

## Prevalence Trend of Ketosis in Dairy Cows in Asia: A Systematic Review and Meta-Analysis

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### ABSTRACT

This research aims to determine the prevalence of ketosis, both subclinical ketosis (SCK) and clinical ketosis (CK), in dairy cows in Asia. This study involves a meta-analysis of studies investigating ketosis detection or prevalence trends using cross-sectional or survey designs. Only articles published in English were included. PubMed, Scopus, ScienceDirect, Agricola, and ProQuest were searched for relevant studies published from inception until February 9, 2025. Guided by the PRISMA guidelines, we carefully selected relevant studies and analyzed the collected data using a random-effects model to determine the overall prevalence of ketosis in Asia. Considering the differences between studies, we used Cochran's Q and I<sup>2</sup> stats, along with sensitivity analysis and meta-regression, to determine the influence of different factors, such as region, diagnostic tools, or study design, on ketosis prevalence. A total of 25 studies, investigating 35 study groups from seven countries, were analyzed. Approximately 29% of dairy cows in Asia had ketosis (95% CI: 23–35%), with subclinical cases slightly more common (32%) than clinical or unclear cases (30%). West Asia had the highest prevalence rate (39%), possibly due to harsher climates or feed-related challenges, followed by East Asia (25%) and then South Asia (19%). Moreover, our analysis reveals an upward trend in ketosis prevalence. The results were stable, as no single study substantially affected the findings. The results show that the prevalence trend of ketosis is increased in Asia, and thus is an urgent health concern in dairy farms in the region.

**Keywords:** Ketosis, Clinical ketosis, Subclinical ketosis, Beta-hydroxybutyrate, Dairy cows, Asia.

### INTRODUCTION

Ketosis is a common metabolic issue affecting transition dairy cows during the early stages of lactation, and it is frequently linked to body weight reduction (Marutsova et al. 2015). Ketosis typically manifests initially as a subclinical condition, referred to as subclinical ketosis (SCK). However, in a smaller proportion of cows, SCK may progress to clinical ketosis (CK) (Zhang et al. 2016). In Egypt, a large study involving 1,179 dairy cows found a prevalence of 6.35%, highlighting the impact of body condition score (BCS > 3.5/5) (Marzok et al. 2024) and higher parity ( $\geq 3$  lactations) and prolonged dry period ( $\geq 65$  days) (Marzok et al. 2024; Elshafey et al. 2024) on risk of ketosis. Consistently, in the United Arab Emirates (UAE), study conducted in 7,511 lactating cows reported the monthly cumulative incidence of SCK (moderate) and

CK (low) with higher winter prevalence, indicating that arid-climate stress likely intensified metabolomic load and energy deficits (Ameni et al. 2025).

SCK is characterized by increased concentrations of ketone compounds, such as  $\beta$ -hydroxybutyric acid (BHBA), acetoacetate, and acetone, in blood, urine, or milk, but it has no obvious clinical signs (Duffield 2000; Ospina et al. 2013). Cows with SCK also display significantly increased serum levels of non-esterified fatty acids (Cao et al. 2017) and insulin (Youssef et al. 2017). Elevated ketone levels adversely affect the health, reproductive capabilities, and ultimately the profitability of dairy cows (Leal Yepes et al. 2019). Specifically, elevated BHBA levels are indicative of underlying metabolic disturbances that negatively impact both cow health and milk production (Yameogo et al. 2008; Abuajamieh et al. 2016; Sabek et al. 2021).

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Recent studies have shed light on other consequences of SCK. Itle et al. (2015) found that cows with SCK at the post-calving stage exhibit reduced lying time during the week leading to the calving stage. The increased  $\beta$ -hydroxybutyrate (BHB) concentrations in milk after calving are associated with reduced milk production, an uptick in health complications, and extended intervals between pregnancies, and increased culling and death rates in the initial phases of lactation (Viña et al. 2017). Elevated BHB levels have been correlated with oxidative stress and liver apoptosis in dairy cows with ketosis (Song et al. 2016). Abdominal adiposity and metabolic imbalances were also noted during the postpartum period (Meléndez and Serrano 2024). Recent findings indicated that 26.3% of early postpartum Holstein Friesians ( $n = 464$ ) developed SCK (Day 7), particularly multiparous cows with remarkably lower milk yield on day 21. Oral administration of gluconeogenic precursors during the early postpartum period can alleviate SCK-related reproductive problems and enhanced fertility (Guner et al. 2025). Further research investigating alterations in the immune system prior to disease onset in dairy cows with SCK has revealed that SCK impairs white blood cells' function, increasing the risk of postpartum diseases (Mezzetti et al. 2019). Moreover, the odds of resumption of postpartum cyclicity and subsequent pregnancy were lower in ketotic cows (Shin et al. 2015). Markedly elevated non-esterified fatty acids (Cao et al. 2017) and insulin (Youssef et al. 2017) was also reported. Interestingly, cows with SCK exhibit lower haptoglobin (Hp) concentrations than those with CK.

Meanwhile, the clinical features of ketosis include neurological symptoms, such as ataxia, sporadic aggression, erratic movements, and altered vocalizations. CK may result in reduced feed intake, digestive disturbances, and reduced milk yield due to disruptions in various physiological processes (Chirivi et al. 2023). Cows with CK show significantly higher levels of interleukin (IL)-6, IL-10, and Hp compared with the healthy control group (Brodzki et al. 2021). Moreover, cows with CK exhibit dyslipidemia, increased lipolysis, and elevated levels of systemic inflammation markers, along with conditions involving associations between endotoxemia and bacteremia (Chirivi et al. 2023).

SCK has considerable economic impacts, as one case of SCK leads to losses amounting to \$289 (McArt et al. 2015). Ketosis adversely affects milk production and overall cow health, leading to significant economic losses for dairy farmers (Meléndez and Serrano 2024; Ping et al. 2024; Rico and Barrientos-Blanco 2024).

BHBA thresholds are often used in SCK diagnosis and monitoring. However, different threshold values have been used (1.0, 1.2, and 1.4mmol/L), potentially leading to differences in SCK prevalence estimates (Macrae et al. 2019). Meanwhile, blood BHB levels have been used to classify cows as either ketotic or nonketotic, with a threshold of 1.4mmol/L as determined by automated techniques (Song et al. 2016). In terms of BHBA detection, on-farm devices have been found to be at par with conventional laboratory techniques. The reported sensitivity values for ketosis detection based on BHBA levels were 98% for ketosis, 85% for SCK, and 100% for CK; the specificity values for the device were 95% for both ketotic and subclinical conditions and 98% for clinical BHBA concentrations (Macmillan et al. 2017). A handheld

BHBA device has demonstrated the highest diagnostic accuracy for detecting hyperketonemia (HYK) at a threshold of 1.2–1.4 mmol/L, as well as the highest sensitivity and specificity for whole blood BHB detection. In addition, Ketostix and Keto test strips demonstrated optimal performance at certain positivity thresholds (Tatone et al. 2016). Newer health management approaches have been introduced to dairy herds. A recent study of integrated peripartum accelerometry demonstrated that cows with SCK or CK had fewer motion activities than euketonemic cows after calving, thus delivering a warning measure for the risk of ketosis. This difference may allow earlier, noninvasive risk screening through automated sensor networks (Ahrens et al. 2025).

Recent research has focused on identifying genetic markers and utilizing milk testing techniques to improve ketosis detection and prediction of ketosis risk. Researchers have identified five new candidate genes associated with HYK in dairy cows, and repeated BHB evaluations increase the accuracy of genomic studies on HYK (Leal Yepes et al. 2019). The use of Fourier Transform Infrared Spectroscopy in analyzing milk specimens shows potential for forecasting HYK, and assessments have indicated its reasonable precision in evaluating BHB concentrations (Walleser et al. 2023). Moreover, milk composition parameters can serve as input variables for radial basis function network models, which can inform breeders and veterinarians regarding ketosis risk in dairy cows (Bauer and Jagusiak 2025).

Although ketosis has been thoroughly researched in countries with well-established dairy industry, there has been a historical deficiency in data regarding its prevalence in dairy herds across Asia. Thus, this research sought to conduct a systematic review and meta-analysis to determine the prevalence of ketosis in dairy cows in Asia, to establish the optimal BHB levels for ketosis detection, to investigate the influence of various factors (e.g., geographical regions, diagnostic methods, sample types, and time of study (year) on prevalence rates, and evaluate trends related to the prevalence of ketosis. The results could serve as a foundation for risk management strategies could help in formulating mitigation approaches in dairy farms.

## MATERIALS AND METHODS

### Ethical approval

All recruited studies were performed by the original authors following relevant guidelines and regulations. In this study, no animal product was used, no animal sampling was conducted and no animal was harmed. Thus, an ethical approval for the use of animals was not required.

### Literature search strategy

Scopus, ScienceDirect, Agricola, ProQuest, and PubMed were searched for relevant articles published from inception until February 9, 2025. Articles were searched using various combinations of keywords, synonymous terms, terms related to ketosis, names of Asian countries, BHBA factors, and diagnostic devices; the terms early lactation, prevalence, and dairy cows were also used. Search strings were formed using the Boolean operators “OR” and “AND”. For ProQuest, the search strings were as follows: (ketosis OR “subclinical ketosis” OR “clinical ketosis” OR hyperketonemia OR acetonemia OR “negative energy balance”) AND (“dairy cow\*” OR bovine\* OR cattle OR

“Holstein cow\*” OR “Jersey cow\*” OR “lactating cows” OR “fresh cows” OR “beef cattle”) AND (Asia OR “Southeast Asia” OR “East Asia” OR “South Asia” OR “Central Asia” OR India OR China OR Japan OR Thailand OR Indonesia OR Pakistan OR Vietnam OR “South Korea” OR “North Korea” OR Philippines OR Malaysia OR Singapore OR Bangladesh OR Nepal OR Bhutan OR Myanmar OR Sri Lanka OR Maldives OR Afghanistan) AND (diagnosis OR “diagnostic method\*” OR “diagnostic test\*” OR “detection method\*” OR BHBA OR “beta-hydroxybutyrate” OR “milk BHBA” OR “blood BHBA” OR “urine BHBA” OR “test strip\*” OR “handheld meter\*” OR “laboratory test\*”) AND (“postpartum” OR “early lactation” OR “negative energy balance” OR “fresh cow\*” OR “transition period” OR nutrition\* OR “feeding management” OR diet\* OR prevalence OR epidemiology OR trend) (O’Connor et al. 2014). Details about the search strings, and the total number of articles retrieved using these search strings is shown in the Appendix. For the literature search, studies involving animals other than cows, human studies, review articles, news items, and other publication types were excluded. Fig. 1 presents the number of ketosis prevalence trend-related studies that were retrieved, reviewed, and collated for the meta-analysis.

#### Eligibility criteria

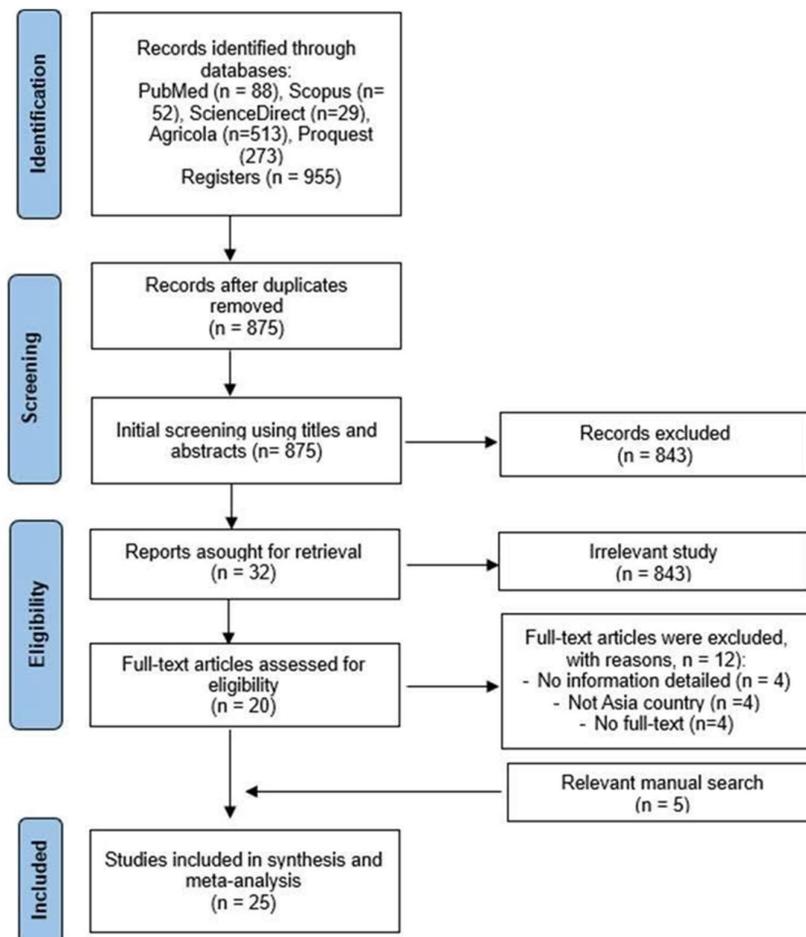
Only articles published in English were selected for the meta-analysis. The relevant articles were screened and selected according to the Preferred Reporting Items for

systematic reviews and meta-analyses (PRISMA) guidelines (Page et al. 2021). Duplicate articles retrieved from various databases were removed using the Rayyan Intelligent Systematic Review. Then, the titles and abstracts were screened by two reviewers (DHD and PS). Next, the full texts of the selected articles were carefully assessed based on certain PIO (population, intervention, and outcome) items. Specifically, the study population should be dairy cows in Asian countries, and the outcome should be the prevalence of ketosis. The other inclusion criteria are as follows: cross-sectional study, published as an original article or published in proceedings, and a sample size of at least 30. The articles that passed the first screening were subjected to a second screening. The guideline for the screening process includes the following questions:

- 1) Does the study report ketosis prevalence in dairy cows in Asia?
- 2) Does the title/abstract include the study’s PIO elements?
- 3) Is the full-text article accessible?
- 4) Is the article written in English?
- 5) Is the article original research with a suitable design?

#### Data extraction

The following information was extracted: author’s name, publication year, title, place of study, animal, sample type, test device, test method, positive sample (SCK, CK, and ketosis unknown status), sample size, and prevalence. The extracted data were organized in Microsoft Excel (Microsoft Corp., Redmond, USA).



**Fig. 1:** The PRISMA flowchart of study selection for systematic review and meta-analysis of ketosis in dairy cows in Asia.

### Quality of the studies

A quality assessment was performed using a checklist with a three-point scale: Yes (2), Unclear (1), and No (0). The score ranges from 0 to 10 (Ding et al. 2017). The screening covers several domains (D), as follows:

D1: Was the goal or research question stated and explained clearly?

D2: Was the sampling procedure thoroughly explained?

D3: Was the study period explicitly stated?

D4: Was the diagnostic procedure explained in detail?

D5: Were the participants divided into various subgroups?

The risk of bias of each study was then assessed by a 3-answer scale of “no” (0, high), “unclear” (1, some concerns), and “yes” (2, low). An overall score of 0–3 indicates high risk of bias, 4–7 indicates that some concerns exist, and 8–10 indicates low risk of bias. Once evaluation was completed, a summary plot and a traffic plot were drawn using Robvis, Web-based tool (McGuinness and Higgins 2021).

### Statistical Analysis

Data was analyzed using the R software version 4.2.2 (Comprehensive R Archive Network, Australia), which includes packages (“metafor”), packages (“tidyverse”), library (metafor), library (dplyr), and library (ggplot2) (Schwarzer, 2022).

### Estimation of the overall pooled prevalence of ketosis

The pooled prevalence of ketosis in dairy cows in Asia was estimated by pooling the results obtained from the relevant studies. Heterogeneity between studies was assessed by  $I^2$  statistic, Q-test,  $H^2$ , and  $\tau^2$  ( $\tau^2$ ). The prevalence of ketosis was visualized through a forest plot, also known as confidence interval (CI) plots, which depict both the prevalence estimation and the 95% CI for each study. In addition, a random-effects model was used to calculate the pooled estimate of ketosis to reflect the variability of the studies. The distribution of ketosis prevalence in dairy cows by country is depicted in the forest plot.

### Subgroup meta-analysis

The subgroup meta-analysis aims to assess the differences in ketosis prevalence as influenced by important characteristics, such as sample type (e.g., blood), region (East Asia, South Asia, and West Asia), ketosis type (SCK, CK, and unknown status), and breed of dairy cows (Holstein Friesian, mixed breed, and unknown). In the mixed-effects model, the differences between subgroups were evaluated by the Q-test, whereas between-group heterogeneity was evaluated by the QE-test.

### Meta-regression

A meta-regression analysis was performed to evaluate the effects of continuous variables on ketosis prevalence. A random-effects model was used to evaluate the trend of ketosis prevalence in dairy cows in Asia in relation to publication year (Loiklung et al. 2022). In addition to a random-effects model, Logit transformation was also used for meta-regression. A scatter plot depicted the trends in the prevalence of ketosis in relation to publication year (Meta-Regression of Logit Event Rate:  $\text{Logit}(p) = \log[p/(1-p)]$ ).

### Sensitivity analysis

Sensitivity analysis was used to test the stability of the meta-analysis, which was assessed through influence analysis, that is, the influence of each study on the heterogeneity of the results were assessed using Cook’s distance. The occurrence of one abnormally high Cook’s distance indicates a significant effect on the stability of the model. The leave-one-out analysis method was also used, wherein each study is removed from the analysis to check whether it significantly affects the overall results; a study that significantly changes the overall ketosis rate will strongly affect the overall results.

### Risk of publication bias

Publication bias was assessed by checking the symmetry of the study data using a Funnel plot to visually predict results discordance (Egger et al. 1997) and Egger’s Regression Test. Quantitatively,  $P < 0.05$  indicates a possibility of publication bias. Egger’s Regression Test examined publication bias by assessing the asymmetry of the Funnel plot. After the publication years were adjusted by estimating and adding missing hypothetical studies, the trim-and-fill method and funnel plot trim-and-fill method were used for analysis. (Duval and Tweedie 2000).

## RESULTS

### Literature search

A total of 955 articles of both review and research articles, were retrieved from five databases from February 9, 2025, to February 24, 2025 (88 from PubMed, 52 from Scopus, 29 from ScienceDirect, 513 from Agricola, and 273 from ProQuest). After the studies were screened based on the exclusion criteria, only 32 research articles were recruited. The full texts of these articles were assessed for eligibility and quality. Twelve articles were removed due to missing information ( $n=4$ ), for not being conducted in an Asian country ( $n=4$ ), and unavailability of the full text ( $n=4$ ). However, performing a manual search, we have identified five eligible studies. Thus, a total of 25 relevant articles were finally included in the synthesis and meta-analysis (Fig. 1). The quality of these 25 studies were assessed based on the five questions shown in Table 1. The total sample size is 53,967; of them, 9,675 were positive for ketosis. The countries where the studies were conducted and the corresponding prevalence rates for ketosis are as follows: China (29%; 95% CI [0.08, 0.49]), Korea (26%; 95% CI [0.21, 0.31]), Iran (45%; 95% CI [0.19, 0.72]), India (19%; 95% CI [0.14, 0.24]), Japan (18%; 95% CI [0.07, 0.29]), and Iraq (19%; 95% CI [0.04, 0.35]) (Fig. 2). For the subgroup analysis, these countries were clustered in three subregions, namely, East Asia ( $n=13$ ), South Asia ( $n=11$ ), and West Asia ( $n=10$ ). A total of 35 subgroups were formed for the meta-analysis. These Subgroups were formed according to the type of ketosis (SCK, CK, and ketosis [unknown status]), type of samples (blood [ $n=20$ ]; other samples [ $n=15$ ]), analysis of samples (automatic analyzers [ $n=243$ ]=14], test strips [ $n=16$ ], and other techniques [ $n=5$ ]), and diagnosis method (detection of bBHBA [ $n=15$ ], bBHBA + AcAc [ $n=7$ ], and other methods) (Table 2).

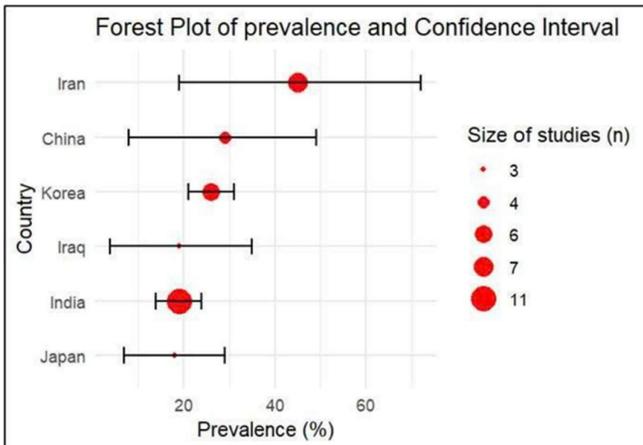
**Table 1:** Study quality assessment presenting the number of studies for each question

Question	No. of study		
	Yes	No	Unsure
1. Does the study report ketosis prevalence in dairy cows in Asia?	25	0	0
2. Does the title and abstract contain the PIO used in current study?	25	0	0
3. Does the full text of article can be retrieved?	19	0	6
4. Is the article written in English?	25	0	0
5. Is the article original research with a suitable design?	25	0	0

**Table 2:** Characteristics of the included studies for meta-analysis of ketosis in dairy cows

References	Study location		Subgroup study	Ketosis type	Cases positives	Sample size	Breed dairy cows	Sample type	Diagnosis Method	Diagnosis Equipments
	Country	Subregion								
Zhang et al. (2024)	China	EA	1	SKC	71	156	HF	Other samples	Other methods	Aa
Zhang et al. (2024)	China	EA	2	CK	10	156	HF	Other samples	Other methods	Aa
Sakha et al. (2007)	Iran	SeA	1	SCK	13	90	HF	Blood	bBHBA	Aa
Faruk et al. (2020)	Korea	EA	1	SCK	27	102	HF	Other samples	bBHBA +AcAc	Ts
Faruk et al. (2020)	Korea	EA	2	CK	19	102	HF	Other samples	bBHBA +AcAc	Ts
Chisato et al. (2024)	Japan	EA	1	SCK	245	1394	HF	Blood	bBHBA	Aa
Markusfeld et al. (1984)	Israel	WA	1	K (us)	347	1162	HF	Other samples	Other methods	Ts
Thirunavukkarasu et al. (2011)	India	SA	1	K (us)	354	3774	MB	Other samples	Other methods	Other techniques
Lee et al. (2024)	Korea	EA	1	SCK	30	112	HF	Blood	bBHBA	Ts
Sahoo et al. (2009)	India	SA	1	SCK	42	250	MB	Other samples	Other methods	Other techniques
Oikawa et al. (2019)	Japan	EA	1	SCK	50	175	HF	Blood	Other methods	Aa
Ren et al. (2024)	China	EA	1	K (us)	6337	37836	HF	Blood	bBHBA	Ts
Meena et al. (2022)	India	SA	1	K (us)	46	350	MB	Other samples	Other methods	Ts
Samiei et al. (2013)	Iran	WA	1	SCK	139	1002	HF	Blood	bBHBA	Ts
Samiei et al. (2013)	Iran	WA	2	CK	34	1002	HF	Blood	bBHBA	Ts
Biswal et al. (2016)	India	SA	1	K (us)	1014	2760	MB	Other samples	bBHBA +AcAc	Other techniques
Mohammed et al. (2019)	India	SA	1	SCK	47	200	MB	Other samples	bBHBA +AcAc	Ts
Mohammed et al. (2019)	India	SA	2	CK	23	200	MB	Other samples	bBHBA +AcAc	Ts
Asl et al. (2011)	Iran	WA	1	SCK	63	100	HF	Blood	Other methods	Aa
Asl et al. (2011)	Iran	WA	2	SCK	68	100	HF	Blood	Other methods	Aa
Asl et al. (2011)	Iran	WA	3	SCK	59	100	HF	Blood	Other methods	Aa
Asl et al. (2011)	Iran	WA	4	K (us)	97	100	HF	Blood	Other methods	Aa
Mohammed et al. (2019)	India	SA	1	SCK	47	200	MB	Other samples	bBHBA +AcAc	Ts
Kachhawaha et al. (2016)	India	SA	1	SCK	29	123	MB	Other samples	bBHBA +AcAc	Other techniques
Jeong et al. (2017)	Korea	EA	1	SCK	150	475	HF	Blood	bBHBA	Ts
Kayano and Kataoka (2015)	Japan	EA	1	K (us)	61	693	HF	Other samples	Other methods	Aa
Wang et al. (2021)	China	EA	1	SCK	30	63	HF	Blood	bBHBA	Aa
Ali and Hassan (2021)	Iraq	WA	1	SCK	22	80	HF	Blood	bBHBA	Aa
Ali and Hassan (2021)	Iraq	WA	2	CK	4	80	HF	Blood	bBHBA	Aa
Ali and Hassan (2021)	Iraq	WA	1	SCK	22	80	HF	Blood	bBHBA	Aa
Ha et al. (2023)	Korea	EA	1	SCK	58	186	HF	Blood	bBHBA	Ts
Ha et al. (2023)	Korea	EA	2	CK	34	186	HF	Blood	bBHBA	Ts
Nazeer et al. (2019)	India	SA	1	CK	40	350	MB	Other samples	Other methods	Other techniques
Francis et al. (2022)	India	SA	1	SCK	27	114	MB	Blood	bBHBA	Ts
Francis et al. (2022)	India	SA	2	CK	16	114	MB	Blood	bBHBA	Ts

Note: bBHBA: β-hydroxybutyric acid; SCK: Subclinical ketosis; CK=Clinical ketosis; K (us)=Ketosis (unknow status); HF=Holstein Friesian; MB=Mixed breed; Aa=Automatic analyzer; Ts=Test strip; SA=South Asia; EA=East Asia; WA=West Asia; SeA=Southeastern Asia.

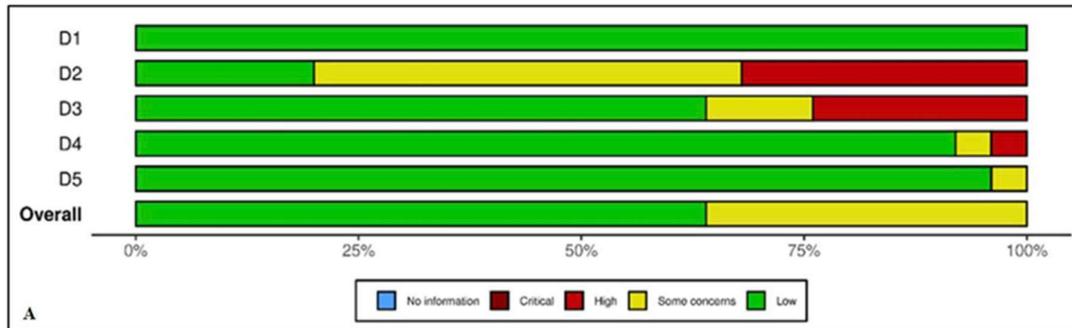


**Fig. 2:** The forest plot showed prevalence of ketosis in dairy cows by countries in Asia (n =34 subgroup studies). After removing the study of Markusfeld et al. (1984) (n = 1).

**Quality assessment of individual studies**

The individual scores for the quality assessment ranged between 6 and 10 (mean ± SD: 7.72 ± 3.18). The traffic plot for 25 studies assessed in relation to the five domains (D1–D5) shows whether each study has a high risk of bias (red x), has some concerns (yellow -), or has a low risk of bias

(green+). The traffic light plot and the summary plot showed that in terms of D1, D4, and D5, all of the studies were of high quality (predominant low risk). In terms of D2 and D3, the studies were of mixed quality, which were related to the sampling method, and study period (Fig. 3). Overall, over 60% of the studies were of high quality.



**Fig. 3:** The summary plot (A) and traffic light (B) plot used to assess risk of bias. Assessment studies for meta-analysis.

**Overall pooled prevalence and subgroup meta-analysis**

Fig. 4 and Table 3 show the overall pooled prevalence of the 25 studies, consisting of 35 subgroups were analyzed according to the trend of ketosis types.

The forest plot shows that the estimated pooled prevalence of ketosis in dairy cows is 29% (95% CI [23–

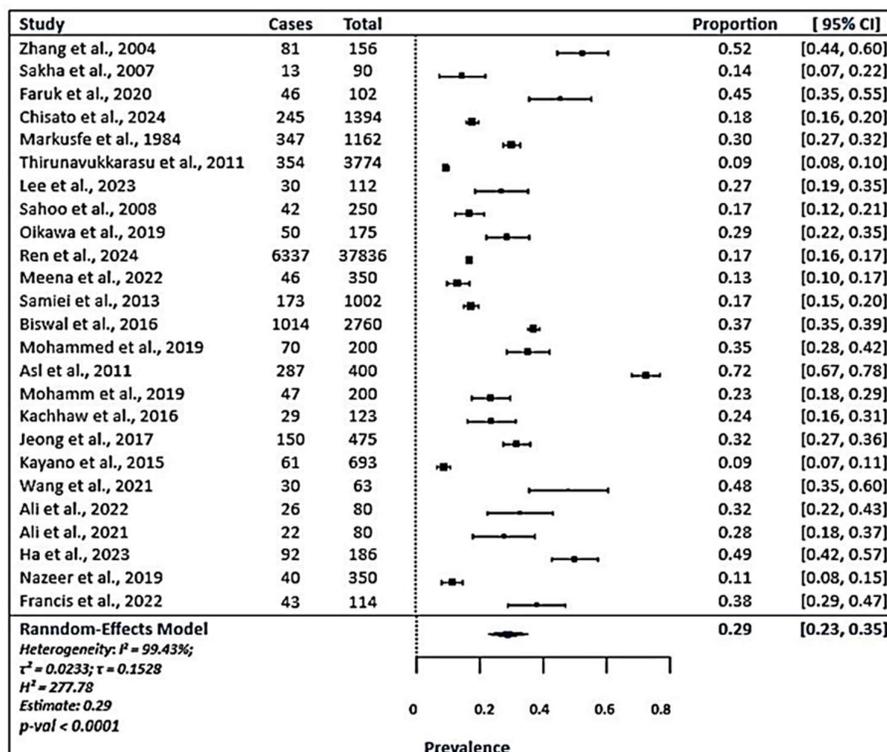
35%]). Moreover, it shows significant heterogeneity between the 25 studies ( $I^2=99.43\%$ ;  $Q=1823.05$ ;  $\tau^2=0.0233$ ;  $\tau=0.1528$ ;  $H^2=277.78$ ;  $P<0.0001$ ) (Fig. 4).

Subgroup meta-analyses were performed based on five characteristics: ketosis type, sample type, subregion, diagnosis method, diagnostic tool, and cow breed (Table 3).

**Table 3:** Overall pooled prevalence of ketosis in dairy cows and subgroup meta-analyses using a random-effects model

Categories	No. of studies and subgroup analysis	Prevalence		Heterogeneity		P-value for subgroup difference
		Estimates	(95% CI)	Q	P-value	
Overall						
Studies	25	0.29	(0.23, 0.35)	1823.05	<0.0001	99.43 NA
Subgroup studies	35	0.27	(0.20, 0.33)	4176.12	<0.0001	99.64 NA
Subgroup analysis						
Ketosis type						
Clinical ketosis	8	0.11	(-0.02, 0.24)	71.86	0.0913	90.3
Unknown status	7	0.30	(0.16, 0.44)	3073.49	<0.0001	99.8 0.02
Subclinical ketosis	20	0.32	(0.24, 0.40)	397.36	<0.0001	95.2
Sample type						
Blood	20	0.32	(0.23, 0.40)	969.84	<0.0001	98.6 0.09
Other samples	15	0.20	(0.11, 0.30)	3197.16	<0.0001	99.4
Subregion						
East Asia	13	0.25	(0.14, 0.35)	248.69	<0.0001	95.2
South Asia	11	0.19	(0.08, 0.30)	735.47	0.0010	99.7 0.04
West Asia	10	0.39	(0.27, 0.51)	3177.27	<0.0001	98.6
Diagnosis method						
bBHBA	15	0.21	(0.11, 0.31)	643.36	<0.0001	95.8
bBHBA + AcAc	7	0.23	(0.09, 0.38)	141.45	0.0015	97.8 0.16
Other methods	13	0.35	(0.24, 0.45)	2995.76	<0.0001	99.6
Diagnosis techniques						
Automatic analyzer	14	0.37	(0.27, 0.47)	2460.68	<0.0001	99.5
Test strip	16	0.20	(0.11, 0.30)	720.34	<0.0001	97.9 0.04
Other techniques	5	0.20	(0.03, 0.36)	711.42	0.0195	99.4
Breed of dairy cows						
HF	24	0.30	(0.23, 0.38)	3428.39	<0.0001	99.3 0.11
MB	11	0.19	(0.07, 0.30)	735.47	0.0014	98.6

Note: Sample types of subgroup analysis were removed one subgroup (n = 1); CI = Confidence interval; NA = Not Available; HF=Holstein Friesian; MB=Mixed Breed.



**Fig. 4:** Forest plot showing pooled prevalence estimates of ketosis in dairy cows.

For the ketosis type, the pooled prevalence of SCK and CK significantly differed from that of ketosis (unknown status) ( $P=0.02$ ). CK has a pooled estimated prevalence of 11% (CI 95% [-2%, 24%];  $n=8$ ), 30 % for ketosis (unknown status) (CI 95% [16%, 44%];  $n=7$ ), and 31% for SCK (CI 95% [24%, 40%];  $n=20$ ).

As for the sample type, the pooled estimated prevalence of ketosis for the blood sample 266 (32%; CI 95% [23%, 40%],  $P<0.0001$ ,  $Q=969.84$ ,  $I^2=98.6$ ,  $n=20$ ) tended to be different ( $P=0.09$ ) from that of the other samples (20%; CI 95% [11%, 30%],  $P<0.0001$ ,  $Q=3197.16$ ,  $I^2=99.4$ ,  $n=15$ ).

The pooled estimated prevalence of ketosis for the three subregions also significantly differed ( $P=0.04$ ), as follows: 25% for East Asia ( $P<0.0001$ ) (CI 95% [14%, 35%],  $Q=248.69$ ,  $I^2=95.2$ ,  $n=13$ ), 39% for West Asia ( $P<0.0001$ ) (CI 95% [27%, 51%],  $Q=3177.27$ ,  $I^2=98.6$ ,  $n=10$ ), and 19% for South Asia ( $P=0.0010$ ) (CI 95% [8%, 30%],  $Q=735.47$ ,  $I^2=99.7$ ,  $n=11$ ).

As for the diagnosis methods, no significant differences in the pooled prevalence of ketosis were noted for the three diagnosis methods ( $P=0.16$ ). The estimated prevalence rates for ketosis in terms of bBHBA detection, bBHBA + AcAc detection, and other methods were significant: 21% (CI 95% [11%, 31%],  $Q=643.36$ ,  $P<0.0001$ ,  $I^2=95.8$ ,  $n=15$ ); 23% (CI 95% [9%, 38%],  $Q=141.45$ ,  $P=0.0015$ ,  $I^2=97.8$ ,  $n=7$ ), and 35% (CI 95% [24%, 45%],  $Q=2995.76$ ,  $P<0.0001$ ,  $I^2=99.6$ ,  $n=5$ ), respectively.

A significant difference in the pooled prevalence of ketosis was observed between the three diagnostic tools ( $P=0.04$ ). Significant pooled prevalence estimates were

obtained when using an automatic analyzer, test strip, and other techniques, namely, 37% (CI 95% [27%, 47%],  $Q=2460.68$ ,  $P<0.0001$ ,  $I^2=99.5$ ,  $n=14$ ), 20% (CI 95% [11%, 30%],  $Q=720.34$ ,  $P<0.0001$ ,  $284I^2=97.9$ ,  $n=16$ ), and 20% (CI 95% [3%, 36%],  $Q=711.42$ ,  $P=0.0195$ ,  $I^2=99.4$ ,  $n=5$ ), respectively.

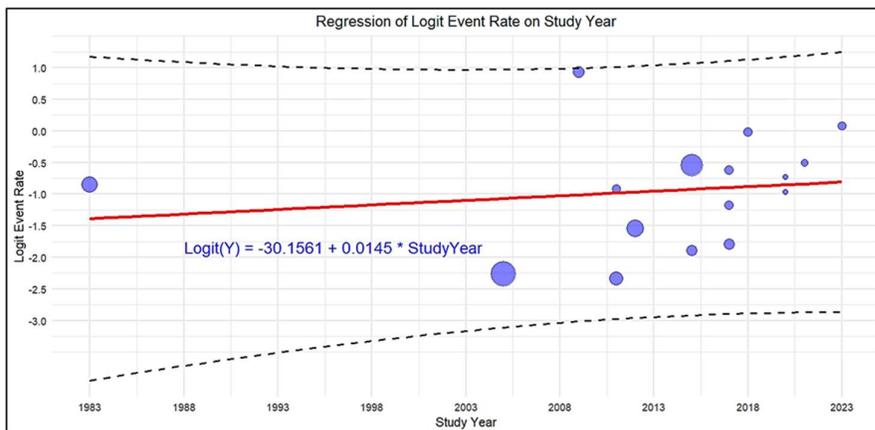
As for the breed of dairy cows, no significant difference in the pooled prevalence of ketosis was noted between the two breeds of dairy cows ( $P=0.11$ ). The HF and mixed breeds were associated with significant pooled prevalence estimates of 30% (CI 95% [23%, 38%],  $n=24$ ,  $Q=3428.39$ ,  $P<0.0001$ ,  $I^2=99.3$ ) and 19% (CI 95% [7%, 30%],  $n=11$ ,  $Q=735.47$ ,  $P=0.0014$ ,  $I^2=98.6$ ), respectively.

**Meta-regression**

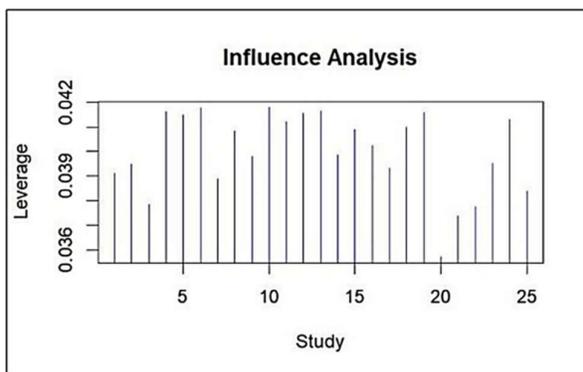
The meta-regression analysis results showed that the prevalence estimates for ketosis in terms of publication year do not significantly differ ( $P=0.3$ ). The equation  $Y = -30.1561 + 0.0145 * Year$  revealed an increasing trend from 1983 to 2023 (Fig. 5).

**Sensitivity analysis**

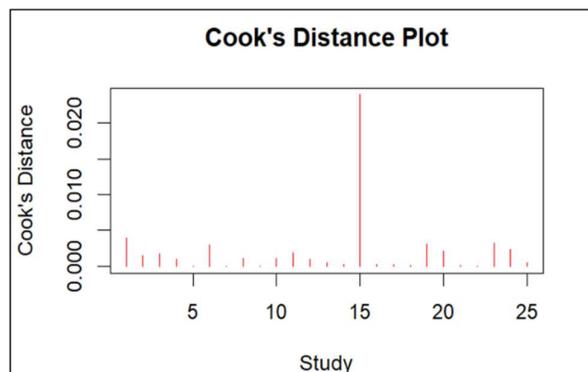
The influence analysis showed that Asl et al. (2011) study had a high Cook's distance, exerted the greatest influence on the results, and had large residuals, indicating its substantial impact on the model. By contrast, the leverage plot (0.036–0.042) shows that it does not significantly affect the model estimates. After Asl et al. (2011) study was excluded, the Q- statistic reduction showed that it contributed significantly to the heterogeneity of the model (Table 4; Fig. 6 and 7).



**Fig. 5:** The scatter plot assessed trends in the prevalence of ketosis in dairy cows by study years by Meta-Regression of Logit Event Rate ( $n=25$ ).



**Fig. 6:** The leverage plot expressed influence analysis of individual studies.



**Fig. 7:** A Cook's distance plot identified influential observations in the study before removing significant influence studies.

**Table 4:** Influence analysis for Meta-regression model

Study	rstudent	Cook's Distance	Covariance Ratio	Q E (Deleted)	Leverage	Weight	Influence
Zhang et al. (2024)	1.5414	0.0943	0.9842	1747.5201	0.0391	3.9113	
Sakha et al. (2007)	-0.9232	0.0355	1.0488	1822.4985	0.0395	3.9473	
Faruk et al. (2020)	1.0428	0.0427	1.0345	1790.9199	0.0379	3.7858	
Chisato et al. (2024)	-0.7358	0.0245	1.0652	1822.8985	0.0416	4.1610	
Markusfeld et al. (1984)	0.0738	0.0001	1.0891	1732.5893	0.0415	4.1475	
Thirunavukkarasu et al. (2011)	-1.3115	0.0716	1.0141	1516.5263	0.0418	4.1755	
Lee et al. (2024)	-0.1227	0.0008	1.0834	1817.7776	0.0389	3.8878	
Sahoo et al. (2009)	-0.7805	0.0269	1.0610	1823.0205	0.0408	4.0817	
Oikawa et al. (2019)	-0.0100	0.0000	1.0859	1811.9087	0.0398	3.9806	
Ren et al. (2024)	-0.7935	0.0284	1.0615	1804.6861	0.0418	4.1789	
Meena et al. (2022)	-1.0348	0.0459	1.0413	1817.9919	0.0412	4.1219	
Samiei et al. (2013)	-0.7561	0.0258	1.0638	1823.0430	0.0415	4.1542	
Biswal et al. (2016)	0.5265	0.0118	1.0757	1354.3911	0.0416	4.1645	
Mohammed et al. (2019)	0.4023	0.0065	1.0779	1795.0880	0.0399	3.9853	
Asl et al. (2011)	3.4903	0.4044	0.7046	1232.4628	0.0409	4.0907	*
Mohammed et al. (2019)	-0.3363	0.0054	1.0821	1818.6007	0.0402	4.0245	
Kachhawaha et al. (2016)	-0.3276	0.0050	1.0805	1820.2549	0.0393	3.9327	
Jeong et al. (2017)	0.1848	0.0013	1.0865	1777.2471	0.0410	4.0996	
Kayano and Kataoka (2015)	-1.3506	0.0751	1.0098	1760.9406	0.0416	4.1589	
Wang et al. (2021)	1.1730	0.0507	1.0217	1799.6409	0.0357	3.5733	
Ali and Hassan (2021)	0.2341	0.0019	1.0780	1814.4881	0.0374	3.7401	
Ali and Hassan (2021)	-0.0764	0.0004	1.0813	1818.7753	0.0378	3.7763	
Ha et al. (2023)	1.3729	0.0765	1.0032	1745.3838	0.0395	3.9519	
Nazeer et al. (2019)	-1.1560	0.0563	1.0300	1811.4762	0.0413	4.1284	
Francis et al. (2022)	0.5683	0.0128	1.0678	1802.5633	0.0384	3.8404	

\*: The study affected analysis.

Table 5 shows that for the random-effect model, the overall estimated prevalence was 29% (95% CI, [23%, 35%]) and 17% for the fixed-effect model (95% CI, [17%, 18%]). As regards the unit of analysis, the estimate for the subgroup studies was 27% (95% CI, [20%, 33%]). For the leave-one-out subgroup studies, the lowest prevalence estimate after the exclusion of Thirunavukkarasu et al. (2011) study was 30% (95% CI, [23%, 36%]), whereas the highest prevalence estimate after the exclusion of Asl et al. (2011) study was 27% (95% CI, [24%, 32%]).

**Table 5:** Sensitivity analysis to assess the robustness of the results

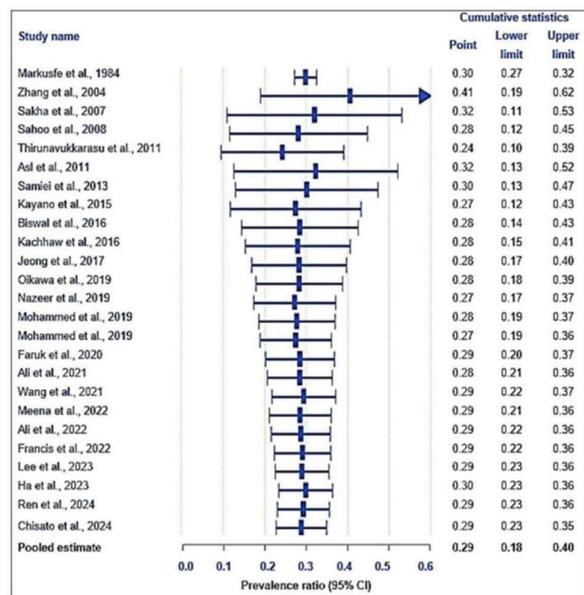
Categories	Number of subgroup studies	Prevalence	
		Estimates	[95% CI]
<b>Model selection</b>			
Fixed-Effect Model	25	0.17	(0.17, 0.18)
Random-Effects Model	25	0.29	(0.23, 0.35)
<b>Unit of analysis</b>			
Studies	25	0.29	(0.23, 0.35)
Subgroup studies	35	0.27	(0.20, 0.33)
<b>Meta-regression coefficient</b>			
All data	25	0.29	(0.23, 0.35)
The lowest estimate <sup>a</sup>	24	0.30	(0.23, 0.36)
The highest estimate <sup>b</sup>	24	0.27	(0.24, 0.32)

Note: C.I = confidence interval; <sup>a</sup>After the removal of 6<sup>th</sup> study of Thirunavukkarasu et al. (2011) from sensitivity analysis; <sup>b</sup>After the removal of 15<sup>th</sup> study of Asl et al. (2011) from sensitivity analysis.

The forest plot displayed the cumulative pooled prevalence of ketosis in dairy cows over time, indicating that the studies included consistently showed an overall effect of approximately 29%, with confidence intervals ranging from 18% to 40% (Fig. 8).

This study's sensitivity analysis, conducted using Cook's distance, identified the study by Asl et al. (2011) as having a disproportionately large influence on the overall results (Table 4). The Cook's distance for this study was 0.4044, the highest among all included studies, indicating

that it had a substantial impact on the meta-analysis. Furthermore, the studentized residual (rstudent) for Asl et al. (2011) was 3.4903, exceeding the typical threshold of  $\pm 2$  (Fig. 9). This suggested that the data from Asl et al. (2011) were poorly fitted by the model, potentially due to the unique characteristics of that study population. Due to this influence, a leave-one-out sensitivity analysis was performed in which we removed the study, although it did not substantially changes the results.

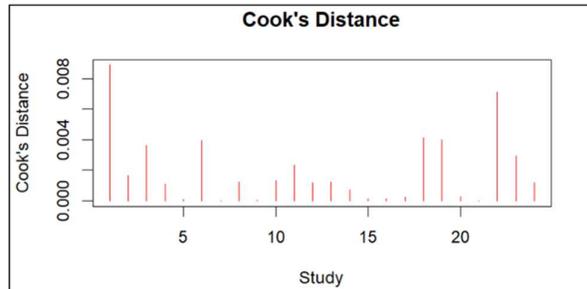


**Fig. 8:** Forest plot of cumulative prevalence and 95% C.I. of ketosis from dairy cows over time.

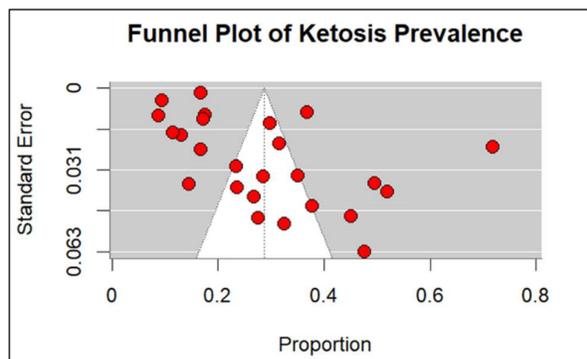
**Risk of publication bias**

The results of the Egger's test involving a mixed-

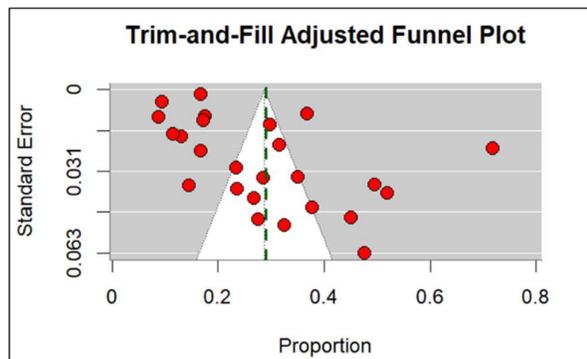
effects model show a significant asymmetry (95% CI [5%–27%],  $P=0.01$ ), indicating the occurrence of publication bias. Moreover, the funnel plot was largely symmetric, suggesting a low likelihood of substantial publication bias, though a minor asymmetry could not be entirely ruled out, but what the plot indicates was not strongly conclusive (Fig. 10).



**Fig. 9:** A Cook's distance plot identified influential observations in the study after removing 15<sup>th</sup> study of Asl et al. (2011).



**Fig. 10:** The funnel plot of ketosis prevalence detected publication bias.



**Fig. 11:** The Trim-and-Fill adjusted funnel plot of ketosis prevalence.

The result of the trim-and-fill analysis showed that the estimated number of missing studies on the left side was 0 (SE=2.90); the model estimates a prevalence proportion of 29% (95% CI [23%–35%]); this result is not different ( $P<0.0001$ ) from the results obtained using the random-effects model. The result of the trim-and-fill analysis thus indicates the absence of strong evidence for a publication bias.

Meanwhile, the Begg's test result ( $P=0.1>0.05$ )

indicates the presence of a mild publication bias. Moreover, the trim-and-fill adjusted funnel plot did not change, indicating the absence of evidence for a publication bias (Fig. 11).

## DISCUSSION

The meta-analysis of 25 studies involving 35 subgroups formed based on the trend of ketosis type showed that the overall estimated pooled prevalence trend of ketosis in dairy cows in Asia is approximately 29% (95% CI: 25%–35%), indicating that ketosis is a significant health concerns in dairy cows. The heterogeneity statistic ( $I^2=99.43\%$ ) suggests a substantial variability among the studies when the random-effects model was used. The results show a considerably varied prevalence of all ketosis types; the prevalence of CK is considerably lower (11%) than that of SCK (32%). This finding shows that SCK is more common, but this result is possibly due to the underdiagnosis of CK. Moreover, the prevalence of SCK reported herein is higher than the reported values; for instance, the estimated prevalence in Asia is 21.9% (95% CI [16.1%–29.1%]), and the prevalence worldwide is 22.7% (95% CI [21.2%–24.3%]) (Loiklung et al. 2022), which was comparable to the present analysis. This finding means that the prevalence of SCK has suddenly increased. As for CK, the lowest estimated prevalence of 11% is still higher than that reported by Raboisson et al. (2014) (7.30%). The prevalence of ketosis (unknown status) is approximately 30%, which is significantly different ( $P=0.02$ ) from the prevalence estimates for SCK and CK. One study indicated a high prevalence of SCK (35.9%) in 780 dairy cows, and this finding emphasizes the need for routine monitoring (Elshafey et al. 2024). In the UAE, a retrospective analysis (2019–2022) found monthly cumulative incidences of 11.6% (95% CI: 10.45, 11.89) SCK and 0.53% (95% CI: 0.38, 0.72) CK, highlighting moderate levels in intensive Asian farming (Ameni et al. 2025).

However, previous studies indicated that most epidemiological studies on ketosis were conducted mainly in the Americas, Europe, and Oceania, but limited reporting in Asian countries (Lei and Simões 2021; Loiklung et al. 2022). The current result may not be then completely comparable with other reports from the different other regions. Moreover, ketosis occurrence in dairy cows were also varied over the times and seasons (Ameni et al. 2025). Multi-factors including climate, care techniques, nutrition, management systems, rumen microbiomes (Kong et al. 2025), and genetics (Lee et al. 2024) could also potentially influence the diverse prevalence ketosis in dairy cows. Recent microbiome studies supported the higher prevalence of ketosis in postpartum, high-producing cows involving rumen microbiota disruption. Kong et al. (2025) demonstrated that shifts in the rumen bacterial community during early lactation may predispose cows to ketosis. Particularly, cows with SCK showed lower microbial diversity and altered metabolite pathways changes that could help explain the rising trend of ketosis in high yielding herds. Another study identified the relationship between nutritional metabolism, immunity, and the genes associated with the occurrence of SCK and reproductive performance in periparturient dairy cows (Lee et al. 2024).

Our study shows that the prevalence of ketosis detected was higher in blood samples (approximately 32%) than in other samples (approximately 20%), and moderate differences between subgroups was detected ( $P=0.09$ ). This finding shows that blood-based diagnosis is more sensitive or that ketosis was not detected in other samples. In Bingöl Province, Turkey, ketosis was diagnosed in dairy cows based on blood BHBA (bBHBA) levels, with CK and SCK being characterized by BHBA levels of  $\geq 2.6$  and  $\geq 1.2$  mmol/L, respectively (Ünal et al. 2024). A study indicated that milk metabolomics can also reveal ketosis, as the milk obtained from healthy and ketotic cows exhibit significantly altered fat and protein ratios, and cows with SCK display reduced milk yield (Huang et al. 2024). The prevalence estimates were strongly influenced by the analytical methods, namely blood BHBA detection (21%), blood BHBA+AcAc detection (23%), and other methods (35%). Compared with other subgroup analyses, no significant differences ( $P=0.16$ ) between the methods were observed. This finding suggests that any method can detect ketosis more frequently. As emphasized by Oetzel (2004) and Duffield et al. (2009), determining the bBHBA threshold for the diagnosis of general ketosis remains difficult, indicating the biological complexity and variation of each individual dairy cow in a strong metabolic state at the early postpartum stage. The overall prevalence of ketosis was significant in 411 dairy cows studied (Ünal et al. 2024). In another study, the prevalence of SCK was 35.9%, and the diagnosis was based on the qualitative determination of BHBA levels in urine, alongside serum biochemical analysis and ultrasonographic examinations (Elshafey et al. 2024). A study comparing different samples found that urine tests for acetoacetate were more sensitive 77.5% at a 15 mg/dL cut-off than milk tests for BHBA, which hit only 61% at 100  $\mu\text{mol/L}$ , when checked against blood BHBA levels of  $\geq 1.2$  mmol/L. Blood tests also detected ketosis sooner, around 5 days in milk, while milk and urine lagged at about 7 days (Serrenho et al. 2022).

The results showed that the majority of the studies used handheld test strips to quickly diagnose ketosis in most farms in Asia, but the result may not be entirely correct. Future studies must compare the effectiveness of these strips with laboratory-based methods and must shed light on diagnostic biases in morbidity. The choice of an appropriate diagnostic method and device affects morbidity, as revealed by the meta-analysis conducted by Tatone et al. (2016). Our study shows that automatic analyzers had achieved the highest prevalence estimate of 37%, higher than the estimate obtained using test strips and other techniques (both at 20%). The difference was significant ( $P=0.04$ ), suggesting that diagnosis techniques affect prevalence estimates for ketosis. This finding leads to the view that advanced methods are possibly more sensitive. Bach et al. (2016) evaluated four handheld ketone meters used for monitoring HYK in dairy cows.

All four meters showed high sensitivity and specificity at a BHB concentration cutoff of 1.2 mmol/L, and the agreement between the gold standard and the meters, especially Nova Vet, was notably strong. In another research, the KetoTest strip demonstrated low sensitivities of 73% and 27% at cutoff values of 100 and 200  $\mu\text{mol/L}$ , respectively, both results showing high specificity (Carrier et al. 2004). In Egypt, a study detected a ketosis prevalence

of 6.35% among 1,179 dairy cows by using a semi-quantitative milk strip test (Marzok et al. 2024).

Another study comparing different diagnostic tools found that blood tests had higher sensitivity (93.8%) than urine tests (58.6%), suggesting that blood tests are more reliable for ketosis detection (Schelkopf et al. 2023).

As for the subregional studies, a significant inconsistency was noted, and factors such as climate, care techniques, nutrition, and management systems are seen to be the underlying reasons behind disparities in ketosis incidence in East Asia, South Asia, and West Asia. It is also possible that differences in concentration areas and development in regions result in differences in incidence rates between regions. Future studies must explore the specific influencing factors in different regions, including genetic and environmental factors (Constable et al. 2016). Our study shows that West Asia had the highest estimated ketosis prevalence at 39%, followed by East Asia (25%) and South Asia (19%). The subgroup differences were statistically significant ( $P = 0.04$ ), indicating that the regional factors, such as environmental conditions, management practices, and genetics, played a role. A study on dairy cows across multiple continents found an overall SCK prevalence of 24.1%, with significant regional variations, highlighting the impact of local dietary practices and management systems (Brunner et al. 2019).

In terms of breed, the estimated prevalence is significantly lower in mixed breeds (19%) than in their counterpart (30%) ( $P=0.11$ ). Different breeds exhibit varying susceptibility, and Holsteins are commonly studied due to their high milk production (Huang et al. 2024). The high energy demand of milk production, which leads to energy deficits during early lactation, often render Holstein cows more susceptible to ketosis (Meléndez and Serrano, 2024). Simmental and crossbred cows also develop ketosis, but the prevalence estimates may differ depending on management practices and genetic factors (Ünal et al. 2024).

As regards the trend for ketosis research in relation to publication year, the result of the regression analysis suggests a slight upward trend in ketosis prevalence over time. The slope coefficient (0.0145) indicates that for every passing year, the logit event rate for ketosis prevalence increases slightly. Every bubble represents a study, with larger bubbles indicating higher weight of ketosis. Some high-weight studies, which were clustered from 2000 to 2015, had key contributions to the trend for ketosis. However, fewer studies were conducted before 2000, rendering the early trends less reliable. Nevertheless, the increasing trend suggests that ketosis is a persistent issue in dairy cows and that it has been becoming more prevalent over time. This finding also underscores the need for standardized diagnostic methods in the future research.

In this study, the fixed-effect model estimated a lower prevalence (17%) compared with the random-effects model (29%). This discrepancy implies a notable degree of heterogeneity among the studies, and that the random-effects model is more suitable, as it accommodates variability across studies. Furthermore, the overall prevalence estimates in the studies (29%) or in the subgroup studies (27%) do not dramatically alter the estimated prevalence, supporting the robustness of the finding. The minor changes in the overall estimates

following the exclusion of both the lowest and highest prevalence estimates suggests that the overall prevalence estimation is stable and is not substantially influenced by specific studies.

Studies conducted prior to the year 2010 demonstrated that a broad CI signifies heightened uncertainty attributable to a paucity of data points. Conversely, numerous studies conducted after 2015 reported narrower CIs, indicating enhanced methodological rigor and improved sampling techniques. Although no definitive increasing or decreasing trend was discernible over time, the prevalence estimates for ketosis have remained stable, fluctuating between 27% and 30% in recent years. Meanwhile, certain individual studies present higher proportional estimates, such as 41% and 32% as reported by Zhang et al. (2024) and Sakha et al. (2007), respectively. By contrast, other investigations yielded lower estimates, such as 24% as reported by Thirunavukkarasu et al. (2011). This heterogeneity may suggest that geographical factors, management practices, and diagnostic factors influence ketosis. Thus, the observed stability implies that the findings are robust and are not excessively reliant on individual studies.

When leverage plots were used to evaluate the influence of individual studies, the findings indicated that certain studies may affect the pooled estimate greatly owing to extreme effect sizes or distinctive characteristics. The Cook's distance plots drawn before and after the exclusion of the influential study of Asl et al. (2011) revealed that Cook's distance enhanced the model's balance, affirming the robustness of the pooled estimates obtained through sensitivity analysis.

The primary limitation of our investigation is the considerable heterogeneity, which is the most important concern. Regarding publication bias, studies presenting favorable outcomes (i.e., research demonstrating a substantial correlation between variables and ketosis) are more likely to be published than studies yielding unfavorable results. This phenomenon results in an inflated estimation of the prevalence of ketosis. Furthermore, data deficiencies in various regions or countries in Asia also contribute to the diminished representativeness of the meta-analysis and restrict the identification of specific locales.

Additional diagnostic threshold parameters must be incorporated in the meta-analysis for a more comprehensive monitoring of ketosis and more accurate determination of the positivity rates for SCK and CK. Concurrently, further investigation is imperative to gain deeper knowledge about the various forms of ketosis, enabling the effective management of milk extraction in dairy cattle, optimizing milk production.

## Conclusion

This meta-analysis confirms a high prevalence of ketosis in dairy cows across Asia, with a pooled estimate of approximately 29% (95% CI [25%–35%]), highlighting its significance as a major concern in the region. This study found a high prevalence of ketosis in Asia, specifically 32% for SCK and 11% for CK. Additionally, prevalence is found to be significantly associated with blood samples, subregion (East Asia, South Asia, and West Asia), and diagnosis techniques (use of automatic analyzers and test

strips). Diagnosis methods, particularly bBHBA and bbHBA+AcAc detection, were strongly correlated with SCK and CK prediction.

By prioritizing these areas of research, we can equip farmers and veterinarians with the necessary tools to make informed decisions and effectively monitor the occurrence of ketosis. The results also underscore the importance of ketosis monitoring in improving herd health in dairy farms in Asia.

Finally, further research must evaluate other diagnostic methods and sample types to gain deeper insights into the relationship between pooled-sample BHBA and key outcomes, such as disease, milk production, and reproduction. Such could provide an effective approach for monitoring CK, SCK, and postpartum energy balance in dairy cow herds across Asia.

## DECLARATIONS

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**Conflict of Interest:** The authors have no conflicts of interest.

**Data Availability:** Supplementary data to this article can be found in the following online Annexures:

[Annexure 1: Study protocol IJVS-25-204](#)

[Annexure 2: Raw data analysis IJVS 25-204](#)

[Annexure 3: Risk of bias Assessment IJVS 25-204](#)

[Annexure 4: Screening process IJVS-25-204](#)

**Ethics Statement:** All analyses were performed by the original authors following relevant guidelines and regulations. Therefore, ethical approval for use of animals in scientific tests were not required in this study. The study protocol was created before the study was conducted (see Data availability: Supplementary data).

**Author's Contribution:** Concept development and study framework were carried out by DHD, PS, and CT; databases collection and screening by DHD and PS; analysis, and interpretation were handled by DHD, PS, and CT; oversight was provided by CT and PS; original draft composition was done by CT; the writing process involved review, editing, and final approval by CT. All authors have thoroughly reviewed and consented to the final manuscript version.

**Generative AI Statement:** The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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