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Chemical Constituents of Kiwifruit (*Actinidia* spp.) and Their Pharmacological Effects

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Abstract Kiwifruit (*Actinidia* spp.) has garnered significant attention due to its rich nutritional content, unique flavor, and considerable economic value. This study systematically analyzes the chemical constituents of kiwifruit, including polyphenols, vitamins, and dietary fiber, as well as their pharmacological effects in areas such as antioxidant, anti-inflammatory, antimicrobial, and cardiovascular protection. The results indicate that kiwifruit is rich in various bioactive compounds that not only have remarkable health-promoting effects but also hold potential clinical significance in the prevention and treatment of chronic diseases. Although existing foundational studies confirm the multiple health benefits of kiwifruit, clinical research remains insufficient, particularly in verifying the chemical composition differences and specific therapeutic effects among different kiwifruit varieties. Kiwifruit holds great potential as a functional food and medicine, and future research should focus on its bioactive mechanisms and sustainable utilization. This study provides valuable insights for the future application of kiwifruit in the fields of food, medicine, and nutritional supplements, facilitating the development of functional foods and the prevention and treatment of chronic diseases.
Keywords Kiwifruit; Chemical constituents; Antioxidant activity; Anti-inflammatory effects; Pharmacological effects; Disease prevention

1 Introduction

Kiwifruit (*Actinidia* spp.) is a highly valued fruit crop known for its unique flavor, nutritional benefits, and economic importance. Originating from China, kiwifruit has gained global popularity and is now cultivated in various regions worldwide. The fruit is rich in essential nutrients such as vitamin C, polyphenols, dietary fiber, and bioactive phytochemicals, which contribute to its health-promoting properties (He et al., 2019; Wang et al., 2020). Different species and cultivars of kiwifruit, including *Actinidia chinensis* and *Actinidia arguta*, exhibit significant variability in their chemical composition and biological activities, making them a subject of extensive research and commercial interest (Latocha et al., 2013; Lin et al., 2022).

Understanding the chemical diversity and bioactivity of kiwifruit is essential. The phytochemical components in kiwifruit, such as antioxidants, vitamins, and polyphenols, demonstrate significant potential in promoting health. Studies have shown that these compounds possess multiple bioactivities, including antioxidant, anti-inflammatory, and antibacterial effects, which may contribute to the prevention and treatment of chronic diseases (He et al., 2019; Wang et al., 2020; Wang et al., 2021). However, despite numerous foundational studies exploring the health benefits of kiwifruit, systematic clinical research remains insufficient, and its specific therapeutic effects are yet to be fully validated (Ma et al., 2019). Additionally, the differences in the chemical composition and bioactivity of various kiwifruit cultivars and parts, such as fruits and leaves, require further in-depth analysis to optimize their application in food and medicine.

Moreover, the metabolic and gene regulatory mechanisms in kiwifruit, especially those related to the accumulation of key bioactive compounds, have not been thoroughly elucidated. This gap in research not only limits a deeper understanding of kiwifruit's nutritional and medicinal value but also hinders the potential to improve fruit quality through the enhancement of chemical constituents in breeding programs (Wang et al., 2021;

Shu et al., 2023). Therefore, uncovering the mechanisms that regulate key metabolites in kiwifruit is crucial for enhancing its commercial value and health benefits.

This study systematically analyzes the chemical constituents and pharmacological effects of kiwifruit, providing a comprehensive understanding of its chemical diversity and bioactivity through integrated research data. The study aims to identify and classify the main chemical components of different species and varieties of kiwifruit, evaluate its pharmacological actions—including antioxidant, anti-inflammatory, and other health-promoting properties—and discuss its potential clinical significance in the prevention and treatment of chronic diseases. This study seeks to elucidate the multifaceted benefits of kiwifruit, offering valuable resources for researchers, healthcare professionals, and the food industry, and providing references for the sustainable utilization and enhancement of the nutritional and medicinal properties of kiwifruit in future research.

2 Chemical Constituents of Kiwifruit

2.1 Polyphenols and flavonoids

Kiwifruit contains a variety of polyphenols and flavonoids, which vary significantly among different cultivars and parts of the fruit. Key polyphenols identified include catechin, epicatechin, quercitrin, and chlorogenic acid (Wang et al., 2020; Zhang et al., 2020; Chen et al., 2023). The total polyphenol content (TPC) and total flavonoid content (TFC) are substantial, with TPC ranging from 75.43 to 316.14 mg GAE/100 g FW and TFC being significant contributors to the antioxidant capacity of the fruit (Table 1) (Zhang et al., 2020; Liang et al., 2021).

Table 1 AAC, TPC, TFC and TAC of 15 kiwifruit cultivars (Adopted from Zhang et al., 2020)

Cultivar	AAC (mg/100 g)	TPC (mg GAE/100 g)	TFC (mg CTE/100 g)	TAC (mg CGE/100 g)
Cuixiang	145.25 ± 0.75 h	131.03 ± 2.84 e	20.39 ± 3.55 de	-
Hayward	92.75 ± 1.75 l	78.04 ± 3.27 h	10.25 ± 2.13 f	-
Xuxiang	105.42 ± 0.63 k	85.49 ± 2.55 g	12.56 ± 3.51 ef	-
Guichang	165.27 ± 3.25 e	133.94 ± 3.52 e	5.69 ± 2.68 f	-
Ruiyu	124.49 ± 0.89 j	110.57 ± 3.46 f	12.00 ± 1.47 ef	-
Jinhong No.1	52.39 ± 1.88 n	80.09 ± 1.91 h	22.19 ± 3.29 d	0.52 ± 0.07 c
Hongshi No.2	248.16 ± 2.67 a	216.37 ± 0.73 a	50.89 ± 3.02 a	3.65 ± 0.27 a
Hongyang	154.57 ± 1.72 g	129.75 ± 1.59 e	40.69 ± 3.01 b	1.02 ± 0.02 b
Jinhong 50	161.04 ± 1.70 f	142.89 ± 3.78 c	31.64 ± 3.69 c	0.72 ± 0.00 c
Oriental Red	181.07 ± 2.10 d	144.53 ± 0.77 c	23.72 ± 5.71 d	1.58 ± 0.13 b
Huayou	187.33 ± 1.88 c	146.46 ± 2.43 c	23.58 ± 1.44 d	-
Sungold	137.42 ± 1.38 i	113.09 ± 3.22 f	16.33 ± 3.06 e	-
Jinyan	73.83 ± 1.28 m	74.06 ± 0.97 h	15.17 ± 1.12 ef	-
Jintao	151.74 ± 1.61 g	141.7 ± 2.19 d	14.69 ± 4.52 ef	-
Puyu	233.99 ± 1.61 b	158.66 ± 2.35 b	19.61 ± 3.26 d	-

Note: The data are given as the mean ± SD ($n = 3$). Mean values in each column with unlike letters are significantly different among cultivars ($p < 0.05$) (Adopted from Zhang et al., 2020)

Polyphenols and flavonoids in kiwifruit play a crucial role in its antioxidant activities. Studies have shown that these compounds are the primary contributors to the fruit's ability to scavenge free radicals, as evidenced by their performance in DPPH and FRAP assays (Zhang et al., 2020; Zhou et al., 2020; Chen et al., 2023). For instance, chlorogenic acid has been positively correlated with ferric reducing antioxidant power (FRAP), while isoquercitrin has shown a negative correlation with DPPH free radical scavenging ability (Chen et al., 2023). The fermentation of kiwifruit with Lactobacillus plantarum has been found to increase the content of these antioxidant compounds, further enhancing the fruit's antioxidant activity (Zhou et al., 2020).

2.2 Vitamins and dietary fiber

Kiwifruit is an excellent source of vitamin C, with concentrations ranging from 47.24 to 171.64 mg/100 g, depending on the cultivar (Zhang et al., 2020; Liang et al., 2021). Vitamin C is well-known for its antioxidant properties, which help in reducing oxidative stress and boosting the immune system. Additionally, it plays a vital role in collagen synthesis, wound healing, and the maintenance of cartilage, bones, and teeth (Tylewicz et al., 2020).

The dietary fiber content in kiwifruit is significant and contributes to its health benefits, particularly in managing glycaemic response. Studies have shown that the non-sugar components of kiwifruit, including dietary fiber, can reduce the amplitude of the glycaemic response by delaying the absorption of carbohydrates (Monro et al., 2022). This effect is attributed to the fiber's ability to slow down the digestion and absorption of sugars, thereby preventing spikes in blood glucose levels.

2.3 Essential oils and fatty acids

Essential oils in kiwifruit oil are composed of various bioactive compounds, including geraniol and α-tocopherol, which have been shown to maintain the bioactive compounds of the fruit during storage (Mthembu et al., 2023). These essential oils contribute to the fruit's overall antioxidant capacity and help in preserving its nutritional quality. The major fatty acids identified in kiwifruit oil include polyunsaturated fatty acids (PUFAs), which are crucial for maintaining cell membrane integrity and function. The presence of these fatty acids has been linked to the fruit's ability to reduce fatty acid oxidation and maintain textural properties during storage (Jiao et al., 2020). The application of polyphenols from kiwifruit has also been shown to inhibit the formation of TBARS and TVB-N, further highlighting the protective effects of these compounds on lipid oxidation.

3 Pharmacological Effects

3.1 Antioxidant properties

Kiwifruit contains a variety of bioactive compounds, including polyphenols, flavonoids, and vitamins, which contribute to its strong antioxidant properties. These compounds work by scavenging free radicals and reducing oxidative stress in the body. For instance, the fermentation of kiwifruit with *Lactobacillus plantarum* has been shown to increase the content of phenolics and flavonoids, thereby enhancing its antioxidant activity (Zhou et al., 2020). Additionally, the presence of compounds such as protocatechuic acid and chlorogenic acid in kiwifruit pulp further contributes to its antioxidant potential.

Kiwifruit is recognized as a rich source of natural antioxidants. Studies have demonstrated that different parts of the kiwifruit, including the peel, pulp, and core, contain significant amounts of phenolic compounds and exhibit strong antioxidant capacities. For example, the peel of New Zealand-grown organic Hayward kiwifruit has been found to have the highest total phenolic content and antioxidant capacity compared to the pulp and core (Liu et al., 2022). The antioxidant capacity of kiwifruit is influenced by its cultivar, with some varieties like Hongshi No.2 showing particularly strong antioxidant properties (Figure 1) (Zhang et al., 2020). When compared to other fruits, kiwifruit stands out for its high antioxidant capacity. The total polyphenol content (TPC) and ascorbic acid content (AAC) in kiwifruit are significant contributors to its antioxidant activity, often surpassing those found in other fruits. For instance, the antioxidant capacity of kiwifruit measured through DPPH and FRAP assays is notably high, making it a superior source of natural antioxidants (Zhang et al., 2020). Additionally, the use of enhanced freshness formulations (EFF) has been shown to maintain the bioactive compounds and antioxidant capacities of kiwifruit during storage, further highlighting its potential as a robust antioxidant source (Mthembu et al., 2023).

3.2 Anti-inflammatory and antimicrobial effects

Kiwifruit exhibits notable anti-inflammatory properties, primarily due to its rich content of antioxidative phenolics. Studies have shown that extracts from certain kiwifruit cultivars, such as *Actinidia eriantha* cv. *Bidan*, significantly reduce the production of proinflammatory cytokines like interleukin-6, interleukin-12, and tumor necrosis factor-α in macrophages (Kim et al., 2018). Additionally, the consumption of functional kiwifruit jelly with chenpi has been found to decrease serum levels of inflammatory factors such as IL-6 and TNF-α in a mouse model, indicating its potential as an anti-inflammatory agent (Peng et al., 2022).

Kiwifruit also possesses antimicrobial properties, which can be attributed to its diverse phytochemical composition. The phenolic compounds present in kiwifruit have been shown to exhibit antimicrobial activities against various pathogens. For instance, the peel, pulp, and core of commercialized kiwifruit cultivars contain unique phenolic compounds that contribute to their antimicrobial efficacy (Liu et al., 2022). These properties make kiwifruit a promising candidate for developing natural antimicrobial agents for food preservation and medical applications.

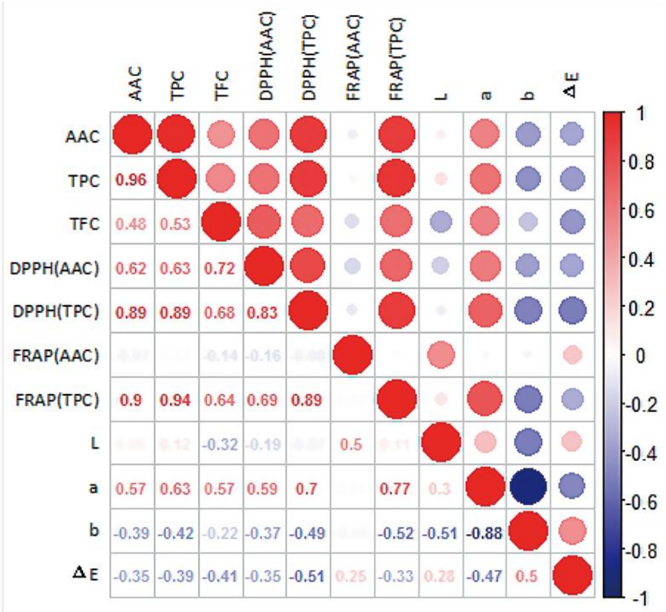

Figure 1 Correlation heat map of the antioxidant analysis (Adopted from Zhang et al., 2020)

Image caption: The figure presents a correlation heat map of the antioxidant analysis of kiwifruit, revealing the relationship between ascorbic acid content (AAC), total polyphenol content (TPC), total flavonoid content (TFC), and antioxidant performance. The figure shows that AAC and TPC are significantly correlated with antioxidant performance (R^2=0.96), with TPC contributing the most to antioxidant capacity. Additionally, the DPPH and FRAP antioxidant assays indicate that TPC plays a dominant role in antioxidant performance, while TFC contributes to some extent in certain cultivars. The figure reveals that kiwifruit's antioxidant capacity is primarily driven by polyphenolic compounds, with red-fleshed cultivars exhibiting stronger antioxidant performance (Adapted from Zhang et al., 2020)

3.3 Cardiovascular benefits

Kiwifruit consumption has been associated with beneficial effects on blood pressure regulation. The presence of bioactive compounds such as potassium and antioxidants in kiwifruit helps in maintaining vascular health and reducing hypertension. Although specific studies on the direct impact of kiwifruit on blood pressure are limited, the overall nutritional profile of kiwifruit supports its role in cardiovascular health (Wang et al., 2020). Kiwifruit has been shown to have a positive impact on cholesterol management. The dietary fiber and polyphenols in kiwifruit contribute to the reduction of LDL cholesterol levels and the improvement of HDL cholesterol levels. This effect is partly due to the antioxidative and anti-inflammatory properties of kiwifruit, which help in maintaining lipid homeostasis and preventing atherosclerosis (Wang et al., 2020).

The combined antioxidant, anti-inflammatory, and cholesterol-lowering effects of kiwifruit contribute to its overall cardiovascular benefits. Regular consumption of kiwifruit can help in reducing the risk of cardiovascular diseases by improving blood lipid profiles, reducing oxidative stress, and enhancing vascular function. Although more clinical studies are needed to establish the direct effects of kiwifruit on cardiovascular health, the existing evidence supports its potential as a heart-healthy fruit (Wang et al., 2020; Mishra et al., 2023).

4 Mechanisms of Action of Kiwifruit

4.1 Antioxidant mechanisms

Kiwifruit demonstrates powerful antioxidant properties, primarily due to its high content of phenolic compounds and flavonoids. Its antioxidant mechanisms involve various pathways, including radical scavenging activity, which is notably effective in neutralizing free radicals and preventing oxidative stress. This effect has been confirmed through DPPH and ABTS assays, where kiwifruit oil showed significant radical scavenging activities with IC50 values of 48.55 μg/mL and 77.00 μg/mL, respectively (Ozden et al., 2023). These assays underscore the fruit's ability to mitigate oxidative damage by neutralizing harmful free radicals.

Kiwifruit oil exhibits strong reducing capabilities, as demonstrated by its performance in iron (Fe^{3+}), copper (Cu^{2+}), and Fe^{3+}-TPTZ assays. These tests reveal the fruit's potential to donate electrons and reduce metal ions, which is crucial for combating oxidative damage (Figure 2) (Ozden et al., 2023). The antioxidant properties of kiwifruit are further enhanced by its phenolic compounds, such as apigenin, epigallocatechin, caryophyllene oxide, and luteolin, which effectively scavenge free radicals and chelate metal ions. Flavonoids, including quercetin derivatives and catechins, also contribute significantly to the overall antioxidant capacity of kiwifruit (Hettihewa et al., 2018; Nie et al., 2020).

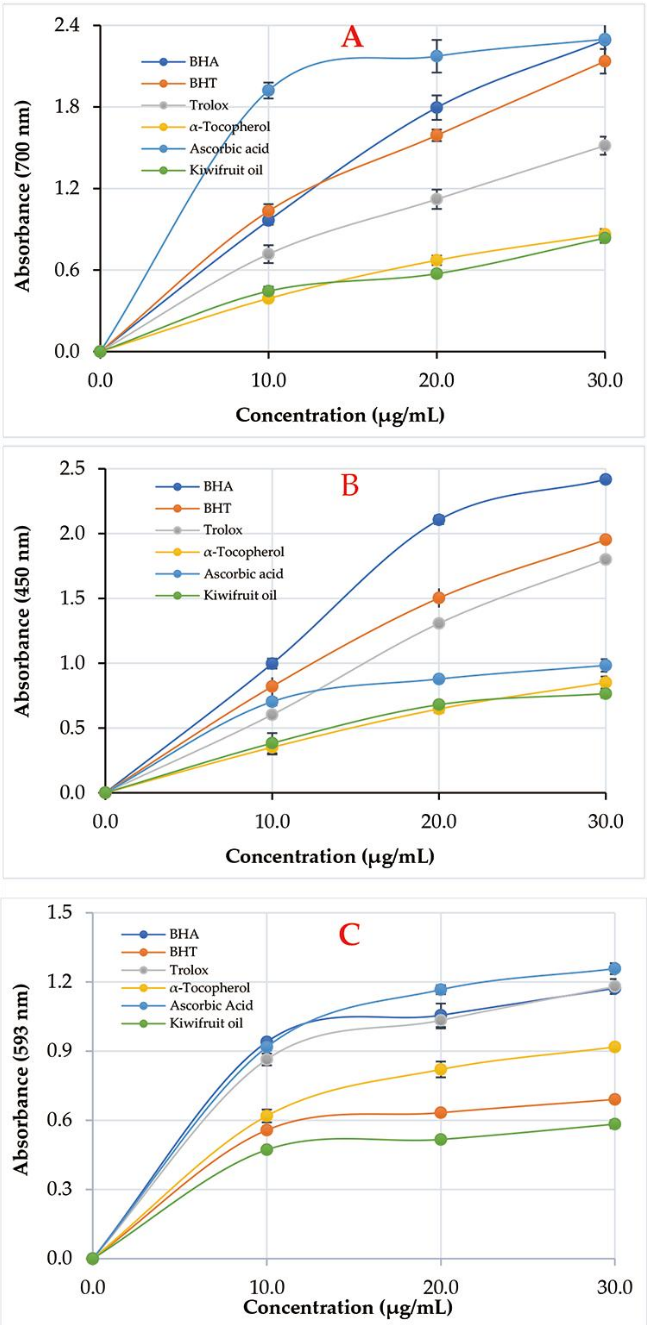

Figure 2 Ferric ions (Fe^{3+})-reducing (A), cupric ions (Cu^{2+})-reducing (B), and Fe^{3+}-TPTZ complexreducing (C) ability of kiwifruit (*A. deliciosa*) oil and standards (Adopted from Ozden et al., 2023)

Figure 2 illustrates a comparison of the reducing abilities of kiwifruit oil (*Actinidia deliciosa*) and standard antioxidants (such as BHA, BHT, and vitamin C) in ferric ion (Fe^{3+}), cupric ion (Cu^{2+}), and Fe^{3+}-TPTZ reduction assays. The figure shows that kiwifruit oil exhibits significant reducing power at different concentrations, though slightly lower than that of the standard antioxidants, it still demonstrates strong antioxidant potential. The results indicate the redox activity of kiwifruit oil, further supporting its application prospects as a natural antioxidant and providing experimental evidence for its potential pharmacological effects.

4.2 Enzyme inhibition

Kiwifruit exhibits notable inhibitory effects on several enzymes associated with metabolic illnesses, which contribute to its health-promoting properties. One such enzyme is acetylcholinesterase (AChE), where kiwifruit oil has demonstrated a substantial inhibition effect with an IC50 value of 12.80 μg/mL. AChE is linked to neurodegenerative diseases like Alzheimer's, and its inhibition can aid in managing such conditions (Ozden et al., 2023). Kiwifruit oil inhibits carbonic anhydrase II (CA II) with an IC50 value of 505.83 μg/mL. This enzyme's inhibition is relevant for conditions such as glaucoma and various metabolic disorders.

Moreover, kiwifruit oil also affects α-amylase, an enzyme involved in carbohydrate metabolism, with an IC50 value of 421.02 μg/mL. This inhibition can be beneficial in managing diabetes by reducing the breakdown of starch into glucose (Ozden et al., 2023). Various kiwifruit varieties have also shown inhibitory effects on pancreatic lipase and α-glucosidase, enzymes essential for fat and carbohydrate digestion, respectively. This inhibition can aid in controlling obesity and diabetes (Li et al., 2018; Nie et al., 2020).

4.3 GABAergic mechanism

Kiwifruit peel extracts have been shown to exert hypnotic effects through GABAergic pathways. These extracts enhance sleep by modulating the GABAergic system, which serves as the primary inhibitory neurotransmitter system in the brain. This mechanism is comparable to the action of GABA(A)-benzodiazepine receptor agonists, which are commonly used as sedatives and anxiolytics (Ozden et al., 2023). The potential sedative effect of kiwifruit peel extracts suggests that they may influence sleep patterns in a manner similar to these well-known pharmaceutical agents (Kim et al., 2022).

Although the specific compounds responsible for these effects in kiwifruit are not yet fully identified, the presence of bioactive compounds such as flavonoids and phenolics indicates a possible interaction with GABA(A) receptors. This similarity to benzodiazepine receptor agonists highlights the potential of kiwifruit as a natural alternative for managing sleep disorders (Ozden et al., 2023). Understanding these mechanisms provides insight into the pharmacological benefits of kiwifruit, emphasizing its potential as a functional food with significant health advantages.

5 Case Studies

5.1 Anti-inflammatory effects of kiwifruit extracts

Studies have shown that kiwifruit possesses significant anti-inflammatory properties, which have been confirmed in multiple studies. For example, Yuan et al. (2021) investigated the effects of kiwifruit polyphenol extract (KPE) on alleviating gut barrier damage and inflammation induced by a high-fat diet (HFD). The study revealed that KPE improved intestinal permeability by regulating the gut microbiota and inhibiting inflammatory responses, while promoting the expression of tight junction proteins such as Claudin-1, Occludin, and ZO-1. KPE increased the relative abundance of probiotics like *Lactobacillus* and *Bifidobacterium*, and reduced the numbers of harmful bacteria such as Clostridium and Desulfovibrio. Additionally, KPE decreased the expression of pro-inflammatory factors like TLR-2, TLR-4, TNF-α, and IL-1β, while increasing the level of the anti-inflammatory factor IL-10 (Figure 3). The results showed that KPE protected the gut barrier function impaired by HFD through modulating the gut microbiota and inhibiting inflammation, demonstrating its potential role in preventing intestinal damage and related diseases (Yuan et al., 2021). In another study on aspirin-induced gastric mucosal damage in rats, a diet containing green and gold kiwifruit (KF) significantly altered the expression of inflammation-related genes, such as NOS2 and TNF-alpha, demonstrating anti-inflammatory effects (Bentley-Hewitt et al., 2020).

Moreover, consumption of whole Zespri® SunGold kiwifruit was associated with a significant reduction in the pro-inflammatory cytokine TNF-alpha in both healthy individuals and patients with constipation-predominant irritable bowel syndrome (IBS-C) (Eady et al., 2020). Collectively, these findings suggest that kiwifruit extracts can effectively reduce inflammation through multiple mechanisms, including the regulation of gene expression and changes in gut microbiota.

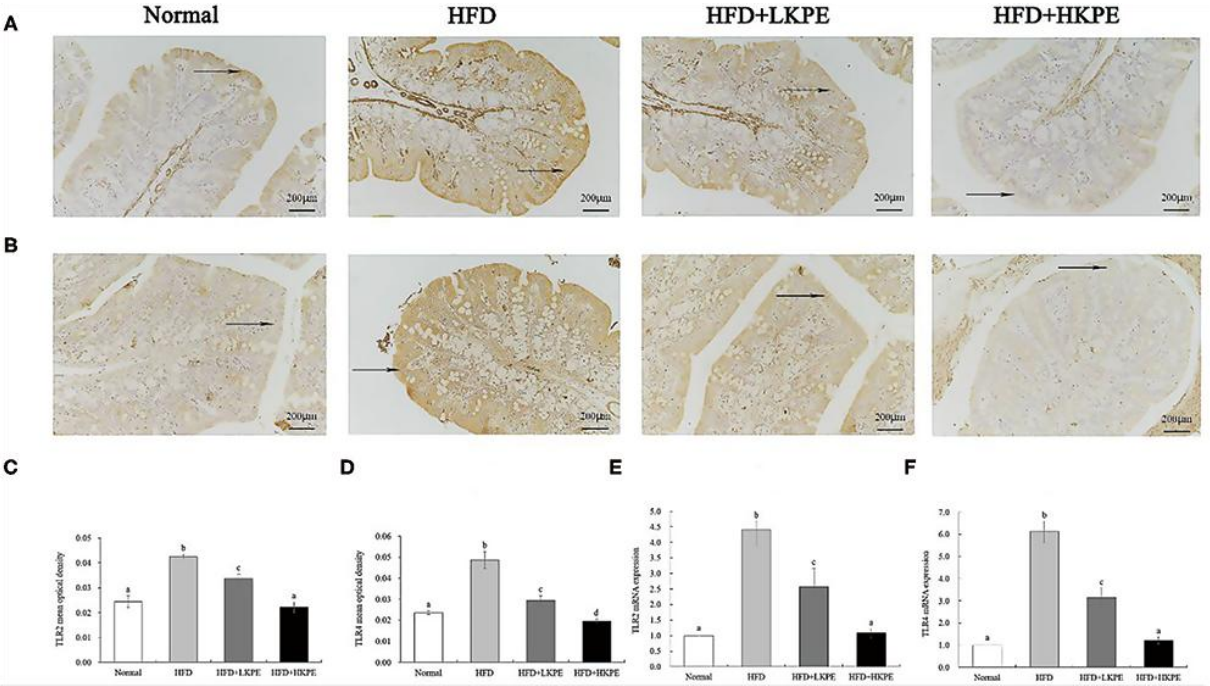

Figure 3 KPE supplementation decreases the expression of TLR-2 and TLR-4 (Adopted from Yuan et al., 2021)

Image caption: (A) Immunohistochemical images of TLR-2; (B) Immunohistochemical images of TLR-4; (C) Mean optical density of TLR-2; (D) Mean optical density of TLR-4; (E) The mRNA expression levels of TLR-2; (F) The mRNA expression levels of TLR-4. Different letters (a–d) are used to express the significant difference ($P < 0.05$) of the same factor among groups (Adopted from Yuan et al., 2021)

The figure shows the regulatory effect of kiwifruit polyphenol extract (KPE) on the expression of TLR-2 and TLR-4 receptors in the intestines of rats fed with a high-fat diet (HFD) (Yuan et al., 2021). Figures A and B represent immunohistochemical staining for TLR-2 and TLR-4, respectively, showing a significant increase in the expression of these pro-inflammatory receptors in the HFD group, while their expression decreased markedly after KPE treatment. Figures C-F further validate these results through optical density analysis and RT-PCR, demonstrating that KPE significantly downregulated TLR-2 and TLR-4 expression. This result indicates that KPE suppresses intestinal inflammation by reducing the expression of pro-inflammatory receptors, confirming its anti-inflammatory effect.

5.2 Cardiovascular benefits of kiwifruit

Kiwifruit consumption has been linked to cardiovascular health benefits. A review highlighted the potential of kiwifruit to improve cardiovascular biomarkers, such as lowering glycaemic response and improving lipid profiles (Richardson et al., 2018).

In a randomized, cross-over study, daily ingestion of two SunGold kiwifruit for six weeks did not show significant changes in metabolic and inflammatory biomarkers, suggesting that the effects might be subtle or require longer intervention periods to become apparent (Mishra et al., 2023). However, the high content of vitamins, particularly vitamin C, and other bioactive compounds in kiwifruit are believed to contribute to cardiovascular health by reducing oxidative stress and inflammation (Richardson et al., 2018). These studies indicate that while the immediate effects on cardiovascular biomarkers may not always be significant, regular consumption of kiwifruit could contribute to long-term cardiovascular health.

5.3 Sleep-promoting effects of kiwifruit peel extract

Insomnia is one of the most common sleep disorders in modern society, with a large number of adults worldwide suffering from varying degrees of sleep problems. Due to the potential for synthetic sedative-hypnotic drugs like diazepam (DZP) to cause tolerance and dependence, increasing attention has been directed toward natural sleep aids (Kodakan et al., 2018). Studies have found that kiwifruit has significant effects in promoting sleep and improving sleep quality, and it is less likely to cause tolerance compared to common medications (Kim et al., 2022; Kanon et al., 2023).

Kim et al. (2022) conducted an experimental analysis of green kiwifruit (*Actinidia deliciosa*) peel ethanol extract (GKPEE) to explore its potential sleep-promoting effects. Polysomnographic monitoring was conducted on mice to evaluate the acute and chronic effects of GKPEE administration. The results showed that GKPEE, in a dose range of 250-1,000 mg/kg, dose-dependently increased the duration of non-rapid eye movement sleep (NREMS) and reduced sleep latency (Figure 4). Compared to the control group, high doses of GKPEE (1,000 mg/kg) significantly shortened sleep onset time, with effects similar to those of diazepam. Notably, GKPEE did not significantly reduce sleep depth, unlike diazepam, indicating a lesser impact on sleep quality. Additionally, results from a 15-day chronic administration test showed that GKPEE did not induce tolerance and had a lasting sleep-promoting effect.

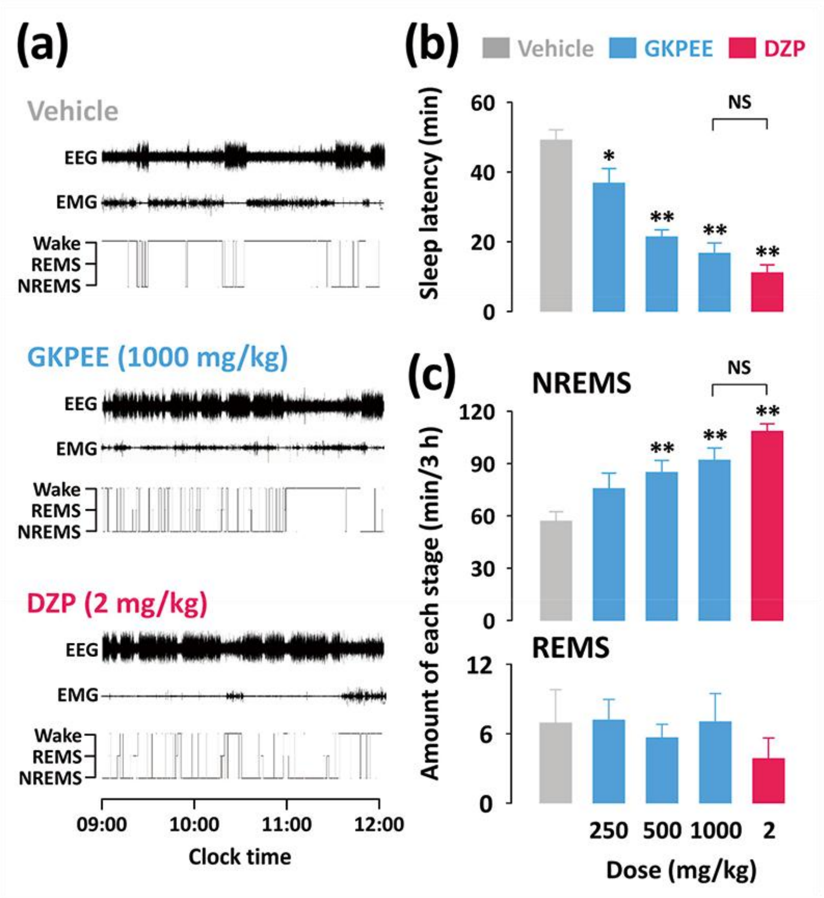

Figure 4 Effects of GKPEE and DZP on sleep profiles in mice (Adopted from Kim et al., 2022)

Image caption: (a) Examples of EEG/EMG signals and hypnograms in a mouse treated with GKPEE and DZP. (b) Changes in sleep latency by administration of GKPEE and DZP. (c) NREMS and REMS amounts during the 3-hour period following injection of GKPEE and DZP. Columns represent the mean ± SEM of 7–8 mice. * $p < 0.05$ and ** $p < 0.01$, are significant compared to the vehicle (Dunnett's test). DZP, diazepam; EEG, electroencephalogram; EMG, electromyogram; GKPEE, green kiwifruit peel ethanol extract; NS, no significance; REMS, rapid eye movement sleep; NREMS, non-REMS; SEM, standard error of mean; Wake, wakefulness. The results showed that GKPEE at doses of 500 mg/kg and 1000 mg/kg significantly reduced sleep latency and increased the duration of NREMS, with effects similar to those of diazepam, but had no significant effect on REMS. This figure confirms the promoting effect of GKPEE on NREMS, demonstrating its potential as a sleep aid (Adapted from Kim et al., 2022)

6 Safety and Toxicity

6.1 Allergens and mycotoxins

Kiwifruit is known to contain several potential allergens that can trigger adverse reactions in sensitive individuals. Thirteen different allergens have been identified in green kiwifruit, with Act d 1, Act d 2, Act d 8, Act d 11, and Act d 12 being the major allergens. These allergens can cause symptoms ranging from oral allergy syndrome (OAS) to severe anaphylaxis. Act d 1 and Act d 2 are particularly notable as they are ripening-related allergens found in abundance in fully ripe kiwifruit. The allergenic potential of these proteins can be influenced by food processing methods, such as thermal, ultrasound, and chemical treatments, which may reduce their allergenicity (Wang et al., 2019).

Mycotoxins, toxic compounds produced by fungi, are another concern in kiwifruit safety. Although specific data on mycotoxins in kiwifruit is limited, the presence of these toxins in other fruits suggests a potential risk. Effective management strategies include regular monitoring and implementing good agricultural practices to minimize fungal contamination and mycotoxin production.

6.2 Pesticides and heavy metals

The presence of pesticides and heavy metals in kiwifruit is a significant safety concern. Studies have shown that pesticides like forchlorfenuron (CPPU) and thidiazuron (TDZ) are commonly used in kiwifruit cultivation to enhance fruit growth. While these pesticides can improve the sensory quality and nutritional content of kiwifruit, they can also reduce antioxidant values and vitamin C content in certain varieties (Shan et al., 2021). Additionally, the residue levels of pesticides such as hexaconazole can be significantly reduced through processing methods like peeling, homogenization, and sterilization, which help decrease dietary risks (Wang et al., 2023).

Heavy metals, including chromium (Cr), copper (Cu), cadmium (Cd), mercury (Hg), and lead (Pb), have been detected in kiwifruit orchard soils and tissues. Although the overall health risk from consuming kiwifruit under current consumption rates is low, a significant percentage of fruit samples have been found to exceed national maximum permissible levels for these metals. Regular monitoring and strict management programs are essential to reduce the use of chemical fertilizers and pesticides, thereby minimizing heavy metal contamination (Guo et al., 2016).

6.3 Safe consumption levels

Determining safe consumption levels of kiwifruit is crucial to avoid potential adverse effects. While kiwifruit is rich in beneficial nutrients and bioactive compounds, excessive intake can lead to side effects, particularly in individuals with allergies or sensitivities. Current studies suggest that moderate consumption of kiwifruit is generally safe and beneficial for health. However, specific recommendations for daily intake and potential side effects are still under investigation. It is advisable for individuals, especially those with known allergies, to consult healthcare professionals for personalized dietary advice (Wang et al., 2019; Wang et al., 2020).

7 Applications in Food and Medicine

7.1 Functional foods

Kiwifruit has shown significant potential as a functional food ingredient due to its rich composition of dietary nutrients, polyphenols, vitamins, dietary fiber, and bioactive phytochemicals. These components contribute to its antioxidative, antiproliferative, anti-inflammatory, antimicrobial, antihypertensive, antihypercholesterolemic, neuroprotective, and anti-obesity properties, as well as its ability to promote gut health (Wang et al., 2020). The food industry can leverage these health benefits by incorporating kiwifruit into various products, thereby enhancing their nutritional value and offering consumers functional foods that support overall health and well-being.

7.2 Pharmaceutical uses

Kiwifruit oil, particularly from the seeds, has been identified as a valuable component in pharmaceutical formulations. It contains a high concentration of unsaturated fatty acids, such as linolenic acid, and exhibits potent antioxidant properties (Deng et al., 2018). The oil has demonstrated significant inhibitory effects on enzymes linked to metabolic illnesses, including acetylcholinesterase (AChE), carbonic anhydrase II (CA II), and α-amylase, which are associated with conditions like Alzheimer's disease, glaucoma, and diabetes (Ozden et al., 2023). However, incorporating kiwifruit extracts into medicine poses challenges, such as ensuring the stability and bioavailability of the active compounds, and addressing potential allergens and chemical hazards like mycotoxins, pesticides, and heavy metals (Wang et al., 2020).

7.3 Natural preservatives

Kiwifruit polyphenols have been explored for their use as natural antioxidants in food preservation. These polyphenols, abundant in kiwifruit oil, exhibit strong radical scavenging activities, which can effectively maintain food quality during storage by preventing oxidative damage (Ozden et al., 2023). The use of kiwifruit-derived antioxidants in food products not only extends shelf life but also enhances the nutritional profile of the preserved foods, offering a natural alternative to synthetic preservatives (Deng et al., 2018). This application is particularly valuable in the context of increasing consumer demand for clean-label products with natural ingredients.

8 Future Research Directions

8.1 Sustainable utilization

Focus on sustainable uses of underutilized kiwifruit resources. The sustainable utilization of underutilized kiwifruit resources, including non-fruit plant parts and agricultural wastes, is crucial. Research indicates that various species and cultivars, as well as non-fruit plant parts, contain valuable bioactive compounds that are currently underutilized (Sanz et al., 2020; Wang et al., 2020). By focusing on these resources, we can reduce waste and create new functional ingredients for various applications (Sha et al., 2023; Wu et al., 2023).

Exploration of non-fruit plant parts and agricultural wastes. The exploration of non-fruit plant parts, such as peels, seeds, and leaves, as well as agricultural wastes, can lead to the discovery of new bioactive compounds with potential health benefits. Studies have shown that these parts of the kiwifruit plant contain significant amounts of antioxidants, phenolic compounds, and other bioactives that can be harnessed for nutraceutical and therapeutic purposes (Dias et al., 2020; Sanz et al., 2020; Nirmal et al., 2023).

8.2 Bioactive compound purification

Techniques for purifying bioactive compounds from kiwifruit. Advanced extraction techniques, such as ultrasound-assisted extraction (UAE), pressurized liquid extraction (PLE), and supercritical fluid extraction (SFE), have shown promise in efficiently purifying bioactive compounds from kiwifruit and its by-products (Kheirkhah et al., 2019; Sha et al., 2023; Wu et al., 2023). These methods can enhance the yield and purity of valuable compounds, making them more suitable for use in functional foods and pharmaceuticals.

Importance of understanding composition-activity relationships. Understanding the composition-activity relationships of bioactive compounds is essential for optimizing their health benefits. Detailed studies on the chemical composition of kiwifruit and its by-products, as well as their biological activities, can provide insights into how these compounds exert their effects and how they can be best utilized (Wang et al., 2020; Mthembu et al., 2023).

8.3 Clinical trials and mechanistic studies

Need for more clinical trials to establish health benefits. While kiwifruit has been shown to possess various health-promoting properties, more clinical trials are needed to establish its efficacy in preventing and treating chronic diseases. Current research highlights the potential of kiwifruit in areas such as antioxidative, anti-inflammatory, and antimicrobial activities, but clinical evidence is still limited (Dias et al., 2020; Sanz et al., 2020; Wang et al., 2020).

Detailed mechanistic studies to understand physiological effects. Detailed mechanistic studies are necessary to understand the physiological effects of kiwifruit bioactive compounds. Investigating the molecular pathways and mechanisms through which these compounds exert their health benefits can provide a scientific basis for their use in therapeutic applications. This includes studying their effects on specific enzymes, receptors, and cellular processes (Kheirkhah et al., 2019; Wang et al., 2020; Wu et al., 2023).

9 Concluding Remarks

Kiwifruit (*Actinidia* spp.) is rich in a variety of chemical constituents, including polyphenols, vitamins (notably vitamin C), dietary fiber, and bioactive phytochemicals such as protease and starch. These components contribute to its antioxidative, anti-inflammatory, antimicrobial, antihypertensive, antihypercholesterolemic, neuroprotective, and anti-obesity properties, as well as its ability to promote gut health. The presence of phenolic compounds like catechin, proanthocyanidin B1, and proanthocyanidin B2, which increase during postharvest ripening, further enhances its antioxidant potential. Additionally, kiwifruit oil has been found to contain significant amounts of phenolic compounds and essential oils, contributing to its antioxidant, antidiabetic, and antiglaucoma effects. The diverse bioactive compounds in kiwifruit make it a valuable fruit for health and disease prevention.

Regular consumption of kiwifruit can offer numerous health benefits. It has been shown to improve lipid homeostasis, fatty acid metabolism, and gut microbiota in healthy rats, suggesting potential benefits for cardiovascular health and metabolic function. Kiwifruit's high vitamin C content and other antioxidants can enhance resistance to oxidative damage, improve DNA stability, and reduce plasma triglycerides, which are beneficial for overall health and disease prevention. The dietary fiber and organic acids in kiwifruit also help in suppressing glycaemic response, making it a good option for managing blood sugar levels. To incorporate kiwifruit into the diet, it can be consumed fresh, added to smoothies, or used in salads and desserts.

The future potential of kiwifruit in the food and pharmaceutical industries is promising. Its rich chemical composition and wide range of pharmacological effects make it a candidate for developing functional foods and natural health products. Continued research is essential to fully understand the physiological mechanisms and clinical significance of kiwifruit's bioactive compounds. This will help in optimizing its use in health promotion and disease prevention strategies. Further studies should also focus on sustainable uses of underutilized kiwifruit resources and the development of high value-added products.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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