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MORALITY BEFORE KNOWLEDGE

Implementing precision feeding in Indonesia's dairy sector: Environmental and socioeconomic impact and adoption challenges

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ABSTRACT

Background: Lack of proper feeding management leads to low milk quality and quantity in some countries, such as Indonesia. Precision feeding (PF), as one of the precision livestock farming (PLF) practices, is a potential solution to address this problem. This study aims to describe PF applications and their impacts on environmental and socio-economic dimensions, analyze potential challenges in its implementation in Indonesia, and propose solutions to support future PF adoption. **Methods**: This study was a literature review initiated by searching scientific articles from three databases (ScienceDirect, MDPI, and ResearchGate), resulting in 16 research articles included in the analysis. **Finding**: There are four main components of PF: nutrient and feed quality adjustment, feed management, technology use, and data-driven model exploration. PF is associated with environmentally friendly practices and can increase farmers' profitability. PF also introduces a new perspective in dairy farming due to technological interventions. In Indonesia, challenges in applying PF are related to the farming conditions dominated by smallholder farmers and the lack of stable internet connectivity and coverage. The presence of cooperatives can serve as a bridge between PF practices and smallholder farmers. **Conclusion:** The PF approach can support sustainable dairy farming in Indonesia, contribute to national goals, and address global challenges to meet increasing demand. **Novelty/Originality of this article**: This study uniquely integrates evidence on precision feeding in dairy farming with its socio-economic impacts, with a focus on Indonesian smallholder systems, linking feeding practices to profitability, sustainability, and farm management across multiple studies.

KEYWORDS: dairy farming; environment; Indonesia; precision feeding; socioeconomic.

1. Introduction

The world currently faces significant challenges as the human population grows. Global food needs are expected to rise significantly between 2011 and 2050, while the proportion of people facing hunger may approach roughly one-fifth of the population (van Dijk et al., 2021). Food derived from the agricultural sector is a primary need that is unavoidable in daily life. One of the agricultural sector is the livestock sector contributes to meeting the demand for animal protein source, such as milk, as a nutritious food for all people at various

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stages of life, especially during the growth phase, thereby improving the quality of human resources in the future.

Milk is nutritionally valuable due to its calcium content, and its proteins can trigger insulin-like growth factor-1 (IGF-1) production, which supports bone development and overall growth (Givens, 2020). However, not all regions of the world can supply milk independently and often rely on imports. The average milk supply in developing countries, such as Southeast Asia, remains relatively low and correlates with low per capita consumption levels. Among Southeast Asian nations, Indonesia records the lowest level of milk intake per person (Daryanto et al., 2021). Milk consumption keeps rising, yet about seventy percent of Indonesia’s supply still relies on imported products (Priyono et al., 2023).

In Indonesia, the low domestic milk demand is partly due to conventional livestock farming practices. The dairy sector is largely operated by small-scale farmers, many of whom are affiliated with centralized cooperatives located in West and Central Java (Fadillah et al., 2023; Jahroh et al., 2020; Nuraina et al., 2021). Dairy cattle are generally raised intensively, not through grazing and the primary feed given is green fodder, including cut-and-carry grass, natural grass, and agricultural by-products such as rice straw (Hamidah et al., 2021). In some areas, farmers also give industrial processing by-products such as tofu by-product (Despal et al., 2021a). In addition, cooperatives also provide concentrate feed (Nuraina et al., 2022).

Generally, feeding practices in smallholder farmers are not accompanied by environmental awareness. However, well-planned feeding can reduce greenhouse gas (GHG), nitrogen (N) and phosphorus (P) emissions (Ma et al., 2024). Environmental pollution from livestock activities has become a global concern, requiring Indonesia not only to improve productivity but also to enhance awareness of sustainability issues. This aligns with SDG point 12, “Responsible Consumption and Production”. One strategy to address this challenge is the implementation of precision feeding (PF).

PF involves supplying animals with exactly the amount of feed they require—neither too little nor too much—to meet their nutritional demands efficiently (Chase & Fortina, 2023). PF is part of precision livestock farming (PLF), which not only improves productivity and sustainability, but also increases profitability, ultimately improves livestock welfare. In dairy farming, feed represents the most significant expense in dairy production, often amounting to around eighty percent of total costs (Gulumbe & Bhat, 2022). The implementation of PF is expected to increase the effectiveness and efficiency of feeding by meeting nutrient needs based on real time individual animal conditions (Zuidhof, 2020).

The PF approach has been widely implemented in several countries, such as the United States, Canada, Brazil, Ireland, and Italy (Bosco et al., 2021; Krampe et al., 2021; Chase & Fortina, 2023; Palma-Molina et al., 2023; Gheller et al., 2024). However, in Indonesia, its implementation is still very limited. Therefore, this review aims to examine PF applications and their impacts on environmental and socio-economic dimensions, analyze potential challenges in its implementation in Indonesia, and offer solutions to support future PF implementation.

2. Methods

This review was written by collecting qualitative data from previous research journals. The approach employed a mindful scientific literature search, referring to Liu et al., (2023). The literature search relied on recent studies related to PLF and PF. Research journals were obtained from three databases: ScienceDirect, MDPI, and ResearchGate. The search in these three databases used primary keywords (precision feeding, dairy sustainability, dairy farming, socio-economic impact, environmental impact, also developed and developing country) combined and linked with the word "AND." Keywords were enclosed in quotation marks ("keywords") to generate relevant sources. The selected journals were filtered by publication year (the last five years, 2020–2025), English-language articles, research article type, and open-access availability. The article selection process is presented in the Figure 1.

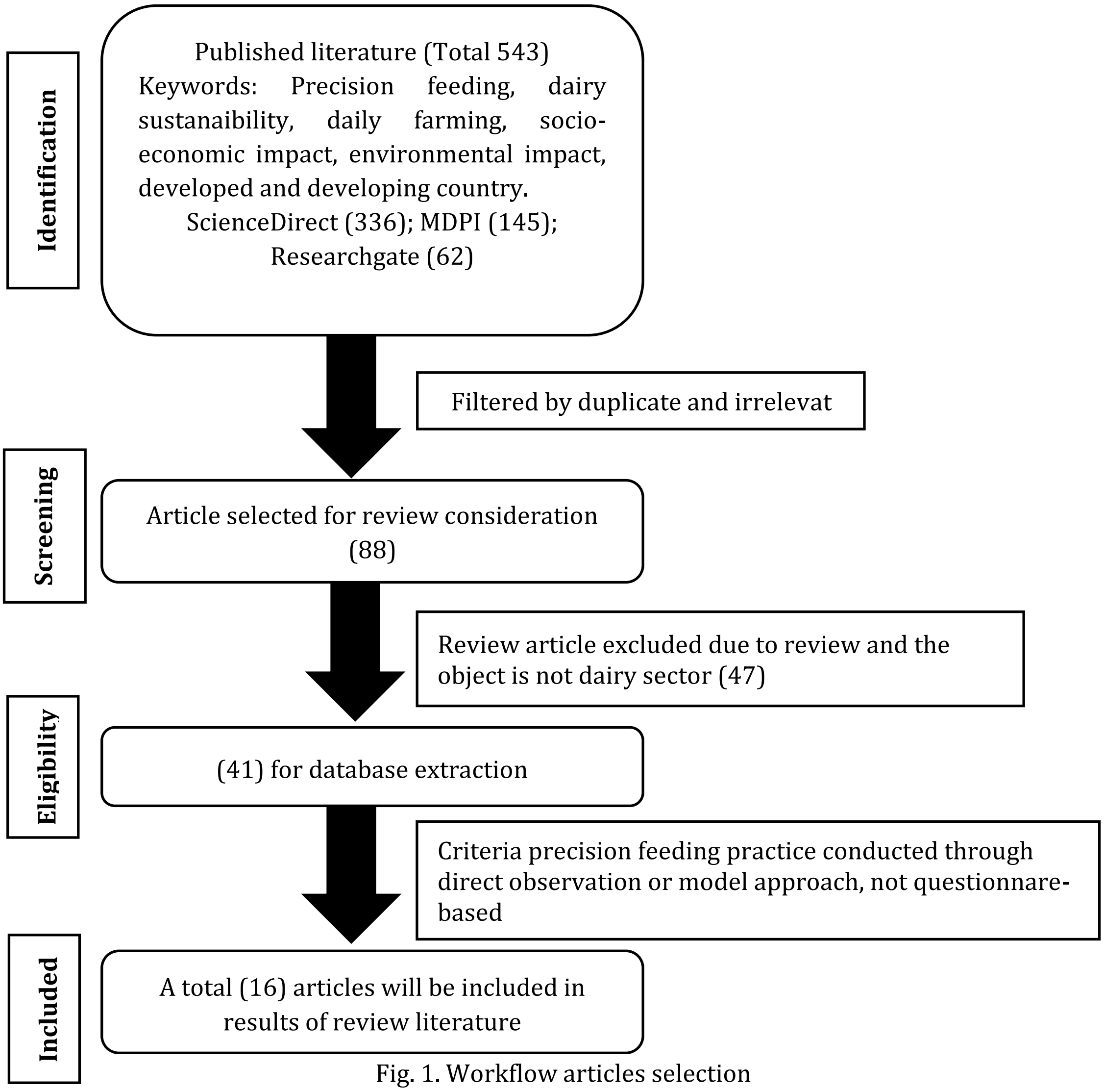

Fig. 1. Workflow articles selection

3. Results and Discussion

3.1 Precision dairy feeding

PF, as part of the PLF concept, has begun to be developed and successfully implemented in various regions around the world. Its goal is to meet dairy cattle nutrient needs in real time with high precision. Table 1 presents the results of the literature review, indicating that PF emphasizes not only the use of technological tools but also proper nutrient balancing and effective feed management practices. The term PF is often associated with technological interventions, which leads to the perception that technology is the central component of PF implementation. In fact, technology in precision feeding practices serves as a tool for comprehensive data collection, enabling farmers to access information more easily.

This allows for quick and precise decisions, such as ration replacements, quantity determinations, and even feed supplementation, to be made accurately, thereby increasing livestock productivity. Using data-based decision making can enhance both the production volume and the nutritional characteristics of animal products (Akintan et al., 2025). Although PF is inherently tied to the use of technology, such as data and automated systems, the essence of this practice remains proper feed management. Therefore, PF will not yield meaningful results unless supported by accurate nutrient modification and well-managed feeding systems. Furthermore, technology will continue to advance, so research related to quality improvement and enhancement will continue, creating new models that are expected to give greater ease, practicality, and data accuracy.

Table 1. Summary of research studies identified about PF in literature (2020-2025)

No.	Author	Finding	Precision feeding approach
1.	Chase & Fortina (2023)	Reducing crude protein (CP) levels can increase milk production, reduce nitrogen (N) excretion into the environment, and improve profitability.	- Feed formulation using CNCPS to adjust CP requirement, - weigh cells on the mixer wagon - Near-Infrared Reflectance Spectroscopy (NIRS) use, - grouping dairy cattle.
2.	Duplessis et al. (2021)	The adjustment of phosphorus (P) is often not accompanied by precision in trace minerals, resulting in the overfeeding of these elements.	Precision feeding based on mineral requirement.
3.	Froldi et al. (2024)	Feed quality improvement can reduce climate change (CC) indicators and photochemical ozone creation potential (POCP).	Gross energy (GE) and digestible energy (DE) are measured precisely.
4.	Arshad et al. (2022)	Installing collars and automatic water units can reduce labor, enable real-time herd management, and lower costs on large-scale farms.	Cow collar and automatic water filling unit operated by intelligent wireless sensor nodes, the Internet of Things (IoT), and a Node-Micro controller Unit (Node-MCU).
5.	Yamada et al. (2024)	Handheld NIRS devices quickly measure forage nutrient on-site.	Handheld NIRS.
6.	Palma-Molina et al. (2023)	PF use can reduce labor.	Automatic parlor feeders, calf feeders, and rising plate meter (RPM).
7.	Campos et al. (2023)	Clustering in feed management reduce feed cost.	- Using non-linear programming with mixed constraints and the NASEM (2021) model to optimize diets, - clustering approach to create two grain mixes and and three partial mixed rations from the collection of Individual diets.
8.	Adrion et al. (2020)	Ultra-High Frequency Radio-Frequency Identification (UHF RFID) can detect cow's feeding visits, eating time data, and the position data.	UHF RFID Antenna.
9.	Kate & Neethirajan (2025)	AI application enables early detection of abnormal feeding behavior, speeding up decisions on feed efficiency, forage availability, and herd health.	Multimodal artificial intelligence (MAI) to decode bovine vocalizations in real-time.
10.	Lee et al. (2024)	The automated analysis facilitates efficient management practices and optimizes feeding strategies and resource allocation.	3D imaging sensors to capture detailed information about various parts of dairy cows.
11.	Leso et al. (2021)	A commercial collar-based sensor system provide accurate data on feeding and rumination time.	A commercial collar-based sensor system (the AFICollar®).
12.	Pereira et al. (2021)	The RumiWatch system evaluated rumination, grazing, standing, and lying behaviors with high precision and accuracy.	RumiWatch system (Itin and Hoch GmbH, Liestal, Switzerland).

13.	Sharpe & Heins (2023)	Forefront weight scales help farmers quickly monitor calf weight for health and treatment decisions	Holm & Laue Calf Expert and Hygiene Station automatic calf feeder (Holm & Laue GmbH & Co. KG, Westerrönfeld, Germany)
14.	Yu et al. (2024)	Res-DenseYOLO can monitor cow behavior accurately and in real time.	Res-DenseYOLO model.
15.	Yu et al. (2022)	TCS-YOLO with Deep SORT tracks multiple cows' foraging behavior accurately, even in noisy conditions.	TCS-YOLO model and combines the Deep Sort algorithm.
16.	Bosco et al. (2021)	PF strategies in sheep milk production can reduce environmental impact by improving production efficiency	Innovative feeding based on precision feeding approach

Based on the results shown in Table 1, PF in dairy cattle can be grouped into four main components that shown in Figure 2, those are feed optimization, feeding management practice, technologies applies, and modeling approaches.

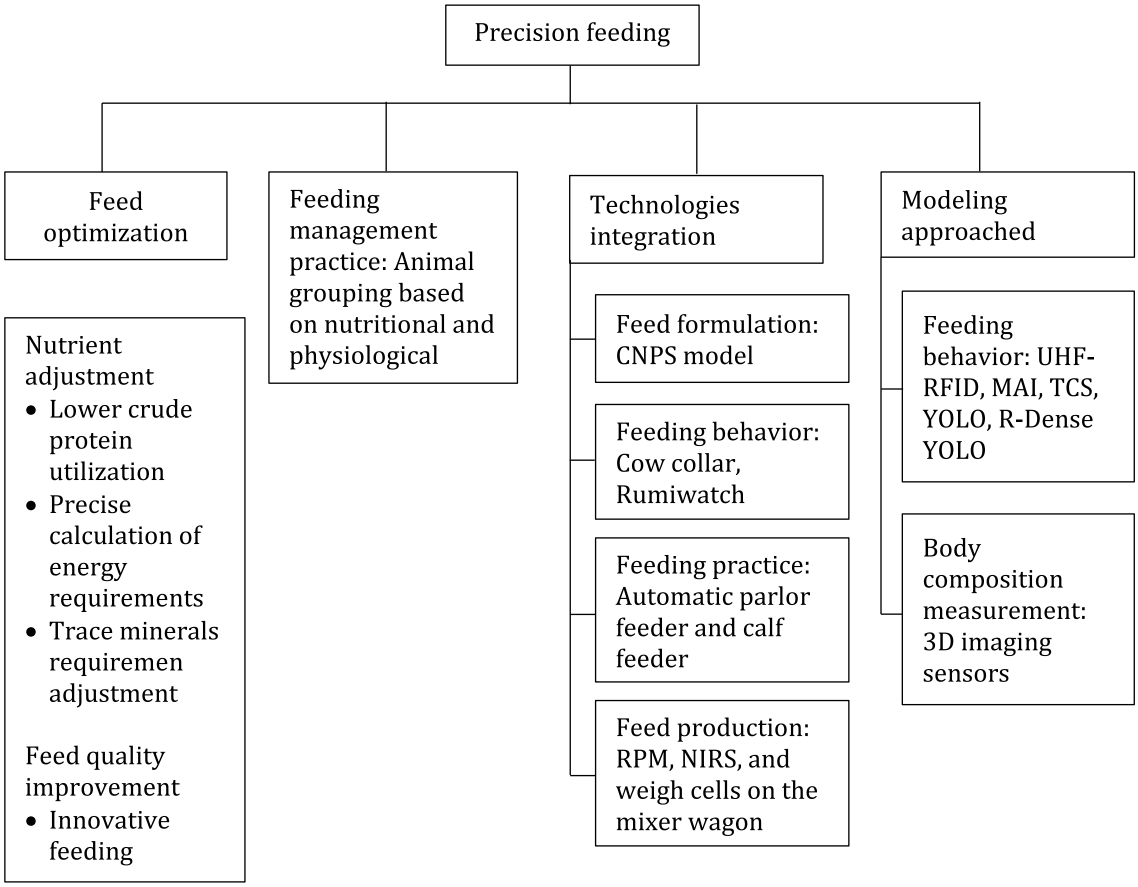

Fig. 2. Precision feeding implementation scope based on the literature review

3.1.1 Feed optimization

Futuristic livestock farming practices, which focus not only on productivity but also on profitability and sustainability, must consider adequate and balanced nutrient content. In fact, before the emergence of PF practices, providing balanced feed with a diverse composition of raw materials to meet livestock needs was common practice. Feed formulations were based on nutrient requirements listed in standards produced by some institution, such as the National Research Council (NRC), Institut National de la Recherche Agronomique (INRA), and European Federation of Animal Science (EAAP) (Duplessis et al., 2021). With the PF concept, these standards serve as a foundation for continued development, necessitating adjustments in feed ingredient selection and improvements in nutrient composition to optimize livestock performance.

From the literature review, Several approaches can be taken to improve feed quality in terms of nutrient content and potential side effects. These include providing high-quality and nutritionally balanced feed, improving feed processing, replacing industrial concentrate with nutritious raw materials (such as grains and legumes), selecting more nutrient-rich perennial forages—such as alfalfa (*Medicago sativa* L.) and sulla (*Hedysarum coronarium* L.), supplementing with vegetable oils, moderately reducing crude protein (CP) levels, and ensuring accurate intake of trace minerals (such as cobalt (Co), manganese (Mn), zinc (Zn), and copper (Cu)) (Bosco et al., 2021; Chase & Fortina, 2023; Duplessis et al., 2021; Froldi et al., 2024).

Good-quality, nutritious and diverse feed is indeed recommended in dairy farming practices. This aims to improve digestibility, nutrient absorption, and performance. These types of mixes, more commonly known as rations, are formulated to meet nutrient requirements in order to optimize livestock performance (Berthel et al., 2022). The term innovative feeding (IF) actually refers to the practice of PF (Bosco et al., 2021). The IF approach essentially improves feed quality by replacing several components, such as growing alfalfa to improve pasture and hay quality, adding grain to reduce the use of industrial concentrate feed, and adding vegetable oils to improve milk quality (Bosco et al., 2021). This means that compared to relying on a single type of forage, a diverse feed can contribute significantly. The finding of Lange et al. (2024) showed that feeding alfalfa alone did not produce better results than red clover alone. Essentially, forage provision must be balanced between fiber and other nutrients. In addition to alfalfa or vegetable oils such as soybean oil and extruded linseed, legumes such as *Indigofera zollingeriana* or other vegetable oils can also be used as forage mix options to contribute energy for dairy cattle (Antari et al., 2022; Riestanti et al., 2024).

The energy stored in feed is GE, the total chemical energy stored in the feed, which is then processed by the body, some of which is absorbed and some is excreted as waste such as feces, gas, urine, or heat from metabolism (Guinguina et al., 2020). From this, DE, metabolizable energy (ME), and net energy (NE) are measured (Carroll et al., 2024). Accurate GE and DE calculations are necessary in PF practices to maximize energy utilization in dairy cattle. The smaller the difference between GE and DE, the greater the proportion of nutrients that can be used by the animal's body, thus expectedly improving performance. Furthermore, energy adjustments are not limited to GE and DE, but also at the NE level to optimize nutrient contribution to the body and avoid overfeeding.

Nutrients are divided into macronutrients, such as protein, and micronutrients, such as minerals. Crude protein is composed of two key fractions: rumen degradable protein (RDP), which is broken down in the rumen, and rumen undegradable protein (RUP), which bypasses rumen degradation (Chase & Fortina, 2023). RDP is protein that is broken down in the rumen and then converted into microbial protein, serving as the primary protein source for dairy cattle, while RUP can bypass directly into the abomasum as a protein source without being converted into microbial protein (Mahboobi et al., 2023; Zain et al., 2024). Therefore, protein intake can be reduced with a moderate approach to avoid energy inefficiencies. Furthermore, nutrient requirement calculations are better if adjusted down to the amino acid level for greater precision (Chase & Fortina, 2023). Research done by Chase & Fortina (2023) showed that reducing crude protein by a certain amount did not show any adverse effects on cow condition or milk production.

Other nutrients that require precise calculation are phosphorus and trace minerals, such as Cu, Zn, Mn, and Co (Duplessis et al., 2021). Although required only in minute quantities, trace minerals must still be supplied at adequate levels. These minerals are associated with immunity, oxidative metabolism, and reproductive performance (Duplessis & Royer, 2023). Both trace mineral deficiencies and overfeeding can impair reproductive (Van Emon et al., 2020). Therefore, to achieve the PF concept, micronutrient levels are crucial. This means that overfeeding has often been considered excessive, as some nutritionists believe it's better to give more than less to meet livestock needs and achieve optimal production. With the PF concept, reducing excessive feed intake is possible without negatively affecting animal productivity.

3.1.2 Feeding management practice

Dairy farming practices vary across regions. Feeding is done using either a cut-and-carry or grazing system. In temperate regions, grazing systems are widely used because they are cost-efficient and promote better animal welfare (Hennessy et al., 2020; Stirling et al., 2021; Verdon et al., 2025). Furthermore, this is also due to the relatively large number of livestock owned and the availability of adequate grazing land. However, sometimes livestock must be penned and fed with a mixture of certain feedstuff or preserved feed, such as hay or silage, because the season is an unavoidable limitation (Stirling et al., 2021). Meanwhile, in tropical regions, livestock activity is intensification type due to limited land and small livestock ownership (Akzar et al., 2023). Despite these differences in systems, the approach taken to achieve the PF concept is essentially the same. While grazing can reduce costs, its lake is lower milk production. Therefore, dairy cattle still require supplemental feed for optimal performance (Batistel et al., 2021; Winsten, 2024). Nutrient requirements are calculated and adjusted to meet their needs, then given to the livestock. PF aims to deliver an accurately measured amount of feed tailored to each individual animal. However, the efficiency and ease of precise feeding per individual is still being developed.

Therefore, a preliminary step toward effective PF is sorting animals into groups with comparable characteristics.This grouping helps calculate feed requirements per group, such as based on dairy cattle species (such as Friesian Holstein (FH) or Jersey), body weight, physiological phase (calf, heifer, male, early lactation, peak lactation, late lactation, dry phase, pregnancy phase), and health condition (Campos et al., 2021; Matzhold et al., 2024). This will make it easier for farmers to adjust feed requirements because they are adjusted for groups. Thus, for example, in one pen consisting of animal group with relatively uniform conditions, feed provision and the amount of nutrients contained in it are more targeted.

3.1.3 Technological integration

When discussing PF, technology is inevitably involved. PF involves automated systems, machines, robots, and various devices that simplify human work and save labor and time. In dairy farming, many tools are already in commercial use, both in feed formulation and feeding practices. Previously, the general reference for dairy cattle nutrient requirements was the NRC (Duplessis et al., 2021), which has now evolved into the National Animal Health and Nutritional Research Institute (NASEM) (Campos et al., 2021).

Feed formulation is often optimized through linear programming, though this method frequently prioritizes cost minimization alone and ignores many constraints. Therefore, feed formulation can be improved using nonlinear programming to address more constraints and optimize calculations (Campos et al., 2021). Once the feed formulation is obtained, simulations can be performed using the Cornell Net Carbohydrate and Protein System (CNCPS) approach using Nutritional Dynamic System (NDS) software (Bosco et al., 2021; Chase & Fortina, 2023). The combination of NASEM, nonlinear programming, and CNCPS operated through NDS is an ideal approach for achieving the PF concept during the feed formulation preparation stage, which is then produced and fed to dairy cattle.

In practice, various tools, including machines, robots, and interconnected technologies, operate to automate the process. These systems operate through sensors and networks, for example, wireless sensor nodes, the Internet of Things (IoT), and Node-Micro Controller Units (Node-MCU) (Arshad et al., 2022). Sensors are used in several PF support tools, such as weigh cell mixer wagons, collars, automatic water filling units, Rumiwatch, automatic feeders, rising plate meters (RPM), and NIRS. All of these tools are used to improve measurement precision through automation.

Weigh cell mixer wagons allow farmers to accurately mix feedstuff without the need to weigh each ingredient individually, which is a time-consuming. Automatic water filling units and automatic feeders also use a similar principle, with sensors sending signals to a database regarding the container's empty condition. In addition, automatic calf feeders include a forefront weight scale that can be used to measure calf body weight (BW), helping farmers make quick decisions by using BW as a benchmark for assessments, for example, in disease identification or determining drug dosages (Sharpe & Heins, 2023).

Determining the nutrient content of feed requires specific analysis. With technology in PF, such as NIRS, measurements can be made more quickly and accurately. NIRS devices are generally used indoors due to their less practicality and are typically reserved for more complex analyses. However, if NIRS is intended for use at the farming activity level, handheld NIRS is preferred due to its ability to measure forage nutrient content in real time (Yamada et al., 2024). Another technology that can be used to measure forage adequacy and quantity in grazing systems is RPM. With this measurement tool, farmers can determine appropriate grazing techniques, such as rotational grazing, or identify forage adequacy in pastures, which can then be compared with the farm's carrying capacity. Based on these results, decisions about maintaining or changing the type of forage planted can be made more accurately.

3.1.4 Modeling approach

The emergence of the PF concept, closely linked to the application of technology, has indirectly encouraged various research and development efforts, both to improve the accuracy of existing tools, simplify their use, and create new devices capable of measuring additional parameters to support optimal livestock productivity. In the initial stages of feeding, nutrient requirements are determined from several parameters, such as BW and physiological phase. With the PF concept, this can be improved by assessing overall body condition, rather than relying solely on BW. Lee et al. (2024) developed 3D imaging sensors to capture detailed information about various body parts of dairy cows. This allows all body areas to be assessed, allowing for tailored nutrient requirements. For example, milk production can be estimated from udder morphometry in FH cows (Soeharsono et al., 2020). With the help of 3D imaging sensors, udder size assessments are more accurate and milk production estimates can be generated, ultimately leading to an assessment of the livestock animals's nutrient needs

To measure feeding behavior, measurements using UHF RFID have emerged (Adrion et al., 2021). Currently, automated sensor systems are used to measure feeding behavior, but these are considered expensive for commercial use and require a substantial power supply (Adrion et al., 2021). UHF RFID allows for the measurement of feeding behavior using passive transponders without an internal power supply. Furthermore, measurements can also be made by recording mastication sounds using multimodal AI (Kate & Neethirajan 2025). The use of multimodal AI does not require the installation of any equipment on the livestock, thus avoiding discomfort that could raise animal welfare concerns.

Feeding behavior can also be assessed through video observation. TCS YOLO and Res-DenseYOLO are models developed from YOLOv5 (Yu et al., 2022; Yu et al., 2024). Both models improve the accuracy of YOLOv5 by increasing the resolution of the observed video, resulting in clearer and more accurate displays. For example, images of cows drinking will appear darker in Res-DenseYOLO compared to YOLOv5, making it easier for controllers, in this case farmers or farm staff, to focus on observing the livestock due to the clearer color contrast compared to their environment (Yu et al., 2024). With the continued development of studies supporting PF, it is not impossible that PF will become tech-savvy and commonplace in the future.

3.2 PF impact on the environment

The concept of PF as part of Precision Livestock Farming (PLF) emerged from the fact that livestock farming contributes to environmental pollution. Ruminant livestock produce over three-quarters of agricultural methane emissions, and within this group, the dairy sector contributes approximately 17% of the livestock industry's global greenhouse gas emissions (Nedelkov et al., 2024; Wang et al., 2024). Therefore, PF practices have been proven to address sustainability challenges while increasing productivity.

The PF practices in this literature review that have the greatest environmental impact are those related to improving feed quality and nutrition, as the intake given to dairy cattle influences the resulting emissions. The better the quality of feed and nutrients with accurate quantities, the less waste is produced. In a study done by Froldi et al. (2024), accurate GE and Digestible DE calculations can reduce CC and POCP indicators. It has been proven that livestock animal fed more digestible feed exhibit high feed efficiency, which has implications for high milk production and quality, and ultimately reduces emissions to the environment, such as methane (CH_4), which can be suppressed (Froldi et al., 2024). Providing highly digestible feed reduces the amount of feed animals need to consume, resulting in a fermentation process that is more efficient and shorter in duration.

Despite this, the primary source of feed for dairy cattle remains fiber (Hamidah et al., 2021). Therefore, combining it with other ingredients can be a solution as a PF approach. Some feed ingredients that can be used to improve digestibility are alfalfa and various legumes, such as *Indigofera zollingeriana* (Bosco et al., 2021; Antari et al., 2022). Based on the findings of Froldi et al. (2024), animals with lower performance often receive feed that is less digestible, typically sourced from the farm's own crop. The PF concept enables farmers to make more informed choices about which crops to grow on their farms, thus preventing the occurrence of such cases. Furthermore, the CC indicator can at least be reduced because output (in this case, milk) increases.

The PF concept also states that feeding must be precise, meaning it must be neither under-nor-over-feeding, both about quantity and nutrient levels. This means that feed should not be voluminous, aiming to prevent leftover feed, which could potentially pollute the environment if not managed properly (Ziaei & Amini, 2020). PF facilitates measurable feed quantity and quality, thus preventing the potential for waste from feed residue. The residue comes from remaining feed due to the less optimum consumption, such as health or palatability problem. By using tools like Rumiwatch and collars, farmers can detect this condition and make quick decisions, such as checking the condition or changing feed if necessary.

The same principle applies to nutrient levels. Most nutrient requirements in dairy cattle are often given in excess due to concerns about deficiencies, even though practice negatively affects sustainability as surplus nutrients are eventually excreted into the environment, for example, in manure containing nitrogen, phosphorus, and other trace minerals (Duplessis et al., 2021; Zahra et al., 2020; Chase & Fortina, 2023). High amounts of nitrogen, phosphorus, and trace mineral excretion can lead to detrimental environmental impacts (Chase & Fortina, 2023).

Therefore, nutrient with the potential to pollute the environment needs to be modified to avoid pollution while still supporting livestock performance. Potential environmental contaminants, such as CP, P, and especially other trace minerals like Cu, Co, Zn, and Mn, can only be effectively mitigated through the application of the PF concept, which involves adjusting nutrient requirements, then measured with precision tools, such as handheld NIRS (with appropriate calibration for minerals). This device can enhance feed-use efficiency while promoting environmentally sustainable practice (Yamada et al., 2024). From this it can be concluded that PF starts from adjustment requirements, then supported by other PF approaches through proper feeding management practices and the use of tools and ongoing model development.

3.3 PF impact on socioeconomic dimension

Precision Feeding (PF) may raise farmers' incomes by reducing feed expenses and simultaneously boosting both milk quantity and quality. Feed reconstruction using the PF approach, which groups livestock animal based on more specific criteria, has shown lower feed costs and higher milk production (Campos et al., 2021). Similarly, research by Chase &

Fortina (2023) found that CP, without ignoring dairy cow performance on feed, can reduce feed purchase costs. With reduced feed costs and increased production, the difference between selling price and production costs will be wider, ultimately increasing farmer income and improving welfare. The fact that PF offers numerous economic and practical benefits to dairy farming has revolutionized the dairy farming industry. The adoption of technology in farming is driven by various factors, including the reduction of labor inputs, maximization of productivity, and improvement of economic returns. This is a key focus in several countries, such as Brazil (Silvi et al., 2021).

Historically, dairy farming in the community was considered a conventional practice. For example, farmers spent time spent time cutting and carrying forag which caused them to bear a relatively heavy workload. Furthermore, demographic data indicate that the farming population is predominantly elderly. In Algeria, approximately 57% of farmers are over 45 years old, whereas in India, the proportion of elderly farmers is about 6% higher than that of younger farmers (Rajput et al., 2023; Meskini et al., 2022). This indicates that younger people tend to show limited interest in pursuing careers in dairy farming. Working in the agricultural sector is considered unpopular, leading to a lack of interest among young people, ultimately leading to increased urbanization (Girdziute et al., 2019). If this trend continues, not only will the number of dairy farmers decline, but the population will also increase in urban areas. Occupational demand in the food supply sector, specifically within dairy farming, is anticipated to decrease. In developing nations, rising urbanization often leads to denser populations and may negatively affect the economic standing of some communities (Rustiadi et al., 2021; Factura et al., 2022)

However, on the other hand, this situation can also be seen as a significant opportunity. Reductions in rural population can enhance the potential for land to be utilized for agricultural production (Wang et al., 2024). One form of this opportunity can be realized through the implementation of PF. PF has the potential to change people's perspectives on the livestock industry, particularly the dairy sector, which was previously seen as offering uncertain returns for business owners. With PF, this perception can change. If PF is implemented in the expansion of dairy farming businesses, it will be a unique incentive, especially for young people, to focus on developing dairy farming in rural areas. This will achieve sustainability, reduce rural migration and urban population density, also enable more equitable development.

3.4 Challenges and PF adoption in Indonesia

In Indonesia, smallholders in rural regions make up the majority of Indonesia's dairy producers, particularly in West and East Java (Ariningsih et al., 2022; Fadillah et al., 2023; BPS, 2024). However, there are also large-scale industries such as Ultra Jaya and Greenfield (Yanuar & Hoebink, 2023). Figure 3 illustrates the precision feeding approaches in Indonesia and the corresponding solutions to address local challenges.

PF applications will be easier to adapt in industrial-scale dairy farming because the large number of cattle makes the use of technology highly useful for increasing efficiency. The technology and models developed also offer opportunities for the growth of the manufacturing industry and research related to PF, which is expected to create new jobs. In contrast, the challenges of implementing PF in Indonesia actually arise from the smallholder dairy farming sector. Before discussing the application of technology further, the dairy cattle sector in Indonesia still faces its own challenges at the nutrient adjustment stage. Farmers typically give feed such as self-produced forage (natural grass and legumes), agricultural by-products, concentrate feed purchased from cooperatives, and other feed source, such as tofu by-product (Hamidah et al., 2021; Despal et al., 2021a). Some farmers also still use agricultural waste such as rice straw, which has low nutritional quality (Hamidah et al., 2021).

If low-quality feed is fed ad libitum to livestock without considering their needs, the potential for environmental pollution can increase. Conversely, livestock's animal fed with a feed composition tailored to their needs can use nutrients more efficiently, resulting in optimal milk production and quality (Adyatama et al., 2024). The next tool to support these nutrient adjustments is technology. PF is synonymous with technology that requires farmers to learn and implement new technologies affect higher production costs. The fact that farmers are predominantly older, have less education, and rely primarily on experience (Hamidah et al., 2021; Firman et al., 2025;) makes the implementation of this approach challenging. Younger farmers tend to be more receptive to new technologies, while older farmers are more likely to adhere to traditional methods (Zhang & Li, 2024). Furthermore, PF also relies on the Internet of Things (IoT), which requires an adequate internet network, which is generally more accessible in urban areas. Conversely, livestock farming in Indonesia is widely distributed in rural areas. Rural communities continue to face gaps in digital infrastructure, especially in obtaining reliable high-speed internet (Amalia et al., 2025).

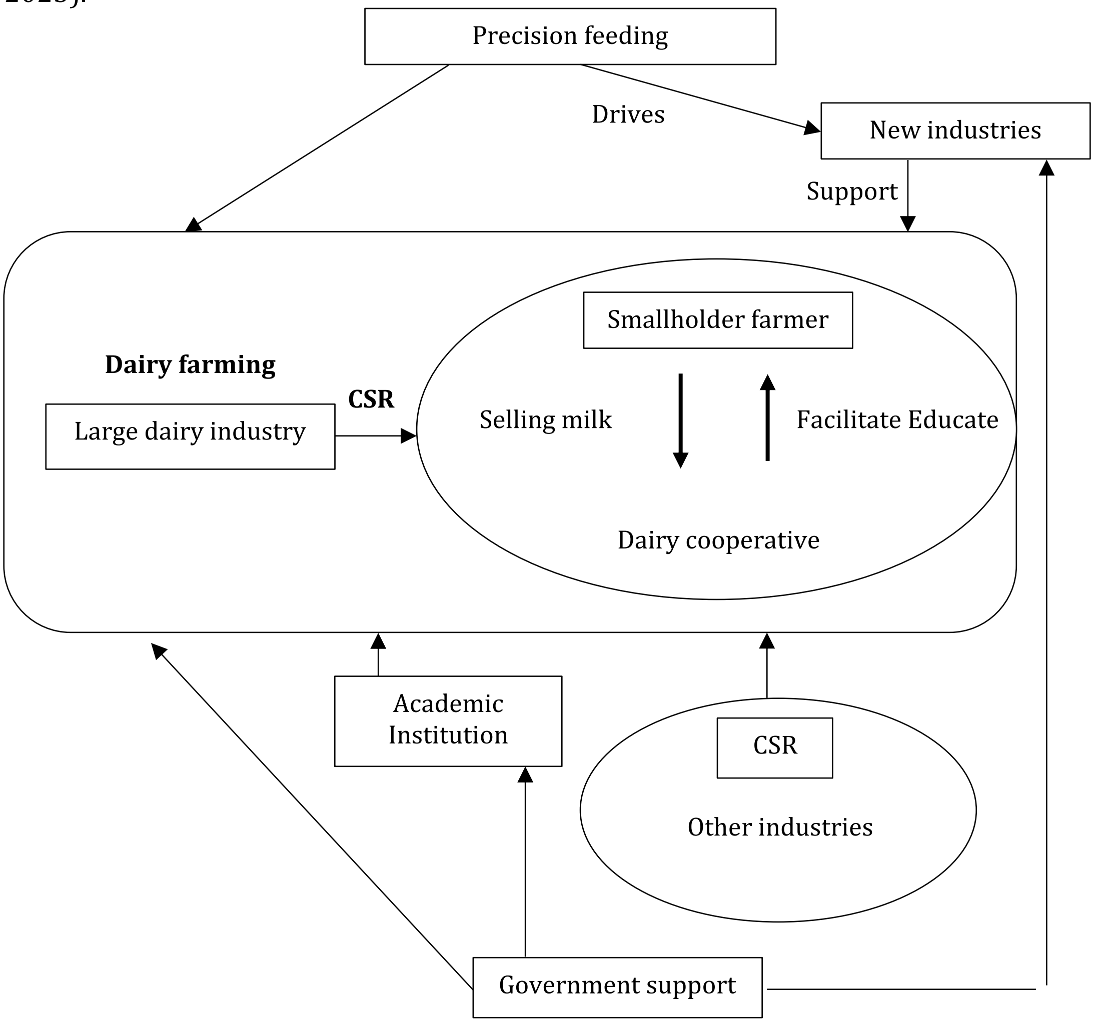

Fig. 3. Precision feeding implementation approach in Indonesia

The challenges that arise in implementing PF should not limit smallholder farmers' efforts to increase productivity. Efforts towards PF can begin with an approach tailored to livestock conditions in Indonesia. The existence of cooperatives actually acts as a facilitator in introducing PF to livestock farmers. Cooperatives play a role in increasing production, ensuring sustainability, and improving food security through interaction and education (Ghauri et al., 2022; Kalogiannidis et al., 2024).

The first step can begin with adjusting nutrient requirements and improving feed quality. Cooperatives serve as key suppliers of concentrate feed for dairy farmers (Nuraina et al., 2021), providing an opportunity to improve feed quality and adapt it to livestock nutrient needs in the field. Furthermore, cooperative managers in the livestock feed division can monitor forage quality using NIRS equipment as part of the PF approach. Forage used by farmers can be sampled to determine quality, allowing concentrate formulations to be tailored to livestock needs. Research on the use of NIRS in measuring forage has actually been initiated by Despal et al. (2021b). Through this research, cooperatives can adjust NIRS calibration by collaborating with academic institutions.

Furthermore, in the production of feed concentrate, the application of NDS with CNCPS as a basis for nutrient adjustment can be used to improve nutrient absorption in livestock. Technological adaptations such as weigh cell mixer wagons can also be used in concentrate mixing to improve accuracy. Other technologies, like automatic feeders, can actually be very helpful for farmers, just as automatic milking has long been widely used at the farm level (Palma-Molina et al., 2023). Nevertheless, the high cost of this technology frequently necessitates financial support through government programs or cooperative efforts supported by corporate social responsibility (CSR) initiatives.

Concentrate feed production within cooperatives is typically categorized by grade, and some cooperatives specialize in producing only one type (Nuraina et al. 2022; Alverina et al., 2025). The label on the concentrate feed adjustments can be addressed by adding more detailed information about recommended feeding amounts to avoid overfeeding and maintain compliance with needs, even if the concentrate feed type is limited. Besides, farmers must be adapted with feed preservation such as hay or silage to minimize their workload.

4. Conclusions

PF is a part of PLF that has many advantages in efforts to increase dairy cattle productivity in terms of milk quantity and quality. PF's scope includes adjusting nutrient needs and improving feed quality, grouping livestock based on more specific criteria beyond physiological status or body weight, using technology to reduce workload, and developing models to improve the accuracy of equipment and nutrient standards in livestock. PF can help lower environmental pollution associated with dairy production, including water, soil, and air pollution, thereby addressing the challenges of the SDGs to achieve sustainability.

Furthermore, PF also brings economic improvements and the welfare of farmers and has the potential to generate novel patterns and dynamics in community-based livestock farming. The implementation of PF in developing countries like Indonesia offers great potential despite significant challenges, particularly in technology application and internet network issues. Dairy farmer cooperatives hold a crucial role in the implementation of PF in Indonesia as a forum for farmers to continue to develop. Support from academic institution and CSR programs can be effectively implemented through cooperative organizations. Furthermore, the role of the government is also crucial to support the implementation of PF in the dairy farming sector through policies, regulations, and funding allocations so that PF runs in line with national goals.

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The authors hereby declare that ChatGPT, a generative AI, was used solely for grammar and language checking. All content, ideas, and analyses are my own. the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

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