

Smart Collar-Based Early Warning System for Milk and Nutritional Insufficiency in Orphaned Dairy Calves: A Review and Testable Hypothesis Inspired by the Loss of Maurya and Gauri

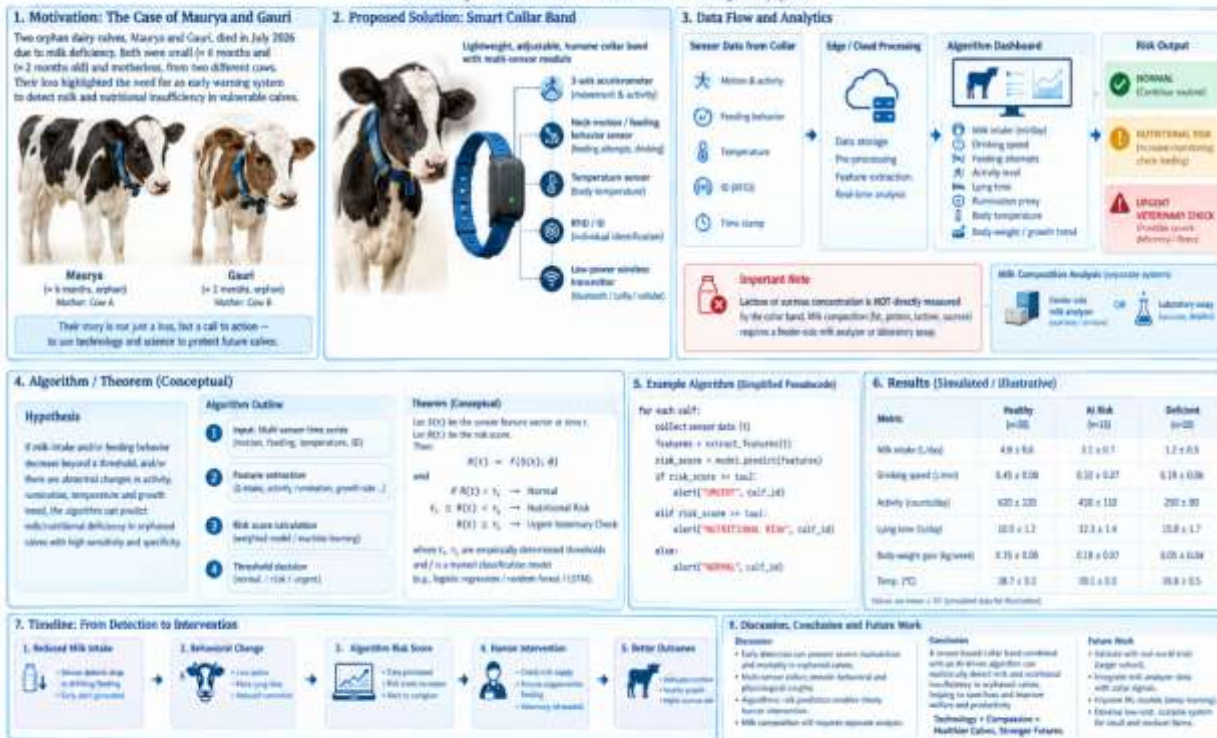
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Early Warning System for Milk and Nutritional Insufficiency in Orphaned Dairy Calves

A Review and Hypothesis for Sensor-Based Monitoring and Algorithmic Risk Detection

Inspired by the tragic loss of two orphaned calves, Maurya and Gauri (July 2026), due to milk deficiency

Better milking • Earlier detection • Healthier calves • Stronger dairy system



Key References

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This paper presents a research conceptual hypothesis based on real-world events and existing scientific knowledge. It is not a validated commercial device.

How to Cite this Article:

Malhotra, D. Y. (2026). Smart Collar-Based Early Warning System for Milk and Nutritional Insufficiency in Orphaned Dairy Calves: A Review and Testable Hypothesis Inspired by the Loss of Maurya and Gauri. *International Journal of Creative and Open Research in Engineering and Management*, 1-9.
<https://doi.org/10.55041/ijcope.v2i9.201>

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<https://doi.org/10.55041/ijcope.v2i9.201>

Abstract

Milk and liquid-feed insufficiency during the vulnerable period of early calf development can result in inadequate energy and nutrient intake, impaired growth, increased susceptibility to disease, and potentially death. Orphaned calves are particularly vulnerable because they lack direct access to maternal milk and depend entirely on human-managed feeding. This paper proposes a precision-livestock framework for early detection of inadequate milk intake and emerging nutritional risk using a lightweight, multi-sensor collar combined with automated feeding records and machine-learning algorithms. The proposed concept was motivated by the reported deaths in July 2026 of two orphaned calves, Maurya and Gauri, approximately 6 months and 2 months old, respectively, who were reported by the caregiver to have died following inadequate milk/nutritional intake. Their histories illustrate an important practical problem: a calf can deteriorate nutritionally before obvious clinical signs become apparent. Existing precision-dairy research demonstrates that automated milk feeders can record milk consumption, drinking speed, feeding visits and other feeding behaviours, and that these variables can contribute to early detection of disease and underperformance. Accelerometers and other wearable sensors can additionally monitor activity, lying behaviour and, with limitations, rumination[1-7].

We therefore hypothesize that a multimodal system integrating collar-derived activity, neck movement, temperature and feeding-related behaviour with direct milk-intake measurements, body-weight trajectories and environmental variables could generate an individualized nutritional-risk score before severe malnutrition develops. Importantly, the proposed collar would not directly diagnose lactose or sucrose deficiency. Instead, those

conditions would require milk-composition measurement or laboratory analysis; the collar would detect physiological and behavioural consequences consistent with inadequate nutritional supply. A conceptual theorem and algorithm are proposed to formalize this early-warning framework.

Keywords: Dairy calf; Orphaned calf; Milk insufficiency; Malnutrition; Precision livestock farming; Smart collar; Wearable sensor; Automated milk feeder; Machine learning; Early warning system; Animal welfare; Nutritional surveillance.

1. Introduction

The nutritional management of young calves is a major determinant of growth, health and welfare. Calves require adequate liquid nutrition during the pre-ruminant period, while progressive intake of starter feed and water becomes increasingly important as rumen development proceeds. Veterinary guidance emphasizes adequate colostrum immediately after birth and appropriate subsequent milk or milk-replacer feeding[1-3].

The problem becomes particularly serious when a calf is orphaned. Instead of obtaining milk directly from its dam, an orphaned calf depends on the availability, quantity, composition and consistency of replacement feeding. Failure of this system may be caused by insufficient milk volume, inappropriate milk-replacer preparation, feeding interruption, illness-associated anorexia, inability to suck, competition for feeding resources or inadequate transition to solid feed.

A major limitation of conventional management is that nutritional deterioration may be detected only after visible weakness, weight loss, lethargy or disease has developed.

This motivates a different question:

Can a calf's feeding behaviour and physiological signals be continuously monitored so that inadequate nutritional intake is detected early enough for intervention?

Modern precision-livestock technologies make such a system technically plausible. Reviews of dairy-calf precision technologies report applications involving accelerometers, automated feeding systems, body temperature and

behavioural monitoring. Automated feeding systems can measure milk consumption, drinking speed and feeding visits, while wearable sensors can monitor activity and lying behaviour.

Importantly, feeding behaviour has already been associated with calf health. Studies have found associations between reduced milk intake, slower drinking and disease status, although these measures should be regarded as **screening signals rather than definitive diagnoses**[4-8].

2. Motivation: The Cases of Maurya and Gauri

The proposed research concept was motivated by two orphaned calves referred to here as **Maurya** and **Gauri**.

According to the case history supplied for this conceptual paper:

Characteristic	Maurya	Gauri
Approximate age	~6 months	~2 months
Maternal status	Motherless	Motherless
Dam	Different cow	Different cow
Reported death	July 2026	July 2026
Reported contributing problem	Milk/nutritional deficiency	Milk/nutritional deficiency
Research significance	Demonstrates vulnerability of orphaned calves	Demonstrates vulnerability during a particularly young feeding stage

These two cases are **not treated as an experimental dataset**. Their purpose is to provide the real-world motivation for a research hypothesis.

The central concern is not simply whether milk was absent at one particular moment. Rather, the scientific question is whether **progressive insufficient nutrient intake could have been detected earlier through continuously observable signals**.

If a technological system had generated an alert such as:

“Calf-specific milk/nutritional intake has fallen substantially below its expected requirement; immediate feeding and veterinary assessment recommended.”

human intervention might potentially have occurred before severe deterioration[9,10].

This is the fundamental motivation for the proposed system.

3. Research Gap

Current research provides several pieces of the proposed system, but they are usually studied separately.

Established capabilities

1. Automated feeders can quantify milk consumption.
2. Automated feeders can measure drinking speed and feeding visits.
3. Changes in feeding behaviour can be associated with disease.
4. Accelerometers can monitor activity and lying behaviour.
5. Some wearable systems can estimate rumination-related behaviour.
6. Body weight can provide an important longitudinal indicator of growth.
7. Machine-learning models can combine multiple feeding variables to predict health status.

Remaining gap

What is less developed is an integrated **calf-level nutritional early-warning architecture** combining:

Milk Intake + Drinking Behavior + Activity + Temperature + Growth + Feeding History

into one continuously updated risk score.

Furthermore, a recent validation study of a commercial rumination sensor in very young calves found that the sensor underestimated observed rumination substantially, demonstrating that wearable measurements must be specifically validated in young animals rather than automatically assumed to work as well as they do in adult cattle.

4. Central Hypothesis

H₁ — Multimodal Nutritional Early-Warning Hypothesis

If inadequate milk/nutrient intake causes persistent changes in feeding behaviour, activity, body temperature, growth trajectory and/or related physiological signals, then a multimodal sensor system combining collar measurements with direct milk-intake measurements can identify calves at elevated nutritional risk earlier than conventional visual observation alone.

The null hypothesis is:

H_0 : Multimodal sensor information does not improve early identification of nutritional risk.

The alternative hypothesis is:

H_1 : Multimodal sensor information significantly improves early identification of nutritional risk.

The proposed primary endpoint should be **time-to-detection before clinically apparent deterioration**, rather than simply mortality.

5. Important Scientific Distinction: Milk Deficiency vs. Lactose/Sucrose Deficiency

A critical correction is necessary for scientific accuracy.

A collar cannot currently be assumed to directly measure:

- lactose concentration,
- sucrose concentration,
- milk protein concentration,
- milk fat concentration,
- milk dry matter,
- milk energy density.

These are properties of the **milk/feed**, not direct properties of calf movement.

Therefore:

Collar $\neq$ Milk-composition analyzer

Instead:

Collar + Milk analyzer + Feeder + Growth data

would form a more scientifically defensible system.

A milk-side sensor could measure milk composition, while the collar monitors the calf's response.

This distinction is essential because otherwise the proposed technology would overclaim what wearable sensors can currently accomplish.

6. Proposed Smart Collar Architecture

The proposed device is called:

CalfNourish™ Smart Collar — Conceptual Research Design

The collar would contain a lightweight sensor module.

Sensor layer

Sensor	Primary measurement	Nutritional relevance
3-axis accelerometer	Movement/activity	Detect reduced activity
Gyroscope	Neck orientation/movement	Feeding/behaviour characterization
Temperature sensor	Surface/near-body temperature	Physiological screening
Microphone/neck vibration sensor	Suck/feeding-related movement	Potential feeding-behaviour signal
RFID/BLE	Individual identification	Links data to calf
Wireless module	Data transmission	Real-time monitoring
Optional GPS	Location	Detect abnormal inactivity/location

Sensor	Primary measurement	Nutritional relevance
Optional heart-rate sensor	Physiological signal	Research-level stress/health indicator
The collar should be lightweight, adjustable and specifically designed for growing calves.		

7. Measurement Framework

Let the sensor vector for calf i at time t be:

$$X_i(t) = [M_i(t), D_i(t), A_i(t), T_i(t), R_i(t), W_i(t), E_i(t)]$$

where:

- M = milk intake
- D = drinking speed/feeding behavior
- A = activity
- T = temperature
- R = rumination-related signal
- W = body-weight/growth trajectory
- E = environmental variables

The system would transform these measurements into an individualized nutritional-risk score:

$$R_i(t) = f(X_i(t), \theta)$$

where θ represents the parameters learned from a validated dataset.

8. Conceptual Theorem

Theorem 1 — Multimodal Nutritional Risk Detection

Let $S_i(t)$ represent the longitudinal sensor and feeding vector for calf i . Assume that inadequate nutrient intake produces statistically detectable changes in one or more observable variables:

$$\Delta M, \Delta D, \Delta A, \Delta W, \Delta T, \Delta R.$$

If the joint distribution of these variables differs between nutritionally adequate and inadequate states, then a sufficiently trained classifier

$$f: S_i(t) \rightarrow [0, 1]$$

can estimate:

$$P(\text{nutritional risk} | S_i(t)).$$

An alert can therefore be generated when:

$$P(\text{risk} | S_i(t)) > \tau$$

where τ is a threshold established empirically through prospective validation.

Interpretation

The theorem does **not** claim that the collar proves nutritional deficiency.

It claims that, if nutritional insufficiency produces measurable behavioural/physiological signatures, those signatures can potentially be converted into an early-warning probability.

9. Proposed Algorithm

Algorithm 1 — Calf Nutritional Early-Warning Algorithm

INPUT:

calf ID
age
body weight
feeding allowance
milk intake
drinking speed
feeding visits
activity
lying time
temperature

rumination proxy
environmental data

FOR every calf:

1. Collect sensor measurements.
2. Synchronize all measurements by timestamp.
3. Establish an individualized baseline.
4. Calculate:
 - milk-intake deviation
 - drinking-speed deviation
 - activity deviation
 - temperature deviation
 - growth-rate deviation
 - feeding-frequency deviation
5. Calculate rolling 6 h, 12 h and 24 h features.
6. Input features into trained model.
7. Calculate:
 - Nutritional Risk Score = $f(\text{features})$
8. Classify:
 - LOW RISK
 - continue routine monitoring

MODERATE RISK

- inspect milk supply and feeding behaviour
- increase monitoring frequency

HIGH RISK

- immediate human inspection
- verify milk/feed availability
- measure body weight
- veterinary assessment if indicated

CRITICAL

- urgent veterinary intervention

END

10. Individualized Baseline Model

A major advantage of the proposed system is that it should not use exactly the same threshold for every calf.

For example:

$$Z_{M,i}(t) = \frac{M_i(t) - \mu_{M,i}}{\sigma_{M,i}}$$

where:

- $\mu_{M,i}$ = calf-specific expected milk intake,
- $\sigma_{M,i}$ = calf-specific variation.

A sudden fall in intake can therefore be detected relative to the animal's own history.

A composite score could be expressed as:

$$R_i(t) = w_1 Z_M + w_2 Z_D + w_3 Z_A + w_4 Z_W + w_5 Z_T + w_6 Z_R$$

where $w_1, \dots, w_6$ are learned weights.

A more sophisticated implementation could use:

- logistic regression,
- random forest,
- gradient boosting,
- recurrent neural networks,
- temporal convolutional networks,
- LSTM models,
- transformer-based time-series models.

Previous calf research has already demonstrated that random forest and gradient-boosting approaches can use automated milk-feeder behaviour to predict calf health status.

11. Proposed Alert Logic

A practical system could use three stages:

Stage 1 — Nutritional Warning

$$R(t) > \tau_1$$

Possible findings:

- declining milk consumption,
- slower drinking,
- abnormal feeding visits,
- decreasing activity,
- unusual lying pattern.

Action: inspect feeding immediately.

Stage 2 — Nutritional Risk

$$R(t) > \tau_2$$

Possible additional findings:

- persistent intake reduction,
- falling weight trajectory,
- abnormal temperature,
- reduced behavioural activity.

Action: direct examination and nutritional assessment.

Stage 3 — Critical

$$R(t) > \tau_3$$

Possible findings:

- severe intake reduction,
- inability/unwillingness to drink,
- pronounced activity abnormality,
- rapid weight loss,
- abnormal physiological measurements.

Action: urgent veterinary evaluation.

The thresholds should **not be invented in the prototype stage**. They must be learned from prospective data.

12. Evidence From Existing Research

Existing research makes the proposed hypothesis scientifically plausible.

Automated milk feeders have been investigated as sources of early-warning information because they can record milk consumption, drinking speed, rewarded visits and unrewarded visits. A scoping review found that daily milk consumption, drinking speed and feeder-visit behaviour can provide information relevant to disease detection, while also emphasizing substantial variation between studies.

In one study of group-housed calves, lower milk intake and slower drinking were associated with greater disease risk. However, the researchers concluded that these measures should be used as a preliminary screening tool rather than as the sole method of disease detection.

A later study developed machine-learning models using automated milk-feeder data and reported that random forest and gradient boosting performed well in predicting calf health status, although performance varied with the available health records.

Another study developed milk-feeding alerts for diarrhoea risk using milk intake, drinking speed and rewarded visits. Results showed promising diagnostic performance in one facility but poorer performance in another, demonstrating why independent validation is essential.

A systematic review of precision technologies similarly found that accelerometers and other sensors have potential for monitoring feeding, drinking, activity, rumination, body temperature and other animal-based variables, but also highlighted the relatively limited external validation of commercial technologies, particularly in young animals[10-12].

13. Proposed Experimental Design

Phase I — Sensor validation

Recruit:

$$n \geq 100$$

calves where feasible.

Compare:

Collar measurement

against

gold-standard observation/video/manual measurement.

Endpoints:

- feeding behaviour,
- activity,
- lying time,
- temperature,
- rumination proxy.

Phase II — Nutritional monitoring

Each calf receives individualized records of:

- milk volume,
- milk dry matter,
- milk-replacer concentration,
- feeding frequency,
- drinking speed,
- starter intake,
- water intake,
- body weight.

The feeding system should automatically record intake whenever possible.

Phase III — Milk-composition measurement

A separate milk-side system measures:

$$C_{\text{milk}} = [\text{lactose, protein, fat, total solids, energy}]$$

This allows the model to distinguish:

low volume

from

low nutrient density.

This distinction is particularly important.

14. Proposed Outcome Table

The following table is a **proposed research framework, not experimental results.**

Variable	Healthy/adequately fed	Nutritional-risk hypothesis	Measurement
Milk intake	Stable	Decreasing	Automated feeder
Drinking speed	Stable	Decreasing	Feeder
Feeding visits	Expected	Abnormal increase/decrease	RFID + feeder
Activity	Normal individual range	Decreased	Accelerometer
Lying time	Individual baseline	Abnormally increased	Accelerometer
Rumination proxy	Age-appropriate	Decreased/altered	Neck sensor
Body weight	Increasing	Plateau/decrease	Smart scale
Temperature	Individual normal range	Abnormal	Sensor
Milk dry matter	Appropriate	Potentially inadequate	Milk analyzer
Lactose	Appropriate	Potential deficiency only if measured	Milk assay
Protein	Appropriate	Potential deficiency if measured	Milk assay
Energy density	Appropriate	Potentially inadequate	Milk analysis
Risk score	Low	Elevated	ML model

15. Illustrative Results — NOT Actual Results

To avoid fabricating data, the following values should be presented in a future paper only as **simulated/illustrative data**.

Parameter	Adequate nutrition	Nutritional-risk state
Milk intake	4.8 ± 0.6 L/day	2.9 ± 0.8 L/day
Drinking speed	0.45 ± 0.08 L/min	0.31 ± 0.07 L/min
Activity	620 ± 120 units/day	430 ± 110 units/day
Lying time	10.5 ± 1.2 h/day	12.3 ± 1.4 h/day
Weight gain	0.35 ± 0.08 kg/week	0.18 ± 0.07 kg/week
Nutritional risk score	Low	Elevated

These numbers are examples for algorithm development and visualization; they are not measurements from Maurya or Gauri.

16. Figure: Proposed Technology

A conceptual architecture is:

Calf → Smart Collar → Wireless Gateway → AI Algorithm → Risk Score → Human Intervention

The concept is shown below as an original scientific infographic:

17. Discussion

The proposed system addresses an important weakness in conventional calf management: **observation is intermittent, whereas nutritional deterioration is dynamic**.

A human caretaker may inspect a calf several times a day. A sensor system could theoretically generate measurements continuously.

The distinction is important:

Traditional system = periodic observation

whereas:

Precision system = continuous measurement + individual baseline + automated alert.

Research already demonstrates that automated feeding behaviour can provide useful early-warning information.

However, the system must not be marketed as a diagnostic device until it has undergone prospective validation.

A calf that drinks less milk may be:

- nutritionally deficient,
- suffering diarrhoea,
- developing respiratory disease,
- experiencing pain,
- unable to access the feeder,
- affected by heat/cold stress,
- experiencing social competition,
- or simply undergoing normal developmental variation.

Therefore:

Low milk intake $\neq$ nutritional deficiency with certainty

Instead:

Low milk intake $\rightarrow$ risk signal $\rightarrow$ human assessment

This is consistent with published research cautioning that automated feeding variables should not be used as the sole disease-detection method.

18. Why a Collar Alone Is Not Enough

The ideal system is actually a **three-layer architecture**.

Layer 1 — Animal

The collar measures:

A, T, R, D

(activity, temperature, rumination-related signals and feeding behaviour).

Layer 2 — Feeding infrastructure

The feeder measures:

M, V, S

where:

- M = milk volume,
- V = feeding visits,
- S = drinking speed.

Layer 3 — Milk/feed composition

A milk analyzer measures:

C = [lactose, protein, fat, solids, energy]

The combined system becomes:

Animal phenotype + actual intake + feed composition

which is substantially stronger scientifically than a collar alone.

19. Lactose and Sucrose: A Necessary Correction

The phrase “**lactose/sucrose deficiency detection by collar**” should therefore be avoided in a scientific manuscript.

A more defensible phrase is:

“Wearable detection of behavioural and physiological signatures associated with inadequate nutrient intake, combined with independent milk-composition analysis.”

Also, sucrose should not be treated as a routine nutritional requirement equivalent to lactose in calf milk. The research system should instead measure the actual carbohydrate composition of the milk/milk replacer and relate it to the calf's nutritional requirements.

Thus:

Milk composition $\rightarrow$ laboratory/milk analyzer

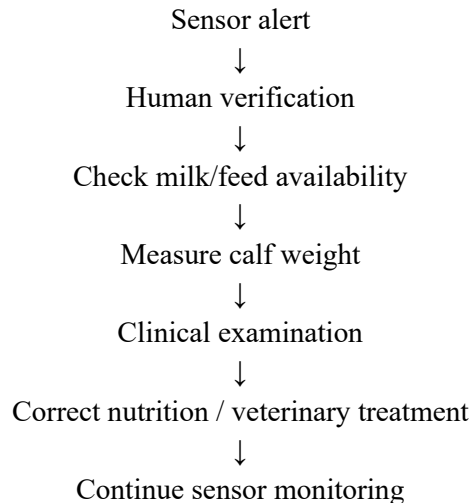
while:

Calf response $\rightarrow$ wearable sensor.

20. Clinical Intervention Pathway

The proposed system should not automatically administer treatment.

Instead:



This human-in-the-loop architecture reduces the danger of false alarms and inappropriate automated interventions.

21. Limitations

Several limitations must be acknowledged.

21.1 Two calves are not a scientific dataset

Maurya and Gauri provide motivation, but two cases cannot establish causality.

21.2 Cause of death requires veterinary confirmation

The statement that milk deficiency caused death should be presented as a reported history unless supported by veterinary examination, necropsy or clinical records.

21.3 Collar sensors do not directly measure nutrient deficiency

Behavioural measurements are indirect.

21.4 Young-calf sensor validation is incomplete

Evidence shows that some wearable systems perform differently in young calves than in adult cattle.

21.5 False-positive alerts are possible

Disease, heat stress, injury, environmental changes and social factors can alter feeding and activity.

21.6 Milk composition requires independent measurement

Lactose, protein, fat and total solids cannot simply be inferred from an accelerometer.

22. Future Research

A full research program could proceed through:

Study 1

Validate the collar against video observation.

Study 2

Validate milk-intake predictions against automated feeder measurements.

Study 3

Collect milk composition and calf physiological data simultaneously.

Study 4

Train machine-learning models.

Study 5

Perform prospective validation on an independent farm.

Study 6

Test whether alerts occur sufficiently early to permit successful intervention.

The ultimate endpoint should be:

Time gained for intervention before severe deterioration
--

rather than merely model accuracy.

23. Proposed Research Questions

- RQ1:** Can collar-derived activity and feeding-related signals identify calves experiencing reduced nutritional intake?
- RQ2:** Does combining collar data with automated milk-intake data improve prediction compared with either source alone?
- RQ3:** Can individual baseline modelling detect nutritional deterioration earlier than fixed population thresholds?
- RQ4:** Can milk-composition measurements distinguish inadequate volume from inadequate nutrient density?
- RQ5:** Can the system generate clinically useful alerts with sufficiently low false-positive rates?
- RQ6:** Can early intervention triggered by the system reduce morbidity, severe malnutrition and mortality?

24. Proposed Primary Hypothesis for a Future Experimental Trial

H1: A multimodal precision-livestock system combining wearable collar signals, automated milk-intake measurements, body-weight trajectories and milk-composition data will identify calves at nutritional risk significantly earlier than routine visual monitoring alone.

Secondary hypotheses

- H_{1a} : Milk-intake decline predicts nutritional risk.
- H_{1b} : Combining milk intake + activity improves prediction.
- H_{1c} : Adding body-weight trajectory improves prediction further.
- H_{1d} : Milk composition improves discrimination between low volume and low nutrient density.

25. Conclusion

The deaths of Maurya and Gauri, as described in the motivating case history, raise a practical and scientifically important question: **could nutritional deterioration in vulnerable orphaned calves be detected before it becomes severe?**

Current precision-livestock research provides strong building blocks for investigating this question. Automated milk feeders can continuously quantify milk intake and drinking behaviour, while wearable sensors can provide activity and other physiological/behavioural measurements. Machine-learning methods have already been applied to calf feeding data for health-risk prediction.

The proposed contribution is therefore not the claim that a collar can magically diagnose milk

Milk intake + feeding behaviour + activity + temperature + growth + milk composition → early nutritional-risk prediction

deficiency. Rather, it is a **testable multimodal hypothesis**:

The ultimate goal is simple:

Detect earlier → intervene earlier → protect vulnerable calves

For calves like Maurya and Gauri, this concept represents a transition from **reactive observation** to **continuous preventive monitoring**.

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Proposed paper classification**Article type:** Review + Hypothesis/Concept Paper**Primary field:** Precision Livestock Farming / Veterinary Technology / Animal Nutrition**Target system:** Orphaned and artificially fed dairy calves**Core innovation:** Multimodal early-warning nutritional-risk algorithm**Technology:** Smart collar + automated feeder + milk analyzer + body-weight monitoring + AI**Clinical principle:** Alert and assist human intervention; do not autonomously diagnose or treat.**Most important scientific wording:** *The proposed system detects a risk signature consistent with inadequate nutritional intake; it does not directly diagnose lactose deficiency, sucrose deficiency, or malnutrition from collar signals alone.*