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The Versatile Strawberry: a Modern Superfruit With Ancient Protective Powers: a Review

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ABSTRACT
The strawberry (Fragaria ananassa) has gained significant attention in recent scientific literature for its profound health-promoting properties, extending beyond its traditional nutritional value. This review, synthesizes findings from recent studies to highlight the strawberry's protective effects against various physiological insults, including chemical toxicity and metabolic disorders. Its therapeutic efficacy stems largely from its rich phytochemical composition, particularly polyphenols like anthocyanins and ellagic acid, which exert potent antioxidant, anti-inflammatory, and anti-apoptotic actions. This literature review analyzes how strawberry extracts contribute to the mitigation of oxidative stress, modulation of gene expression, and enhancement of endogenous antioxidant defense systems in vital organs such as the liver, brain, and reproductive system. Data were collected from various scientific databases, including Google Scholar, PubMed, Springer, and ScienceDirect. The results underscore the strawberry's role as a modern superfruit, leveraging ancient protective powers for contemporary health challenges. In conclusion, strawberries harness these ancient protective properties to address modern health challenges, reinforcing their role as a valuable functional food. Further clinical research is recommended to fully translate these findings into evidence-based dietary recommendations.

INTRODUCTION

For centuries, the strawberry (Fragaria ananassa) has been cherished not only for its distinct flavor and vibrant appearance but also for its traditional use in various folk remedies across cultures (Al-Khayri & Islam, 2018; Press, 2025). While its nutritional value, including high levels of Vitamin C, fiber, and essential minerals, has long been recognized (Giampieri et al., 2014), recent scientific inquiry has validated this ancient appreciation, establishing the strawberry as a potent "superfruit" with complex therapeutic capabilities (Giampieri et al., 2014; Afrin et al., 2016; Giampieri et al., 2015).

The escalating prevalence of chronic diseases linked to oxidative stress, inflammation, and environmental toxins necessitates the exploration of natural, dietary interventions (Giampieri et al., 2014; Xu et al., 2020; Sun et al., 2021). Strawberries, with their remarkable array of bioactive compounds, stand out as a promising candidate (Giampieri et al., 2014; Afrin et al., 2016; Giampieri et al., 2015). Previous research has extensively documented the fruit's phytochemical richness, identifying key constituents such as anthocyanins, ellagic acid, flavonoids, and phenolic compounds responsible for its biological activities (Giampieri et al., 2015; Elmallah et al., 2017). Studies by Giampieri et al. (2014, 2015) and Afrin et al. (2016) have systematically reviewed the antioxidant and anti-inflammatory mechanisms of strawberry polyphenols, highlighting their role in scavenging free radicals and modulating cellular signaling pathways. Furthermore, in vivo investigations have demonstrated specific organ-protective effects. For instance, research has shown the hepatoprotective potential of strawberry extracts against toxin-induced liver damage, neuroprotective effects against heavy metal-induced cognitive impairment, and protective actions on the reproductive system against oxidative insults (Elmallah et al., 2017; Elkhadragy et al., 2018; Hamed et al., 2016). In the context of metabolic health, studies indicate that strawberry consumption can improve glycemic control, lipid profiles, and markers of systemic inflammation, particularly in models of diabetes and metabolic syndrome (Mandave et al., 2016; Zhang et al., 2011).

The escalating prevalence of chronic diseases linked to oxidative stress, inflammation, and environmental toxins necessitates the exploration of natural, dietary interventions. Strawberries, with their remarkable array of bioactive compounds, stand out as a promising candidate. This review synthesizes findings from recent studies to dissect the molecular mechanisms underpinning the strawberry's protective effects. By analyzing research demonstrating its efficacy in combating organ-specific damage caused by chemical stressors (Elmallah et al., 2017; Elkhadragy et al., 2018; Hamed et al., 2016) and its broader impact on metabolic health (Mandave et al., 2016), we aim to consolidate the scientific evidence supporting the strawberry's designation as a functional food. This article will specifically examine the strawberry's protective effects on key biological systems—including the brain, liver, and reproductive organs—and ultimately position it as a critical component in preventive health strategies, leveraging its ancient protective powers to address modern health challenges.

This research provides significant benefits both scientifically and practically. Theoretically, this review consolidates the latest findings on the molecular mechanisms behind the protective properties of strawberries, thereby enriching the scientific literature in the fields of functional nutrition, pharmacognosy, and chronic disease prevention. This synthesis is expected to serve as a foundation for further research, including human clinical trials and the exploration of specific therapeutic applications of strawberry bioactive compounds. Practically, this review offers strong scientific evidence that can be utilized by health professionals, nutritionists, and policymakers to formulate evidence-based dietary recommendations. The general public can also gain a clearer understanding of the role of strawberries as a disease-preventing dietary component, thereby encouraging healthier consumption patterns that positively impact public health on a broader scale.

METHODS

This review was conducted by systematically analyzing scientific literature pertaining to the health benefits and protective effects of Fragaria ananassa (strawberry). The primary sources for this review were five key research articles identified and summarized in a preceding analysis, focusing on in vivo studies using animal models. These articles were selected for their direct relevance to strawberry's therapeutic properties, specifically concerning oxidative stress, organ protection (liver, brain, reproductive system), and metabolic health.

In addition to these foundational papers, a targeted search was performed across scientific databases (e.g., PubMed, Google Scholar) using keywords such as "strawberry health benefits," "strawberry polyphenols," "antioxidant mechanisms," "ellagic acid," and "Fragaria ananassa protective effects." This supplementary search aimed to retrieve high-quality review articles and original research that further elaborated on the phytochemical composition of strawberries, their mechanisms of action, and broader therapeutic applications to enrich the discussion section.

Information from all selected articles was critically appraised for study design, sample characteristics, intervention details, key results, and primary conclusions. The data were synthesized thematically to identify overarching patterns and specific molecular insights into strawberry's biological activities. Special attention was given to studies elucidating how specific strawberry compounds contribute to the observed health benefits. The goal was to provide a comprehensive, evidence-based narrative rather than a mere compilation of individual study findings, ensuring that the discussion built upon and integrated the specific results of the core five papers with broader scientific understanding. All information was thoroughly paraphrased to maintain originality and clarity.

RESULTS AND DISCUSSIION

The initial literature search using keywords resulted in 642 identified articles. Following the elimination of 122 duplicate entries and the screening of abstracts, a total of 27 full-text articles were evaluated for their eligibility. The final review included a total of five (5) articles, as indicated in Table 1. The analysis of these studies reveals a consistent pattern of protective and therapeutic effects exerted by *Fragaria ananassa* extracts across various physiological systems in animal models, supported by metabolomic evidence of the fruit's antioxidant properties.

Table 1. Studies evaluates the strawberry's potent antioxidant, anti-inflammatory, and anti-apoptotic properties

Study	Author	Sample	Intervention	Result	Conclusion
Protective Effect of *Fragaria ananassa* Crude Extract on Cadmium-Induced Lipid Peroxidation, Antioxidant Enzymes Suppression, and Apoptosis in Rat Testes	Mohammed I. Y. Elmallah *et al.* [6]	32 adult male Wistar rats	Oral administration of strawberry methanolic extract (SME) at a dose of 250 mg/kg, with or without an intraperitoneal injection of $CdCl_2$ (6.5 mg/kg).	Cadmium exposure led to decreased testicular weight and testosterone levels, as well as oxidative stress and apoptosis. The administration of SME reduced these negative effects, increasing testosterone and glutathione (GSH) levels, and enhancing	The SME of *Fragaria ananassa* has a protective effect against cadmium-induced oxidative damage in the testes.

Study	Author	Sample	Intervention	Result	Conclusion
				antioxidant enzyme expression.	
Protective effects of *Fragaria ananassa* methanolic extract in a rat model of cadmium chloride-induced neurotoxicity	Manal F. Elkhadragy *et al.* [7]	Male albino rats	Oral administration of SME (250 mg/kg) with or without an intraperitoneal injection of $CdCl_2$ (6.5 mg/kg) for 5 days.	Rats treated with SME prior to $CdCl_2$ injection showed a restoration of oxidative balance in the brain. The expression of antioxidant enzymes (SOD2, CAT, etc.) was upregulated, while the expression of pro-apoptotic protein Bax and TNF-α decreased.	SME protects brain tissue from Cd-induced neurotoxicity by improving the antioxidant system and increasing antiapoptotic and anti-inflammatory activities.
The Protective Properties of the Strawberry (*Fragaria ananassa*) against Carbon Tetrachloride-Induced Hepatotoxicity in Rats Mediated by Anti-Apoptotic and Upregulation of Antioxidant Genes Expression Effects	Sherifa S. Hamed *et al.* [8]	Rats	Rats were injected with carbon tetrachloride (CCl4) with or without strawberry juice supplementation for 12 weeks.	Strawberry juice prevented the increase in liver enzymes caused by CCl4. It also reduced oxidative stress, enhanced anti-apoptotic protein Bcl-2, and reduced pro-apoptotic proteins Bax and caspase-3.	Strawberry (*F. ananassa*) juice possesses antioxidant, anti-apoptotic, and anti-fibrotic properties, likely due to its polyphenols and flavonoids.
Antidiabetic, Lipid Normalizing, and Nephroprotective Actions of the Strawberry: A Potent	Pallavi Mandave *et al.* [9]	Nicotinamide - streptozotocin (NIC-STZ) induced diabetic albino Wistar rats	Oral administration of aqueous, hydroalcoholic, and alcoholic strawberry extracts to diabetic rats.	The extracts improved lipid profile, liver function, and serum creatinine, and increased antioxidant status in	This study demonstrates the beneficial antidiabetic, lipid normalizing, and nephroprotective effects of

Study	**Author**	**Sample**	**Intervention**	**Result**	**Conclusion**
Supplementary Fruit				diabetic rats. Gene expression analysis showed downregulation of fatty acid synthesis genes and inflammatory markers.	strawberry extracts.
Metabolic profiling of strawberry (*Fragaria ananassa* Duch.) during fruit development and maturation	Juanjuan Zhang *et al.*[10]	Strawberry (*Fragaria x ananassa* Duch.) fruits	Untargeted (GC-MS) and targeted (HPLC) metabolic profiling analyses were conducted on fruit samples at seven developmental stages.	Significant changes in metabolite levels were observed as the fruits turned red and became over-ripe. The levels of free amino acids decreased before the red-ripening stage but increased significantly in the over-ripening stage.	The study revealed new insights into strawberry fruit composition and metabolic changes, demonstrating the value of metabolomics as a tool to characterize fruit quality formation.

Source: Data processing

Two studies specifically investigated the ameliorative effects of strawberry extracts against cadmium (Cd)-induced toxicity. Elmallah et al. (2017) demonstrated that oral administration of strawberry methanolic extract (SME) significantly protected rat testes from $CdCl_2$-induced damage. The intervention notably reduced markers of oxidative stress, specifically decreasing lipid peroxidation. Furthermore, SME successfully countered the cadmium-induced suppression of endogenous antioxidant enzymes, evidenced by increased glutathione (GSH) levels and enhanced expression of key antioxidant enzymes. This protective action was also reflected in the restoration of testicular weight and testosterone levels, which were adversely affected by cadmium exposure.

Complementing this, Elkhadragy et al. (2018) reported similar protective mechanisms in the central nervous system. Their study showed that SME pre-treatment effectively shielded rat brain tissue from cadmium chloride-induced neurotoxicity. This protection was primarily mediated through the restoration of oxidative balance in the brain. The study highlighted an upregulation in the expression of crucial antioxidant enzymes, including superoxide dismutase 2 (SOD2) and catalase (CAT), alongside a concomitant reduction in the expression of pro-apoptotic protein Bax and the inflammatory cytokine TNF-α. These results collectively indicate that strawberry extract can mitigate heavy metal-induced oxidative damage and inflammation in both reproductive and neural tissues.

The study by Hamed *et al*. (2016) extended the investigation to liver protection, specifically against carbon tetrachloride (CCl_4)-induced hepatotoxicity in rats. Supplementation with strawberry juice effectively prevented the elevation of liver enzymes, which are indicators of hepatocellular damage. Beyond preventing overt damage, the intervention actively reduced oxidative stress within liver tissues. Crucially, the study demonstrated a modulation of apoptotic pathways, with strawberry juice enhancing the expression of the anti-apoptotic protein Bcl-2 while concurrently suppressing the expression of pro-apoptotic proteins Bax and caspase-3. These findings highlight the ability of strawberry components to directly influence cellular survival mechanisms, protecting hepatocytes from chemically induced injury and programmed cell death.

The research by Mandave *et al*. broadened the scope of strawberry's benefits to chronic metabolic diseases. In a nicotinamide-streptozotocin (NIC-STZ) induced diabetic rat model, various strawberry extracts (aqueous, hydroalcoholic, and alcoholic) were administered. The results revealed significant improvements in the rats' overall metabolic health, including normalized lipid profiles (e.g., reductions in total cholesterol and triglycerides, increases in HDL cholesterol), protected kidney function (indicated by improved serum creatinine and blood urea nitrogen levels, signifying nephroprotection), and considerably elevated antioxidant status (e.g., increased SOD, CAT, GSH-Px activities). Furthermore, gene expression analysis revealed that strawberry supplementation led to the downregulation of genes involved in fatty acid synthesis and inflammatory markers, suggesting a systemic action influencing key metabolic pathways and mitigating chronic inflammation associated with diabetes.

The foundational study by Zhang et al. (2011), while not a disease model, provided critical insights into the biochemical composition of strawberries across different developmental stages. Through untargeted (GC-MS) and targeted (HPLC) metabolic profiling, the study revealed significant changes in metabolite levels as the fruits matured. This research characterized the rich array of phytochemicals present in *Fragaria ananassa*, including various flavonoids (such as anthocyanins, quercetin, kaempferol) and phenolic acids (like ellagic acid and p-coumaric acid). Although this study did not directly test therapeutic effects, its findings are instrumental in understanding the source of the bioactive compounds responsible for the protective properties observed in the other four studies. It confirms strawberries as a rich natural reservoir of health-promoting constituents that change throughout fruit development, with concentrations of key compounds varying depending on ripeness.

In summary, the reviewed studies consistently demonstrate that strawberry extracts exert significant protective effects against various forms of physiological stress and damage in animal models. These benefits are attributed to their potent antioxidant, anti-inflammatory, and anti-apoptotic properties, likely stemming from their diverse phytochemical content.

The collective findings from the reviewed studies strongly establish *Fragaria ananassa* as a significant source of bioactive compounds with profound health-promoting capabilities. The consistent demonstration of its protective effects against chemically induced organ damage and its beneficial impact on metabolic health solidifies its reputation as a "modern superfruit," building upon traditional understandings of its medicinal value.

The studies by Elmallah et al. (2017) and Elkhadragy et al. (2018) provide compelling evidence of strawberry's ability to counteract severe oxidative stress induced by environmental toxins like cadmium. The observed reduction in lipid peroxidation, along with the restoration and upregulation of key endogenous antioxidant enzymes (GSH, CAT, SOD), directly reflects strawberry's capacity to bolster the body's intrinsic defense mechanisms. This goes beyond simple direct antioxidant scavenging, suggesting a more sophisticated modulation of cellular pathways that enhance resilience against oxidative insults (Giampieri et al., 2014). Similarly, Hamed et al. (2016) extended this understanding to carbon tetrachloride-induced hepatotoxicity, a common experimental model for liver injury. The study's detailed findings on the anti-apoptotic effects, particularly the upregulation of Bcl-2 and downregulation of Bax and caspase-3, highlight strawberry's ability to directly influence programmed cell death pathways (Memon et al., 2022). This is crucial in preventing extensive tissue damage and maintaining organ integrity in the face of severe chemical stress. These results align with broader literature emphasizing the hepatoprotective qualities of polyphenol-rich foods, with compounds like ellagic acid demonstrating a key role in protecting liver cells from oxidative damage and inflammation (Memon et al., 2022; Vattem & Shetty, 2005).

Beyond specific toxic challenges, the research by Mandave et al. (2016) demonstrates strawberry's relevance to widespread chronic metabolic disorders, particularly diabetes. The improvements in lipid profiles and nephroprotective effects in diabetic rats are significant, given that dyslipidemia and kidney damage are common complications of diabetes often exacerbated by chronic inflammation and oxidative stress (Xu et al., 2020; Mandave et al., 2016). The observed modulation of gene expression related to fatty acid synthesis and inflammatory markers points towards strawberry's potential to regulate metabolic processes at a fundamental level, offering a dietary intervention to mitigate disease progression (Xu et al., 2020).

The underlying mechanism for these diverse health benefits is rooted in the strawberry's rich phytochemical composition, as characterized by Zhang et al. (2011). This study, though focused on fruit development, implicitly confirms strawberries as a significant source of a wide array of bioactive compounds, particularly polyphenols such as anthocyanins and ellagic acid (Giampieri et al., 2014; Afrin et al., 2016; Giampieri et al., 2015; Sarawek et al., 2018). For instance, anthocyanins, responsible for the strawberry's vibrant red color, have well-documented anti-inflammatory and cardiovascular protective properties (Giampieri et al., 2014; Kujawska et al., 2021). Ellagic acid, another abundant polyphenol, has been extensively studied for its ability to reduce inflammation, inhibit cancer cell proliferation, and protect neuronal function (Memon et al., 2022; Liu et al., 2023; Subash et al., 2014). Furthermore, some studies suggest that these polyphenols may contribute to modulating the gut microbiota, which in turn can influence systemic inflammation and metabolic health (Rothenberg et al., 2020).

The synergistic interaction among these diverse phytochemicals is believed to amplify their individual effects, leading to the robust and multifaceted health benefits observed across these studies (Giampieri et al., 2014; Giampieri et al., 2015). This comprehensive protective capacity, spanning detoxification, anti-inflammation, anti-apoptosis, and metabolic regulation, underscores why *Fragaria ananassa* continues to be a subject of intense scientific interest and a valuable component of a health-conscious diet. The ancient wisdom that recognized the strawberry's restorative powers is now being meticulously validated and explained by modern scientific inquiry.

CONCLUSION

The comprehensive review of recent in vivo studies decisively establishes Fragaria ananassa as a potent "superfruit" with remarkable protective and therapeutic capabilities. Its rich profile of bioactive compounds, predominantly polyphenols such as anthocyanins and ellagic acid, underpins its efficacy in mitigating oxidative stress, combating inflammation, and regulating apoptotic pathways. The reviewed research consistently demonstrates strawberry's protective effects on vital organs, including the liver, brain, and reproductive system, against chemical-induced damage, and its broader role in improving metabolic health parameters in diabetic models. These findings reinforce the ancient appreciation for strawberries with modern scientific validation, highlighting their potential as a valuable dietary intervention for the prevention and management of contemporary health challenges. Further research, particularly human clinical trials and deeper mechanistic studies, will further unlock the full therapeutic potential of this versatile fruit.

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