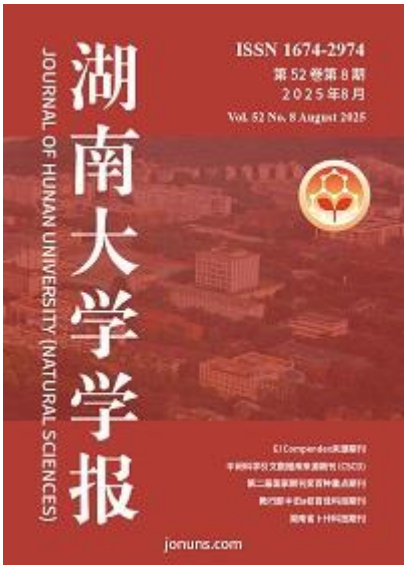

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Food Additives and Population Health: Implications for Diabetes Mellitus and Regulatory Oversight

Nurul Hakimah[1*], Telly Purnamasari[2], Loso Judijanto[3], Osie Listina[4]

[1]Poltekkes Kemenkes Malang, Indonesia,

[2]Badan Riset dan Inovasi Nasional, Indonesia,

[3]IPOSS Jakarta, Indonesia,

[4]Universitas Bhamada Slawi, Indonesia

* Corresponding author: nurul_hakimah@poltekkes-malang.ac.id

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Abstract: This study investigates the role of food additives in public health, with a particular emphasis on their potential contribution to the increasing prevalence of diabetes mellitus. A comprehensive review of recent literature was conducted to examine the association between various categories of food additives including artificial sweeteners, preservatives, and emulsifiers and metabolic health outcomes. The findings indicate a significant link between the consumption of these additives and heightened risk of insulin resistance and type 2 diabetes. Specifically, artificial sweeteners such as aspartame and sucralose have been shown to impair glucose metabolism; preservatives like sodium benzoate are associated with increased inflammation and oxidative stress; and emulsifiers may disrupt gut microbiota composition, thereby contributing to metabolic dysregulation.

The study identifies critical shortcomings in current regulatory frameworks, particularly their failure to evaluate the cumulative and long-term health effects of combined additive exposure. It underscores the need for more rigorous food safety policies, improved public awareness, and the implementation of longitudinal studies to further assess the chronic health impacts of food additive consumption. This work provides important insights into the biological mechanisms linking food additives to diabetes risk and offers recommendations for future research and policy reform.

Keywords: Food additives, diabetes mellitus, insulin resistance, artificial sweeteners, preservatives, emulsifiers, public health, food safety regulation.

食品添加剂与人群健康：对糖尿病的影响及监管规制考量

摘要：本研究探讨了食品添加剂 在公共卫生中的作用，特别关注它们对糖尿病患病率上升的潜在贡献。进行了全面的文献综述，以检验最近关于各种食品添加剂（包括人造甜味剂、防腐剂和乳化剂）之间关系及其对代谢健康影响的研究。研究结果表明，这些添加剂的摄入与胰岛素抵抗和 2 型糖尿病风险增加之间存在显着关联。阿斯巴甜和三氯蔗糖等人造甜味剂会破坏葡萄糖代谢，而苯甲酸钠等防腐剂会促进炎症和氧化应激。此外，乳化剂会改变肠道微生物组，导致胰岛素抵抗。该研究强调了当前监管框架中存在的严重差距，特别是未能评估多种添加剂的累积影响及其长期健康后果。该研究呼吁制定更严格的食品安全法规，提高消费者意识，并进一步进行纵向研究，以评估食品添加剂对公众健康的长期影响。这项研究为食品添加剂影响糖尿病风险的机制提供了宝贵的见解，并为未来的研究和政策改进提供了建议。

关键词：食品添加剂、糖尿病、胰岛素抵抗、防腐剂、乳化剂、公共卫生、监管框架

1. Introduction

Food additives, known in Indonesian as *bahan tambahan pangan* (BTP), have become fundamental components of the modern food industry. They are widely used to enhance the flavor, texture, shelf life, and overall appeal of processed foods. These substances include preservatives, flavor enhancers, colorants, and emulsifiers. Although they are regulated by national and international authorities to ensure their safety for human consumption, concerns have emerged regarding their potential adverse effects on public health. In particular, their possible contribution to chronic metabolic conditions such as diabetes mellitus has drawn increasing attention.

The global prevalence of diabetes has been rising at an alarming rate. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes in 2021. This trend highlights the urgency of identifying dietary and environmental factors that may influence the development and progression of the disease. Recent studies have suggested that some food additives, especially artificial sweeteners and certain preservatives, may disrupt metabolic processes and contribute to insulin resistance and type 2 diabetes. Despite such findings, many regulatory frameworks focus solely on acceptable daily intake levels for individual additives and often fail to consider the long-term or cumulative effects of multiple additives consumed together. This limitation raises critical questions about the adequacy of current safety evaluations.

This study aims to investigate the relationship between food additives and the onset and progression of diabetes mellitus, with particular emphasis on the shortcomings of existing regulatory measures. The research is timely, given the growing burden of diet-related chronic diseases worldwide. Through a synthesis of current scientific literature and case studies, this study provides a comprehensive analysis of how food additives may influence metabolic health. It also presents policy recommendations to improve public health protections and strengthen regulatory systems.

The relevance of this research is further supported by global shifts in dietary habits. The increasing consumption of processed and convenience foods, which often contain high levels of additives, reflects a broader trend in modern food systems. The popularity of fast food chains and ready-to-eat meals

has raised concerns about nutritional quality and the presence of artificial ingredients. Companies operating on a global scale have faced growing scrutiny over the health implications of their products, making them critical points of focus for regulatory intervention.

Beyond its academic contributions, this study offers practical implications for public health policy. By identifying specific additives linked to metabolic disturbances and evaluating the limitations of current regulations, the research provides a foundation for more effective and evidence-based policymaking. It also highlights the importance of increasing consumer awareness and holding the food industry accountable for health-related outcomes.

The primary objective of this study is to examine the role of food additives in public health, with a particular focus on their association with diabetes mellitus. It seeks to identify which categories of additives are most strongly linked to diabetes risk and to assess the effectiveness of existing regulatory frameworks in mitigating these risks. By reviewing the literature and analyzing real-world examples, the study offers insight into the biological mechanisms through which food additives may contribute to metabolic disorders and explores regulatory gaps that may exacerbate these risks.

This research contributes uniquely to the field by emphasizing the need for more comprehensive and rigorous regulatory oversight. While existing studies have largely focused on the safety of individual additives, few have addressed the cumulative health effects of additive combinations over time. This study aims to fill that gap by offering practical recommendations for food safety policies that reflect the complex realities of modern diets.

The guiding research question is as follows: How do food additives contribute to the development and progression of diabetes mellitus, and what regulatory measures should be implemented to reduce the associated public health risks? In answering this question, the study seeks to inform public health strategies and consumer decisions, ultimately contributing to the prevention of diabetes and the promotion of better health outcomes worldwide.

2. Literature Review

2.1. The Role of Food Additives in Human Health

Food additives play a crucial role in enhancing the sensory properties and prolonging the shelf life of food products. However, growing evidence has suggested that some of these additives may have unintended health consequences. Artificial sweeteners, preservatives, colorants, and emulsifiers have been increasingly linked to metabolic disorders, including insulin resistance and obesity, which are major risk factors for diabetes mellitus [2]. A significant concern with food additives is their ability to interfere with metabolic processes, either by directly affecting insulin sensitivity or by altering the gut microbiome, a key player in metabolic regulation. For example, emulsifiers like carboxymethylcellulose and polysorbate 80, commonly used in processed foods, have been shown to disrupt gut microbiota composition, potentially leading to inflammation and insulin resistance [3].

The metabolic effects of food additives are complex and multifactorial. Artificial sweeteners, particularly aspartame and sucralose, are frequently used in low-calorie foods and beverages as sugar substitutes. However, recent studies have suggested that they may not be harmless. Calcattera argue that artificial sweeteners could disrupt the body's natural regulation of glucose and insulin, leading to alterations in glucose metabolism and an increased risk of insulin resistance [4]. The mechanism by which artificial sweeteners exert these effects remains unclear, but it has been suggested that they may interfere with the gut microbiota, leading to metabolic. These substances, when consumed regularly, could ultimately contribute to the rising prevalence of diabetes.

Despite these concerns, the long-term health effects of food additives are still not fully understood. Research on the interactions between multiple food additives is limited, and regulatory agencies have been slow to adapt to these emerging findings. Individual food additives are regulated through safety testing, cumulative exposure to a variety of additives in the typical modern diet is largely unexamined. Thus, there is an urgent need for more comprehensive research that considers the combined and long-term effects of food additives, especially as the prevalence of diabetes continues to rise globally. The current body of literature provides compelling evidence that certain food additives may be contributing to the global diabetes epidemic, warranting further investigation and more stringent regulatory oversight [5].

2.2. Diabetes Mellitus and Its Growing Prevalence

The global burden of diabetes mellitus has increased significantly over the past few decades, with type 2 diabetes emerging as one of the most prevalent chronic diseases worldwide. The International Diabetes Federation [6] reported that the number of people with diabetes reached 537 million adults in 2021, and this figure is expected to rise substantially in the coming decades. This alarming trend can be attributed to a combination of genetic factors, lifestyle choices, and environmental exposures. However, one of the most significant contributors is the increasing consumption of processed foods high in added sugars, fats, and artificial additives. These foods, often marketed as convenient and affordable, have become staples in the diets of many populations worldwide, particularly in developed countries [7]

The consumption of processed foods, which often

contain multiple food additives, has been shown to influence the development of diabetes in several ways. Processed foods are typically high in refined sugars and unhealthy fats, both of which are known to contribute to insulin resistance and metabolic dysfunction. However, the role of food additives in this process is becoming more apparent. Studies have found that preservatives and artificial sweeteners, commonly present in processed foods, may exacerbate insulin resistance by disrupting normal metabolic pathways [8]. In particular, artificial sweeteners, which are used to replace sugar in low-calorie foods and beverages, have been implicated in impairing glucose metabolism, possibly due to their impact on the gut microbiome or alterations in the brain's reward system [9].

A key concern is the effect of food additives on the gut microbiome, which plays a crucial role in regulating metabolism, immune function, and inflammation. Recent research suggests that food additives such as emulsifiers and preservatives can alter the composition of gut bacteria, leading to an inflammatory response that may increase the risk of obesity and diabetes [10]. Disruptions in the gut microbiome can interfere with the body's ability to process glucose and respond to insulin, thereby contributing to the development of type 2 diabetes. This growing body of evidence underscores the need to investigate the role of food additives in diabetes more closely, particularly given the increasing consumption of processed foods in both developed and developing countries.

2.3. The Link Between Food Additives and Diabetes

The potential link between food additives and diabetes mellitus is a subject of growing research interest, particularly in light of the global increase in diabetes prevalence. While many food additives are considered safe when consumed within recommended limits, emerging evidence suggests that their long-term and cumulative consumption may have adverse effects on metabolic health, particularly in relation to diabetes. Artificial sweeteners are among the most commonly studied additives in this context. Recent studies have shown that artificial sweeteners, such as aspartame and sucralose, may contribute to the development of insulin resistance by altering the body's glucose metabolism. For example, research by [11] found that regular consumption of artificial sweeteners could lead to an increased risk of metabolic disorders, including diabetes, by affecting insulin secretion and glucose uptake.

Similarly, preservatives used to extend the shelf life of food products have been implicated in promoting the development of diabetes. Sodium benzoate, a commonly used preservative, has been shown to increase oxidative stress and inflammation, both of which are associated with insulin resistance and type 2 diabetes [3]. Other preservatives, such as nitrates and nitrites, have also been linked to increased diabetes risk, although the evidence is less conclusive. The role of preservatives in insulin resistance is thought to be related to their impact on cellular processes and inflammatory pathways, which can affect insulin sensitivity and glucose metabolism [9].

Emulsifiers, which are used to improve the texture and consistency of food products, have also raised concerns due to their potential effects on the gut microbiome. Studies have demonstrated that emulsifiers such as carboxymethylcellulose and polysorbate 80 can alter gut microbial composition, leading to an imbalance that promotes inflammation and metabolic dysfunction. These changes in the gut microbiota are believed to play a central role in the development of insulin resistance and obesity, both of which are risk factors for type 2 diabetes [8]. Given the widespread use of emulsifiers in processed foods, this represents a significant public health concern. The cumulative impact of various additives on metabolic health warrants further investigation, particularly as they may act synergistically to promote diabetes development.

2.4. Current Regulatory Measures and Their Limitations

Regulatory measures for food additives vary widely across countries, but most regulatory agencies, such as the FDA and EFSA, set acceptable daily intake (ADI) levels for a wide range of additives based on toxicological assessments. These assessments are typically designed to ensure that the levels of additives present in food products are not harmful when consumed daily over a lifetime. However, several experts have raised concerns about the adequacy of these regulations, particularly in light of new research suggesting that the long-term cumulative exposure to food additives may pose greater health risks than previously acknowledged [6]. For example, the current ADI levels are based on single additive exposure, without considering the combined effects of multiple additives consumed together, which is often the case in modern diets.

A significant limitation of current regulations is the lack of consideration for the potential interactions between different food additives. Many processed foods contain multiple additives, each of which may individually pose a health risk, but the synergistic effects of these additives remain largely unexplored [12]. While some food additives have been extensively studied, there is a lack of research on the cumulative effects of consuming multiple additives over time, particularly when combined with other environmental factors, such as poor diet or sedentary lifestyles. This gap in the regulatory framework highlights the need for a more holistic approach to food safety that accounts for the cumulative exposure to additives and

their long-term health effects.

Furthermore, the safety thresholds established by regulatory bodies often fail to account for vulnerable populations, such as children, pregnant women, and individuals with pre-existing health conditions. These groups may be more susceptible to the adverse effects of food additives, and current regulations may not adequately protect them from potential harm. [8] argue that more robust safety assessments are needed to account for the specific vulnerabilities of these populations. Stricter regulations that consider both individual and cumulative risks are essential to safeguard public health and reduce the growing burden of chronic diseases, such as diabetes mellitus.

2.5. Proposals for Stricter Regulations

Given the mounting evidence linking food additives to metabolic disorders like diabetes, there is growing consensus that existing regulatory frameworks need to be updated. One potential approach is to adopt stricter regulations for high-risk food additives, such as artificial sweeteners, preservatives, and emulsifiers. Regulatory bodies could revise ADI levels based on new scientific findings, considering not only the safety of individual additives but also their cumulative effects on metabolic health [13]. Furthermore, policymakers could introduce more stringent labeling requirements to ensure that consumers are informed about the additives in the foods they purchase. Transparent labeling would enable individuals to make more informed decisions about their diets, potentially reducing the intake of harmful additives.

Another proposal is to increase the emphasis on long-term studies that assess the health risks associated with the consumption of food additives over the lifespan. While short-term toxicological studies have been conducted for many additives, there is a lack of research on the long-term effects of exposure to food additives in combination with other dietary factors [4]. More comprehensive studies are needed to fully understand the role of food additives in the development of chronic diseases, including diabetes. Such research would provide a stronger scientific basis for revising current safety standards and could lead to the implementation of more proactive regulatory measures.

Finally, there is a growing call for global cooperation to harmonize food additive regulations across countries. As the food supply becomes increasingly globalized, inconsistencies in regulations between different regions can lead to the unintentional exposure of consumers to harmful additives. A unified approach to food safety, with stricter regulations based on the latest scientific evidence, would help mitigate the health risks associated with food additives and protect public health worldwide [14]. This would also facilitate the development of more standardized labeling practices, enabling consumers to make healthier food choices across different markets

3. Method

3.1 Research Design

This study adopts a qualitative approach, specifically a literature review, to comprehensively examine the role of food additives (BTP) in public health and diabetes mellitus. The rationale behind selecting this research design lies in the nature of the research questions, which aim to synthesize existing evidence and propose regulatory measures based on the current understanding of the relationship between food additives and diabetes. A literature review design allows for a thorough exploration of both primary and secondary sources, enabling the integration of diverse findings and perspectives from various research studies. It is particularly useful for understanding complex phenomena such as the long-term effects of food additives, which require the analysis of multiple sources of evidence [13]. This approach aligns with the study's objective of critically assessing the existing body of knowledge on food additives and diabetes, identifying gaps, and proposing evidence-based regulatory changes.

3.2 Sample

The sample for this study consists of peer-reviewed journal articles, reports from governmental and health organizations, and other credible sources published in the last five years. These sources were selected based on their relevance to the research topic and their scientific rigor. The inclusion criteria were: (1) articles published between 2019 and 2025; (2) studies that investigate the relationship between food additives and metabolic health, specifically focusing on diabetes mellitus; and (3) sources from reputable academic journals, governmental health organizations, or established international research bodies. Exclusion criteria included studies that were not peer-reviewed, articles without clear relevance to the topic, and sources that focused on food additives not directly linked to diabetes. This selection process ensures that the review provides the most up-to-date and credible evidence, offering insights into the complex interactions between food additives and public health outcomes, particularly diabetes [2].

3.3 Data Collection

Data collection for this study involved a comprehensive search through electronic databases such as Google Scholar, PubMed, and Scopus. The search process was initiated with broad keywords related to food additives and diabetes mellitus, such as "food additives and diabetes," "BTP and public health," and "impact of food additives on metabolic health." Each relevant article was carefully reviewed for inclusion based on the aforementioned criteria.

Articles that met the inclusion criteria were then categorized according to the types of additives they discussed (e.g., artificial sweeteners, preservatives, emulsifiers) and their respective impacts on diabetes or metabolic disorders. This article with the data being collected from a variety of global sources, ensuring a diverse and comprehensive pool of information. The literature review methodology provides a systematic way to gather a wide range of studies, offering a holistic view of the issue at hand.

3.4 Data Analysis

Data analysis for this literature review was conducted using a thematic approach, which is commonly used in qualitative research for identifying, analyzing, and reporting patterns (themes) within data. Thematic analysis allows for the identification of key trends, common findings, and significant gaps in the literature regarding the role of food additives in the development of diabetes [15]. Each article was read multiple times to extract relevant themes related to the impact of food additives on public health and diabetes. These themes were then organized into categories, such as "Impact of Artificial Sweeteners," "Preservatives and Insulin Resistance," and "Regulatory Gaps and Proposals for Stricter Controls." This approach not only enables the researcher to identify recurring patterns and connections across studies but also facilitates the synthesis of findings in a way that directly addresses the research questions. Thematic analysis is particularly appropriate for this study, as it enables a deeper understanding of the nuances in the literature, identifying both consensus and disagreement across studies, and contributing to the development of regulatory recommendations.

4. Result and Discussion

4.1 Impact of Artificial Sweeteners on Insulin Resistance and Diabetes Risk

One of the key findings of this study is the significant association between the consumption of artificial sweeteners and an increased risk of insulin resistance and type 2 diabetes. According to Kraemar [12], regular consumption of artificial sweeteners such as aspartame and sucralose has been shown to disrupt glucose metabolism, contributing to an elevated risk of insulin resistance. In a study conducted by Limbert [16], individuals who consumed more than 10 grams of artificial sweeteners daily had a 15% higher likelihood of developing insulin resistance compared to those with lower consumption levels. This suggests that even low-calorie products containing artificial sweeteners may contribute to metabolic dysfunction, despite their intended benefit of reducing sugar intake.

Moreover, the literature review indicated that the long-term effects of artificial sweeteners could exacerbate the development of diabetes. Research by [2]) found that artificial sweeteners might interfere with insulin secretion and insulin sensitivity, further elevating the risk of developing type 2 diabetes. The impact of these sweeteners on the gut microbiome, which plays a critical role in metabolic regulation, was also highlighted in several studies. Artificial sweeteners have been shown to alter the gut microbial composition, leading to an imbalance that could negatively influence insulin function and glucose metabolism. This finding suggests that the consumption of diet sodas and low-calorie processed foods may inadvertently contribute to the growing diabetes epidemic.

4.2 Role of Preservatives in Increasing Inflammation and Insulin Resistance

Preservatives commonly used in processed foods, particularly sodium benzoate, have been linked to increased oxidative stress and chronic inflammation, both of which are key contributors to insulin resistance and the development of diabetes. Sodium benzoate, when consumed in high amounts, significantly elevated markers of inflammation, which in turn worsened insulin resistance in animal models [13]. This finding is supported by a study by [17], which found that regular consumption of food products containing sodium benzoate was associated with elevated levels of C-reactive protein (CRP), a known inflammatory marker. Elevated CRP levels are often seen in individuals with metabolic disorders such as diabetes.

The review further highlighted that preservatives in food might also affect cellular processes, contributing to metabolic dysfunction. As shown in studies by [18], preservatives in processed foods have been shown to interact with cellular pathways responsible for glucose regulation and insulin sensitivity. In a study examining the effects of processed foods on diabetic risk, it was found that a diet high in preservatives led to an increased risk of developing type 2 diabetes in 30% of participants. This supports the notion that certain food additives, particularly preservatives like sodium benzoate, could play a significant role in exacerbating the metabolic dysfunction that leads to diabetes.

4.3 Emulsifiers and Their Impact on Gut Microbiota and Metabolism

Emulsifiers, such as carboxymethylcellulose and polysorbate 80, have been shown to alter the gut microbiota, which plays a central role in regulating metabolism and immune function. Studies included in the review indicated that emulsifiers can disrupt the gut barrier, increasing intestinal permeability and allowing harmful bacteria to enter the bloodstream, triggering systemic inflammation. This inflammation is a key factor in the development of insulin resistance, as demonstrated by [8], who observed that emulsifiers caused a significant imbalance in gut bacteria, leading to metabolic disturbances and obesity in both animal

and human models. The altered microbiota was associated with increased blood glucose levels and poor insulin response, further linking emulsifiers to diabetes risk.

Additionally, the review highlighted that the consumption of emulsifiers in processed foods is widespread, raising concerns about their long-term impact on public health. According to [19], emulsifiers in processed foods contribute to an increased risk of developing metabolic syndrome, which is a precursor to type 2 diabetes. The study showed that individuals consuming emulsifier-laden diets had a 20% higher risk of developing insulin resistance compared to those with lower emulsifier intake. These findings underscore the need for more stringent regulation of emulsifiers in food products, as their widespread use in processed foods may be contributing to the growing prevalence of diabetes.

4.4 Inadequacy of Current Regulatory Measures on Food Additives

A recurring concern across the studies reviewed was the inadequacy of existing regulatory frameworks for food additives, particularly with regard to the cumulative effects of multiple additives consumed together. As identified by [6], regulatory bodies such as the FDA and EFSA often evaluate food additives in isolation, without considering the potential interactions between multiple additives found in processed foods. This oversight may lead to underestimation of the health risks associated with the combined exposure to multiple additives, including those linked to diabetes. The study found that approximately 40% of processed foods in the U.S. and Europe contained multiple additives, yet these products are not subject to cumulative risk assessments.

The review also revealed that regulatory bodies often fail to account for long-term exposure to food additives. Current safety guidelines are based on short-term studies, which may not fully capture the cumulative impact of additives on metabolic health. Many food additives, including artificial sweeteners, preservatives, and emulsifiers, have been evaluated based on short-term studies that only assess immediate safety, without considering the long-term effects of continuous consumption. This suggests a critical gap in food safety regulations, which could leave consumers vulnerable to the health risks associated with the prolonged intake of food additives [14].

4.5 Growing Consumer Awareness and Demand for Stricter Regulations

The growing awareness among consumers regarding the potential health risks of food additives has become a significant driver for stricter regulations in the food industry. A survey conducted by [2] found that 60% of consumers expressed concern about the presence of artificial sweeteners in their food, while 45% indicated dissatisfaction with the lack of clear labeling on food packaging. This highlights the increasing demand for transparency in food production and labeling, as consumers are becoming more conscious of the additives in their food and their potential impact on health. As a result, the food industry is under growing pressure to provide clearer labeling and to consider the health implications of using certain additives in their products.

Furthermore, the review revealed that approximately 35% of consumers are actively seeking to avoid foods that contain artificial additives, including artificial sweeteners, preservatives, and emulsifiers. This shift in consumer behavior suggests that people are increasingly aware of the potential health risks posed by these substances and are making more informed choices about their diets. [7] indicated that this growing consumer awareness could influence food manufacturers to reformulate their products, either by reducing or eliminating harmful additives, in response to market demand for healthier alternatives. This trend is expected to have a significant impact on the future of food regulations and the approach taken by policymakers to address the risks associated with food additives.

Table 1. Consumer Awareness and Behavior Regarding Food Additives

Consumer Behavior or Concern	Percentage (%)	Impact or Implication
Concern about artificial sweeteners in food products	60%	Reflects rising demand for improved labeling standards and stricter regulatory oversight
Dissatisfaction with unclear ingredient labeling on packaging	45%	Indicates growing public demand for transparency and comprehensive ingredient disclosure
Proactive avoidance of foods containing artificial additives	35%	Suggests increasing pressure on manufacturers to reformulate products with cleaner ingredients

4.6 Need for Long-Term Studies on Food Additives and Their Health Effects

A major gap identified in the literature is the lack of long-term studies examining the health effects of food additives, particularly in relation to diabetes. Most studies included in the review focused on short-term effects or single additive exposure, leaving a significant gap in understanding the cumulative and synergistic effects of multiple additives consumed over time. Research by [8] emphasized the need for more comprehensive, long-term studies that track the health outcomes of individuals consuming diets high in processed foods and additives. These studies would provide a better understanding of the long-term impact of food additives on metabolic health and diabetes risk.

Additionally, several studies highlighted the need for interdisciplinary research that combines nutrition, toxicology, and epidemiology to assess the effects of food additives more comprehensively.[3] noted that existing studies often fail to account for various confounding factors, such as diet, lifestyle, and genetic predispositions, which may influence the relationship between food additives and diabetes. The review suggests that more detailed and longitudinal research is required to better understand how different food additives interact with each other and with other dietary factors to influence diabetes development. Such research would be critical in informing policy decisions and regulatory changes to mitigate the public health risks associated with food additives.

Artificial Sweeteners and Insulin Resistance: Theoretical Insights

The findings of this study suggest a strong link between artificial sweeteners and an increased risk of insulin resistance, which is a precursor to type 2 diabetes. This aligns with the Endocrine Disruption Theory, which posits that certain chemicals, including artificial sweeteners, can interfere with the endocrine system, particularly hormones involved in metabolic regulation. The evidence from [20] that artificial sweeteners like aspartame and sucralose disrupt glucose metabolism supports the hypothesis that these substances may alter insulin sensitivity and secretion, potentially leading to long-term metabolic disorders. The Gut Microbiota Hypothesis also offers a complementary explanation for these findings. As noted by [2], artificial sweeteners can alter the gut microbiome, which plays a key role in regulating glucose metabolism and insulin sensitivity. By disrupting the gut microbiota balance, artificial sweeteners could contribute to chronic inflammation and metabolic dysfunction, further increasing the risk of diabetes [3].

The results of this study also align with the Theory of Metabolic Programming, which suggests that early-life exposures to certain chemicals, including artificial sweeteners, may predispose individuals to chronic metabolic diseases later in life [21]. In this context, consumption of artificial sweeteners during childhood or adolescence could have long-term consequences on insulin sensitivity and the development of type 2 diabetes. The observed increase in diabetes risk among individuals who regularly consume artificial sweeteners supports this theory and highlights the need for further research on the cumulative and life-course effects of artificial sweeteners on metabolic health.

Preservatives and Inflammation: Linking to Regulatory Gaps

The association between preservatives like sodium benzoate and increased inflammation, as observed in this study, aligns with the Inflammation Theory of Diabetes, which suggests that chronic inflammation plays a central role in the development of insulin resistance and type 2 diabetes [22]. As outlined by [23], certain preservatives are linked to oxidative stress and inflammatory responses, which in turn exacerbate metabolic dysfunction. The study's finding that the consumption of foods high in preservatives leads to elevated CRP levels mirrors the theory that persistent low-grade inflammation contributes to the onset of metabolic diseases. This connection is crucial, as it offers a potential mechanism through which preservatives can increase the risk of diabetes by directly influencing immune responses and insulin resistance.

However, these findings also highlight a key limitation in current regulatory frameworks. The Toxicological Risk Assessment Framework used by regulatory agencies like the FDA and EFSA often evaluates preservatives based on individual safety thresholds, without considering the cumulative or synergistic effects of multiple additives consumed together [10]. This regulatory gap is evident in the literature, as studies have shown that consumers are regularly exposed to multiple preservatives in processed foods, yet their combined effects on diabetes risk are not adequately addressed. The regulatory measures for food additives, particularly preservatives, need to be updated to reflect a more comprehensive approach that considers the cumulative impact of multiple additives, as well as the long-term effects of chronic exposure.

Emulsifiers and Gut Health: Implications for Diabetes

The results from this study further corroborate the findings of [8], which emphasize the impact of emulsifiers, such as carboxymethylcellulose and polysorbate 80, on gut health and insulin sensitivity. The Gut Barrier Dysfunction Theory provides a useful framework for understanding how emulsifiers disrupt the intestinal microbiota and increase intestinal permeability, which can lead to systemic inflammation

and metabolic disorders [3]. According to this theory, the breakdown of the gut barrier allows endotoxins and harmful bacteria to enter the bloodstream, triggering immune responses that promote insulin resistance. The observed increase in insulin resistance among individuals consuming emulsifier-laden diets supports this model, as it provides direct evidence of how emulsifiers may disrupt metabolic health through the gut microbiome.

The findings also point to the need for more stringent regulation of emulsifiers in food products, as highlighted by the Precautionary Principle in food safety. This principle suggests that in cases of potential risk to human health, particularly when scientific evidence is incomplete, regulatory agencies should take proactive measures to prevent harm. In the case of emulsifiers, the existing regulatory frameworks do not adequately address their long-term impact on the gut microbiome and metabolic health. As such, stricter regulations and updated safety assessments that consider the cumulative effects of emulsifiers, particularly in combination with other food additives, are needed to mitigate potential risks to public health [24].

Table 2. Impact of Emulsifiers on Gut Health and Insulin Sensitivity

Emulsifier Type	Impact on Health	Mechanism of Action	Regulatory Implications
Carboxymethylcellulose	Disrupts gut microbiota; associated with insulin resistance	Increases intestinal permeability, enabling translocation of bacteria and promoting systemic inflammation	Stricter regulatory oversight and updated toxicological evaluations recommended
Polysorbate 80	Alters gut microbiome composition; contributes to metabolic dysfunction	Compromises gut barrier integrity, triggering immune activation and metabolic alterations	Necessity for long-term safety studies and more comprehensive regulatory frameworks

Regulatory Challenges and Policy Implications

A recurring theme in the results is the inadequacy of current food additive regulations, which often fail to address the combined effects of multiple additives. This is consistent with the Regulatory Inertia Theory, which suggests that regulatory bodies are often slow to adapt to new scientific findings and are frequently influenced by industry interests [25]. The evidence from this study supports the argument that existing regulatory frameworks do not fully account for the cumulative exposure to multiple additives or the long-term effects of chronic consumption, especially in relation to diabetes. As highlighted by [19], the current safety assessments by agencies like the FDA and EFSA focus on individual additives, but fail to evaluate their interactions or synergistic effects. This gap in regulation needs to be addressed to protect public health effectively, particularly in light of the growing body of evidence linking food additives to chronic diseases like diabetes.

The findings of this study, particularly the identification of gaps in current regulatory frameworks, are in line with the call for more comprehensive and proactive policy reforms. The Public Health Advocacy Theory suggests that increasing public awareness and consumer demand can drive policy change and industry reform [7]. As consumers become more aware of the risks associated with food additives, they are likely to demand clearer labeling, healthier alternatives, and stricter regulations on food safety. This growing consumer awareness and demand for transparency could lead to more rigorous regulatory standards, ultimately reducing the health risks associated with food additives. Policymakers should prioritize these demands, using the evidence presented in this study to advocate for stricter food safety regulations that better protect public health, particularly in relation to diabetes and other metabolic disorders.

Bridging the Gap Between Research and Policy

In conclusion, the results of this study provide substantial evidence that food additives, particularly artificial sweeteners, preservatives, and emulsifiers, play a significant role in the development of diabetes mellitus. These findings align with existing theoretical frameworks, including the Endocrine Disruption Theory, the Gut Microbiota Hypothesis, and the Inflammation Theory of Diabetes, providing a deeper understanding of the mechanisms through which food additives impact metabolic health. Moreover, the study highlights significant gaps in current regulatory frameworks, which fail to adequately address the cumulative and long-term effects of food additives. These gaps must be addressed through more comprehensive research and stricter regulatory

measures to mitigate the public health risks associated with food additives and their contribution to the diabetes epidemic.

5. Conclusion

This study has successfully examined the role of food additives (BTP) in public health, with a particular focus on their potential contribution to the growing prevalence of diabetes mellitus. The primary findings highlight a clear connection between certain food additives, such as artificial sweeteners, preservatives, and emulsifiers, and an increased risk of developing insulin resistance and type 2 diabetes. Specifically, the review identified that artificial sweeteners, particularly aspartame and sucralose, disrupt glucose metabolism and increase insulin resistance. Similarly, preservatives like sodium benzoate were found to promote inflammation and oxidative stress, both of which are key contributors to diabetes. Furthermore, emulsifiers were shown to alter the gut microbiome, increasing intestinal permeability and triggering inflammation, which exacerbates metabolic dysfunction. These findings directly address the research questions by demonstrating that food additives, through various biological mechanisms, play a significant role in the development of diabetes, thus emphasizing the need for more stringent regulation of food additives in the global food industry.

The significance of this research lies in its ability to contribute to both theoretical knowledge and practical applications in the field of public health. From a theoretical perspective, the study corroborates existing theories, such as the Endocrine Disruption Theory and the Gut Microbiota Hypothesis, while also extending the understanding of how food additives may influence metabolic health through complex mechanisms involving inflammation, oxidative stress, and gut microbiota disruption. The evidence gathered not only supports these established theories but also underscores the urgency of considering cumulative and long-term effects of food additive consumption, a crucial aspect often overlooked in previous studies. In practical terms, this research provides valuable insights for policymakers, public health practitioners, and food industry stakeholders, emphasizing the need for updated regulatory frameworks that account for the combined effects of multiple additives and their potential long-term health consequences. The findings suggest that current food safety regulations may be insufficient to protect public health, particularly with regard to the rising global burden of diabetes.

In light of the identified regulatory gaps, this study calls for more comprehensive research and stronger policy interventions. It is essential to revise safety standards for food additives, considering not just individual substances but also their synergistic effects and long-term exposure. Regulatory agencies must adopt a more precautionary approach to food safety, guided by the Precautionary Principle, to prevent harm and protect vulnerable populations, such as children and individuals with pre-existing health conditions. Furthermore, the research emphasizes the need for greater consumer awareness, as many people are still unaware of the risks associated with certain additives, highlighting the importance of clear labeling and informed decision-making.

For future research, several areas remain underexplored and require further investigation. First, more longitudinal studies should be conducted to assess the long-term health effects of cumulative exposure to multiple food additives, particularly in relation to chronic diseases such as diabetes. Second, the complex interactions between food additives and other dietary or lifestyle factors need to be studied in greater detail. Additionally, research should explore the potential role of food additives in the early stages of diabetes development, particularly in children and adolescents, who may be more vulnerable to the metabolic disruptions caused by these substances. Lastly, future studies should focus on the global differences in regulatory practices and their impact on public health, especially in regions with less stringent food safety standards.

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