and μ is the derived integral coefficient that minimizes the mean square error of the given score (28):

$If\ C_1 \leq C_2\ then\ P_1 = C_1 + (C_2 - C_1)\ \mu_2$
$If\ C_2 \leq C_1\ then\ P_1 = C_2 + (C_1 - C_2)\ \mu_1$

Step 4. Classification of welfare by production unit. The scores obtained for the three environmental criteria of well-being by PU were used to classify well-being into four categories or levels: excellent, good, acceptable and not acceptable (6).

RESULTS

a) Evaluation of the indicators of the criteria of well-being. Of the 14 environmental indicators of animal welfare analyzed, the results highlight that in four of the five indicators associated with the milking parlor and management of the cows, a large percentage of the PUs present serious problems in terms of the duration of cow presence in the milking parlor (95% of the PUs); 60% of the Pus did not meet the minimum requirements for exit corridor width; 48% of the PUs showed problems due to a lack of cleanliness in the milking parlor; and the teats of the cows were not sufficiently cleaned in 39% of the PUs (Table 3).

Table 3. Summary of the parameters obtained from the indicator and welfare criteria.

Criterion	Indicator	Adequate	Moderately problematic	Very problematic
Prolonged absence of food	1. Body condition	Fat cows: 3%	Normal cows: 54%*	Lean cows: 43%
	2. Food sufficiency	90% rotational grazing	10% continuous grazing	
Prolonged absence of water	3. Sufficient water supply	42.1%	26.3%	31.6%
	4. Water quality			
	Ph	91.3%	0.0%	8.7%
	Presence of silt	43.5%	34.8%	21.7%
Location, construction and equipment (holding pen)	5. Door width	91%	0.0%	35%
	6. Area per cow	39%	26%	35%
	7. Cleanliness of the cows	60%	29%	11%
	8. Drainage	52%	-	48%
	9. Striped	49%	5%	56%
Location, construction and equipment (milking parlor)	10. Waiting time	5%	0.0%	95%
	11. Exit corridor width	40%	0.0%	60%
	12. Cleanliness of the nipple	18%	43%	39%
	13. Premilking stimulation	22%	78%	0.0%
	14. Cleanliness of the room	31%	21%	48%

*This result does not represent a moderate problem since the cows were classified as normal.
Source: The findings of this study.

The results also show critical parameters in four of the five indicators related to the characteristics of the waiting room and hygiene of the cows, highlighting the absence of scratching on the floors in 56% of the PUs, the lack of drainage in 48% of the PUs, and door widths and surfaces that do not meet the required space per cow in 35% of the PUs (Table 3). Serious problems in the holding pens and milking parlors are part of the criteria for location, construction and equipment.

Other indicators for which the PUs showed severe problems were body condition since, on average, 43% of the cows at the studied ranches were classified as lean (CP1) and sufficient water supply, for which 31.6% of the PUs showed problems. The finding related to body condition corresponds to the criterion of adequate nutrition, while that related to water supply corresponds to the criterion of adequate hydration.

b) Standardization and integration of values. Table 4 shows the food sufficiency per production unit and the values per production unit for both body condition and food sufficiency.

When applied to the entire system, the following is obtained (Figure 1):

P1=56.9+(80-56.9)*0.27
P1 = 63.4

Table 4. L-spline function for body condition and food sufficiency.

LPU	CC	SA	LPU	CC	SA	LPU	CC	SA
1	28.6	84	**9**	75	60	**17**	25	84
2	70.6	100	**10**	66.7	68	**18**	62.5	84
3	61.5	84	**11**	55	84	**19**	82.5	84
4	40	100	**12**	78.3	84	**20**	66.7	84
5	68.7	84	**13**	37.5	68	**21**	54.2	68
6	33.9	100	**14**	35.7	84	**22**	59.1	68
7	63.2	52	**15**	61.1	84	**23**	68.7	100
8	74	84	**16**	40.6	68	**All**	56.9	80

LPU: Livestock production unit; CC: body condition; SA: food sufficiency.
Source: Own elaboration.

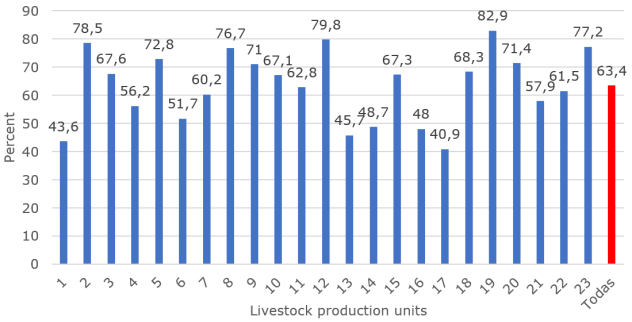

Figure 1. Choquet integral values for the adequate feeding criterion (P1).
Source: The findings of this study.

The values of sufficient water supply and water quality in the production units ranged from 0 to 100 points (Table 5).

Table 5. L-spline function for sufficient water supply and water quality (decision tree).

LPU	PSA	CA	LPU	PSA	CA	LPU	PSA	CA
1	64	12	**9**	100	100	**17**	100	100
2	76	28	**10**	100	100	**18**	76	28
3	40	28	**11**	40	100	**19**	16	12
4	16	12	**12**	64	28	**20**	64	28
5	16	100	**13**	40	0	**21**	64	12
6	16	100	**14**	16	100	**22**	64	28
7	100	100	**15**	64	100	**23**	16	12
8	76	100	**16**	16	28	**All**	**54**	**77**

LPU: Livestock production unit; PES: sufficient water supply; CA: water quality.
Source: The findings of this study.

It should be remembered that the water quality criterion was calculated from 2 indicators (a) pH and b) the presence of silt), both of which were weighted with equal importance. For these indicators, the weighting was determined according to the type of problem, assigning a weight of 4 for moderate problems and 9 for severe problems. The theoretical maximum that can be reached with this scoring system is 9x2=18.

To obtain a value between 0 and 100, where zero represented the worst situation and 100 represented the best situation, the L-spline function was used. In this case, the value of L was determined by:

$$l = 100 - \frac{4 * No.of\ moderate\ problems + 9 * No\ of\ serious\ problems}{18} * 100$$

The value for water quality per unit is presented in Table 5; for the entire system, it was represented by:

$$l = 100 - \frac{4 * No.of\ PUs\ with\ moderate\ problems + 9 * No.of\ PUs\ with\ serious\ problems}{414} * 100$$

$$l = 100 - \frac{4*8+9*7}{414} * 100 l = 77$$

Applying the general formula, the following was obtained:

x=0 + 0.2216596254 * 77 - 0.0027707453 * 77^2 + 0.0000592709 * 77^3
X = 28

When the Choquet integral was applied to integrate the two values of the adequate hydration criterion (P2), the following was obtained:

If C1 <C2 then P2=C1+(C2-C1) μ2
If C1> C2 then, P2 = C2+ (C1-C2) μ1
If C1 = 50 and C2 = 50 P2 = 50
*P2=54+(77-54)*0.27*
P2 = 60.2

When applied to the entire system, the following results were obtained (Figure 2).

The percentages with which the physical characteristics of the waiting area were evaluated were designated from the decision tree. The global value slightly exceeded 50%; therefore, we can confirm that this criterion is not being met for the majority of the farms studied (Figure 3).

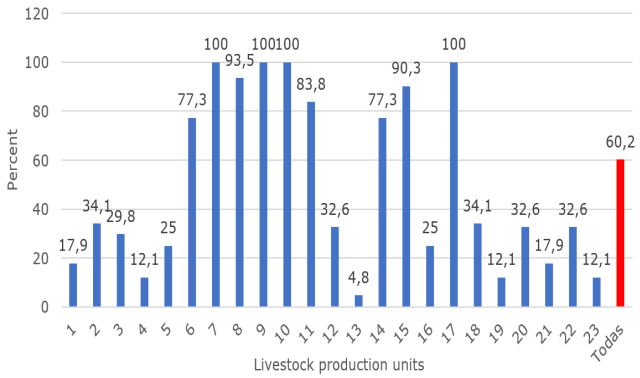

Figure 2. Choquet integral values for the adequate hydration criterion (P2).
Source: The findings of this study.

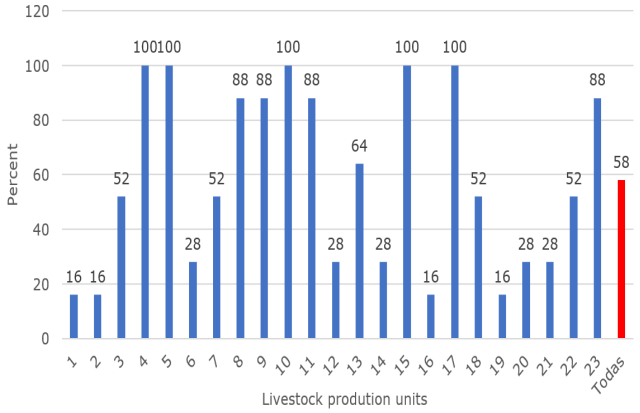

Figure 3. Results of the L-spline function for holding pen and cow hygiene.
Source: The results of this study.

Based on the mathematical assessments of the rest of the criteria, the severity of the problems arising from the lack of comfort during the premilking and milking stages of cattle production was determined. Given its importance, problems associated with milking were given a weight of 3; those associated with the holding pen, 2; and those associated with cleaning, 1. Each type of problem was given a weight of 4 for moderate problems and 9 for serious problems. Thus, the theoretical maximum for this type of problem was 9 * 21 = 181.

For the L-spline function, the index L is given by:

$$l = 100 - \frac{4 * No.of\ PUs\ with\ moderate\ problems + 9 * No\ of\ PUs\ with\ serious\ problems}{181} * 100$$

Once the L index was determined for each production unit, the general formula for the function was applied, and the results shown in Figure 4 were obtained:

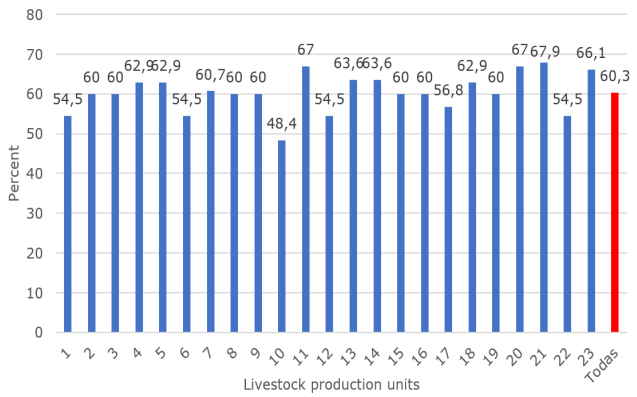

Figure 4. Scores for location, construction and equipment (L-spline function).
Source: Own elaboration.

To integrate the values of the ten indicators of the location, construction and equipment criteria (P3), the Choquet integral was used (Figure 5):

If C1 <= C2, then P3 = C1+ (C2-C1) μ4
If C1> C2, then P3 = C2+ (C1-C2) μ3
If C1 = C2, then P3 = C1
P3=58+(60.3-58)*0.11
P3 = 58.3

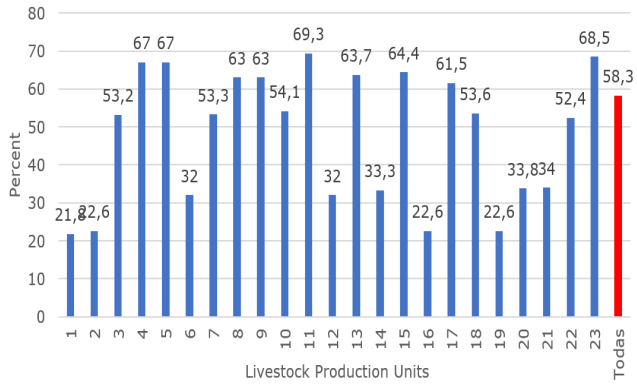

Figure 5. Choquet integral values for the location, construction and equipment criteria (P3).
Source: The results of this study.

c) Estimation of welfare levels. To determine the levels of well-being, the following scale was used: Excellent (17%), no value was below 55, and at least one was greater than 80; good (43%), no value was below 30, and at least one exceeded 55; acceptable (34%), no value was below 10, and at least one exceeded 30; and not acceptable (6%), any other case (1,6,10).

DISCUSSION

The units analyzed are dedicated to milk production, and the characteristic cattle in these units are crosses of *Bos taurus* and *Bos indicus* (brown Swiss x Zebu) since these cattle have shown good results in terms of production and adaptation (29).

The classification of the entire system is between good and acceptable, which indicates that despite the efforts of the producers, animal welfare should be improved in the study area; however, for the production units in the state of Hidalgo, Mexico, all the producers fall into the category of poor animal welfare (1). In Loma Bonita, the results are comparatively better, although it should be noted that the units were analyzed only according to the welfare protocol criteria and 5 freedoms in addition to various indicators well-being; furthermore, a different race (Holstein) from the predominant crosses observed in tropical regions was analyzed, so the results are not completely comparable.

The results also contrast with the findings reported in a study of 25 dairy LPUs under grazing conditions in the Colombian tropics, where the general welfare received a rating of 82 points on a scale of 0 to 100. In the study, an A excellent level of welfare was assigned to two farms (8%), 20 (80%) of the farms received a rating of good and three farms (12%) were rated as acceptable (18). The results of the present study also differ from an evaluation of 60 dairy cattle farms carried out in Costa Rica; in this case, the Welfare Quality® protocol was used, and the results demonstrated that no farm was classified as having excellent animal welfare, 55% of the farms had good animal welfare, 36.7% had acceptable animal welfare and 8.3% had animal welfare that was rated as not acceptable (30).

The two aforementioned studies were carried out in a tropical climate; therefore, it is possible that the differences in the levels of well-being observed with respect to the present study are due to the types of indicators used in the evaluations, the types of cattle management applied or the probable socioeconomic differences among the producers, as well as the technological levels of the LPUs.

Regarding the "prolonged absence of hunger" criterion, in this study, 43% of the lean cows and 3% of the fat cows had values greater than 19.3% and 0.6%, respectively. Similar findings were reported in a similar study (1), although that study was conducted on a family farm with different environmental and management conditions. Another study of dairy cattle welfare in Ecuador, focused mostly on the Brown Swiss breed, found 6.5% lean cows and 9.7% fat cows (31), which also contrasts with the results of the present study. In the latter case, rotational grazing was predominant, as in 90% of the LPUs in Loma Bonita, Oaxaca; however, the difference (i.e., the finding that 83.8% of cows had normal or appropriate body condition) may be because in the study in Ecuador, forage silage is carried out in times of abundance, which allows for food availability during drought. This approach represents a viable strategy for producers who face problems of food availability in dry periods, and technical advice is essential for the transfer of this knowledge.

Some authors (14) consider having lean or obese cows problematic because these cows have a higher risk of presenting complications at the time of calving; fat cows tend to have weaker contractions than cows with a good body condition, while lean cows are unable to meet the energy demand necessary for calving.

In the case of the criterion "prolonged absence of thirst", 31.6% of the LPUs did not have adequate space in their drinkers to guarantee optimal hydration of cattle; this value was higher than the 22% of LPUs reported in the evaluation of the welfare of dairy cattle in Colombia (18). It is worth mentioning that this indicator has been determined to be an appropriate way to evaluate the prolonged absence of thirst since it demonstrates whether an adequate number of drinkers of suitable size are present; however, an adequate amount of water can be provided despite this indicator (32). Therefore, producers should ensure the maintenance of sufficient availability or flow of water in quality and quantity, thus enabling adequate consumption (2). It has been stated that the troughs should have a flow greater than the amount ingested by the cattle, thus avoiding shortages (31).

With respect to water quality, 91.3% of the bovine PUs of Loma Bonita had an adequate pH of between 6.5 and 8.5, similar to that reported for a dairy cattle system on a university farm in Ecuador, where the quality and quantity of water administered, number of troughs and time spent drinking by animals were evaluated (33). A total of 21.7% of the PUs were observed to have a

serious problem related to the presence of silt, and this value was similar to drinkers on dairy farms in Colombia, where 28% were classified as dirty (18). Dirty drinking troughs were also reported in Ecuador, where they were washed once a month although the ideal is to wash the troughs daily to guarantee a supply of clean, fresh water for the animals (31). The results obtained in a similar study in Costa Rica indicate problems in more than half of the farms analyzed in terms of an insufficient number of waterers and inadequate hygiene (30).

With respect to the location, construction and equipment criterion for the holding pens, more than a third (35%) of the PUs in Loma Bonita have serious problems in terms of the minimum width of the access door and the surface area per cow. Some authors (2) mention that it is necessary to pay attention to the design and capacity of the facilities to ensure that they provide conditions under which the cattle can manifest a natural behavior, avoid accidents and express their potential productivity. Other arguments highlight the importance of providing living space to cattle in confined situations, defined by the square meters available per animal, to reduce competitiveness, tension, and aggression between individuals (34).

The finding that there were serious problems with surface area per cow in 35% of the PUs differ from the results reported by a previous study (31) in which the size of the holding pen guaranteed the physical comfort of the animals by providing enough space for the cattle to sleep, wander, eat and drink water. This situation, in addition to having a nonslip floor, resulted in 100% clean cows, unlike the PUs in Loma Bonita, Oaxaca, where 11% of the cows were classified as clean, with the indicator suggesting serious problems.

In addition to the design and capacity of the facilities, another important factor that determines animal welfare is the hygiene of the facilities; 48% of the PUs had serious problems because they lacked floor drainage and 56% lacked scratched or rough floors. The slope and roughness of the floors are fundamental to preventing slipping, injuries, falls and even fractures of the extremities of cattle as well as preventing flooding or the accumulation of manure, urine, and water, which favors the formation of sludge and thus the development of bad odors and potential for diseases due to the development of bacteria (2).

For the criterion location, construction and equipment, for the milking parlor, the most critical indicators in order of importance were the waiting time of the animals, width of the exit corridor of the waiting room, cleanliness of the parlor and cleanliness of the nipple with values of 95%, 60%, 48% and 39% for the PUs, respectively. The percentage of cleanliness observed for the milking parlor was well above the 12% observed for 25 dairy farms with poor hygiene in Colombia (18). The combination of poor management, poorly designed or poorly maintained facilities, and lack of hygiene directly affects animal welfare by not preventing collisions, falls, bruises and even deaths (2).

Conclusions and future implications. Animal welfare in the PUs of Loma Bonita, Oaxaca, ranges from good to acceptable. This study allowed us to determine the statuses of the LPUs in the municipality of Loma Bonita, Oaxaca; of the 14 welfare indicators analyzed, 11 had percentages higher than 20%, which is considered critical. The 95% of PUs that have problems associated with the waiting time of the cattle before being milked and the 60% that do not have exit corridors leading out of the milking parlor of an appropriate width are highlighted. In contrast, only three indicators had percentages below 20%; thus, the levels of most of the indicators for the PUs, such as feed sufficiency, cow cleaning and premilking stimulation, are considered appropriate.

Even when various environmental criteria are used to evaluate the welfare of dairy cattle, the result tends to be more accurate when a mathematical approach is used.

The lowest value was observed for the location, construction and equipment criterion. This is somewhat logical, as it is the criterion that causes the least concern for farmers because in this case, it refers only to the conditions of the waiting room and milking parlor. However, it is noteworthy that the criterion of adequate hydration of the herd during the day presents the greatest variation and largest extremes, resulting in a production unit having an inadequate level of access to hydration.

In relation to the holding pen, few units met the requirements of minimum size, cleanliness and particularly adequate waiting time. Although the majority of the producers interviewed agree on the importance of maintaining sanitary conditions for the animals and even claim to clean the

drinking troughs and facilities frequently, the results show that cleaning is neglected and represents a latent problem. Even though the training of personnel who work with dairy cattle is considered essential within the literature consulted, among the producers of Loma Bonita, training seems to be done rather empirically, and although no serious mistreatment was observed during milking, the protocols meant to ensure animal care are neglected.

In general, cattle welfare in the Loma Bonita production system was classified as good with respect to the environmental factors related to adequate access to feed and hydration and location, construction and equipment; however, further evaluation may be necessary. Other important criteria of well-being, such as the absence of diseases and behavior, could change the criteria evaluated and thus the classification; therefore, their inclusion in future studies is recommended.

In relation to public policy and decision-making, these results facilitate the development of guidelines and the creation of policies and regulatory frameworks that can be used to create awareness and regulations to protect animals during production from a holistic perspective. These guidelines are consistent with the Universal Declaration for Animal Welfare and the Terrestrial Animal Health Codes, among others. In the private sector, education is envisaged as two alternatives: the first part is a transverse process aimed at the basic and middle levels to instill a sense of respect for animals and the need to protect them, as living and sensitive beings that are part of nature; the second part consists of specific education focused on responsible animal ownership. These educational initiatives are based on the fact that in the private sector, ignorance is more common than bad intentions.

Conflict of interest

There are no conflicts of interest.

Acknowledgments

We thank PRODEP for the financing of the project entitled "Characterization of the bovine zootechnical management of the Papaloapan in terms of animal welfare". We also thank Francisco Javier Sagastume García for his unconditional support during fieldwork and the cattle producers of Loma Bonita, Oaxaca, who kindly agreed to share information about their farms.

REFERENCES

1. Silva SMG, Torres CMG, Brunett PL, Peralta JJG, Jiménez-Badillo MR. Evaluación del bienestar de vacas lecheras en sistema de producción a pequeña escala aplicando el protocolo propuesto por Welfare Quality®. Rev Mex Cienc Pecu. 2017; 8(1):53-60. http://dx.doi.org/10.22319/rmcp.v8i1.4306

2.|Rosas-Valencia U, Ortega-Cerilla ME, Pérez RP, Ayala RJM, Aranda OG, Sánchez Torres-Esqueda MT. Producción de ganado bovino de carne con bienestar animal. Agro Productividad. 2019; 12(10):41-46. https://doi.org/10.32854/agrop.vi0.1453

3. Mancipe-Arias MA, Ariza-Suárez ÁC. Evaluación animal mediante indicadores conductuales en una planta de beneficio bovino en Boyocá, Colombia. Rev Inv Vet Perú. 2020; 31(2):1-11. http://dx.doi.org/10.15381/rivep.v31i2.16213

4. Villamañe R, Trevisi D, Yuño M. Criterios de evaluación para el bienestar animal en planta de faena de aves. Rev Vet. 2020; 32(1):58-63. https://revistas.unne.edu.ar/index.php/vet/article/view/5636

5. Alejos JI, Almaraz BI, Peralta JG, Meza NM, Torres MG. Indicadores de alojamiento relacionados al bienestar animal en vacas lecheras. Rev Vet. 2021. 32(2)174-180. https://revistas.unne.edu.ar/index.php/vet/article/view/5728

6. Hoyos-Patiño JF, Hernández-Villamizar DA, Velásquez-Carrascal BL. Medición del bienestar animal en el aprisco de la granja experimental de la Universidad Francisco de Paula Santander Ocaña, usando el Protocolo Welfare Quality®. Aibi Rev Inv Adm Ing. 2021; 9(1):1-7. http://dx.doi.org/10.15649/2346030x.745

7. Muñoz D, Strappini A, Gallo C. Indicadores de bienestar animal para detectar problemas en el cajón de insensibilización de bovinos. Arch Med Vet. 2012; 44(3):297-302. http://dx.doi.org/10.4067/S0301-732X2012000300014

8. Pérez-Linares C, Figueroa-Saavedra F, Estrada-Angulo A, Sánchez-López E, Barreras-Serrano A, Bolado-Sarabia JL, et al. Indicadores de bienestar animal durante el aturdimiento de bovinos sacrificados en establecimientos Tipo Inspección Federal del noroeste de México. Arch Med Vet. 2015; 47(3):375-380. http://dx.doi.org/10.4067/S0301-732X2015000300015

9. Losada-Espinosa N, Trujillo-Ortega ME, Galingo F. The welfare of pigs in rustic and technified production systems using the Welfare Quality protocols of pigs in Mexico: Validity of indicators of animal welfare as part of the sustainability criteria of pig production systems. Vet Mex. 2017; 4(4):1-15. http://dx.doi.org/10.21753/vmoa.4.4.521

10. Hoyos-Patiño JF, Quitero-Meza M, Velásquez-Carrascal BL. Bienestar animal en el proyecto avícola de la Universidad Francisco de Paula Santander Ocaña. Mundo Fesc. 2020; 10(19):88-101. https://www.fesc.edu.co/Revistas/OJS/index.php/mundofesc/article/view/513

11. de Vries M, Bokkers EAM, van Schaik G, Botreau R, Engel R, Dijkstra T, de Boer IJM. Evaluating results of the Welfare Quality multi-criteria evaluation model for classification of dairy cattle welfare at the herd level. J Dairy Sci. 2013; 96(10): 6256-6273. http://dx.doi.org/10.3168/jds.2012-6129

12. Carizi CV, Garzón JP, Alvarado JP, Marini PR. Condición corporal y su relación con producción láctea, reproducción y perfil metabólico en vacas lecheras del trópico boliviano. Rev Inv Vet Perú. 2019; 30(1):107-118. http://dx.doi.org/10.15381/rivep.v30i1.14459

13. Giménez CV, Martínez VB, Villalba PP. Determinación de bienestar animal en equinos de tiro de la ciudad de Concepción. Compend Cienc Vet. 2020; 10(2):21-25. https://doi.org/10.18004/compend.cienc.vet.2020.10.02.21

14. Mateus JR, Paranhos da C, Tarazona MAM. Abordaje práctico sobre cómo mejorar el bienestar en los bovinos. Rev Colomb Cienc Pecu. 2011; 24(3):347-359. https://revistas.udea.edu.co/index.php/rccp/article/view/324693

15. Mejía-Díaz E, Mahecha-Ledesma L, Angulo-Arizala J. Consumo de materia seca en un sistema silvopastoril de Tithonia diversifolia en trópico alto. Agron Mesoam. 2017; 28(2):389-403. https://doi.org/10.15517/ma.v28i2.23561

16. González MJV. ¿Cuánta agua necesitan mis vacas? Frisona Española. 2014; 34(201):96-98. https://www.revistafrisona.com/Portals/0/articulos/n201/temario%20agua.pdf

17. Monge-Rojas CR, Elizondo-Salazar JA. La importancia del agua en la crianza de remplazos de lechería. Nutr Anim Trop. 2016; 10(1):1-9. http://dx.doi.org/10.15517/nat.v10i1.24396

18. Medrano-Galarza C, Zuñiga-López A, García-Castro FE. Evaluación de bienestar animal en fincas bovinas lecheras basadas en pastoreo en la Sabana de Bogotá, Colombia. Rev MVZ Córdoba. 2020; 25(2):1-14. https://doi.org/10.21897/rmvz.1708

19. Grandin T. Temple Grandin's guide to working with farm animals: Safe, humane livestock handling practices for the small farm. North Adams, MA: Storey Publishing; 2017.

20. Cedeño-Alcívar DC, Vera-Macías LA, Gavilanes-López, PI, Saltos-Solórzano JV, Cusme L, Zambrano-Ruedas JF, Demera LFM, Almedida VAM, Moreira PJC. Factores que afectan la calidad higiénico-sanitaria de leche cruda en Calceta-Bolívar-Manabí, Ecuador. Avances Inv Agrop. 2015; 19(3):37-54. http://ww.ucol.mx/revaia/anteriores.php?id=95

21. Álvarez PJ, Martínez MM, Cardona AJ. Transtornos podales en bovinos de sistemas de producción doble propósito en el Departamento de Córdoba, Colombia. Rev Colombiana Cienc Anim. 2017; 9(2):171-180. https://doi.org/10.24188/recia.v9.n2.2017.554

22. Pinilla JC, Flórez P, Sierra M, Morales E, Sierra R, Vásquez MC, et al. Prevalencia del parasitismo gastrointestinal en bovinos del departamento Cesar, Colombia. Rev Inv Vet Perú. 2018; 29(1):278-287. http://dx.doi.org/10.15381/rivep.v29i1.14202

23. O'Brien B, Jago J, Edwards JP, Lopez-Villalobos N, McCoy F. Milking parlour size, pre-milking routine and stage of lactation affect efficiency of milking in single-operator herringbone parlours. J. Dairy Res. 2012; 79(2):216–223. https://doi.org/10.1017/s0022029912000088

24. Dagnino SJ. Medidas de posición central y de dispersión. Rev Chil Anest. 2014; 43(2):112-115. https://doi.org/10.25237/revchilanestv43n02.07

25. Trincado VG, Vidal BJ. Aplicación spline cúbica en la estimación de volumen. Bosques. 1999; 20(2):3-8. https://doi.org/10.4206/bosque.1999.v20n2-01

26. Thibaud B, Davy A, Optimization of Image B-spline Interpolation for GPU Architectures. Image Processing On Line. 2019; 9:183–204. https://doi.org/10.5201/ipol.2019.257

27. Candeloro D, Mesiar R, Sambucini AR. A special class of fuzzy measures: Choquet integral and applications. Fuzzy sets and Systems 2019; 355(15):83-99. https://doi.org/10.1016/j.fss.2018.04.008

28. WQ®. Welfare Quality Consortium. Welfare quality assessment protocol for cattle. Lelystad, The Netherlands; 2009. https://edepot.wur.nl/233467

29. Martínez CCJ, Cotera RJ, Forsythe ED, Arceo MOL. Canal de comercialización de carne de ganado bovino en Loma Bonita, Oaxaca. Temas Cienc Tecnol. 2012; 15(47):51-56. https://www.utm.mx/edi_anteriores/temas47/index.html

30. DiGiacinto VA, Rojas GM, Estrada KS, Romero ZJJ. Bienestar animal en hatos lecheros especializados en Costa Rica asociados a una cooperativa de productores de leche. Rev Cienc Vet. 2014; 32(1):7-19. http://www.revistas.una.ac.cr/index.php/veterinaria/index

31. Álvarez DCA, Ruiz PAM, Vargas GON, Sánchez QÁR. Valoración del bienestar animal en una finca lechera bovina. Rev Cien Agro. 2020; 8(3):83-92. https://aes.ucf.edu.cu/index.php/aes/article/view/431

32. Zamora SR, Camacho SJ, Castañeda SMP, Elizondo SJ. Evaluación de pollos con el protocolo Welfare Quality® Project a nivel comercial en Costa Rica. UNED Res J. 2021; 13(2):1-18. https://doi.org/10.22458/urj.v13i2.3682

33. Carangui QAB, Faicán FRP. Efecto de la calidad y cantidad de agua administrada a los bovinos de leche y su relación con el bienestar animal. RECA. 2019; 3(2):176-187. http://www.revistaecuatorianadecienciaanimal.com/index.php/RECA/article/view/142

34. Romo-Valdez A, Pérez-Linares C, Ríos-Rincón F, Figueroa-Saavedra F, Barreras-Serrano A, Castro-Pérez, Isabel. Importancia del espacio vital en la respuesta productiva y bienestar del ganado bovino productor de carne en confinamiento. Abanico Vet. 2021; 11:1-15. http://dx.doi.org/10.21929/abavet2021.42