animal - open space 1 (2022) 100028

Contents lists available at ScienceDirect

animal - open space

Method paper

Monitoring dairy heifer growth through control charts

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ARTICLE INFO

Article history:
Received 17 June 2022
Revised 27 September 2022
Accepted 4 October 2022

Handling editor: Tony Waterhouse

Keywords:
Alert
Control limits
Decision-making
Statistical Process Control
Weight

ABSTRACT

The efficiency of replacement programmes in dairy farms depends largely on the heifers' growth rate. We provide a case study of control chart application to monitor the weight of dairy replacement heifers. A research dairy farm in Córdoba province, Argentina, provided the monthly samples of BW measurements of 2, 9, and 14.5-month-old heifers born between 2017 and 2019. The data were used to build control charts for the mean and for SD, with moving range control limits in order to consider varying sample sizes. In each age group, control charts for the mean showed at least one out-of-control sample, whereas control charts for SD showed one sample out of control for 9-month-old heifers. Each sample outside the control limits implies that a potentially identifiable cause has occurred. Therefore, the producer could identify the event causing the deviation and make the necessary changes according to the heifer's age. Control charts provide the producer and consultant with graphical information and quick alerts to support the decision-making process of the replacement programme. These tools are useful at the farm level to monitor heifer weights and support management decisions.

Implications

The efficiency of replacement programmes in dairy farms depends largely on the heifers' growth rate. To monitor the heifers' weight, we built control charts with different age groups. Within each group, control charts for the mean and for SD showed some samples out of control. These out-of-control points imply that a potentially identifiable cause has occurred and it is worth investigating and undertaking corrective action if necessary. We found control charts as simple tools that provide the producer and consultant with quick alerts to support the decision-making process of the replacement programme so that investigation of the process and corrective action may be undertaken before many nonconforming units are manufactured.

Specification table

Subject	*Livestock Farming Systems*
Type of data	Table.
How data were acquired	Heifers were weighed with a scale.
Data format	Excel sheet.
Parameters for data collection	Data provided by farm personnel, who weighed all the replacement animals approximately once a month.
Description of data collection	The heifers were moved to the facilities where the scale was.
Data source location	Institution: EEA INTA Manfredi City/Town/Region: Oncativo, Córdoba Country: Argentina −31.85, −63.73
Data accessibility	Repository name: Mendeley Data Data identification number: https://data.mendeley.com/datasets/594nwzz47x/3
Related research article	None

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https://doi.org/10.1016/j.anopes.2022.100028
2772-6940/

Introduction

The dairy herd replacement programme determines part of the farm's economic efficiency as it is one of the greatest costs of production and, within this programme, feeding is the main cost (Heinrichs et al., 2013). Age at first calving (and thus age at conception) is an important factor which affects the cost of the replacement heifer in dairy herds and has a direct impact on the total cost of heifer rearing, milk yield, culling rate, and reproductive performance (Hutchison et al., 2017; Turiello et al., 2020b). Although from an economic perspective, the recommended age at first calving for Holstein cows is between 22 and 24 months (Hutchison et al., 2017; Turiello et al., 2020b), a recently published study in Argentina showed that 50% of dairy cows calve for the first time at 27 months of age or older (Turiello et al., 2020b). Setting weight benchmarks and monitoring heifer growth is necessary to ensure optimum age and weight at first calving. However, arithmetic means may yield a biased measure of central tendency, and a better strategy would be using targets based on proportions of heifers within a given weight range for their age (Archer, 2021).

In any production process, such as the production of replacement females in a dairy farm, there will always exist some variation in the output. This natural variation is the result of non-assignable causes, but occasionally, some assignable causes may appear, and a process that occurs with assignable causes is called an out-of-control process (Montgomery, 2019). One of the main objectives of control charts is to detect assignable causes of variation occurrence (Montgomery, 2019). They may also be used to reduce variability, estimate process parameters, and provide useful information to improve a given process. Statistical process control (**SPC**) techniques were applied to dairy herds to identify and monitor some variables – such as the incidence of subclinical mastitis by means of bulk tank somatic cell analysis –, to detect disease in automatically fed group-housed preweaned dairy calves, to monitor fertility, and to detect lameness (Mertens et al., 2011). In addition, a case study by Stewart et al. (2011) provided an example of control chart application for feed management, allowing dairy producers to easily identify problems associated with loading individual ration ingredients. Recently, Adriaens et al. (2019) tested the implementation of a control chart system to improve the consistency of on-farm luteolysis detection with good results, and Dittrich et al. (2021) showed good sickness detection rates, monitoring behavioural variables with control charts. To our knowledge, there are no previous studies applying control charts to monitor cattle growth.

As control charts enable the identification of process shifts, they can be used to monitor a variable and to reduce variability (Mertens et al., 2011). Usually, it is necessary to consider both the mean value of the variable of interest and its variability: the control chart for the mean (**x-bar control chart**) is used to monitor the mean quality level and the control chart for the SD (**s control chart**) or for the range (**R control chart**; Montgomery, 2019) is used to monitor the process variability. When all measurements fall within the control limits, the process is said to be under control, which means the measurements are probably within the expected random variability. On the contrary, when any unexpected process variation occurs, one or more measurements fall out of the control limits, and the process is said to be out of control. Preliminary results (Turiello et al., 2020a) showed that building control charts allowed the evaluation of the growing process of replacement programme. In this sense, we hypothesised that control charts are useful to monitor real-time heifer weights considering their own variability over the rearing period. Thus, the aim of the case study was to provide an example of control chart application to monitor the dairy replacement heifer weights.

Material and methods

Data

Control charts were built from monthly BW data of 2, 9 and 14.5-month-old Holstein heifers born between the years 2017 and 2019. The data were provided by a 360-cow research dairy farm in Oncativo, Córdoba province, Argentina. Calves were kept and milk-fed individually, and water and starter were offered ad libitum until weaning, after which heifers were housed in dry lots and fed total mixed rations. Calves and young heifers were individually weighed by farm personnel every 30 days approximately, and older heifers were weighed 3–5 times a year. To weigh the heifers, a Magris (Rufino, Argentina) 1,000 kg cell scale with a resolution of 1 kg was used. The weighing scale was checked by the manufacturer's technical service once every 3 months. The heifers' identification, weight, and recording days used in this case study were provided by the farm and are shown in the *Data* Sheet in the Mendeley data repository. Sampling days with less than three heifer measurements were deleted from the database. One anomalous heifer weight in the 9-month-old rational subgroup was deleted, as it was three times the value of the sample mean.

Each rational subgroup included samples of heifers of the same age which were weighed the same day before the feed delivery. The rational subgroup of 2-month-old heifers consisted of 23 weight sampling and recording days, with an average of 10.3 heifers weighed on each sampling and recording day (ranging from 3 to 26). Twenty weight sampling and recording days (average = 13.5, range = 4–26 heifers weighed) were used to build the 9-month-old heifer charts. For the 14.5-month-old heifers' rational subgroup, 11 weight sampling and recording days with an average of 7.6 heifers weighed (range: 3–31) were used. More than half of the heifers (57%) were selected in just one rational subgroup and only 16% in all of them. The data of two rational subgroups (2 and 14.5-month-old heifers) followed a normal statistical distribution, whereas the 9-month-old heifer rational subgroup did not.

Charts

All analyses were performed with a Microsoft ® Excel ® 2016 spreadsheet considering the available data and the constant factors for constructing variable control charts from Montgomery (2019). Unlike most commercially available SPC software, the Excel spreadsheet accepts variable sample sizes, and sets variable control limits. Excel spreadsheet templates (Levinson and Tumbelty, 1997) were used for this analysis (shown in the Mendeley data repository). For each rational subgroup, x-bar and s control charts were built considering varying sample sizes.

For the x-bar control chart, the mean of the weights in each sample was graphed as x_bar. The centreline (x_bar_bar) was created averaging all the rational subgroup weights. The upper and lower control limits (**UCL_x** and **LCL_x**, respectively) were calculated as follows:

$$UCL_x = x\_bar\_bar + s\_bar \times A3$$
$$LCL_x = x\_bar\_bar - s\_bar \times A3$$

where s_bar = average (SD/c4) × c4; A3 = 3/(c4 * $\sqrt{n}$); c4 = [4(n − 1)]/(4n − 3); n = sample size.

For the s control chart, weight variation in each sample was evaluated for every rational subgroup considering the size and the SD (**s**). The centreline (**s_bar**) was created averaging s values adjusted by c4, a constant affected by the size of the sample. The upper and lower control limits (**UCL_s** and **LCL_s**, respectively) were calculated as follows:

$UCL_s = s\_bar \times B4$
$LCL_s = s\_bar \times B3$

where $B3 = [1 - (3/(c4 * \sqrt{2(n-1)})]$; $B4 = [1 + (3/(c4 * \sqrt{2(n-1)})]$. All the factors considered in the formulae (A3, B3, B4, c4, in our case) are shown in the *Factor* Sheet in the Mendeley data repository. In both control charts for each rational subgroup, process changes were considered significant if a single point fell outside the upper or lower limits (Montgomery, 2019).

Results

We monitored the heifers' weight through the use of control charts at different ages. For the 2-month-old heifers, the x-bar control chart revealed one data point in the fourth sample that exceeded the UCL_x, signalling that the process was out of control. This means that the average BW of the heifers was higher in 1 out of 23 samples (Fig. 1a), probably because of an assignable cause. The s control chart showed no data points outside the limits (Fig. 1b). Although the s_bar varied over the study period, none of them varied enough to exceed the control limits.

For 9-month-old heifers, the x-bar control chart showed three points out of control, on the dates 9-21-2017, 12-26-2018 and 5-3-2019; while the first and the last exceeded the LCL_x, the other exceeded the UCL_x, indicating that the process was out of control in 3 out of 20 samples (Fig. 2a). The s control chart showed one point out of control above the UCL_s from 20 total samples (Fig. 2b). For 14.5-month-old heifers, the x-bar control chart showed three values outside the control limits, two of them exceeding the LCL_x on the dates 1-25-2017 and 6-22-2018, and the remainder, exceeding the UCL_x on the date 1-29-2019 (Fig. 3a). As for the s control chart, no points exceeded the limits, indicating that the variation in BW of these samples was not out of control (Fig. 3b).

Author's point of view

One of the goals of the replacement programme is to achieve an adequate age at first calving along with an adequate BW (Bach

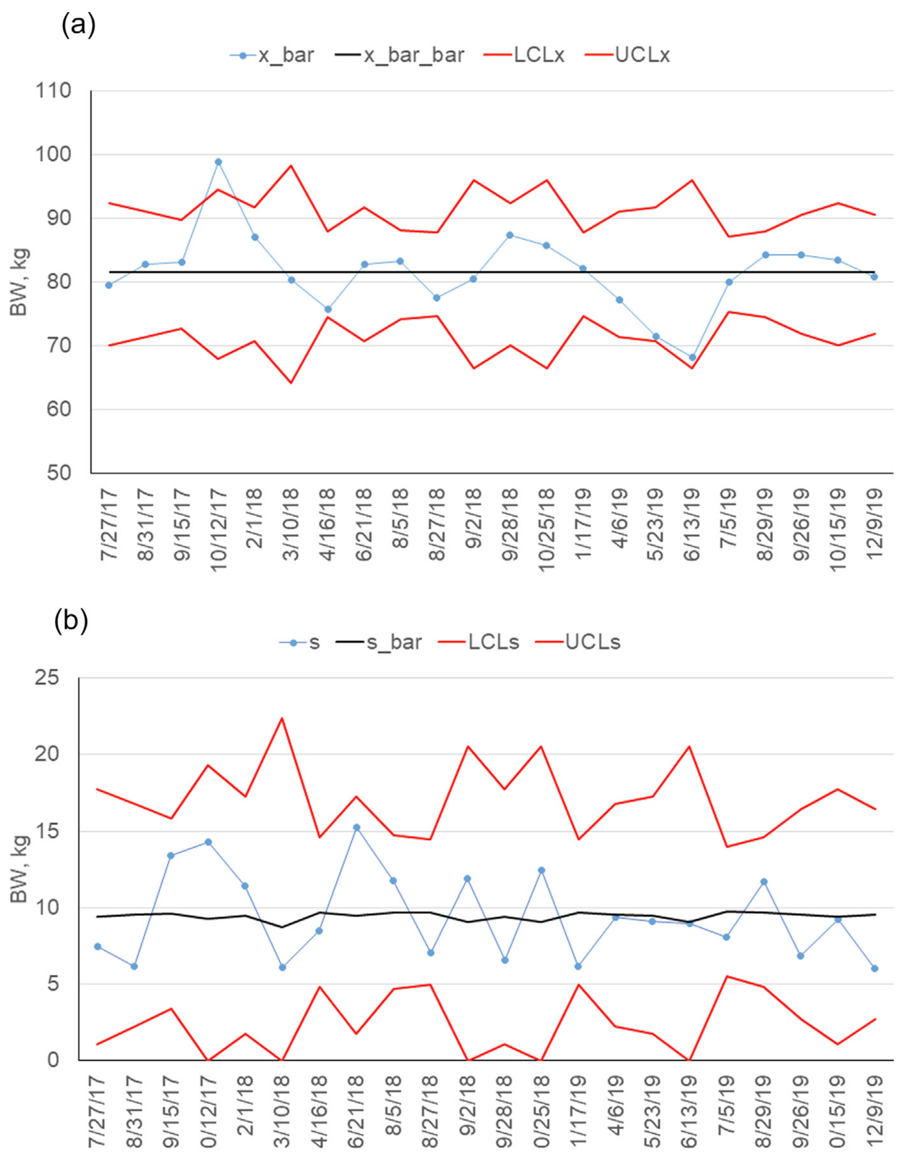

Fig. 1. Control charts for BW of 2-month-old heifers born during the years 2017–2019 in a research dairy farm in Córdoba, Argentina. (a) Control chart for the mean, where x_bar = average sample weight, x_bar_bar = average of the sample averages, UCLx/LCLx = upper/lower control limit. (b) Control chart for the SD, where s = sample SD, s_bar = average sample SDs, UCLs/LCLs = upper/lower control limit.

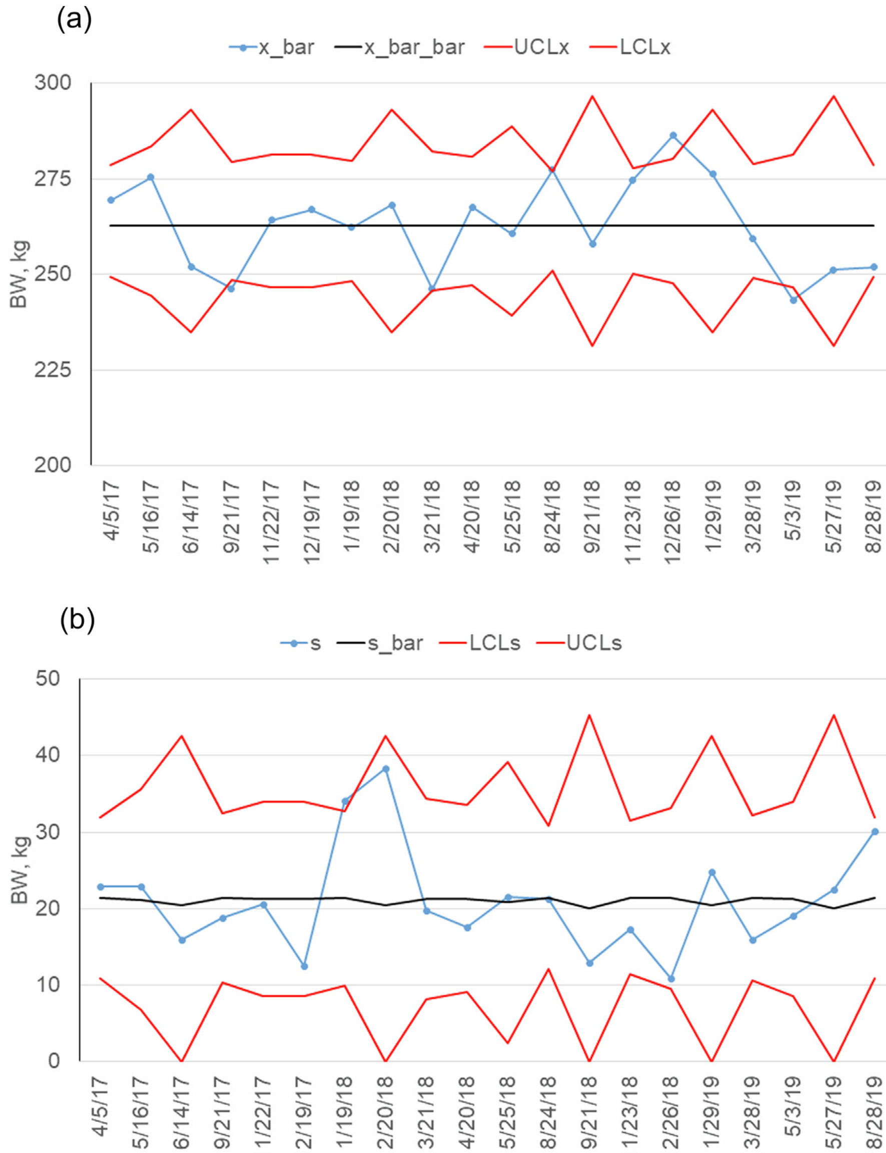

Fig. 2. Control charts for BW of 9-month-old heifers born during the years 2017–2019 in a research dairy farm in Córdoba, Argentina. (a) Control chart for the mean, where x_bar = average sample weight, x_bar_bar = average of the sample averages, UCLx/LCLx = upper/lower control limit. (b) Control chart for the SD, where s = sample SD, s_bar = average sample SDs, UCLs/LCLs = upper/lower control limit.

et al., 2021). We consider that control charts could help managers and consultants to monitor heifer weights in a simple manner and make objective decisions about the replacement programme. An advantage of using control charts is that they use farm variability to detect an out-of-control measurement and to rapidly determine when action is required. Mean and variation control charts are used to monitor central tendency indicators as well as variation parameters. Another advantage of our study is that the manager can use these monitoring tools in a flexible way, with a variable number of heifers on each sampling day, given that control limits are adjusted by the sample size. Nevertheless, three assumptions are required to use the control charts appropriately: the production process must be stationary, there should be statistical serial independence of consecutive process recording, and data must follow a normal statistical distribution (Mertens et al., 2011). In our study, all the assumptions were met in every rational subgrouping: (1) as it can be seen in the graphs, mean and SD were not affected in time, showing the stationarity of the process; (2) sampling heifers allowed us to reduce the dependence between subsequent samples (most of the heifers were weighed just once during the study); (3) normal distribution was demonstrated for 2 and 14.5-month-old rational subgroups and the central limit theorem could be a justification of approximate normality for 9-month-old heifers (Montgomery, 2019).

Control charts could be used for different ages throughout rearing to help in the management decision-making process. However, as this involves several tasks, such as weighing, measuring, registering and analysing data, a control chart application with only three rational subgroups at key age points could be representative of the whole rearing programme. At around 60 days of age, it is the first break point in diet, feeding and general management for the heifers, and monitoring their weight at this age allows the manager to evaluate the result of the preweaning period and to make some changes if needed. At 9 months of age, the heifer's weight reflects their growth performance from weaning to puberty and, in this period, there is an important economic benefit of achieving high growth rates and feed efficiency (Bach et al., 2021). At 14.5 months of age, heifers are at breeding or during early pregnancy, and the

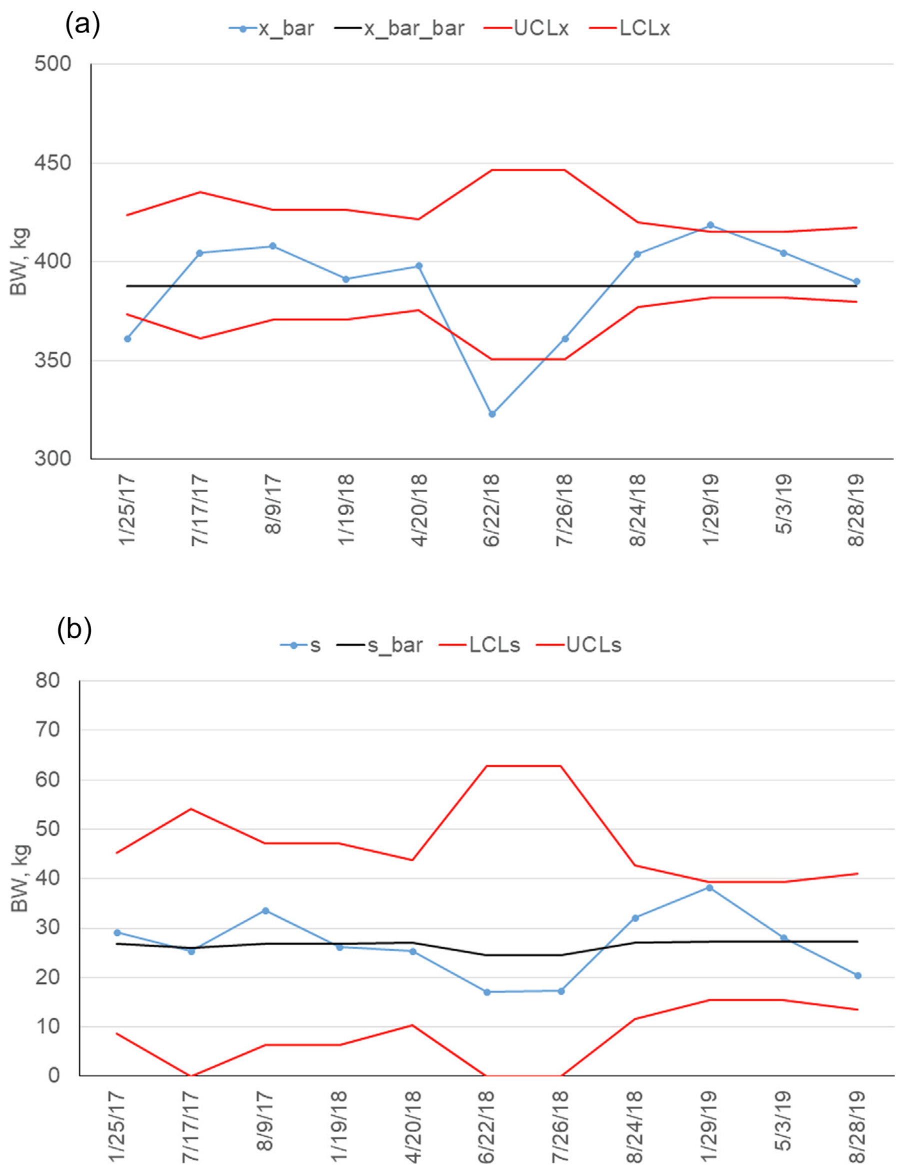

Fig. 3. Control charts for BW of 14.5-month-old heifers born during the years 2017–2019 in a research dairy farm in Córdoba, Argentina. (a) Control chart for the mean, where x_bar = average sample weight, x_bar_bar = average of the sample averages, UCLx/LCLx = upper/lower control limit. (b) Control chart for the SD, where s = sample SD, s_bar = average sample SDs, UCLs/LCLs = upper/lower control limit.

identification of out-of-control weights at this age could lead to management strategies before advanced pregnancy, when promoting growth efficiently is more difficult.

Heinrichs and Jones (2016) suggest monitoring mean and deviation weights for Holstein heifers to achieve optimum BW and age at first calving. Regarding variability, they recommend keeping the majority of heifers near the 75th percentile and the entire herd between the median and the 95th percentile considering their table values. The mean and the average difference between the median and the 95th percentile recommended by Heinrichs and Jones (2016) are in agreement with the results of the x-bar and s control charts for the three rational subgroups. However, for the 9-month-old heifers, the s control chart showed a point out of control while this value did not seem to be out of the range recommended by these authors. Therefore, the s control chart could be a very useful tool to monitor variability, demonstrating more sensitivity to detect alerts and promoting a more rapid decision-making process.

When comparing on-farm growth parameters with arbitrary standards, it must be taken into account that those standards are generally set wide considering different groups of animals around the world (Mertens et al., 2011). Heifer growth varies from farm to farm and depends on the veterinary practices considered (Archer, 2021); therefore, a universal standard may not apply to all dairy herds. In agreement with Archer (2021) and Mertens et al. (2011), we think a simple way to identify variability and appropriately interpret outcomes would be to monitor heifer weights using control charts as we did. What is more, as BW does not entirely reflect the process performance and the heifer development, age at first calving, height and body condition score could also be considered.

Control charts can also be used for monitoring planned interventions in under-control processes, when rapid and large changes in the results are expected (Montgomery, 2019). In future studies, this goal could be also pursued, for example by testing different management strategies and observing the changes caused by the intervention. To our knowledge, this is the first time control charts are applied to monitor heifer growth data, providing the producer and consultant with graphical information and quick alerts to support the decision-making process in the replacement programme. An on-farm real-time validation of control charts as supporting tools is required to determine their practical relevance (Mertens et al., 2011). For this purpose, more data at the farm level (i.e., management, environmental conditions and economic factors) should be taken into account to identify assignable causes every time an out-of-control point is found.

Ethics approval

Not applicable.

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Author contributions

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Florencia Torres: Methodology, Visualization.

Sergio Chesniuk: Methodology, Formal analysis, Software, Resources, Visualization.

Paula Turiello: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original draft preparation, Writing - Review & Editing, Visualization, Supervision.

Declaration of interest

None.

Acknowledgements

The authors thank José Simondi and EEA INTA Manfredi for providing the data.

Financial support statement

This research received no specific grant from any funding agency, commercial or not-for-profit section.

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