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BRIDGING THE KNOWLEDGE GAP IN PRECISION DAIRY FARMING: AN IN-DEPTH SURVEY ON ARTIFICIAL INTELLIGENCE AWARENESS AND APPLICATION IN SMALL, MEDIUM, AND LARGE DAIRY FARMS OF NELLORE DISTRICT

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Abstract: This study explores the adoption of Artificial Intelligence (AI) technologies across dairy farms of varying sizes in Nellore district, focusing on technologies such as sensors and wearables, automated feeding systems, and smart barns. A total of 48 dairy farms were surveyed, categorized into small (up to 10 milch animals), medium (11 to 20 milch animals), and large (more than 20 milch animals) sizes, with equal representation from each category.
Results from the study indicated a clear trend larger farms are more likely to adopt advanced technologies compared to their smaller counterparts. Specifically, adoption rates for health monitoring and smart feeding technologies showed a positive correlation with farm size. For instance, large farms demonstrated significantly higher utilization rates for environmental sensors (87.50%) and automated feeding systems (93.75%) compared to small farms (50.00% and 43.75%, respectively). Medium-sized farms often showed intermediate adoption rates, but interestingly led in reproduction management technology.
The adoption patterns can be attributed to factors such as financial capacity, economies of scale, and risk management capabilities that are typically stronger in larger operations. These farms also exhibit a greater propensity towards technological engagement, likely driven by the potential for higher returns on investment and efficiency gains.
Despite the advantages observed in larger farms, the disparity in technology adoption raises concerns about a growing digital divide within the agricultural sector. Small and medium-sized enterprises (SMEs) face barriers such as cost, lack of technical expertise, and perceived irrelevance, which may hinder their competitive edge and sustainability.
The findings underscore the need for targeted support, including financial assistance, subsidies, and training programs tailored to smaller farms, to ensure broad-based access to beneficial technologies. This approach could help mitigate the digital divide and enhance productivity and sustainability across all sizes of dairy farms.
Keywords: Artificial Intelligence, Precision Dairy Farming, Dairy farms.

Introduction

Precision dairy farming represents a technological and management revolution in the dairy industry, focusing on the optimization of both production and animal welfare through the use of advanced technologies (Ellis *et al*.2020). This approach integrates various digital tools,

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sensors, and data analytics to monitor and manage the health, nutrition, and productivity of individual cows, ultimately leading to more efficient and sustainable dairy farming practices (Kumari *et al.* 2021). Awareness and adoption of AI in dairy farming depend on factors such as the level of technological infrastructure, education, and economic conditions in a particular region. Developed regions with advanced agricultural, animal management practices often exhibit higher levels of AI awareness and adoption compared to less developed areas.

In the realm of agriculture, dairy farming stands as a cornerstone industry, providing essential sustenance to communities worldwide (Raj *et al*. 2020). However, the traditional image of a farmer tending to their herd under the vast expanse of the sky has undergone a significant transformation. In its place, a new era has emerged – one driven by innovation, efficiency, and precision.

Precision dairy farming represents a paradigm shift in agricultural practices, propelled by cutting-edge technologies that optimize every facet of dairy production. At the heart of this revolution lie sensors and wearable's, miniature marvels that have reshaped how farmers monitor the health, behavior, and productivity of their livestock (Dora *et al*.2022) These devices, equipped with an array of sensors and sophisticated algorithms, offer real-time insights into the well-being of each individual animal, empowering farmers to make informed decisions and intervene promptly when necessary.

Accompanying this technological leap is the automated feeding system, a game-changer in the quest for efficiency and sustainability. Gone are the days of manual feeding routines; in their place stand automated systems that precisely dispense feed tailored to each cow's nutritional needs (Morota *et al*.2018) By leveraging data analytics and machine learning, these systems optimize feed utilization, minimize waste, and ensure that every animal receives the ideal diet for optimal health and productivity.

Furthermore, smart barns have emerged as the cornerstone of modern dairy operations, seamlessly integrating various technologies to create an environment conducive to the well-being of both livestock and farmers. Equipped with climate control systems, automated ventilation, and advanced monitoring capabilities, these intelligent structures provide a comfortable and stress-free habitat for dairy cows, enhancing their overall welfare and performance.

In this introductory exploration of precision dairy farming, we delve into the transformative potential of technology in revolutionizing traditional agricultural practices. From sensors and wearable's to automated feeding systems and smart barns, each innovation plays a pivotal role in shaping the future of dairy farming. As we navigate the intricate intersection of agriculture and technology, we uncover a world of possibilities, where efficiency, sustainability, and animal welfare converge to redefine the very essence of dairy farming.

Methodology

Study Area

The present research study was undertaken in the dairy farms of Nellore district on awareness of Artificial Intelligence and its application on dairy farming activities, categorizing them into small-sized (up to 10 milch animals), medium-sized (11 to 20 milch animals), and large-sized (more than 20 milch animals). During the investigation, dairy farm owners were interviewed using a predefined proforma to gather information on the adoption of various technologies. The technologies in focus included i) sensors and wearables, ii) automated feeding systems, iii) smart barns and climate control, iv) genomic technologies, and v) drones and satellite technology. The data analyzed using standard statistical procedure.

Results

The survey data collected from 48 Dairy farms, divided evenly into small, medium, and large operations (n=16 each), provided insights into the adoption rates of various Sensors and wearable's, automated feeding systems and Smart Barns and Climate across different farm sizes. The results demonstrated a clear trend that larger farms tend to have higher adoption rates of various Sensors and wearable's, automated feeding systems and Smart Barns and Climate technologies compared to smaller farms.

Table 1 indicates that Activity Monitors Utilization rates were 50.00% for small, 62.50% for medium, and 81.25% for large farms, with an overall adoption rate of 64.58%. Health Monitoring a substantial adoption with rates ascending from small (56.25%) to medium (75.00%) and peaking at large (93.75%), averaging 75.00% across all farms. Location Tracking Adoption varied significantly with size, starting at 37.50% for small, 68.75% for medium, and 87.50% for large farms, with a total of 64.58%. Environmental Sensors these were implemented by 50.00% of small farms, 75.00% of medium farms, and 87.50% of large farms, leading to an overall adoption of 70.83%. Feed Management Observed adoption rates were 43.75% for small, 68.75% for medium, and 93.75% for large farms, totaling 68.75%. Reproduction Management Usage was highest among medium farms (81.25%), followed by small (62.50%), and then large farms (68.75%), resulting in an overall rate of 70.83%. Robotics Here, a substantial disparity was noted, with adoption rates of 37.50% for small, 87.50% for medium, and 93.75% (rounded from 93.57%) for large farms, amounting to

72.91%. Wearable Technology Adoption was robust across farm sizes with 56.25% for small, 81.25% for medium, and 93.75% for large farms, averaging 75.00%. Data Analytics and Connectivity the rates were 43.75% for small, 75.00% for medium, and 87.50% for large farms, totaling 68.75%.

Table 1: Sensors and wearable's

S.No	Farming activity	Small (n=16)	Medium (n=16)	Large (n=16)	Total (N=48)
1	Activity Monitors	8 (50.00)	10 (62.50)	13 (81.25)	31(64.58)
2	Health Monitoring	9 (56.25)	12 (75.00)	15 (93.75)	36 (75.00)
3	Location Tracking	6 (37.50)	11(68.75)	14 (87.50)	31 (64.58)
4	Environmental Sensors	8 (50.00)	12 (75.00)	14 (87.50)	34(70.83)
5	Feed Management	7 (43.75)	11(68.75)	15(93.75)	33 (68.75)
6	Reproduction Management	10(62.50)	13(81.25)	11(68.75)	34 (70.83)
7	Robotics	6 (37.50)	14(87.50)	15(93.57)	35(72.91)
8	Wearable Technology	9 (56.25)	13(81.25)	15(93.75)	36(75.00)
9	Data Analytics and Connectivity	7 (43.75)	12(75.00)	14(87.50)	33(68.75)

(Values in parentheses are percentages)

Table 2 demonstrated the Precision Feeding Smart Feeders these devices were significantly more prevalent on larger farms (93.75%) compared to medium (75.00%) and small farms (37.50%). Overall, 68.75% of all surveyed farms used smart feeders. Data-driven Decision Making Feed Management Software Usage was highest among large farms (87.50%), followed by medium (62.50%) and small farms (25.00%), with a total adoption rate of 58.33%. Real-time Monitoring Sensors and Cameras Adoption were relatively high with 81.25% on large farms, 68.75% on medium farms, and 31.25% on small farms, indicating a total usage of 60.41%. Automatic Silage and Grain Dispensers Automated Silage Cutters and Grain Dispensers Both technologies showed similar trends with the highest adoption on large farms (93.75% for cutters, 87.50% for dispensers) and lowest on small farms (43.75% for cutters, 50.00% for dispensers). Robotic Feed Pushers Robotic Systems Larger farms again showed a higher adoption rate (81.25%) compared to medium (68.75%) and small farms (18.75%). Mobile Feeding Robots Autonomous Vehicles These were utilized by 87.50% of large farms, 75.00% of medium farms, and only 12.50% of small farms. Automated Mixing

Systems TMR Mixers Adoption was notably high on large (93.75%) and medium (81.25%) farms, with smaller farms lagging at 37.50%. Remote Monitoring and Control Internet of Things (IoT) This technology saw a steady increase in adoption with increasing farm size (31.25% on small farms to 87.50% on large farms). Integration with Precision Agriculture Precision Agriculture Technologies Adoption rates ranged from 18.75% on small farms to 81.25% on large farms. Adaptive Feeding Strategies Weather and Environmental Sensors Again, larger farms (87.50%) had higher rates of adoption compared to medium (62.50%) and small farms (31.25%).

Table 2: Automated feeding system

S.No	Farming activity	Small (n=16)	Medium (n=16)	Large (n=16)	Total (N=48)
1	Precision Feeding				
	a. Smart Feeders	6(37.50)	12(75.00)	15(93.75)	33(68.75)
2	Data-driven Decision Making				
	a. Feed Management Software	4(25.00)	10(62.50)	14(87.50)	28(58.33)
3	Real-time Monitoring				
	a. Sensors and Cameras	5(31.25)	11(68.75)	13(81.25)	29(60.41)
4	Automatic Silage and Grain Dispensers				
	a. Automated Silage Cutters	7(43.75)	13(81.25)	15(93.75)	35(72.91)
	b. Grain Dispensers	8(50.00)	12(75.00)	14(87.50)	34(70.83)
5	Robotic Feed Pushers				
	a. Robotic Systems	3(18.75)	11(68.75)	13(81.25)	27(56.25)
6	Mobile Feeding Robots				
	a. Autonomous Vehicles	2(12.50)	12(75.00)	14(87.50)	28(58.33)
7	Automated Mixing Systems				
	a. TMR (Total Mixed Ration) Mixers	6(37.50)	13(81.25)	15(93.75)	34(70.83)
8	Remote Monitoring and Control				
	a. Internet of Things (IoT)	5(31.25)	10(62.50)	14(87.50)	29(60.41)
9	Integration with Precision Agriculture				
	a. Precision Agriculture Technologies	3(18.75)	9(56.25)	13(81.25)	25(52.08)
10	Adaptive Feeding Strategies				
	a. Weather and Environmental Sensors	5(31.25)	10(62.50)	14(87.50)	29(60.41)

(Values in parentheses are percentages)

Table 3 findings are as follows Environmental Monitoring Temperature sensors, humidity sensors, and ventilation systems are more commonly implemented as the size of the farm increases, with large farms showing the highest adoption (up to 93.57% for ventilation systems). Automated Heating and Cooling A dramatic rise in adoption was noted in larger farms, particularly for heating (81.25%) and cooling systems (93.57%), compared to significantly lower rates in small and medium farms. Lighting Control LED lighting adoption rates showed a strong size correlation, with small farms at 18.75% and large farms at 87.50%. Automated Curtains and Blinds Adoption was generally low but increased with farm size, particularly for curtain systems in large farms (68.75%).IoT Integration IoT sensors and data analytics showed notably low adoption across all sizes but increased notably on larger farms (50.00% and 43.75%, respectively).Feeding and Watering Automation Again, there was a marked increase in adoption as farm size increased, especially with automated watering systems where large farms reported 93.57% adoption. Livestock Tracking and Monitoring Adoption of RFID tags and GPS, as well as health monitoring devices, was higher in large farms, indicating a trend towards more sophisticated monitoring systems correlating with farm size. Security Systems Surveillance cameras and intrusion detection systems were more commonly used on larger farms, with adoption rates at 93.75% and 68.75%, respectively. Automated Waste Management There was a considerable increase in the implementation of manure handling systems on larger farms, reaching a 75.00% adoption rate. Integration with Precision Agriculture Farm management software adoption was highest in large farms at 87.50%, indicating a trend towards greater technological integration in larger operations.

Table 3: Smart Barns and Climate

S.No	Farming activity	Small (n=16)	Medium (n=16)	Large (n=16)	Total (N=48)
1	Environmental Monitoring				
	a. Temperature Sensors	3 (18.75)	10 (62.50)	12 (75.00)	25 (52.08)
	b. Humidity Sensors	4 (25.00)	9 (56.25)	14 (87.50)	27 (56.25)
	c. Ventilation Systems	5 (31.25)	11(68.75)	15 (93.57)	31(64.58)
2	Automated Heating and Cooling				
	a. Heating Systems	2 (12.50)	4 (25.00)	13(81.25)	19 (39.58)
	b. Cooling Systems	4 (25.00)	7 (43.75)	15 (93.57)	26 (54.16)
3	Lighting Control				
	a. LED Lighting	3 (18.75)	12 (75.00)	14(87.50)	29(60.41)
4	Automated Curtains and Blinds				
	a. Curtain Systems	2 (12.50)	3(18.75)	11(68.75)	16(33.35)

	b. Blinds	1(6.25)	2 (12.50)	9(56.25)	12(25.00)
5	IoT Integration				
	a. Internet of Things (IoT) Sensors	1(6.25)	2 (12.50)	8 (50.00)	11(22.91)
	b. Data Analytics	0	1(6.25)	7(43.75)	8 (16.66)
6	Feeding and Watering Automation				
	a. Automated Watering Systems	4(25.00)	8(50.00)	15(93.57)	27(56.25)
	b. Smart Feeders	3(18.75)	6(37.50)	14(87.50)	23(47.91)
7	Livestock Tracking and Monitoring				
	a. RFID Tags and GPS	2(12.50)	8 (50.00)	15(93.57)	25(50.00)
	b. Health Monitoring Devices	3 (18.75)	5 (31.25)	13(81.25)	21(43.75)
8	Security Systems				
	a. Surveillance Cameras	5(31.25)	9(56.25)	15(93.75)	29 (60.41)
	b. Intrusion Detection Systems	2(12.50)	4(25.00)	11(68.75)	17(35.41)
9	Automated Waste Management				
	a. Manure Handling Systems	3(18.75)	5(31.25)	12(75.00)	20(41.66)
10	Integration with Precision Agriculture				
	a. Farm Management Software	2(12.50)	6(37.50)	14(87.50)	22(45.83)

(Values in parentheses are percentages)

Discussion

The results of Table 1 underscore a consistent trend where larger farms are more likely to adopt sophisticated sensor and wearable technologies. Several factors influence this pattern Financial Capacity Larger farms generally have more financial resources, enabling them to invest in advanced technologies that can be cost-prohibitive for smaller operations. Economies of Scale The larger scale of operations on big farms often justifies the initial high investment costs of technologies due to more significant benefits and efficiencies gained. Risk Management Advanced technologies help in better managing risks associated with livestock health and environmental conditions, a critical factor for larger farms aiming to optimize productivity and prevent losses. Technological Engagement There is often a greater willingness and capacity on larger farms to engage with and implement new technologies, which may include having staff with specialized technical skills.

However, the data also reveals interesting insights regarding certain technologies like reproduction management, where medium farms lead in adoption rates, possibly indicating specific needs or benefits perceived in this category that align closely with the operational scale and focus of medium-sized farms. Overall, while the trend towards higher technology adoption on larger farms is clear, it is crucial for the agricultural sector to consider how smaller farms can be supported in accessing these technologies. This may involve the development of more cost-effective solutions or offering financial assistance and training to small and medium-sized enterprises (SMEs) to reduce the digital divide in agriculture.

The survey results Table 2 clearly indicate that the size of the farm correlates with the adoption of automated feeding systems, with larger farms more likely to implement sophisticated technologies. This could be attributed to several factors Economic Scale Larger farms typically have more resources and capital to invest in advanced technologies, which can be expensive and complex to implement. Labor Efficiency Automation can significantly reduce labor costs, which is a more critical factor for larger operations where the scale of activities can justify the investment. Return on Investment (ROI) Larger operations may achieve quicker and higher ROI due to the volume of production, making the upfront costs of technology more manageable. Technological Adoption Larger farms may also have more technical expertise and are more inclined to adopt innovations that can further optimize their operations.

This trend raises concerns about the digital divide in agriculture, where smaller farms might lag behind in technological adoption, potentially affecting their competitiveness and sustainability. Efforts to provide more scalable and affordable solutions or subsidies could help bridge this gap, ensuring that smaller farms are not left behind in the agricultural technology revolution.

The data in Table 3 clearly illustrates that larger farms are more likely to adopt technologies associated with smart barns and climate control. This trend can be attributed to several factors. Resource Availability Larger farms typically have greater financial and human resources, which allows them to invest in advanced technologies that may be cost-prohibitive for smaller operations. Economies of Scale**:** The benefits of these technologies, such as increased productivity, efficiency, and risk management, are more pronounced in larger operations, justifying the initial investment. Operational Complexity**:** Larger farms often face more complex operational challenges, which these technologies can help mitigate.

However, the relatively lower adoption rates in small and medium-sized farms indicate potential barriers such as cost, lack of technical expertise, or perceived relevance of the technology to their operations. Addressing these barriers through targeted support programs, subsidies, and education could help increase technology adoption across all farm sizes.

Conclusion

As farm operations become increasingly data-driven, integrating the latest technologies could provide substantial benefits in terms of operational efficiency, environmental sustainability, and animal welfare. The data suggests that there is still substantial room for growth in the adoption of these technologies, especially among smaller farms. Encouragingly, as technology costs decrease and access to technical support improves; these barriers may lessen, leading to wider adoption across the livestock and agricultural sector. The importance of modern technologies in dairy farming cannot be overstated. They revolutionize traditional practices, making dairy farms more efficient, sustainable, and profitable while ensuring high standards of animal welfare and quality production. As technology continues to advance, its role in shaping the future of dairy farming is set to become even more significant, heralding a new era of smart, sustainable agriculture.

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