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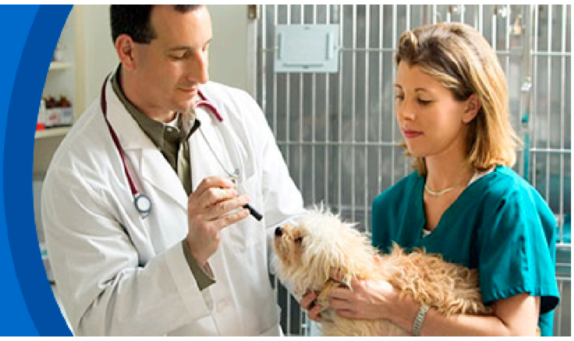

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Prevalence of ketosis in Indian dairy bovines: A meta-analysis

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Abstract
Ketosis remains one of the most significant metabolic disorders affecting dairy production worldwide. This study aimed to conduct a meta-analysis to estimate the pooled prevalence of clinical (CK) and subclinical ketosis (SCK) in dairy bovines across India using published literature from various regions. The findings indicate a substantial burden of ketosis among dairy animals in India, with crossbred cows particularly susceptible, especially during the early postpartum period. A meta-analysis of 12 published research studies from 1996-2023 assessed the prevalence of ketosis in India across dairy cows and buffaloes. Data were analyzed using the ‘meta’ package in R with a generalized linear mixed model and Logit transformation. A random-effects model estimated pooled prevalence rates for clinical and subclinical ketosis. The pooled prevalence of subclinical ketosis was estimated at 13% (95% Confidence Interval [CI]: 7%-22%), with a Prediction Interval (PI) of 1%-63%, based on 4,314 dairy bovine samples. Significant heterogeneity was observed across studies (I^2 =95.0%, τ^2 =1.23, Q =301.38 ($p \leq 0.01$). Similarly, the pooled prevalence of clinical ketosis was 11% (95% CI: 6%-18%), with a PI of 2%-47%, based on 7,880 samples. Heterogeneity remained high (I^2 =97.6%, τ^2 =0.74, Q =416.02, ($p \leq 0.01$).

Keywords: Heterogeneity, Meta-analysis, Sub-clinical and Clinical ketosis, Prevalence

Introduction
The dairy sector in India plays a crucial role in improving the socio-economic status of rural households by providing a stable source of income through dairy animal rearing, while also contributing to the nutritional security of the population. According to the Basic Animal Husbandry Statistics [2], India accounted for approximately 25% of global milk production, with an estimated output of 239.30 million tonnes in 2023-24, thereby retaining its position as the world’s largest milk producer. Despite high milk production, limited adoption of balanced feeding practices among dairy farmers increases the risk of metabolic disorders, especially in high-yielding cows. Nutritional imbalances can lead to reduced milk yield and health issues such as milk fever, ketosis, and downer cow syndrome, all of which affect productivity and profitability. The transition period three weeks before to three weeks after calving is particularly critical due to major physiological and metabolic changes. During this time, elevated nutritional demands heighten susceptibility to metabolic and infectious disorders, including milk fever, mastitis, and ketosis, which can impair both milk yield and reproductive performance [23].

In early lactation, dairy cows face high energy demands for milk production, but reduced dry matter intake often leads to a negative energy balance. To compensate, cows mobilize body fat, raising blood levels of non-esterified fatty acids (NEFAs). Ketosis in dairy cows is broadly classified into two forms: (1) Clinical ketosis, characterized by elevated concentrations of ketone bodies in the blood, urine, or milk, along with observable clinical signs such as reduced feed intake, rapid body weight loss, and firm, dry feces; and (2) Subclinical ketosis (SCK), defined by increased serum β-hydroxybutyrate (BHBA) concentrations exceeding 1.4 mmol/L during early lactation, in the absence of overt clinical symptoms [26].

Several studies have highlighted key biochemical changes in dairy cows with ketosis, particularly during early postpartum. The β-hydroxybutyrate (BHBA) is widely recognized as the primary biomarker for SCK, with diagnostic thresholds ranging from 1.2 to 3.0 mmol/L

([18]; cows above this range are at elevated risk of developing clinical ketosis. Gulinski (2021) [7] noted that a milk fat-to-protein (F/P) ratio >1.4 is a key marker of ketosis, typically associated with high milk fat (>5%) and low protein (<2.9%). Kushwah *et al.* (2022) [16] reported that SCK cows had significantly lower blood glucose (42.44 ± 0.82 mg/dL) and higher BHBA levels (1.69 ± 0.09 mmol/L) than healthy cows, along with a strong negative correlation between glucose and both NEFA (r = -0.772) and BHBA (r = -0.578), indicating a clear link to negative energy balance especially in high-yielding crossbreds.

Meta-analysis is a statistical method that integrates results from multiple studies to enhance the reliability and generalizability of findings [21]. It is a formal epidemiological approach for synthesizing existing research [8] and is increasingly used in veterinary science to estimate disease prevalence across regions [12]. This study aimed to estimate the pooled prevalence of clinical and subclinical ketosis in Indian dairy cattle and buffaloes (1996-2023) and highlight its significance and economic impact on the dairy sector.

Materials and Methods

A meta-analysis was conducted to assess the prevalence of bovine ketosis in India using published literature from various regions of the country. Relevant studies reporting the prevalence of clinical and subclinical ketosis in dairy cows and buffaloes from 1996 to 2023 were systematically collected through electronic databases, including Google Scholar (http://scholar.google.co.in/), ResearchGate, PubMed, Elsevier, Springer, IndianJournals.com, and the Consortium of e-Resources in Agriculture (CeRA) under the Indian Council of Agricultural Research (ICAR). In addition, journals, abstracts, theses, reports, and conference proceedings were also included. Further studies were identified by screening the reference lists of the collected articles. Data extracted from the prevalence studies included details such as the author(s), year of publication, study location and period, type of ketosis, the total number of dairy cattle or buffaloes examined, and the proportion of affected animals. These data were systematically recorded in Excel spreadsheets. The meta-analysis was performed using the 'meta' package in R software (version 4.5.0), available through the Comprehensive R Archive Network. The analysis was based on data extracted from the identified studies. Following the approach of Lipsey and Wilson (2001) [17], a generalized linear mixed model was used, with the Logit transformation ("sm = PLOGIT") applied to the proportions for analysis. A random-effects model, as proposed by DerSimonian and Laird (1986) [6], was then used to calculate pooled prevalence estimates for both clinical and subclinical ketosis in dairy cows and buffaloes as follows.

$$\text{Pooled prevalence estimate } \hat{\beta}_w = \frac{\sum_{i=1}^{k} w_i \hat{\beta}_i}{\sum_{i=1}^{k} w_i}$$

$$\text{Standard Error of } \hat{\beta}_w = \frac{1}{\sqrt{\sum_{i=1}^{k} w_i}}, \text{ where } w_i = \frac{1}{s_i^2 + \delta^2}$$

The pooled prevalence estimate is denoted by $\hat{\beta}_w$, while $\hat{\beta}_i$ represents the prevalence estimate from the i^{th} study, and w_i denotes the corresponding study weight. The terms s_i^2 and δ^2 represent the within-study variance and the between-study variance, respectively. Between-study heterogeneity in prevalence estimates was assessed using Cochran's Q statistic (Cochran, 1954) [4] and further quantified by the I² statistic, as proposed by Higgins and Thompson (2002) [9] and Higgins *et al.* (2003) [10].

$$Q = \sum_{i=1}^{k} \left[w_i \left(\hat{\beta}_i - \hat{\beta}_w \right)^2 \right] \text{ and } I^2 = \frac{Q - df}{Q} \%$$

The results of the meta-analysis were visually represented through forest plots, which are also referred to as confidence interval plots. These plots display the prevalence estimates and their corresponding 95% confidence intervals (CIs) for each study included in the analysis. The prevalence estimate is represented by a square, while the horizontal line extending from either side of the square indicates the CI. Below the forest plot, the PI at the 95% level is illustrated as a thick shaded line. Heterogeneity among the studies was assessed using the I-squared (I^2) statistic, Tau-squared (τ^2), and the associated P-values, as indicated in the forest plot.

Result and Discussion

The present study conducted a meta-analysis to estimate the prevalence of clinical and subclinical ketosis in dairy cattle and buffaloes in India. Details of the included studies such as author(s), dairy animal categories, study locations, and reported prevalence rates are summarized in Table 1.

A total of 12 published literature studies met the inclusion criteria. Of these, nine studies reported prevalence data for dairy cattle, including crossbred, indigenous, and non-descriptive native breeds, while three studies only provided prevalence estimates for buffaloes. The prevalence of both clinical and subclinical ketosis in dairy cattle was reported from studies conducted in the states of Tamil Nadu, Telangana, Andhra Pradesh, Kerala, Rajasthan, Odisha, Jammu and Kashmir, and Haryana. In contrast, studies on buffaloes were limited to Haryana and Tamil Nadu. According to the reviewed studies, the highest prevalence of subclinical ketosis was observed in crossbred cows, with a peak of 43.56% reported in 1996 at Tirupati, Andhra Pradesh. The lowest prevalence of subclinical ketosis was reported as 2.04% in non-descript cows in Tamil Nadu (2023), 2.67% in buffaloes and 4.00% in non-descript cows at NDRI, Haryana (2021).

The forest plot (Fig. 1) presents the proportion of dairy animals affected by subclinical ketosis in each study, along with the pooled prevalence estimate and tests for heterogeneity among the studies. For clinical ketosis, the highest prevalence was reported as 30.26% in indigenous cows and 26.16% in crossbred cows in Odisha (2016). The lowest prevalence was observed in buffaloes (2.92%) and native cows (3.12%) in Tamil Nadu (2010), and 5.00% in Rathi breed cows (a native breed) at Bikaner, Rajasthan (2019). Additionally, the forest plot (Fig. 2) illustrates the proportion of dairy animals affected by clinical ketosis in each study, along with the pooled prevalence estimate and results of heterogeneity testing among the studies. Ketosis poses a significant challenge to dairy production, leading to both direct and indirect economic losses. According to Isha *et al.* (2025) [11], the estimated direct economic loss per cow affected by ketosis in Kheri district, Uttar Pradesh, was ₹1,733.65. This estimate included costs for medicines, veterinary services, and nutritional supplements, along with an average loss of ₹1,056 attributed to reduced milk production.

Table 1: Details of the ketosis prevalence studies in India included in the meta-analysis

S. No.	Study	Animal category	Study place	Events#	Total*	Prevalence (%)	Type
1.	Venkateswarlu (1996) [28]	Crossbred	Tirupathi	88	202	43.56	SCK
2.	Thirunavukkarasu *et al.* (2010) [25]	Crossbred	Tamil Nadu	327	2909	11.24	CK
		Native cows		27	865	3.12	CK
		Buffaloes		10	342	2.92	CK
3.	Sainath Reddy (2015) [22]	Crossbred	Telangana	20	106	18.87	SCK
4.	Kumar *et al.* (2015) [13]	Buffaloes	Hisar	24	145	16.55	CK
5.	Biswal *et al.* (2016) [3]	Crossbred	Odisha	244	2076	11.75	SCK
				543	2076	26.16	CK
		Indigenous cows		207	684	30.26	CK
6.	Kumar *et al.* (2016) [16]	Cattle	Rajasthan	40	350	11.43	CK
7.	Dar *et al.* (2017) [4]	Crossbred	Kashmir	81	309	26.21	SCK
				28	309	9.06	CK
8.	Mohammed *et al.* (2019) [20]	Crossbred	Bikaner	47	200	23.50	SCK
				23	200	11.50	CK
9.	Mohammed *et al.* (2019) [19]	Native cows	Bikaner	4	49	8.16	CK
		Rathi		3	60	5.00	CK
		CrossbredHF		16	91	17.58	CK
		Native cows		7	49	14.29	SCK
		Rathi		6	60	10.00	SCK
		CrossbredHF		34	91	37.36	SCK
10.	Kushwah *et al.* (2021) [15]	Crossbred- Farm level	NDRI-Haryana	20	55	36.36	SCK
		Non-Descript cows -Farm level		2	50	4.00	SCK
		Cattle -Field level		5	70	7.14	SCK
		Buffaloes- Farm level		2	75	2.67	SCK
		Buffaloes- Field level		2	75	2.67	SCK
11.	Anjaly *et al.* (2022) [1]	Crossbred	Kerala	31	114	27.19	SCK
12.	Sujatha *et al.* (2023) [24]	Crossbred	Tamil Nadu	39	200	19.50	SCK
		Non-Descriptive cows		2	98	2.04	SCK

*- Total nos. of animals screened for ketosis, # - Total nos. of animal tested positive for ketosis, CK – Clinical ketosis, SCK- Sub-clinical ketosis.

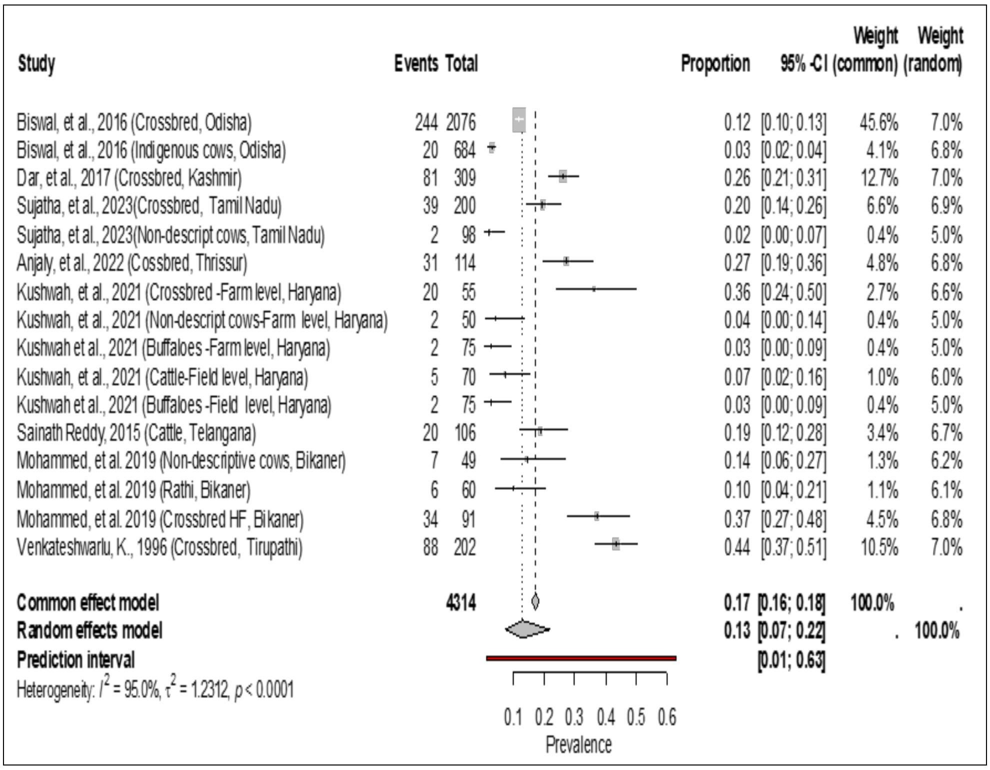

Fig1: Forest plot showing the sub-clinical ketosis and their prevalence estimates in India

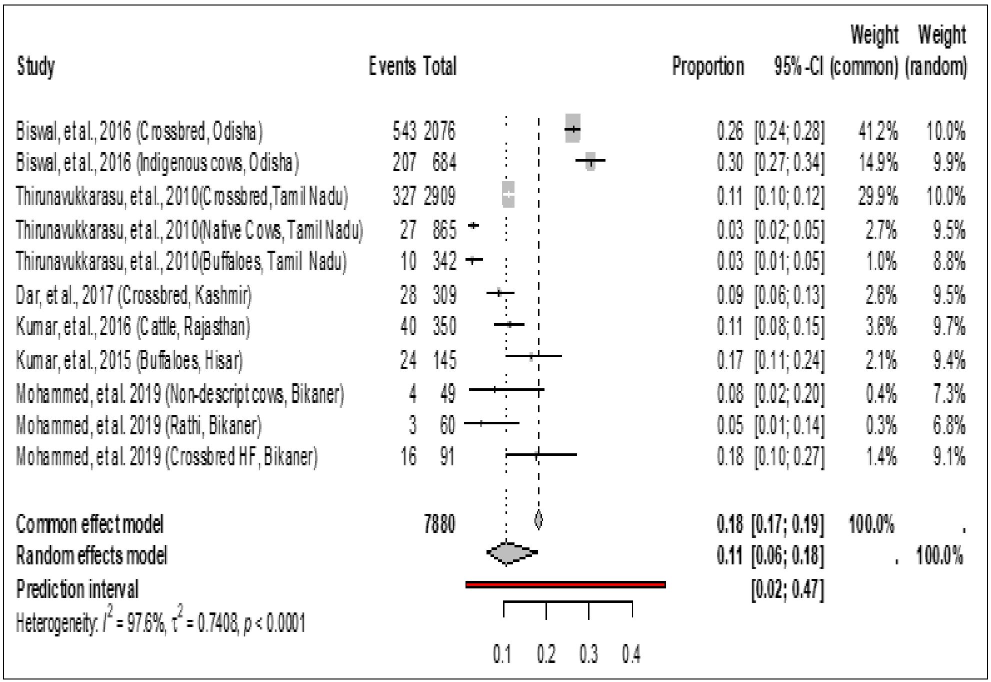

Fig 2: Forest plot showing the clinical ketosis and their prevalence estimates in India

The pooled prevalence estimates, along with prediction intervals and tests for heterogeneity for sub-clinical and clinical ketosis in dairy animals, derived from a meta-analysis of studies across various states in India, are summarized in Table 2. A total of 11 data on clinical ketosis and 16 data on sub-clinical ketosis, categorized by different types of dairy animals, were included, covering data from 2015-2019 and 1996-2023, respectively. The pooled prevalence estimate for SCK was found as 13%, with a 95% Confidence Interval (CI) ranging from 7% to 22%, and a Prediction Interval (PI) of 1% to 63%, based on 4,314 dairy bovine samples. Significant heterogeneity was observed among the studies, as indicated by an I^2 value of 95.0%, τ^2 of 1.23, and a Cochran's Q statistic of 301.38 ($p \leq 0.01$). Similarly, the pooled prevalence estimate for clinical ketosis was 11%, with a 95% CI of 6% to 18%, and a PI of 2% to 47%, based on 7,880 samples. Heterogeneity among these studies was also highly significant, with an I^2 value of 97.6%, τ^2 of 0.74, and a Cochran's Q statistic of 416.02 ($p \leq 0.01$).

Table 2: Prevalence estimates of ketosis in bovines in India based on a meta-analysis

Particulars	Period	No. of data	Total samples	Prevalence [CI %]	PI (%)	Tests for heterogeneity			
						I^2 value (%)	τ^2	DF	Q
CK	2015-2019	11	7880	11% [6 -18]	2-47	97.6	0.74	10	416.02**
SCK	1996-2023	16	4314	13% [7-22]	1-63	95.0	1.23	15	301.38**

The meta-analysis in this study revealed high heterogeneity in the prevalence estimates of both subclinical and clinical ketosis across different states and animal types. The pooled prevalence was 13.00% for subclinical and 11.00% for clinical ketosis. This variation is likely due to differences in animal categories (crossbred, indigenous, non-descript, and buffaloes), management practices, and diagnostic methods. Several studies across different regions of India have reported varying prevalence rates of clinical and subclinical ketosis in dairy animals, reflecting regional, breed, and management differences (Table 1). Historical data from Hyderabad reported by Venkateswarlu (1993) [27] showed a 14.69% incidence of subclinical ketosis among 313 crossbred cows across three organized dairy farms. The highest incidence was recorded during the first month of lactation (23.52%), followed by a gradual decline in the second (20.00%), third (10.25%), and fourth (2.85%) months postpartum, indicating a strong association with the early lactation period. Collectively, these findings indicate that crossbred cows are more prone to subclinical and clinical ketosis, especially in the early postpartum period. The variation in prevalence among regions and breeds underscores the importance of region-specific surveillance, targeted management, and nutritional strategies to mitigate the impact of ketosis on dairy productivity.

Conclusion

The meta-analysis highlights a considerable prevalence of both subclinical (13%) and clinical ketosis (11%) among dairy bovines in India, with crossbred cows in the early postpartum period being particularly vulnerable. The high heterogeneity across studies underscores the influence of regional, managemental, and diagnostic variations. These findings emphasize the need for targeted intervention strategies and improved metabolic health monitoring to mitigate the impact of ketosis on dairy productivity in India. A key limitation of this study is the scarcity of published data, which may not fully represent the national and regional prevalence of bovine ketosis in India. This highlights the need for increased research focus and region-specific epidemiological studies to inform effective control strategies and improve dairy herd health and productivity.

Conflict of Interest

Not available.

Financial Support

Not available.

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