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On the market appeal of smart pedometer-based services within dairy cow farms

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ABSTRACT

The rapid advancement of new technologies has significantly transformed livestock production systems, with Precision Livestock Farming (PLF) playing a crucial role in improving economic, social, and environmental sustainability. Among PLF tools, pedometers stand out for their ability to monitor livestock activity, detect health issues, and optimize resource management. Despite their recognized advantages, pedometers remain underutilized, mainly due to concerns about complexity, battery life, and cost. To address these limitations, an innovative Stand-Alone Smart Pedometer was developed within a European Commission-funded project, incorporating an oestrus detection algorithm. Dairy farmers' willingness to pay (WTP) to adopt and use this innovative pedometer was elicited using experimental auctions and the Multiple Price List (MPL) approach. The findings indicate strong interest from farmers, suggesting that the innovative and cost-effective design could facilitate broader adoption, particularly among small and medium-sized farms, contributing to a more sustainable livestock sector.

1. Introduction

The development of new advanced technologies has determined rapid changes into livestock production systems. Nowadays, precision livestock farming (PLF) technologies can measure physiological, behavioral and production indicators (Adenuga et al., 2020; Larsen et al., 2024). This set of information allows farmers to optimize economic, social, and environmental farm performances (Lovarelli et al., 2020; Selvaggi et al., 2024a).

Among the various instruments associated with PLF, pedometers are important because of the many functions they are capable of performing. In particular, the use of pedometers in livestock farms offers a range of environmental benefits stemming from the optimization of animal and resource management.

For example, pedometers allow for monitoring animal activity, detecting anomalies such as decreased movement that may indicate health problems (Barkema et al., 2015; Kleen and Guatteo, 2023). This enables precise adjustment of feed rations, avoiding overfeeding and reducing feed waste. Obviously, better feed management lowers the environmental impact associated with feed production, including the use of agricultural land, water, and fertilizers (Andretta et al., 2016; Caro et al., 2016).

Another advantage of using pedometers is that healthy, optimally managed animals emit fewer greenhouse gases, such as methane and nitrous oxide, due to improved metabolic efficiency (Dawkins, 2017; Tullo et al., 2019; Papakonstantinou et al., 2024). By detecting heat or fertile periods early through pedometers, reproduction can be optimized, improving the ratio of productive to non-productive animals and reducing the number of animals raised unnecessarily (Lovarelli et al., 2024). Moreover, early detection of diseases through the analysis of data collected by pedometers limits the use of medications and antibiotics, reducing the risk of chemical substances dispersing into the environment (Džermeikaitė et al., 2023; Neculai-Valeanu et al., 2024).

Furthermore, the use of pedometers allows to reduce need for oversized spaces leading to more efficient farm designs, avoiding excessive use of agricultural land reducing the risk of overgrazing or excessive animal density (Escribano et al., 2020; Pardo et al., 2022). This limits soil erosion and the contamination of water resources due to waste runoff.

On overall, pedometers not only enhance livestock management but also help reduce the overall environmental impact, supporting a more sustainable and efficient approach to modern livestock farming

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(Correddu et al., 2024; Bianchi et al., 2024).

Despite the extensive scientific debate to find sustainable solutions in the agricultural sector (Zarbà et al., 2023) and the unanimous recognition of the functionality of PLF devices in terms of improvement of the sustainability, they still remain underutilized among dairy farmers and the reasons for this low uptake are deeply debated by scientific literature (Dela Rue and Eastwood, 2017; Rutten et al., 2018).

One of the main reasons for the low adoption rate of PLF devices is the convenience of use (Pretto et al., 2024; Selvaggi et al., 2024b). In fact, digital devices may be perceived as too complex to set up or use regularly. Another important issue is the battery used to active the devices. Pedometers that require frequent battery changes or charging may be less appealing to users who prefer low-maintenance devices. If users have to remember to charge their pedometers regularly, they may be more likely to forget or simply not bother. Moreover, cost can also be a barrier to adoption. Some pedometers may be perceived as too expensive for the value they provide, especially if users are unsure of the benefits they will receive or if there are cheaper alternatives available (Lovarelli et al., 2023). Aware of these limitations that inhibit the adoption of these devices, an innovative Stand-Alone Smart Pedometer (SASP) was developed in the framework of a research project financially supported by European Commission. As part of this project, an algorithm, based on moving mean for oestrus detection of dairy cows, was also developed and runs in the firmware hosted by the proposed pedometer prototype (Porto et al., 2022). In this framework, dairy cattle farmers' willingness to pay (WTP) for this innovative pedometer was investigated using experimental auctions (EAs) and the Multiple Price List (MPL) approach (Selvaggi et al., 2021).

The study area was Ragusa province, in Sicily (Italy). According to statistics provided by the Italian Veterinary Information System in the year 2023, Sicily ranks tenth in the ranking of Italian regions in terms of the number of dairy cattle raised on its territory (VETINFO, 2023). Specifically, the province of Ragusa stands out for a considerable number of dairy cattle, recording 29,449 head, 68 % of the regional total, distributed over 312 breeding facilities.

It is important to point out that, excluding the top five regions that stand out for the greatest number of heads raised (among which Lombardy stands out, which alone holds about 50 % of the heads raised in the entire country), the numbers recorded in the province of Ragusa turn out to be not only significant, but even greater than or equal to those of other provinces in the top Italian regions.

For this reason, it was considered that the sample of breeders selected within the provincial territory of Ragusa represents a significant and representative choice for the analysis and study of the dynamics related to dairy cattle breeding in Sicily.

In general, the results of our survey show a clear interest of farmers in adopting this type of pedometer, and this is probably because of the innovative system of operation that make it affordable even for small and medium-sized farms.

2. Materials and methods

A total of 103 dairy cattle farmers were involved in a non-hypothetical field experiment conducted in the province of Ragusa (Sicily) which is one of the most important Italian areas for dairy production.

Starting in June 2023, dairy farmers were recruited to participated in the EA sessions through the support of local stakeholders (i.e., veterinarians, agronomists and others). Farmers who agreed to participate were randomly assigned to one of the 14 EA group sessions held between July 24 and August 2, 2023.

The subject of the experimental auctions was an innovative prototype of a Stand-Alone Smart Pedometer (SASP) developed in compliance with the guidelines of the Green Deal, choosing recyclable and biocompatible materials so to achieve an eco-sustainable product for intensive livestock farming (Bonfanti et al., 2022, 2024; Porto et al., 2023; Selvaggi et al., 2024c).

2.1. Background information on the Stand-Alone Smart Pedometer (SASP) auctioned

The target of the research was providing a low-cost and eco-sustainable service to farmers for the real-time detection of oestrus events in dairy cows. For this reason, this study was a part of a project financed with European fundings and focused on the development of a prototype of an automatic system for monitoring cow behavior, based on a wireless network infrastructure and wearable sensors, to improve welfare and productive and reproductive performance. In this direction, the first step was the design of smart devices (pedometers) with upgradeable firmware, capable of processing raw data and sending results through wireless networks.

Great attention was paid to the design of an eco-biocompatible model for SASP, suitable for hosting a customized electronic device enabled for wireless communication systems within intensive livestock farming (Porto et al., 2023). First of all, an anatomical acquisition of the cow was performed directly in the stable using a portable 3D scanner EinScan Pro HD, so as to perform a three-dimensional reconstruction of the leg thanks to the software integrated into the scanner (Fig. 1). In detail, the paw dimensions were calculated by the average of the dimensions acquired on 10 healthy specimens chosen among those subjected to the experimentation for the oestrus detection.

The final design of the prototype for SASP was achieved through 3D modeling techniques and numerical analysis (FEA) in ANSYS environment.

A pseudo-cylindrical shape for SASP was defined for the wellness of the cow and the part in direct contact to the animal foreleg was profiled respecting the anatomical comfort.

The main element of novelty in the design was the choice of a double-casing geometry. So, the SASP prototype was provided with an external casing to ensure adequate protection both from chemical agents (corrosion) and from impacts (mechanical resistance), and an internal casing for the housing of sensors, electronic components and power supply (Fig. 2). The internal casing was designed to provide a battery compartment, a main board compartment, and a battery charging terminal compartment. Battery and main boards compartments are delimited by a separating partition. At the bottom of the inner casing, there is a hole for the battery terminal connector to pass through. The internal casing was also designed to be removable and interchangeable, in order to reduce the overall number of pedometers required on a dairy farm and, consequentially the management costs. In fact, while the external casing (less expensive because it has no electronics) will be installed in all the cows being analyzed, the internal casing will only be installed in cows about to come into heat. Once oestrus event ended, the farmer can transfer the internal casing into a different cow.

The upper part of the internal casing was given a hexagonal shape to facilitate the screwing/unscrewing operation. Furthermore, the cap of the external casing was designed to preserve the internal thread during periods of non-use.

The chosen printing material for the SASP prototype was Nylon SDS, because it is bio-ecological, recyclable, with high chemical and mechanical resistance (Fig. 3). 3D printing was performed using the high-quality 3D printer Ultimaker S5 Pro Bundle.

The electronic components to be housed into the SASP are: a triaxial accelerometer, a rechargeable power supply unit, a microcontroller and a wireless communication module (Fig. 4). A commercially available two-component gel (Magic Gel 1000 Ray Tech, Settimo Milanese, Italy) was used to protect the circuitry from the risk of accidental inner disconnections and dangerous corrosion phenomena (Porto et al., 2023).

An upgradeable firmware allows to run an algorithm based on prefixed acceleration thresholds and implemented in a software tool and a customized WebApp for farmer use. This solution leads to a double benefit for the breeder: plug-and-play installation and on-board

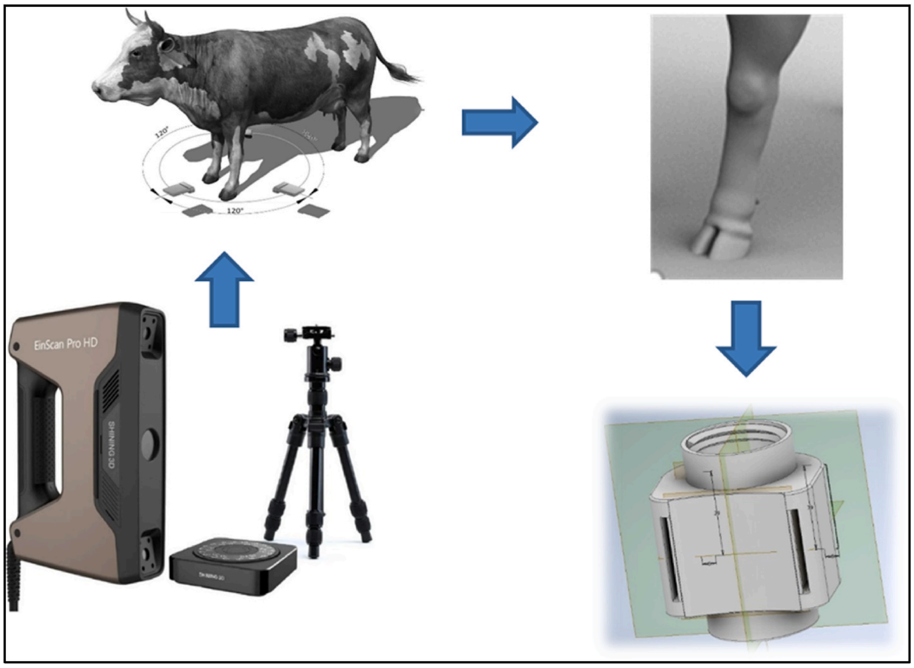

Fig. 1. Anatomical acquisition procedure.

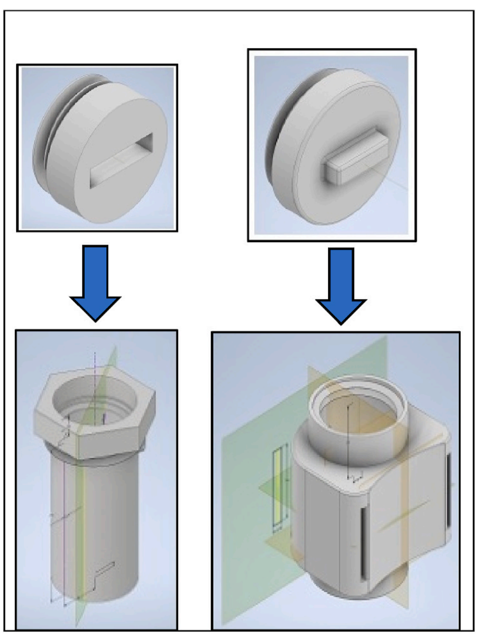

Fig. 2. Schematic drawing of the prototype for SASP (source Selvaggi et al., 2024c, pag.4).

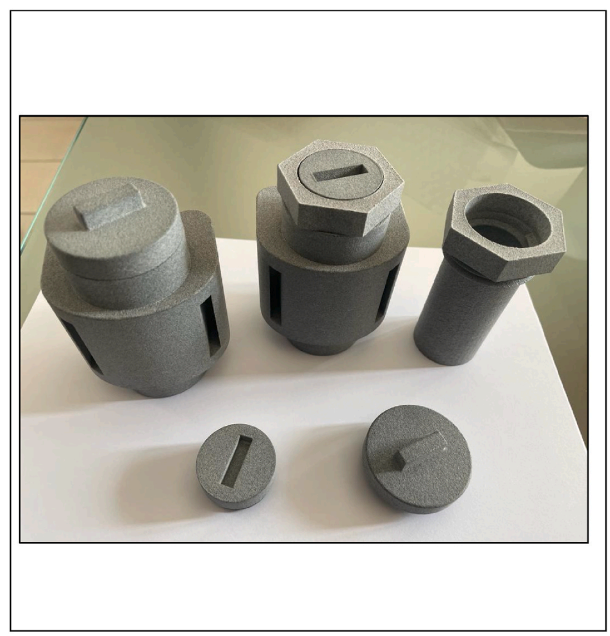

Fig. 3. D printing of the prototype for SASP (source Selvaggi et al., 2024c, pag.4).

computing (Porto et al., 2022; Bonfanti et al., 2024).

The anchor system to the cow foreleg represents a critical and strategic part of the prototype. The anchor was ensured by using a fastening belt fixed through the insertion of 2 locking pins inside two trapezoidal-shaped seats appropriately made on the external casing of the pedometer. Longitudinal and lateral protrusions on each locking pin improve belt fastening. The adoption of a fastening belt allowed achieving a gradual increase in the locking force (Fig. 5).

Notably, adopting oestrous monitoring services based on smart pedometers can mitigate the environmental impact associated with their disposal. This is achieved by minimizing the number of devices required and utilizing biocompatible, recyclable printing materials.

2.2. Experimental auction methodology

Experimental auction procedures are a methodology used in experimental economics to study participants' behavior and preferences in a controlled environment that mimics a real market setting (Lusk and Shogren, 2007). They offer a controlled environment for studying complex market dynamics and can help inform real-world decision-making in areas such as pricing strategies, product development, and policy formulation.

Before starting each experimental auction, each participant received an anonymous ID and was notified that he/she would make a series of non-hypothetical choices using a MPL approach, which is incentive

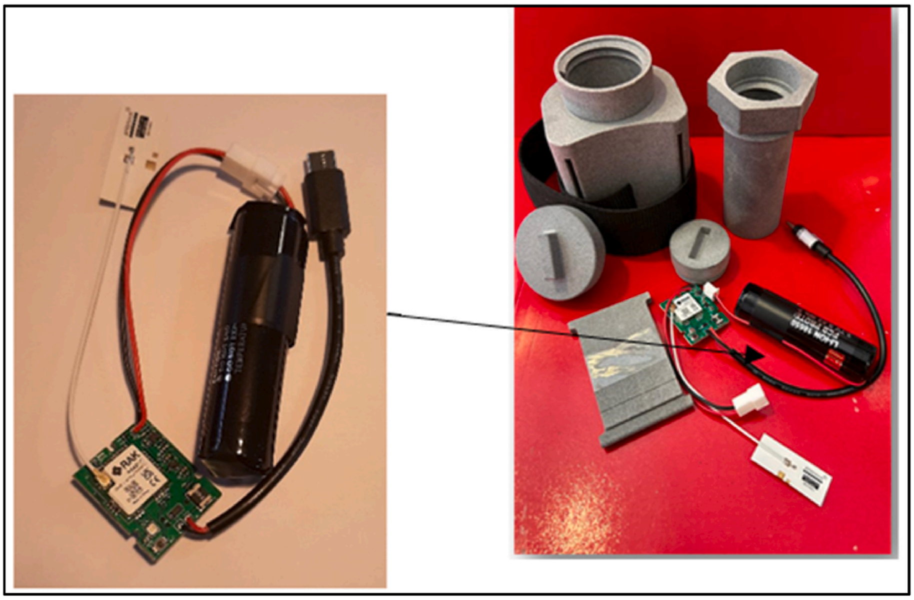

Fig. 4. SASP prototype and its electronic components.

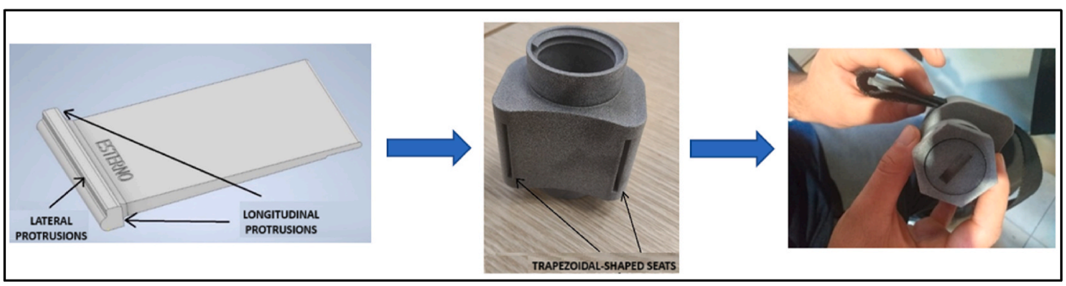

Fig. 5. Anchor system assembly.

compatible (Klain et al., 2014). In particular, the experiment consisted of a real choice between "to have a pedometer" or "to have a voucher" useable everywhere to buy foods, as cash money. Before the first round, the moderator explained the characteristics of the good being auctioned: an innovative stand-alone smart device pedometer, useful to predict oestrus of dairy cattle, rechargeable and capable of communicating through LoRa network (low power and long range).

We performed 11 rounds with an increasingly higher price being assigned to the voucher (+15€ from one choice to the next one – from 0€ to 150€). First choice question in the MPL asked respondents whether they wanted pedometer or voucher where the prices of both were 0€.

The price at which an individual switches from the pedometer to the voucher reveals a bound on his/her WTP.

After participants made all 11 choices, the EA moderator randomly picked both the ID of the winner and the number of the round to determine which choice was binding. The winner received what he/she had chosen in the selected round: a pedometer or the amount of the voucher.

At the end of each session, everyone received a gadget as a reward for the time spent in research.

After completing the EA each participant completed a survey with socio-demographic questions, technical issues and others Likert scales.

2.3. Data analysis

By observing when a respondent switched his/her choice between the increasingly higher priced voucher and the pedometer, the MPL provides a range on respondent WTP (Andersen et al., 2006). If a respondent chose the pedometer on the previous question but the voucher on the next one, then his/her WTP for the pedometer was between the value of the voucher of the previous round and the next one. In particular, let WTP_i* be respondent i's true WTP for the pedometer. As shown by Cameron (1988), WTP_i* can be expressed as in equation (1):

$$WTP_i^* = \beta + X_i\rho + \varepsilon_i \quad (1)$$

where β is a constant, X_i is a vector of explanatory variables including dummy variables describing the particular experimental treatment and variables defining the socioeconomic characteristics of individual i, ρ is a vector of coefficients, and ε_i is a stochastic error term.

3. Results

3.1. Characteristics of the sample

As shown in Table 1, the sample is predominantly male (85 %), with a balanced age distribution. The most common educational levels are high school diploma and bachelor degree. These characteristics partially reflect the broader trends reported by ISMEA (Institute of Services for the Agricultural Food Market). According to ISMEA data, livestock farming in Sicily shows a clear predominance of male farmers and a very limited female presence. Among these, over 11 % hold a university degree – either agricultural or non-agricultural – while more than 20 % possess a high school diploma. These figures are generally consistent with averages observed in other Italian regions. However, it is important to note that these data are derived from the National Rural Network

Table 1
Socio-demographic characteristics (total sample 103 individuals).

Variable	n.	%
Gender		
Male	88	*85,44*
Female	15	*14,56*
Age		
18-35	36	*34,95*
36-50	35	*33,98*
Over 50	32	*31,07*
Level of education		
Middle school	9	*8,74*
High school	42	*40,78*
Degree	43	*41,75*
Post-graduation	9	*8,74*

program of 2013 and may not fully reflect the current situation (National Rural Network, 2020).

Within this context, in the context of our study, the representative sample analyzed perfectly reflects the characteristics of the population.

In addition, in the context of the survey conducted for the present study, data deemed relevant were collected and analyzed in order to provide a meaningful information picture regarding the habits of the dairy farms under study. The results of the analysis are showed in Table 2.

Initially, the simple question was asked whether they owned pedometers or not, and it was found that as many as 90 % stated that they did not own pedometers.

These results indicate a strong level of unfamiliarity among dairy farmers regarding pedometers, although they are aware of the use of such devices by others in the livestock industry. The evaluation of these perceptions and their influence on pedometer adoption is a significant aspect in the analysis of willingness to pay for the pedometer prototype conducted in this survey.

Moreover, dairy cattle breeds raised and the main destination of milk produced on these farms were investigated. Data analysis revealed the Friesian breed was found to be the most common, other cattle breeds, such as Modicana, Pezzata Rossa and Bruna, are raised in significantly smaller proportions. The total number of breeders reporting involvement with different breeds exceeds the total number of participants interviewed, as some breeders are involved in raising multiple breeds. This overlap highlights the multidimensional nature of their activities and indicates that individual breeders often diversify their practices by managing more than one breed simultaneously.

Regarding to the main destination of the milk produced, it was pointed out that about 55 % of the farms choose to use it for co-operatives, while about 30 % choose to use it for industry; the remaining percentage stated that they use the milk produced for cheese making on their own farms.

Finally, the research investigated the level of agreement of farmers for various statements regarding the impact of pedometer adoption in agricultural or livestock management.

To assess the perceptions of livestock farmers regarding the adoption of pedometers in farm management, a 7-point Likert scale was used, where 1 corresponded to "completely disagree" and 7 to "completely agree." The questionnaire included five statements aimed at evaluating the extent to which farmers believe that adopting pedometers: (1) saves time in daily routines, (2) increases the profitability of the company, (3) improves breeding management, (4) enhances the welfare and health of farm animals, and (5) improves reproductive efficiency. Table 3 shows a summary of the collected responses analyzed to identify overall trends in beliefs. For each statement, the mean, minimum, and maximum scores were calculated to summarize the responses and provide a descriptive overview of farmers' attitudes towards the potential benefits of pedometer adoption.

The results reflect a generally positive perception of pedometer adoption, particularly in areas such as breeding management and reproductive efficiency.

3.2. Farmers' willingness to pay for the Stand-Alone Smart Pedometer

The graph in Fig. 6 shows the heterogeneous results of the MPL considering the raw mid-points of the elicited intervals. The dependent variable WTP is only observed as intervals and the statistical method used to elicit the mean WTP value is an interval regression. 23 dairy farmers of our sample (22 %) chose to have the pedometer until the last round of auction performed, rejecting the maximum value voucher (150€).

Only 14 breeders (13.5 %) from the first choice showed no interest in the presented pedometer prototype.

4. Discussion

The study focused on the adoption of innovative pedometers by dairy farmers, highlighting the potential interest in these digital devices. Among the participants, 22 % of farmers expressed significant interest in the stand-alone pedometer, even when offered a voucher alternative at its maximum value (€150). This result indicates a tangible willingness among farmers to invest in innovative technologies, whereas previous studies (Eastwood et al., 2017; Gargiulo et al., 2018) has often depicted them as reluctant to pay for the adoption of digital technologies in livestock farming due to socioeconomic and cultural factors as well as limited trust in technological innovations.

The very limited number of farmer (n. 14) not available to adopt the auctioned pedometer is very encouraging for scientific research because

Table 2
Characteristics of companies.

Variable	n.	%
Do you already have pedometers in your company?		
Yes	10	*9,71*
No	93	*90,29*
What breed do you breed on your farm? (a)		
Friesian	72	
Modicana	8	
Pezzata rossa	13	
Bruna	5	
Others	31	
What is the main destination of the milk produced on the farm?		
Cooperative	60	*58,25*
Industry	34	*33,01*
In-house cheese-making	9	*8,74*

[a] The total number of breeders reporting involvement with different breeds exceeds the total number of participants interviewed, as some breeders are involved in raising multiple breeds.

Table 3
Results of the scores assigned to statement used to investigate different aspect of potential benefits of pedometer adoption in livestock management.

Statements	Mean	Maximum	Minimum
"Adoption of pedometers saves time in daily routine"	5,06	7	1
"The adoption of pedometers leads to an increase in the profitability of the company."	5,42	7	1
"Adoption of pedometers leads to improved breeding management."	5,67	7	1
"The adoption of pedometers leads to an improvement in the welfare and health of the animals reared on the farm."	4,76	7	1
"Adoption of pedometers leads to improved reproductive efficiency"	5,77	7	1

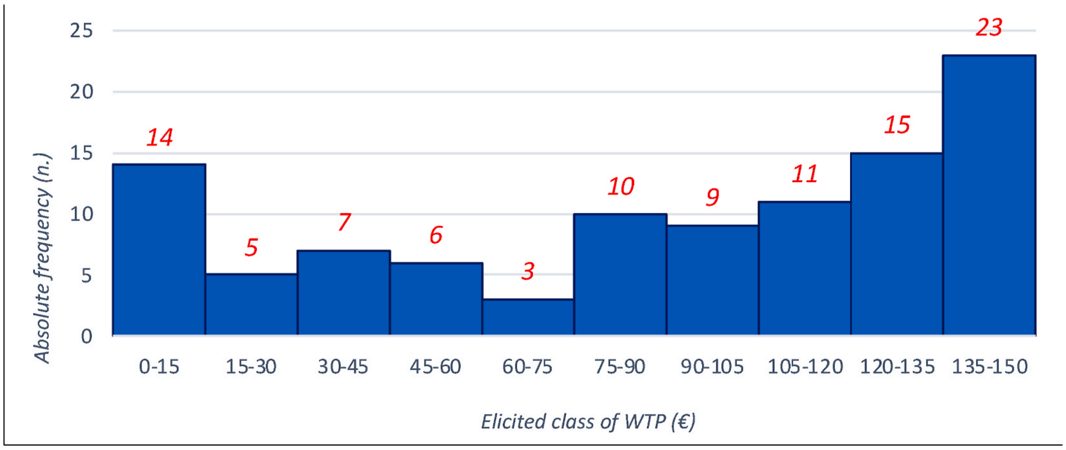

Fig. 6. Willingness to pay classes (€).

it is a great symptom of interest in a digital device that is not widely used. This result demonstrates a strong interest among farmers in the potential benefits that pedometers can offer their livestocks.

Despite their likely limited familiarity with digital tools such as pedometers, the openness displayed by farmers aligns with the technology adoption curve described by Rogers (2003) in his "Diffusion of Innovations" theory. Initial unfamiliarity is a typical barrier to emerging technologies, but the perceived benefits can lead to increased acceptance over the medium to long term. However, the diffusion of technologies like pedometers requires coordinated educational and marketing efforts, which may still be insufficient, along with economic incentive programs.

Moreover, the willingness of farmers to pay for low-cost, stand-alone pedometers over more expensive alternatives currently on the market is a noteworthy finding. It suggests a potential reduction in the initial barriers to adoption stemming from high upfront investment costs. This represents an interesting shift compared to current scientific literature, which highlights cost as one of the primary barriers for farmers, along with complexity and difficulties in integrating new technologies with existing systems (Kutter et al., 2011).

One of the key takeaways from the results is the generally positive reception towards pedometers. For instance, the mean scores across most statements of different aspect of potential benefits of pedometer adoption in livestock management (Table 3) hover around or above 5, indicating that a majority of respondents recognize tangible benefits. The variability in responses, as indicated by the range from 1 to 7 for each statement, suggests that the benefits of pedometer adoption may be influenced by factors such as the specific implementation context, the existing management practices, and the overall farm infrastructure. The variation in responses, with minimum scores of 1 for each statement, suggests that some users did not perceive the same benefits, pointing to a diversity of experiences. This variability could stem from differences in how pedometers are integrated into farm operations or possibly from initial challenges during implementation.

Statements such as "improved breeding management" and "improved reproductive efficiency" show higher average scores, suggesting that many users have experienced significant enhancements in these areas. This aligns with the expectation that pedometers, by tracking animal activity, can help in detecting oestrus and optimizing breeding schedules, ultimately contributing to better reproductive outcomes. The potential benefits of pedometers in improving production and reproductive performance have been demonstrated in previous studies (Caja et al., 2016). Farmers' interest in low-cost, stand-alone pedometers may reflect a latent awareness of the importance of digital monitoring for animal health and welfare.

On the other hand, perceptions about time savings and profitability also lean towards the positive side but show slightly lower mean scores. This could imply that while pedometers are useful tools, their impact on daily routines and financial returns might depend on factors such as the size of the farm or the specific management practices adopted in specific farms.

This aspect suggests that the findings of our research could lead to direct and indirect improvements in the environmental impact of production processes in livestock farms, related to the adoption of innovative pedometers for cattle farming.

Interestingly, the statement regarding animal welfare and health has the lowest mean score (4.76), indicating a more mixed perception. While some respondents did note improvements, others may not have observed significant changes. This suggests that while pedometers offer potential in monitoring animal well-being, their effectiveness in this regard may be less consistent or more dependent on additional factors, such as how the data is interpreted and acted upon.

This variability in perceived benefits suggests that, when optimally integrated, pedometers could lead to broader improvements, not only in operational efficiency but also in reducing the environmental impact of production processes. The findings of our research indicate that adopting innovative pedometers for cattle farming has the potential to foster both direct and indirect enhancements in sustainability and resource management.

From an environmental perspective, adopting digital devices such as pedometers can improve herd management. For instance, pedometers can enhance animal health and welfare by monitoring behavior and reducing the risk of diseases or reproductive issues. A healthier herd leads to greater production efficiency (e.g., more milk per unit of input), reducing the need for additional resources like feed and medicine, which have significant environmental impacts.

Furthermore, waste and emissions could be reduced. Accurate monitoring provided by pedometers can optimize farming practices, minimizing resource waste (e.g., food and water) and greenhouse gas emissions per unit of product. For example, better monitoring of reproductive activity could reduce the number of animals maintained unnecessarily without producing milk or meat, thereby decreasing methane emissions. In addition, according to the current literature (Rutten et al., 2013), the use of the low-cost stand-alone pedometer improves welfare management during the breeding phase for example by reducing unproductive cycles and emissions per unit of milk produced. This represents an important contribution to environmental sustainability, a priority theme in the contemporary literature on sustainable agriculture.

The dissemination of accessible, stand-alone devices like pedometers could also encourage smaller farmers to improve their practices, contributing to environmental sustainability on a local scale. If the device is affordable and user-friendly, it could be adopted by a larger number of farms, amplifying its impact. This aspect ties into a potential reduction in the impact of large IT infrastructures. Low-cost, stand-alone pedometers operate independently of complex IT infrastructures, meaning their adoption could reduce the need for centralized data management systems, which require energy and other resources to function. The interest in pedometers not associated with costly IT infrastructures is a significant development. Previous studies, such as Bewley et al. (2010), have highlighted that integrated management systems are often not adopted due to their costs and complexity. An independent pedometer eliminates these challenges, expanding the market to small and medium-sized farmers, who are often excluded from the benefits of advanced technologies.

Finally, improvements in farmer education and environmental awareness should not be overlooked. Promoting digital technologies among farmers also raises awareness of sustainable farm management practices. This could create a ripple effect, leading farmers to adopt other practices that reduce environmental impact, such as improved management of organic waste.

5. Conclusions

Our research provides an insightful analysis of the potential for pedometers in dairy farming. Scientific literature supports many of our findings, such as the role of initial investment costs as a barrier to adoption and the ease of use of the device as a facilitator in decision-making for adopting pedometers and digital innovations in general.

However, the generalizability of the results is limited and requires further investigation. The study has certain limitations, including the prototypical nature of the low-cost, stand-alone pedometer (not yet commercially available) and the lack of similar evaluations in different geographic and socioeconomic contexts. In the future, comparative studies in diverse contexts could provide more robust external validity and contribute to a broader understanding of WTP and the factors influencing the adoption of digital technologies in livestock farming.

Nevertheless, our findings have interesting implications for policymakers and businesses. The study suggests a potentially significant role for policymakers and companies in promoting technological innovations. For example, policies that incentivize adoption, such as tax breaks or subsidies for purchasing digital technologies, could increase uptake among farmers. Similarly, companies could use the data from this study to design targeted devices that meet the needs of farmers, including smaller-scale operations.

Finally, although our results were obtained in a specific geographic context, the methodology used has strong potential for replication in other areas. In general, future efforts should combine economic and engineering studies, market research, and pilot projects in various contexts to confirm our findings and promote the broader adoption of these technologies.

CRediT authorship contribution statement

M. Bonfanti: Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation. **R. Selvaggi:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **G. Pappalardo:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Conceptualization. **C. Bellia:** Visualization, Data curation. **B. Pecorino:** Visualization, Validation, Supervision. **S.M.C. Porto:** Supervision, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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