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Pesticide Exposure and the Incidence of Type 2 Diabetes Mellitus Among Farmers: A Literature Review

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ABSTRACT

Introduction: Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by hyperglycemia resulting from insulin resistance or inadequate insulin secretion. While lifestyle factors are established contributors, prolonged exposure to environmental chemicals is also implicated in its etiology. The intensification of agricultural practices has led to the widespread application of various pesticides, including fungicides, insecticides, and herbicides. Consequently, hazardous compounds from these pesticides can accumulate in the human body, either through direct occupational exposure, as seen in farmers, or indirectly via the consumption of contaminated food and water.
Methods: This study employed a PRISMA-guided systematic literature review of peer-reviewed observational studies published between 2015 and 2025. Relevant articles were retrieved from Google Scholar, ScienceDirect, and the Undip E-Journal using predefined keywords related to pesticide exposure, farming populations, type 2 diabetes mellitus, and cholinesterase activity. Studies were included if they assessed occupational pesticide exposure among farmers and reported T2DM-related outcomes, while experimental, animal, review articles, and studies lacking relevant exposure or outcome data were excluded. The PRISMA-based selection process yielded 10 studies for qualitative synthesis.
Results: The review identified several occupational factors significantly associated with an increased risk of T2DM. These include a long working period (over 10 years), inadequate use of Personal Protective Equipment (PPE), gender, and the application of more than one type of pesticide. The underlying mechanism involves certain pesticide compounds, particularly Persistent Organic Pollutants (POPs) like organochlorines (e.g., DDE) and organophosphates, which act as endocrine disruptors. Exposure to these chemicals is linked to reduced cholinesterase enzyme levels and pancreatic beta-cell dysfunction, leading to insulin resistance and glucose intolerance.
Conclusions: There is a significant relationship between pesticide exposure and the incidence of T2DM among farmers. Key risk factors are prolonged exposure, unsafe work practices, and the use of specific pesticide types. Mitigation efforts, such as strict enforcement of PPE usage and farmer education on the risks of pesticide handling, are crucial as preventive measures to reduce the burden of T2DM in this vulnerable group.

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INTRODUCTION

Diabetes is a chronic disease caused by high blood sugar levels in the body (1). Type 2 diabetes mellitus (T2DM) is a major public health problem worldwide, with increasing prevalence in both developed and developing countries. The International Diabetes Federation (IDF) noted that in 2021 there were 537 million adults aged 20-79 years with diabetes and it continues to increase every year (2). Based on data released by the Ministry of Health (Kemenkes) in the 2023 Indonesian Health Survey (SKI) Report, as many as 19.5 million Indonesians have diabetes (3). Type 2 diabetes mellitus is a multifactorial disease influenced not only by lifestyle-related factors but also by chronic exposure to environmental chemical compounds.

Pesticides are chemical compounds that are often used to treat pests and diseases in plants. Based on data released by the Indonesian Ministry of Agriculture in 2022, it shows that there is an increase in the use of pesticides in Indonesia. This is marked by an increase in the number of pesticides registered as many as 507 types of pesticides from 2019 to 2021 (4). Excessive use of pesticides can cause side effects to the environment as well as to its users (5). Pesticides can enter the human body through contact with the skin, respiratory system, or consumption of foods that contain pesticides (6).

Serum cholinesterase (ChE), an enzyme synthesized primarily in the liver, has been associated with metabolic and inflammatory conditions, including type 2 diabetes mellitus. The increased concentration of ChE is caused by the inability of insulin to secrete lipids and glucose in the body. This is due to the increased flow of non-esterified fatty acids into the liver, causing resistance to glucose absorption as an insulin response that causes hyperglycemia in T2DM cases. The concentration of ChE in the body is often used as an early identification in the analysis of T2DM patients (7).

Chemical compounds such as organochlorine (OCPs) or organophosphate (OPs) are often found accumulating in the bodies of patients with health conditions such as diabetes, respiratory disorders, and cardiovascular diseases (8–10). Low knowledge of the dangers of using OCPs and OPs pesticides increases the risk of health problems in humans (11).

Previous research noted that there was a correlation between pesticide use and diabetes, with an Odds Ratio (OR) value of 7.4 (Cl 95% 7.0 – 8.8) (12). In addition, the use of PPE also affects the risk of diabetes through direct exposure to pesticides (OR: 2.45; Cl 95%: 0.17 – 11.10) (13). This study aims to identify the relationship between pesticide exposure and T2DM in farmers.

METHOD

This study was conducted as a literature review using a systematic search and selection process guided by the PRISMA framework (PRISMA, 2020) to examine the association between pesticide exposure and the incidence of type 2 diabetes mellitus (T2DM) among farmers (14). Relevant literature was identified through electronic searches of Google Scholar, ScienceDirect, and the Undip E-Journal database. The search was conducted for articles published within the last 10 years (2015–2025) to ensure scientific relevance and up-to-date evidence. The search strategy employed combinations of the following keywords: “pesticide”, “type 2 diabetes mellitus”, “T2DM”, “farmer”, and “cholinesterase enzyme”

Studies were included if they were peer-reviewed original research articles published between 2015 and 2025, employed observational study designs, examined occupational pesticide exposure among farmers or agricultural workers, and reported type 2 diabetes mellitus or related metabolic outcomes. Studies were excluded if they were experimental animal or in vitro studies, focused on gestational or type 1 diabetes mellitus, were review articles or editorials, or did not provide sufficient data on pesticide exposure or diabetes-related outcomes.

The article selection process followed the PRISMA flow diagram and consisted of four stages: identification, screening, eligibility assessment, and inclusion. Duplicate articles were removed prior to screening. The following data were extracted: author(s), year of publication, study location, study design, population characteristics, type and duration of pesticide exposure, biological markers assessed (including cholinesterase enzyme levels), and key findings related to T2DM. A qualitative synthesis approach was applied to integrate findings across studies, with particular emphasis on occupational exposure patterns, pesticide types, and proposed biological mechanisms linking pesticide exposure to T2DM. The article screening process can be seen in **Figure 1**.

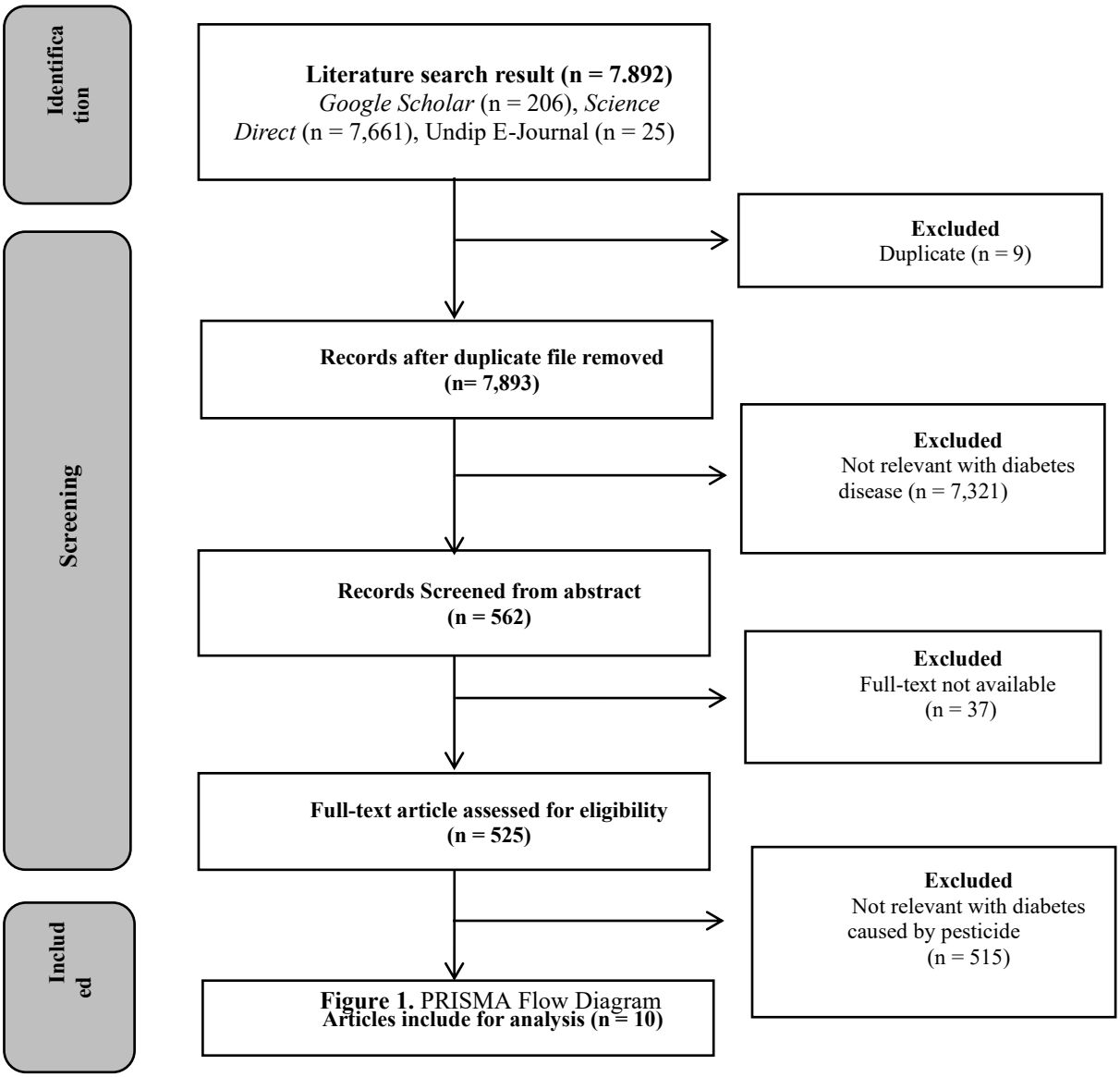

Figure 1. PRISMA Flow Diagram

RESULTS

From the results of the article selection, 10 articles are presented in **Table 1**

Table 1. Literature Review Matrix

No	Author(s)	Study Focus	Method	Research Results
1	Saftarina F, et al (2023)	Deteminants of Type 2 Diabetes Mellitus in Agricultural Community	case control with 41 respondents for diabetics and non-diabetics (control	The results of the observations were based on body mass index, blood pressure, questionnaire interviews, and Brinkman index measurements. Calculations using Chi-Square show several factors that cause type 2 diabetes mellitus in farmers, including the use of more than two types of pesticides, hereditary factors, and low physical activity.

No	Author(s)	Study Focus	Method	Research Results
2	Masyithah W, et al (2025)	Association Between Pesticide Exposure and Type 2 Diabetes Mellitus Among Female Farmers	Analytical observation study with a cross-sectional design involved 162 female farmers with inclusion criteria farmers who were involved in spraying pesticides and were less than 60 years old	There are 5 main factors that cause diabetes in women farmers in Sumowono Village, low cholinesterase levels ($p < 0.001$), have been working for more than 10 years ($p = 0.010$), duration of pesticide spraying ($p = 0.020$), inadequate PPE ($p = 0.007$) and use of more than 2 types of pesticides ($p = 0.023$). This research showed pesticides, particulary organophosphates, and carbomates, act as endocrine-disrupting chemicals that impair pancreatic function and increase oxidative stress, contributing to insulin resistance.
3	Juntarawijit C, et al (2018)	Association between diabetes and pesticides: A case-control study among Thai farmers	case-controlled study among residents in the Bang Rakam district. 866 people with diabetes cases and 1021 control were used in research	After adjusting based on, gender, age, BMI, smoking, alcohol consumption, and family history of diabetics There are 3 types of insecticide that are closely related to the risk of type 2 diabetes. Pesticides of organochlorine, organophosphate, and carbamate types as well as fungicides that have an Odds Ratio (OR) value of more than 1.
4	Kim S K, et al (2022)	Pesticide Exposure in Relation to the Incidence of Abnormal Glucose Regulation	Retrospective cohort study among 217 Korean farmers with pesticide exposure	The results showed that subjects who were directly exposed to pesticides had a higher risk of developing diabetes with an RR value of 1.32 (95% Cl = 1.03 – 1.69). On the other hand, men have a higher risk level than women (RR = 1.81; 95% Cl = 1.22 – 2.67).
5	Mahmood AAJ, et al (2019)	Cholinesterase Activities in Diabetic and Hyperlipidemic Patient	case control comparative study in 5 groups with 30 patient each group in Al Wafaa Center for Diabetes	After test 5 ml blood of the patient, the results indicate that there is a relation between the BChE and diabetes. Which is in each group showed elevated the BChE level. Same result showed for indication of dyslipidemia with elevated level of AChE and BChE.
6	M. Rashid H, et al (2021)	In Vitro Inhibition of Blood Cholinesterases by the Organophosphate Dichlorvos in Type-2 Diabetic Patients	case control sudy among 32 patients for each diabetic patient and cotroll subject from Azadi Hospital, Duhok, Iraq	The results showed an increase in cholinesterase activity in patients with type 2 diabetes mellitus with a p value of ≤ 0.05. In addition, this study also showed that exposure to the organophosphate insecticide dychlorophyte can inhibit plasma activity of ChE and erythrocytes. This is shown in both subject groups
7	Saha A, et al (2025)	Decoding the role of serum cholinesterase	cross sectional study among 176	The results showed an increase in the concentration of cholinesterase enzyme in diabetics with an average level of 9272.18 ± 3062.92. Meanwhile, in control, the average

No	Author(s)	Study Focus	Method	Research Results
		among type 2 diabetes mellitus patients at RIMS, Ranchi A hospital based study	participants, divided into two group, 88 diagnosed with T2DM and 88 non diabetic indiviuls from Medicine Department of RIMS, Ranchi.	cholinesterase level was 3504.93 ± 1520.74 with a *P* value of < 0.001. This study also showed that cholinesterase concentration has a correlation with the occurrence of type-2 diabetes mellitus.
8	Daniels SI, et al (2018)	Elevated Levels of Organochlorine Pesticides in South Asian Immigrants are Associated with an Increased Risk of Diabetes	Case control study with 120 South Asians people of Tamil or Telugu descent and 72 European whites people	The results showed that the Tamil population had three to nine times higher concentrations of Organochlorine (OC) pesticides compared to the white European population. Meanwhile, the Telugu population shows a concentration of OC nine times higher than that of white Europeans. In addition, this study also shows a positive relationship between high OC pesticide content and the incidence of diabetes. This is characterized by the discovery of high concentrations of OC pesticide in diabetics.
9	Mansouri EH, and Reggabi M (2020).	Association between type 2 diabetes and exposure to chlorinated persistent organic pollutants	Case control Study among 361 subject to whom the plasma levels of selected biomarkers were determined on GC-MS of Algerian people	The results showed that subjects with diabetes had higher levels of organochlorine *Persistent organic pollutants* (POPs) than non-diabetic subjects (controls). With an OR value for DDE of 12.58% and for Hexacholorbenzene (HCB) of 3.69%.
10	Wei D, et al (2024)	Unraveling the pesticide-diabetes connection integrating Mendelian randomization analysis with a focus on physical activity's mitigating effect	*Case control study* with monitoring and observation using Mendelian randomization (MR) analysis	After 3 years of observation in subjects with indications of Impaired Fasting Glucose (IFG), they had a tendency to develop type 2 diabetes due to exposure to pesticides. Especially pesticides with Isofenphos, malathion, and deltamethrin content with a p value of < 0.05. In addition, regular exposure to pesticides also increases the risk of diabetes (OR = 1.05; 95% Cl 1.01 – 1.10)

DISCUSSION

Pesticides are an inseparable part of the world of agriculture. Pesticides are often used to repel pests or weeds on plants. However, Pesticides have negative effects on the human body if exposed and accumulated in the body (15)**.** Research shows that pesticides can accumulate in the environment through air, water, and even soil exposed to pesticides. This causes chemical compounds in pesticides to enter the human body through the food and drinks consumed (16,17)**.** Research shows that direct exposure to pesticides is more likely to increase the occurrence of diabetes (18). Research conducted on farmer groups in Korea showed a relative risk of 1.32 in farmers who were directly exposed to pesticides (19). This shows that farmers are the most vulnerable group to experience type-2 diabetes mellitus due to exposure to pesticides(20–22). Other studies have also shown that women farmers are more

susceptible to pesticide exposure. This condition is affected because during premenopause and menopause, women have low estrogen levels(23). This evidence suggests that pesticide exposure contributes to diabetes risk primarily through cumulative and chronic pathways rather than isolated exposure events, with sustained low-dose exposure progressively amplifying metabolic vulnerability over time. The consistency of associations observed across diverse agricultural settings indicates that exposure intensity and environmental persistence may be more critical determinants of risk than individual pesticide compounds alone. Moreover, the observed sex-specific susceptibility highlights the interaction between endocrine modulation and chemical exposure, underscoring the importance of incorporating biological vulnerability into occupational risk assessment and preventive strategies.

Indications of diabetes in patients can be identified by measuring the activity of the cholinesterase enzyme. Research shows an increase in cholinesterase enzyme activity in diabetic patients (24). This occurs through disruption of the process of glucose homoestasis in the blood. The cholinesterase enzyme serves as a catalyst in the process of hydrolysis acetylcholine into choline and acetic acid can be an indicator in the screening process of diabetic patients. The concentration of cholinesterase will increase when there is an increase in the level of non-esterified fatty acids that often occur in diabetic patients (7). This is also in line with previous research where there was an increase in cholinesterase enzyme activity in diabetics with an average of 0.304 ± 0.072 while in normal subjects it was 0.263 ± 0,046 (25) Elevated cholinesterase activity reflects an intermediate biological pathway through which neurotoxic and endocrine-disrupting effects contribute to the development of insulin resistance and impaired glucose regulation. This positions cholinesterase activity as both an indicator of exposure and a potential mediator linking agricultural pesticide exposure to metabolic dysfunction and increased diabetes risk.

There are many types of pesticides used in the agricultural industry, such as fungicides, insecticides, herbicides, organochlorine pesticides (OCPs), and organophosphates (OPs). Research conducted. Research shows that organochlorine pesticides and organophosphate pesticides are the cause of several diseases in humans, such as respiratory disorders, diabetes mellitus, and cardiovascular desease (8,9). The diversity of pesticide classes and active ingredients used in agricultural settings likely amplifies biological risk through additive and potentially synergistic effects on endocrine and metabolic pathways. Concurrent exposure to multiple pesticide types may therefore intensify pancreatic β-cell dysfunction and hormonal disruption (26), reinforcing the cumulative impact of pesticide mixtures on diabetes development.

Research conducted on the Indian community by Daniel et al (2018) showed a fairly high content of organochlorine in the body. This is indicated to be the cause of the high cases of type-2 diabetes mellitus in India (27). This statement is reinforced by research conducted on Algerian people. OCPs content such as 4.4'DDE (OR = 12.58; 95% Cl 4.76 – 33.26), and HCB (OR = 2.28; Cl 95% = 1.20 – 4.39) (28) in the body of people who show symptoms of diabetes. Organophosphate pesticide showed same result in effect of T2DM. Studies in Chile and Cameroon showed people exposed to OPs pesticides have a higher risk of diabetes (29,30). Findings from studies conducted in several different countries show a consistent and reproducible association between pesticide exposure and the risk of type 2 diabetes. Elevated internal burdens of organochlorine and organophosphate compounds among farmers have been repeatedly linked to an increased risk of diabetes, despite substantial variation in environmental conditions and agricultural practices.

CONCLUSION

Pesticide exposure among farmers is associated with type 2 diabetes mellitus (T2DM) through complex occupational and biological mechanisms that extend beyond a simple epidemiological relationship. Evidence from epidemiological, toxicological, and occupational health studies suggests that chronic exposure to pesticides particularly organophosphate and organochlorine compounds may play a role in the development of insulin resistance and pancreatic β-cell dysfunction via pathways involving cholinesterase inhibition, oxidative stress, and endocrine disruption. The consideration of exposure-related factors, such as duration and frequency of exposure, pesticide mixtures, and the use of protective practices, in relation to metabolic disease pathways provides a more comprehensive understanding of how occupational pesticide exposure may influence T2DM development among farmers. This interpretation underscores the importance of preventive strategies in occupational health and highlights the need for longitudinal and biomarker-based research to further elucidate causal mechanisms and support the formulation of evidence-informed regulatory policies.

AUTHOR CONTRIBUTION STATEMENT

Dyah Pramesti Pusparwadaya contributed to the conceptualization, literature review, and drafting of the main manuscript. Suhartono provided scientific supervision, content review, and contributed to the methodology and discussion sections. Onny Setiani reviewed the final draft, performed editorial revision, and ensured compliance with journal guidelines. All authors have read and approved the final version of this manuscript.

CONFLICTS OF INTEREST

The authors declare that there are no financial or personal conflicts of interest that could influence the objectivity of this study. The entire research and writing process was conducted independently without any external influence.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors acknowledge that generative artificial intelligence (AI) tools, such as ChatGPT (OpenAI), were used in a limited manner to refine grammar and clarify scientific terminology. All content, analysis, and interpretation remain the sole responsibility of the authors and have been fully verified prior to publication.

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