Biointerface Research in Applied Chemistry
Open-Access Journal (ISSN: 2069-5837)

Article
Volume 16, Issue 2, 2026, 52
https://doi.org/10.33263/BRIAC162.052

Anti-aging Properties of *Curcuma mangga* Val. Powder in Skin Aging Wistar Rats Induced by D-galactose

Dwiyati Pujimulyani [1,*], Chatarina Lilis Suryani [1], Astuti Setyowati [1]

[1] Faculty of Agroindustry, University of Mercu Buana Yogyakarta, Jl. Wates, Karanglo, Argomulyo, Sedayu, Bantul, 55752, Yogyakarta, Indonesia; dwiyati@mercubuana-yogya.ac.id (D.P.); chlilis@mercubuana-yogya.ac.id (C.L.S.); astuti@mercubuana-yogya.ac.id (A.S.);
* Correspondence: dwiyati@mercubuana-yogya.ac.id;

Received: 20.08.2025; Accepted: 4.02.2026; Published: 15.04.2026

Abstract: Skin aging is characterized by the appearance of wrinkles, dull skin, and decreased skin elasticity. White turmeric (*Curcuma mangga* Val.) is a natural antioxidant containing curcuminoids and polyphenols that can fight free radicals and help rejuvenate the skin. This study aims to evaluate the potential of white turmeric as an anti-aging agent in Wistar rats induced with D-galactose. The treatment was carried out for 3 weeks on 5 groups of rats, namely: control (standard feed), negative control (D-galactose induction with aquabidest), two treatment groups with D-galactose induction and white turmeric doses of 27 mg/200 g and 81 mg/200 g BW, and positive control (D-galactose induction and vitamin E). The results showed that administration of white turmeric at a dose of 81 mg/200 g BW had a significant effect on increasing antioxidant activity, as indicated by increased SOD (81.43%) and VEGF levels (28.47 pg/mL), decreased MDA levels (2.22 nmol/mL), MMP-1 level (9.77 ng/mL), and blood glucoses level (87.42 mg/dL) as well as better histopathological observations of skin tissue compared to the D-galactose-induced model group without treatment. Thus, white turmeric shows potential as an anti-aging agent in Wistar rats induced to age using D-galactose.

Keywords: anti-aging; antioxidants; white turmeric; skin aging; D-galactose.

1. Introduction

Aging is characterized by the accumulation of progressive changes, including increased susceptibility to disease, higher mortality rates, and cellular and tissue damage from free radical reactions [1]. Cell and tissue damage leads to a progressive loss of physiological integrity, which triggers dysfunctional bodily functions, mental health problems, and an increased risk of death. Aging is primarily caused by the accumulation of free radicals, which damage the body's cells and tissues. However, this process can be prevented or slowed down with the help of antioxidants. The aging process is closely associated with oxidative stress resulting from an excess of free radicals in the body. These free radicals can damage cells and tissues, gradually disrupt physiological functions, and ultimately contribute to the development of various age-related diseases, such as cardiovascular disease, cancer, and neurodegenerative disorders [2]. The body has an endogenous antioxidant system that depends on certain cofactors and can be aided by exogenous antioxidants obtained from food to counteract the effects of free radicals [3]. A balanced interaction between free radicals, antioxidants, and cofactors is essential for

maintaining health and slowing the aging process. Oxidative damage occurs when the amount of free radicals exceeds the body's defense capacity. Therefore, the body requires external sources of antioxidants, such as rhizomes like *Curcuma*, which are known to contain bioactive compounds with strong antioxidant activity.

The skin aging process occurs due to the accumulation of cellular and tissue damage triggered by complex interactions between internal and external factors. Internally, a decrease in collagen and elastin production by fibroblasts in the dermis causes the skin to lose its firmness and elasticity. A reduction in the activity of endogenous antioxidant enzymes, such as superoxide dismutase (SOD), can impair the body's ability to neutralize free radicals. Free radicals are harmful reactive molecules that can damage cell membranes, proteins, and DNA. Exposure to ultraviolet radiation and environmental pollution accelerates the formation of free radicals, leading to oxidative stress and chronic inflammation. This oxidative stress activates matrix metalloproteinases (MMPs), which degrade collagen and elastin, accelerating the breakdown of skin tissue. Persistent inflammation can further trigger tissue degeneration and reduced cellular function, thus accelerating the appearance of aging signs such as wrinkles, dull skin, and decreased skin elasticity [4,5].

WT rhizome is one of the herbal plants that has great potential as a source of natural antioxidants. Research by [6,7] shows that *Curcuma mangga* contains alkaloid, flavonoid, tannin, and saponin compounds. The bioactive compounds in white turmeric have significant pharmacological effects, including curcumin as an antitumor and anti-inflammatory agent [8], saponins as anticancer agents [9,10], and polyphenols that function as antioxidants, helping ward off free radicals [11]. White turmeric extract can inhibit the oxidation process due to its antioxidant components. According to [12], processed products of white turmeric, including syrup, instant powder, and effervescent tablets, possess antioxidant activity that can support the immune system. Antioxidant compounds can protect the skin from oxidative stress, thereby helping prevent aging [13]. Previous studies have shown that blanching enhances the antioxidant activity of white turmeric compared to fresh samples and also demonstrates potential antidiabetic properties [14]. Additionally, the results showed that older harvest ages of *Curcuma* species yield higher levels of essential oils. Specifically, turmeric harvested at 11 months contains more essential oils than that harvested at 9 months [15].

Testing antioxidant activity and protective mechanisms against oxidation-induced skin tissue damage can be done by adding D-galactose to test animals. Accumulated D-galactose reacts with amino acids in proteins and peptides that form Schiff bases, thereby forming unstable compounds [16]. High concentrations of D-galactose can be oxidized by galactose oxidase to form hydrogen peroxide (H_2O_2), which causes a decrease in superoxide dismutase (SOD). Several studies have shown that D-galactose causes mutations in mitochondrial DNA that can lead to aging [17]. Previous studies on white turmeric have been conducted on its antioxidant, antifungal, anticancer, immunomodulatory, and antidiabetic properties. However, no *in vivo* studies have been conducted on the anti-aging properties of white turmeric powder with blanching pretreatment. The objective is to evaluate the potential of white turmeric to reduce oxidative stress and slow the aging process (anti-aging) in male Wistar rats (*Rattus norvegicus*) induced by D-galactose.

2. Materials and Methods

2.1. Materials and equipment.

The main ingredient used in this study was white turmeric (*Curcuma mangga* Val.) obtained from CV. Windra Mekar, Yogyakarta. Other materials included D-galactose (1000 mg/kg body weight), distilled water (Aquadest), and standard AIN-93 feed, which is a nutritional formulation developed by the American Institute of Nutrition for experimental animals. Vitamin E (100 mg/mL) was also used as a reference antioxidant. Analysis of antioxidant activity and related parameters was carried out using specific chemicals and equipment, including 50 µL of standard or sample solution, 50 µL of biotinylated detection antibody, 350 µL of wash buffer, 100 µL of HRP conjugate working solution, 90 µL of substrate reagent, and 50 µL of stop solution. The absorbance of each sample was measured using a microplate reader at a wavelength of 450 nm. The instruments used in this study included rat SOD ELISA kits, human VEGF ELISA kits (Quantikine, R&D Systems, USA), cell culture media as incubation medium, and a spectrophotometer (Beckman Colter DTX-880).

2.2. Research procedure.

This study used Wistar rats that were maintained and treated according to the procedures established by the Center for Food and Nutrition Studies, Gadjah Mada University, as stated in Certificate No: 39/UN1/PSPG/S. Ket/III/2019 concerning the maintenance and euthanasia of laboratory animals.

2.2.1. Experimental design.

This study was conducted using 2-month-old male Wistar rats weighing between 166 and 180 g. After a 7-day adaptation period, D-galactose was administered on the 8th day to four groups of rats, while one group remained untreated. The study consisted of five groups, each comprising five rats:

Group I consisted of normal Wistar rats without D-galactose injection and were fed the standard AIN-93 diet.

Group II served as the negative control, receiving D-galactose injection and aquabidest administration.

Group III served as the positive control, injected with D-galactose and administered vitamin E at a dose of 90 mg per 200 g body weight.

Group IV was injected with D-galactose and administered white turmeric at a dose of 27 mg/200 g of rat body weight.

Group V was injected with D-galactose and administered white turmeric at a dose of 81 mg/200 g body weight.

On day 28, blood samples were collected from each rat to measure the levels of SOD, MDA, and VEGF, MMP, and blood glucose levels. The *in vivo* anti-aging test is presented in Figure 1.

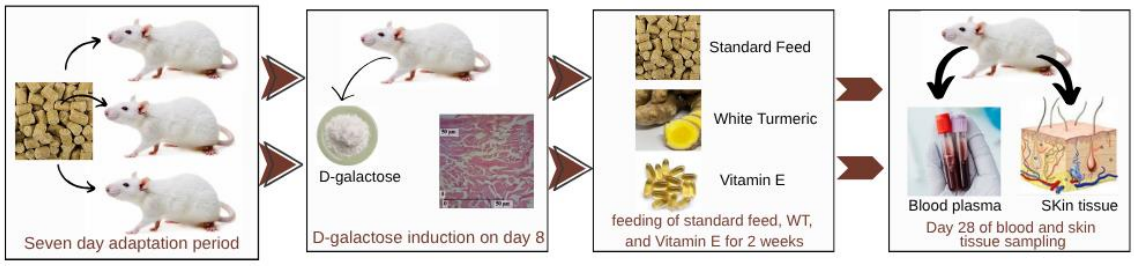

Figure 1. Anti-aging test with *in vivo* methods.

2.2.2. Feeding procedure during Wistar rats adaptation.

The rats were acclimated for 7 days and fed a standard AIN-93 diet (Standard Rodent Diet), which consists of approximately 18–22% protein, 4–6% fat, 5% fiber, 50–60% carbohydrates, along with added vitamins and minerals. Feeding was carried out daily, with the amount adjusted to the normal consumption of rats, approximately 15–20 g per animal per day.

2.2.3. Blood plasma analysis.

The blood plasma analysis began with anesthetizing the Wistar rats using ketamine at a dose of 60 mg/kg. Blood samples were then collected via the orbital sinus using EDTA as an anticoagulant. The collected blood was centrifuged at 3000 rpm for 10 minutes to obtain plasma. Glucose levels were measured enzymatically using the DiaSys kit, with absorbance read at 500 nm. Superoxide dismutase (SOD) levels were measured using the GenWay kit, and the results were expressed as percentage inhibition. Malondialdehyde (MDA) levels were determined by the thiobarbituric acid reactive substances (TBARS) method and measured at 532 nm [14].

2.2.4. Skin histopathology.

Skin samples were collected from the dorsal area of male Wistar rats and sectioned using a microtome into thin slices approximately 2×2 cm in size, then fixed in formalin. The skin tissue sections were stained using the Hematoxylin-Eosin (HE) method. The stained preparations were examined under an Olympus CX21 light microscope connected to OptiLab Advance and OptiLab Viewer 2.2 software. Observations were performed at 40× and 100× magnification by anatomical pathologists, with multiple repetitions. The microscopic parameters observed included the histological structure and integrity of the rats' skin tissue.

2.2.5. Body weight measurement.

The body weight of the Wistar rats was measured weekly during the treatment period using a digital scale with an accuracy of 0.01 g. Each rat was weighed individually, and the results were averaged for each treatment group. The weight data were analyzed by calculating the mean and standard deviation to assess variations within each group. A weight loss of ≥10% from the initial body weight was considered biologically significant and could indicate toxic effects or physiological stress [18].

2.3. Analysis.

2.3.1. SOD measurement.

The determination of superoxide dismutase activity was conducted to evaluate the antioxidant enzyme activity in the blood of Wistar rats. Blood samples were collected from the orbital sinus of the rats and mixed with the anticoagulant EDTA. The samples were centrifuged at 3000 rpm for 10 minutes to separate red blood cells from plasma. The obtained red blood cells were then homogenized in distilled water at a ratio of 1:200 (v/v), producing hemolysate equivalent to approximately 75 µg of hemoglobin. A volume of 50 µL of hemolysate was used to measure SOD levels using the RANSOD Kit (Randox Laboratories, Ltd., UK). The measurement was based on the ability of SOD to inhibit the reduction of 2- para(iodophenyl)-3-(nitrophenyl)-5-(phenyl)tetrazolium chloride (INT) by superoxide radicals. The results of the SOD assay were expressed as a percentage of inhibition [19].

2.3.2. MDA measurement.

The procedure for determining malondialdehyde (MDA) levels in this study was conducted to assess lipid peroxidation as an indicator of oxidative stress. A volume of 50 µL of rat blood plasma was mixed with 750 µL of phosphoric acid in a polypropylene tube. Then, 250 µL of 40 mM thiobarbituric acid (TBA) solution and 450 µL of distilled water were added. The mixture was tightly sealed and heated for one hour. After cooling on ice, the solution was filtered using a Sep-Pak C18 column that had been pre-washed with methanol and distilled water. The thiobarbituric acid reactive substances (TBARS), formed from the reaction between MDA and TBA, were then eluted from the column using 4 mL of methanol. The absorbance of the eluted solution was measured using a spectrophotometer at a wavelength of 532 nm, with tetraethoxypropane (TEP) used as an external standard. MDA levels were expressed in nanomoles (nmol), reflecting the degree of lipid oxidative damage due to dietary treatment in the test animals [19].

2.3.3. VEGF level analysis.

VEGF levels were analyzed using the ELISA method with a human recombinant VEGF ELISA kit (Quantikine, R&D Systems, USA). Cell clusters from a maintenance culture (CP cells) were incubated in 1 mL of fresh media at 37°C with 5% CO_2. After incubation, 200 µL of the conditioned media was collected and mixed with 50 µL of substrate solution. The optical density was then measured at a wavelength of 450 nm using a spectrophotometer (Beckman Colter DTX-880). The obtained values were compared to a standard VEGF curve by logarithmic curve fitting. The final VEGF concentration was expressed as pg/mL per 24 hours per 100,000 cells, normalized based on DNA quantification results [20].

2.3.4. MMP-1 measurement.

MMP-9 levels were measured using a sandwich Enzyme-Linked Immunosorbent Assay (ELISA). Tissue samples were collected from the abdominal aorta of Wistar rats in each group on day 28 after treatment. The analysis was performed using a Rat MMP-1 ELISA Kit, which has a sensitivity of 46.88 pg/mL and a detection range of 78.13 to 5000 pg/mL. In this method, the MMP-9 antigen is captured by a specific antibody pre-coated on the microtiter plate and then detected by a secondary antibody conjugated with an enzyme, which produces a

colorimetric reaction. Blood serum samples were prepared, and the absorbance of the reaction was measured using a spectrophotometer. MMP-1 concentrations were expressed in ng/mL [21].

2.3.5. Blood glucose measurement.

Blood glucose levels were measured using a commercial kit from DiaSys Diagnostic Systems (Germany), which operates based on the enzymatic glucose oxidase (GOD-PAP) reaction. Blood samples were collected from Wistar rats injected with D-galactose and processed to obtain plasma. A volume of 10 µL of fresh plasma was mixed with 1.0 mL of reagent solution containing phosphate buffer (pH 7.5), phenol, 4-aminoantipyrine, glucose oxidase, and peroxidase enzymes. In the reaction, glucose in the sample is oxidized by glucose oxidase to produce hydrogen peroxide, which then reacts with phenol and 4-aminoantipyrine to form a quinoneimine-colored compound. The reaction mixture was incubated at 25°C for 10 minutes, and the absorbance was measured at 500 nm using a spectrophotometer. Glucose concentration was determined by comparing absorbance values with a standard glucose curve, and results were expressed in mg/dL. This method provides accurate and sensitive detection of glucose within the range of 1 to 400 mg/dL [14].

2.4. Statistical analysis.

The experimental design used in this study was a Completely Randomized Design (CRD). The data obtained were analyzed statistically using one-way ANOVA with a 95% confidence level ($\alpha = 0.05$) to determine significant differences among treatment groups using IBM Statistics 25. If the ANOVA results indicated significant differences, a post hoc test was conducted using Duncan's Multiple Range Test (DMRT). All statistical analyses were performed using IBM SPSS Statistics version 20.0 software.

3. Results and Discussion

3.1. SOD enzyme activity in Wistar rats.

SOD analysis measured the activity of the superoxide dismutase enzyme, a key indicator of the antioxidant system's ability to neutralize superoxide free radicals in the tested tissues. SOD enzyme activity in Wistar rats injected with D-galactose and subjected to various treatments is shown in Figure 2.

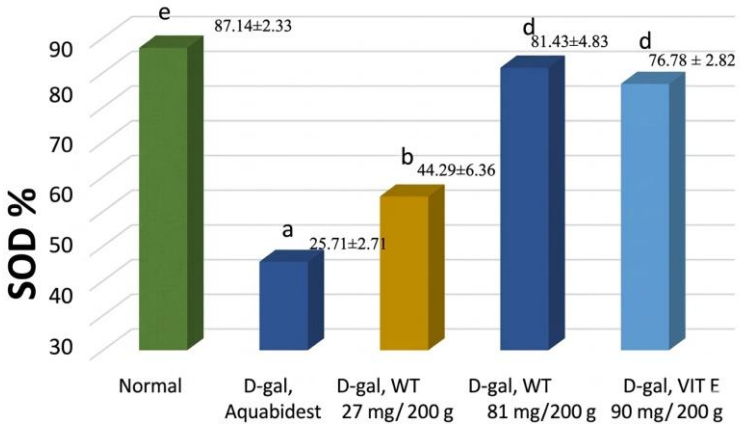

Figure 2. SOD enzyme activity in the blood of Wistar rats injected with D-galactose. Different letter notation indicates a significant difference ($p<0.05$); WT is white turmeric.

Figure 2 showed that SOD enzyme activity differed significantly ($p < 0.05$) among the treatment groups. The group of rats induced with D-galactose after WT administration was able to restore SOD levels. Both doses of WT administered to Wistar rats showed the highest results at 81 mg/200 g body weight, which were comparable to those of the normal group. Increased SOD levels in the WT-treated group of rats due to the curcumin and polyphenol compounds contained therein. The curcumin content in WT was 37.5 mg/100 g dried extract [14]. These compounds can scavenge and neutralize free radicals, inhibit oxidative reactions, and enhance the activity of endogenous antioxidant enzymes such as SOD [22]. The flavonoid compound content of *Curcuma mangga* Val. the extract with 96% ethanol, is 10.22% [23]. This compound also acts as a natural antioxidant in white turmeric, helping ward off free radicals. According to [24], curcumin, the primary active component in turmeric rhizomes, can enhance antioxidant enzyme activity under both acute and chronic oxidative stress conditions. Curcumin functions in two ways: directly as a free radical scavenger and indirectly by activating the Nrf2 pathway, which upregulates antioxidant enzyme expression. It also suppresses the pro-inflammatory NF-κB pathway, which is known to inhibit endogenous antioxidant mechanisms. The restoration of SOD activity to near-normal levels with high-dose white turmeric administration highlights its potential as an effective antioxidant in mitigating D-galactose-induced oxidative stress. This aligns with previous studies demonstrating that *Curcuma mangga* Val. extract has anti-aging potential by inhibiting enzymes involved in the skin aging process, such as elastase, hyaluronidase, and tyrosinase [25]. Research by [26,27] also supports this finding, showing that bioactive compounds in the *Curcuma* genus, particularly curcuminoids and flavonoids, can enhance the activities of antioxidant enzymes (SOD, CAT, and GPx) and reduce free radical levels through the upregulation of antioxidant gene expression, confirming their efficacy in managing oxidative stress.

3.2. MDA levels in Wistar rats.

MDA analysis was performed to measure malondialdehyde levels, a marker of lipid peroxidation and an indicator of tissue oxidative damage. MDA levels reflect the degree of oxidative stress experienced by cells. The blood MDA levels of Wistar rats injected with D-galactose are presented in Figure 3.

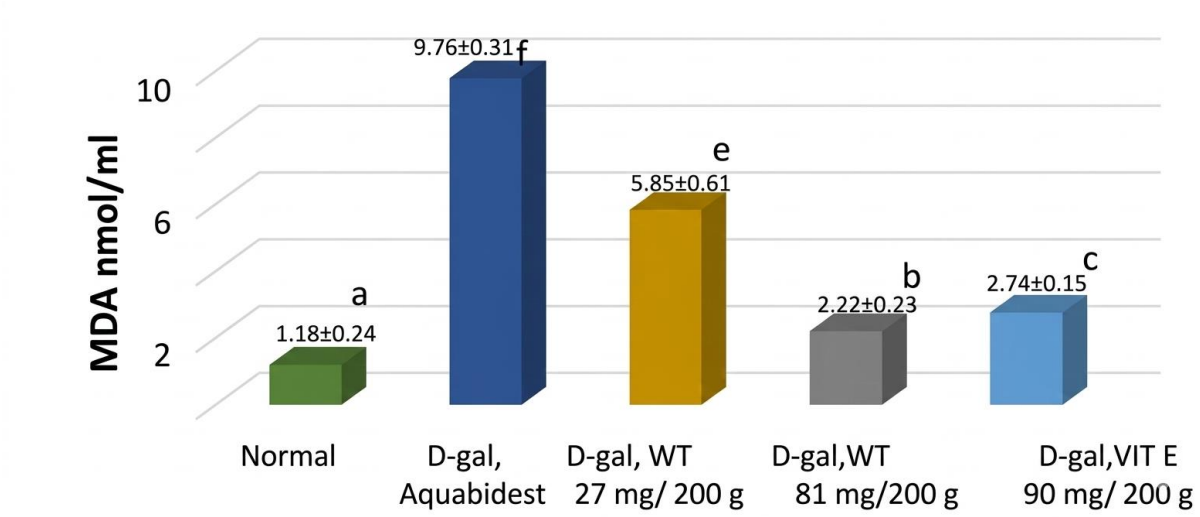

Figure 3. Blood MDA levels of Wistar rats injected with D-Galactose. Different letter notation indicates a significant difference ($p<0.05$); WT is white turmeric.

The group of D-galactose-induced rats with the highest MDA levels indicated that they had been exposed to free radicals. The group of rats given WT showed an improvement effect, as indicated by low MDA levels that were close to those of the normal group. This shows that WT treatment at a dose of 81 mg/200 g body weight was better than Vit. E treatment. These reductions in MDA levels are likely due to the antioxidant properties of curcuminoids and polyphenols in white turmeric, which scavenge free radicals and minimize lipid peroxidation, thus reducing oxidative stress [28]. Curcumin and its derivatives have a positive effect on wound healing and help prevent skin redness, such as rosacea and flushing [29]. This supports the idea that curcumin in WT can maintain skin health due to its exposure to free radicals. The greater effectiveness observed at higher doses suggests a dose-dependent protective effect of white turmeric against oxidative damage. These effects are similar to the results reported by Ramírez-Mendoza *et al*. [24], who reported that curcumin administration to ozone-exposed Wistar rats significantly inhibited MDA formation under both acute and chronic exposure. In that study, curcumin treatment suppressed MDA formation by up to 97%, while the control group exhibited only 18% inhibition. Previous studies have consistently demonstrated the strong antioxidant activity of curcumin, the main bioactive compound in *Curcuma longa*. Curcumin significantly reduces MDA levels under oxidative stress conditions [30] and contributes to decreased ROS production and lipid peroxidation by enhancing antioxidant enzyme activity in various degenerative disease models [31]. The observed increase in SOD activity, along with the reduction in MDA levels, suggests that white turmeric enhances the body's antioxidant defense system, effectively mitigating cellular oxidative damage.

3.3. Vascular endothelial growth factor (VEGF) levels in Wistar rats.

VEGF analysis was conducted to evaluate the expression of vascular endothelial growth factor (VEGF), an important marker for angiogenesis and tissue regeneration. The blood VEGF levels of Wistar rats injected with D-galactose can be seen in Figure 4.

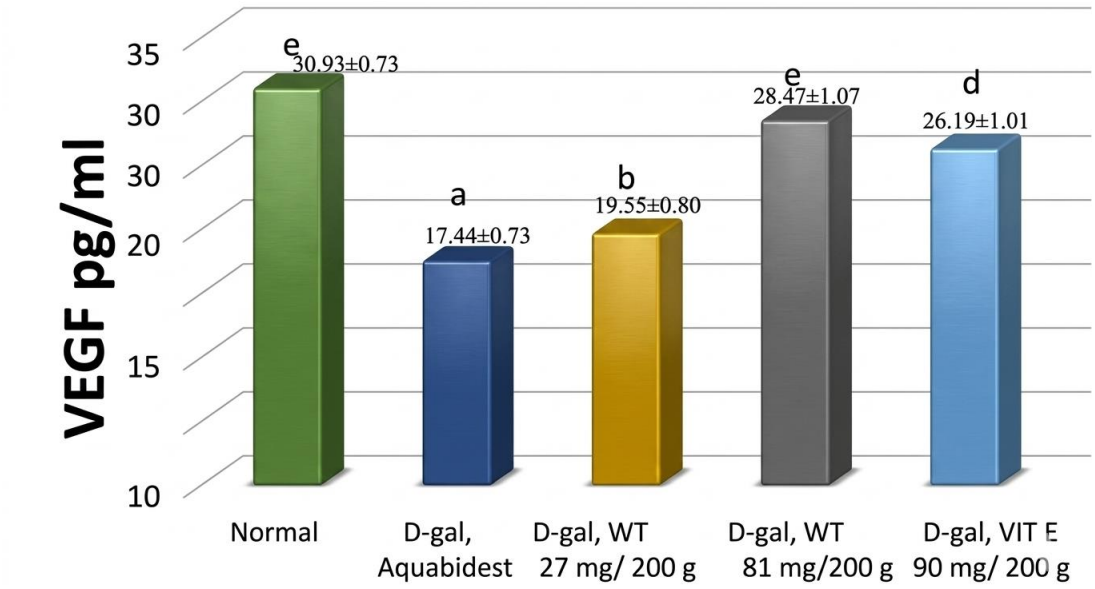

Figure 4. Blood VEGF levels in Wistar rats injected with D-galactose. Different letter notation indicates a significant difference ($p<0.05$); WT is white turmeric.

The normal group of rats had significantly higher VEGF levels compared to the D-galactose-induced group. This indicates that D-galactose induction has a detrimental effect on VEGF levels in mice. Rats administered WT showed improvement, as indicated by VEGF

levels returning to near-normal levels. The bioactive compound WT normalized rats exposed to D-galactose or free radicals. The results indicate that high-dose white turmeric treatment effectively counteracts D-galactose-induced reductions in VEGF levels. This protective effect is likely due to the presence of curcuminoids and polyphenols in white turmeric, which enhance VEGF expression through antioxidant and anti-inflammatory mechanisms [32].

Antioxidant compounds have been shown to improve the cellular microenvironment and activate signaling pathways that promote angiogenesis. Cui *et al*. [33] reported that curcumin, the primary bioactive component in *Curcuma longa*, enhances VEGF expression by activating the PI3K/Akt and MAPK signaling pathways, both of which are crucial in tissue repair and neovascularization under oxidative stress. Research by Li *et al*. [34] demonstrated that four weeks of curcumin treatment (100 mg/kg BW) in a thoracic aortic aneurysm rat model reduced aneurysm size and improved elastin integrity by regulating VEGF expression impaired by $CaCl_2$ induction. Furthermore, curcumin has been shown to reduce oxidative stress and inflammation, thereby creating a favorable microenvironment for increased VEGF production and vascular remodeling [35]. The observed increase in VEGF, alongside enhanced SOD activity and reduced MDA levels, supports the hypothesis that white turmeric plays a protective role against skin aging. These findings collectively suggest that white turmeric can strengthen the antioxidant defense system while promoting angiogenesis and tissue repair.

3.4. Average MMP levels in Wistar rats.

MMP analysis was conducted to measure matrix metalloproteinase levels as an indicator of collagen degradation and skin tissue damage associated with the aging process. The MMP–1 blood level of Wistar rats injected with D-galactose is shown in Figure 5.

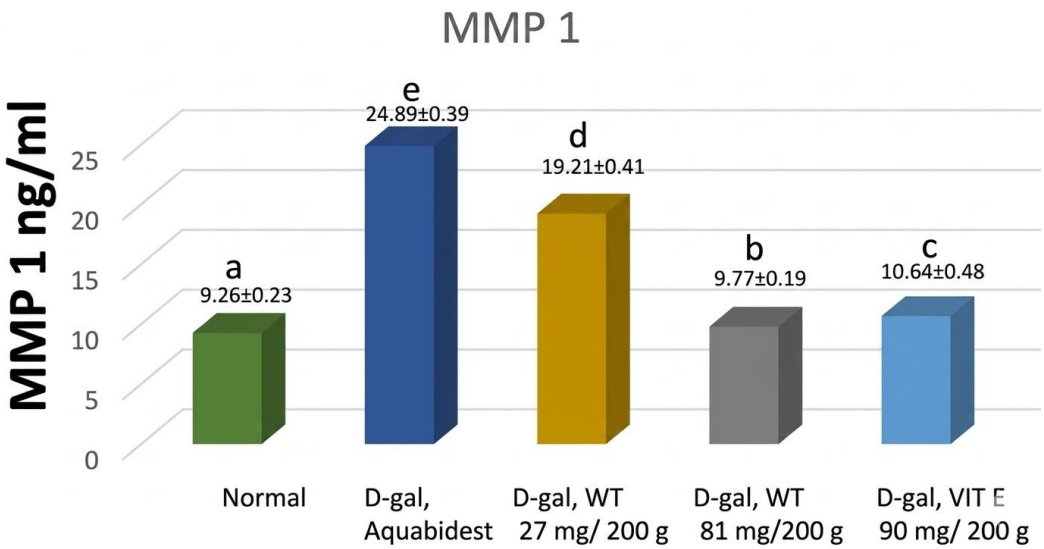

Figure 5. MMP-1 levels of Wistar rats injected with D-Galactose. Different letter notation indicates a significant difference ($p<0.05$); WT is white turmeric.

MMP-1 (Matrix Metalloproteinase-1) is a proteolytic enzyme responsible for breaking down type I and III collagen (the main collagen components of the skin). The enzyme is produced by fibroblasts, keratinocytes, and macrophages when the skin experiences oxidative stress or inflammation. The D-galactose-induced group of rats showed high MMP-1 levels, while the control group showed lower levels. This indicates that D-galactose causes oxidative stress in rats' skin. Administration of WT to the D-galactose-induced group of rats resulted in a decrease in MMP-1 levels, indicating that this treatment had a remedial effect after exposure

to the source. D-galactose can damage skin tissue structure by breaking down the extracellular matrix, especially collagen. WT administration was able to suppress MMP expression because the bioactive compound curcumin inhibits inflammatory signaling pathways such as NF-κB and PKCδ/JNK/c-Jun, which regulate MMP gene transcription. Curcumin can reduce wound-healing time and collagen deposition and increase fibroblast density [36]. According to Pujimulyani *et al*. [37], curcumin has strong potential as a natural anti-aging agent by protecting skin tissue from damage caused by free radicals and inflammation. Supporting evidence from [38] confirmed that curcumin can reduce MMP-1 and MMP-9 expression under oxidative stress by inhibiting NF-κB activation. Similar results occurred in the study Safitri *et al*. [39], which reported that administering 1% methanolic turmeric extract to Wistar rats induced with *Porphyromonas gingivalis* significantly reduced MMP-8 and MMP-13 expression on both day 1 and day 7 of observation. Activation of NF-κB is known to trigger the transcription of various inflammatory genes and matrix-destroying enzymes such as MMP, which play a role in the collagen degradation process [40]. Research by Rinnerthaler *et al*. [41] demonstrated that vitamin E can protect skin integrity by suppressing lipid peroxidation and reducing MMP activation under oxidative stress. The significant reduction in MMP levels observed in the groups treated with high doses of white turmeric and vitamin E indicates a synergistic mechanism involving both antioxidant and anti-inflammatory pathways. These effects support the development of white turmeric as a natural anti-aging agent, particularly in supplements or cosmetic products that target the inhibition of collagen-degrading enzymes, such as MMP.

3.5. Glucose levels in Wistar rats.

Glucose level analysis was conducted to evaluate the effect of treatment on blood sugar metabolism, serving as an indicator of physiological condition and metabolic system health. The glucose levels of Wistar rats injected with D-galactose are presented in Figure 6.

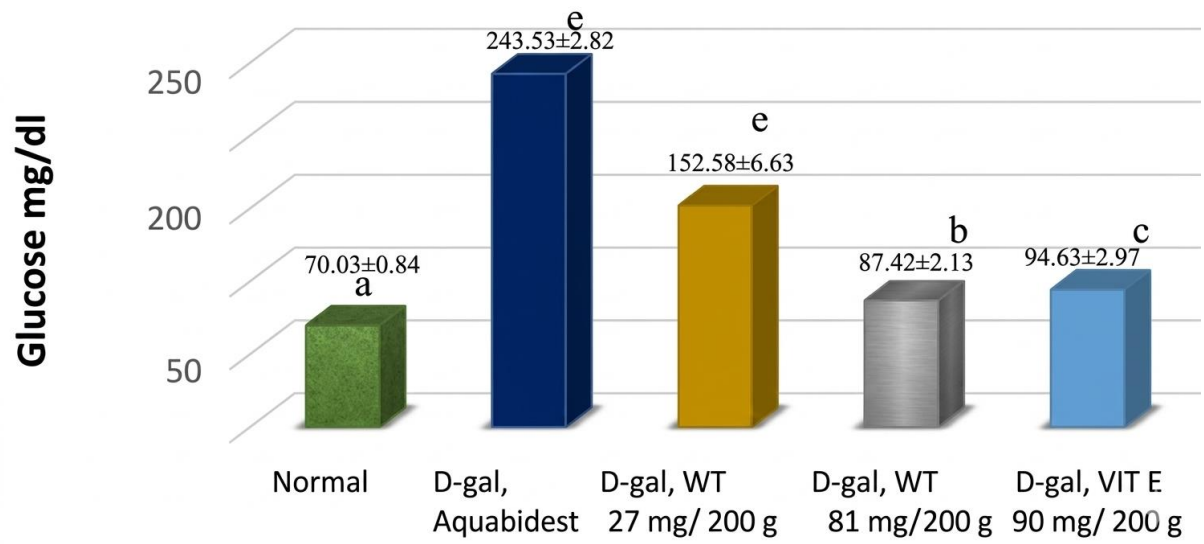

Figure 6. Glucose levels of Wistar rats injected with D-Galactose. Different letter notation indicates a significant difference ($p<0.05$); WT is white turmeric.

High blood glucose levels react with proteins, lipids, and DNA to form AGEs (Advanced Glycation End products). The accumulation of AGEs causes hardening and damage to skin collagen, leading to wrinkles, roughness, and dullness. Blood glucose levels in D-galactose-induced rats were higher than in normal rats and rats given WT and vit. E. D-galactose causes an increase in blood sugar levels because it has a monosaccharide form and is

then broken down into glucose through the Leloir pathway. This increase in blood glucose levels will be neutralized again by WT and vit. E. The greatest decrease in blood glucose levels was observed with the administration of 81 mg/200 g body weight of WT. The decrease in blood glucose levels indicates improved pancreatic function. This is due to the bioactive compounds in curcumin, which act as natural antioxidants. A similar study by Júnior *et al.* [42] showed that oral administration of *Curcuma longa* at a dose of 200 mg/kg BW, three times per week for four weeks, significantly lowered blood glucose levels in alloxan-induced type 1 diabetic Wistar rats.

Vitamin E administration, used as a positive control, also showed a significant glucose-lowering effect, with a recorded level of 94.63 mg/dL. Significant differences between treatment groups ($p < 0.05$) are denoted by different superscript notations in the accompanying table. The D-galactose + aquabidest group differed markedly from all other groups, highlighting a condition of untreated hyperglycemia. This effect is likely attributed to the active compounds in white turmeric, such as curcuminoids, which possess antioxidant and antidiabetic properties. These compounds may enhance insulin sensitivity and reduce hepatic glucose production. Curcumin has been shown to inhibit gluconeogenesis in the liver by downregulating key enzymes such as phosphoenolpyruvate carboxykinase (PEPCK) and glucose-6-phosphatase (G6Pase) [43]. According to Mohiti-Ardekani *et al*. [44], curcumin also lowers fasting blood glucose levels and increases the expression of GLUT-4 in skeletal muscle and adipose tissue, which is crucial for glucose uptake by cells.

3.6. Overall weight graph of the rats.

Weight analysis was conducted to monitor physiological changes and to assess the effects of the treatment on the general health condition of the study subjects. The overall weight changes of the rats are presented in Figure 7.

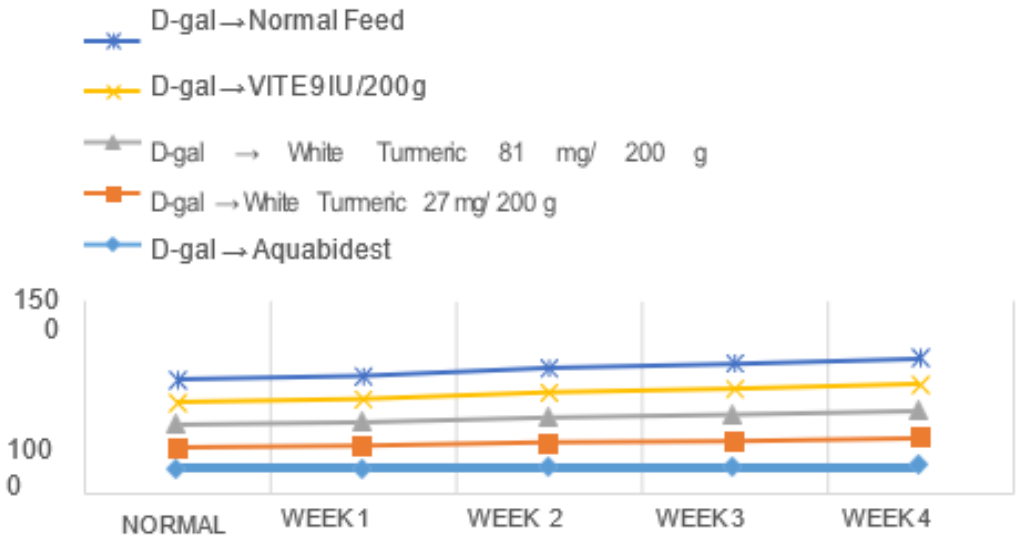

Figure 7. Overall body weight of Wistar rats during the treatment period.

Figure 7 shows the changes in body weight of Wistar rats from week to week across different treatment groups. In general, the weight of all groups tended to increase over time, although distinct patterns were observed between the control group and the groups receiving D-galactose treatment with or without additional interventions. The normal group (Wistar rats fed a standard diet without D-galactose injection) exhibited stable, consistent weight gain throughout the observation period, with the highest values among the groups. This reflects

normal physiological conditions in the absence of metabolic disturbances. In contrast, the group that received only D-galactose and aquabidest showed the lowest weight gain, indicating that D-galactose injections induced oxidative stress and worsened metabolic conditions, which may suppress growth or even lead to weight loss. The administration of white turmeric extract at two doses (27 mg/200 g BW and 81 mg/200 g BW) resulted in better weight gain patterns compared to the D-galactose + aquabidest group. Notably, at the higher dose (81 mg/200 g BW), the rats' weight increased significantly and approached that of the normal group, suggesting a protective effect against D-galactose-induced metabolic disturbances. This implies that white turmeric extract may improve metabolic conditions and support growth through its antioxidant and anti-inflammatory properties, attributed to active compounds such as curcuminoids [14]. This relationship is supported by increased SOD activity and decreased MDA levels, indicating reduced oxidative stress, as well as lower MMP levels, suggesting protection against extracellular matrix degradation. Additionally, the upregulation of VEGF expression supports tissue regeneration and angiogenesis. These combined biomarker changes reinforce the role of white turmeric extract in maintaining cellular homeostasis and overall metabolic function. The group treated with vitamin E as a positive control also showed a similar weight-gain pattern to the high-dose white turmeric extract group, and in some cases was even slightly higher. This further confirms the effectiveness of vitamin E as a potent antioxidant in mitigating oxidative stress.

3.7. Microscopic appearance of Wistar rat skin.

Histopathological analysis was conducted to evaluate microscopic changes in skin tissue structure as indicators of damage or repair induced by D-galactose aging, and to assess the effect of white turmeric extract treatment. The microscopic appearance of the skin in each group is presented in Figures 8a to 8e.

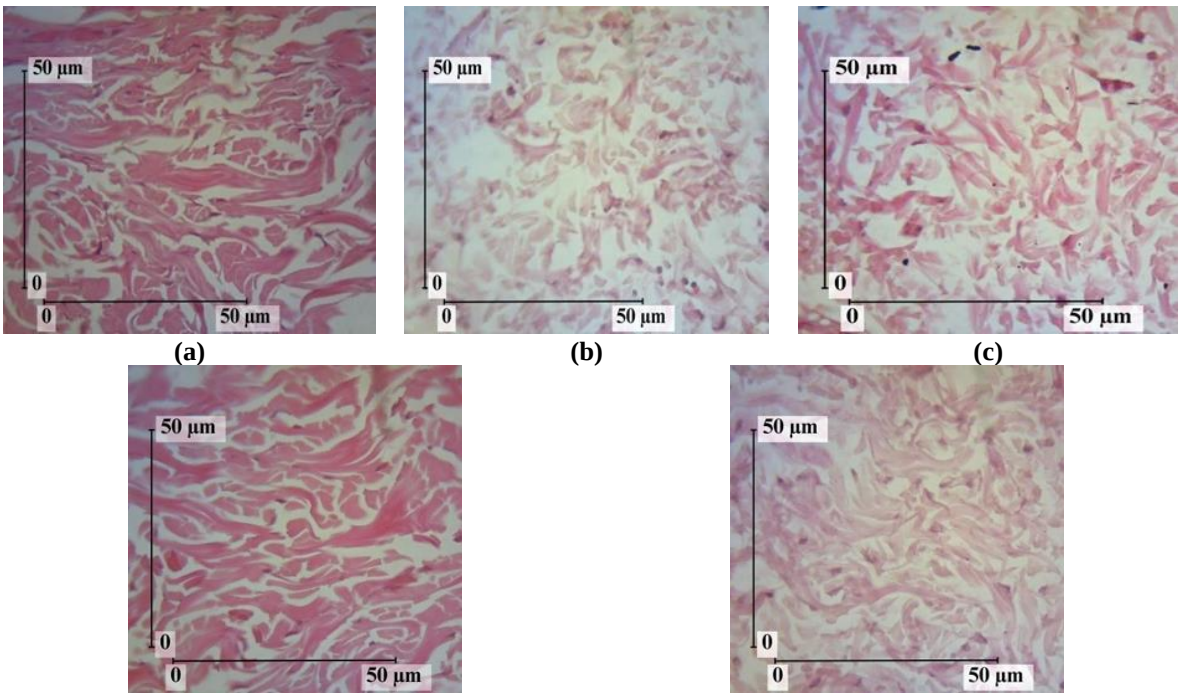

Figure 8. Microscopic appearance of the skin of **(a)** Group 1 rats (control); **(b)** Group 2 rats (D-gal, *Aquabidest*); **(c)** Group 3 rats (White turmeric 27 mg/200 g); **(d)** Group 4 rats (White turmeric 81 mg/200 g); **(e)** Group 5 rats (VIT E 90 mg /200 g).

Figure 8a shows that the skin tissue of Wistar rats in the normal feed (Group 1) appeared healthy. The dermal layer exhibited a thick, dense, and homogeneous structure of collagen fibers, neatly arranged without interstitial gaps. The even eosin staining indicated the absence of collagen degradation and reflected intact tissue without oxidative stress.

In contrast, Figure 8b reveals that rats in Group 2, which received only D-galactose and aquabidest, showed signs of tissue damage. Collagen fibers appeared fragmented and disorganized, with widened spaces between them. The eosin stain was faint, suggesting decreased collagen density and tissue degeneration. These histological changes are consistent with oxidative stress induced by D-galactose, which elevates reactive oxygen species (ROS) and leads to collagen degradation. Previous studies have reported that D-galactose exposure shortens and disrupts collagen fibers in experimental animals [45,46].

Figure 8c, representing Group 3 (D-galactose + white turmeric extract at 27 mg/200 g BW), shows improved skin structure compared to Group 2. Collagen fibers appeared thicker and more tightly packed, and eosin staining increased, suggesting the initiation of collagen regeneration. These findings indicate that even a low dose of white turmeric extract can begin to counter oxidative effects and stimulate collagen synthesis. A study by Mohiti-Ardekani *et al*. [47] showed that administering turmeric parent extract gel with concentrations of 1%, 5%, and 10% on a 2 cm long cut wound on the back of male white rats significantly accelerated the wound healing process. The best results are obtained at a concentration of 10%, where the average cure time is reached in 7.10 days. This effect is supported by increased migration of epithelial cells, fibroblasts, and macrophages, as well as increased re-epithelialization of wound tissue.

Figure 7d illustrates Group 4 (D-galactose + white turmeric extract at 81 mg/200 g BW), where the skin tissue structure showed significant recovery. Collagen fibers were dense, neatly organized, and closely resembled the normal control. Eosin staining was more intense, and interstitial spaces were minimal, indicating that high-dose turmeric extract effectively restored collagen integrity and prevented degradation due to aging. These results are supported by evidence that oxidative stress disrupts collagen fiber arrangement and density, leading to reduced skin elasticity and strength. Antioxidant-rich compounds, such as curcuminoids in white turmeric, can mitigate this damage and support tissue regeneration [48].

Figure 8e shows the skin of Group 5 rats (D-galactose + vitamin E at 90 mg/200 g BW). Collagen fibers appeared more regular and organized than in Groups 2 and 3, with narrower tissue gaps and stronger eosin staining. Although the improvement was not as prominent as in Group 4, vitamin E still demonstrated a protective effect. Compared with the D-galactose-only group, the collagen structure in this group was noticeably better but slightly less dense than in the high-dose turmeric group, suggesting a moderate antioxidant effect [49]. Overall, the histological analysis revealed that high-dose white turmeric extract (81 mg/200 g BW) provided the most notable recovery in skin tissue structure. Collagen fibers appeared dense, homogeneous, and well-organized, consistent with elevated SOD activity and reduced MDA levels, indicative of enhanced antioxidant defenses and reduced oxidative stress. Additionally, increased VEGF expression suggests improved tissue regeneration and angiogenesis. Together, these findings confirm the protective and reparative potential of white turmeric extract against D-galactose-induced skin aging.

4. Conclusions

The results of this study demonstrated that administration of white turmeric at a dose of 81 mg/200 g body weight significantly increased SOD enzyme activity, reduced MDA and MMP-1 levels, and markedly elevated VEGF levels in Wistar rats subjected to oxidative stress induced by D-galactose. The bioactive compounds in white turmeric, such as polyphenols, play a crucial role in mitigating oxidative damage, promoting tissue regeneration, and inhibiting the aging of the skin. White turmeric can be used as an anti-aging agent in D-galactose-induced Wistar rats. However, this study only used one type of rhizome and did not compare it with other similar types of rhizomes. Therefore, further research could be conducted to compare it with other types of rhizomes.

Author Contributions

Conceptualization, D.P.; methodology, C.L.S.; software, D.P.; validation, A.S., D,P., and C.L.S.; formal analysis, D.P. and A.S.; investigation, D.P.; resources, C.L.S.; data curation, D.P..; writing—original draft preparation, D.P.; writing—review and editing, C.L.S. and A.S.; visualization, D.P. and C.L.S.; supervision, A.S.; project administration, D.P.; funding acquisition, D.P. All authors have read and agreed to the published version of the manuscript.

Informed Consent Statement

This study utilized experimental animals (rats) that were maintained and handled in accordance with the protocols established by the Center for Food and Nutrition Studies at Gadjah Mada University, as outlined in Certificate No. 39/UN1/PSPG/S. Ket/III/2019 regarding the Methods of Maintenance and Euthanasia of Test Animals.

Data Availability Statement

Data supporting the findings of this study are available upon reasonable request from the corresponding author.

Funding

This research was funded by the Directorate of Research and Community Service, Directorate General of Research and Development Strengthening, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, under Contract No. 109/SP2H/LT/DRPM/2018.

Acknowledgments

The authors would like to express their sincere gratitude to the Directorate of Research and Community Service, Directorate General of Research and Development Strengthening, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, for funding this research under Contract No. 109/SP2H/LT/DRPM/2018. The authors also acknowledge the valuable technical assistance and administrative support provided by colleagues and staff during the course of this study.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Guo, J.; Huang, X.; Dou, L.; Yan, M.; Shen, T.; Tang, W.; Li, J. Aging and aging-related diseases: from molecular mechanisms to interventions and treatments. *Signal Transduct. Target. Ther.* **2022**, *7*, 391, https://doi.org/10.1038/s41392-022-01251-0.
2. Leyane, T.S.; Jere, S.W.; Houreld, N.N. Oxidative Stress in Ageing and Chronic Degenerative Pathologies: Molecular Mechanisms Involved in Counteracting Oxidative Stress and Chronic Inflammation. *Int. J. Mol. Sci.* **2022**, *23*, 7273, https://doi.org/10.3390/ijms23137273.
3. Engwa, G.A.; EnNwekegwa, F.N.; Nkeh-Chungag, B.N. Free Radicals, Oxidative Stress-Related Diseases and Antioxidant Supplementation. *Altern. Ther. Health Med.* **2022**, *28*, 114-128. https://pubmed.ncbi.nlm.nih.gov/32827401/
4. Qian, H.; Shan, Y.; Gong, R.; Lin, D.; Zhang, M.; Wang, C.; Wang, L. Mechanism of action and therapeutic effects of oxidative stress and stem cell-based materials in skin aging: Current evidence and future perspectives. *Front. Bioeng. Biotechnol.* **2023**, *10*, 1082403, https://doi.org/10.3389/fbioe.2022.1082403.
5. Singh, I.; Kharb, M. A Study of Consumers' Buying Behaviour on Herbal Products (with special reference to cosmetic products). *J. Surv. Fish. Sci.* **2023**, *10*, 3939-3945, https://doi.org/10.53555/sfs.v10i1.1802.
6. Muchtaromah, B.; Nurul Mutmainah, F.; Agung Prahardika, B.; Ahmad, M. Antioxidant and Antifungal Activities of Temu mangga (*Curcuma mangga* Val.) Extract in Some Solvents. *Iran. J. Pharm. Sci.* **2020**, *16*, 1-18, https://doi.org/10.22037/ijps.v16.40400.
7. Sasanti, A.D.; Widanarni, W.; Sukenda, S.; Wahjuningrum, D.; Yuhana, M.; Setiawati, M.I.A. Phytochemical screening and antibacterial activity test of *Curcuma zedoaria*, *C. aeruginosa*, and *C. mangga* extracts against *Aeromonas hydrophila*. *Biodivers. J. Biol. Divers.* **2025**, *26*, 1574-1581, https://doi.org/10.13057/biodiv/d260409.
8. Herisman, M.W.; Gani, A.P.; Murwanti, R. Effect of *Curcuma mangga* and *Curcuma longa* on Oxidative Stress-related Diseases and ROS Level: A Recent Study. *Trop. J. Nat. Prod. Res.* **2022**, *6*, 668-672.
9. Ganur, A.N.A.; Rahayu, D.U.C.; Dianhar, H.; Irwanto, I.; Sugita, P. Terpenoid from Indonesian temu mangga (*Curcuma mangga*, Val) rhizomes and review of its anticancer towards MCF-7 breast cells. *AIP Conf. Proc.* **2021**, *2349*, 020044, https://doi.org/10.1063/5.0051538.
10. Devi, S.T.; Sanatombi, K. Bioactive Compounds and Biological Activities of *Curcuma* Species. In Bioactive Compounds in the Storage Organs of Plants; Murthy, H.N., Paek, K.Y., Park, S.-Y., Eds.; Springer Nature Switzerland: Cham, **2023**; pp. 1-57, https://doi.org/10.1007/978-3-031-29006-0_19-1.
11. Anggraeni, W.; Ginting, C.N.; Chiuman, L.; Ginting, S.F.; Wardhani, F.M. Antioxidant and Anti-inflammatory Activities of Extract Ethanol Curcuma zedoaria. *Open Access Maced. J. Med. Sci.* **2022**, *10*, 1126-1131, https://doi.org/10.3889/oamjms.2022.7511.
12. Pujimulyani, D. LEBIH SEHAT DENGAN KUNIR PUTIH JENIS MANGGA; Gramata Publishing: Bekasi, **2016**.
13. Michalak, M. Plant-Derived Antioxidants: Significance in Skin Health and the Ageing Process. *Int. J. Mol. Sci.* **2022**, *23*, 585, https://doi.org/10.3390/ijms23020585.
14. Pujimulyani, D.; Yulianto, W.A.; Setyowati, A.; Prastyo, P.; Windrayahya, S.; Maruf, A. White saffron (*Curcuma mangga* Val.) attenuates diabetes and improves pancreatic β-cell regeneration in streptozotocin-induced diabetic rats. *Toxicol. Rep.* **2022**, *9*, 1213-1221, https://doi.org/10.1016/j.toxrep.2022.05.014.
15. Rezica Kanza, N.; Tusy, T.; Nia, T.; Efrida, W. Uji Sensitivitas Kunyit Kuning dan Kunyit Putih Terhadap Bakteri Pencemar Susu. *Arteri J. Ilmu Kesehat.* **2020**, *1*, 263–269, https://doi.org/10.37148/arteri.v1i4.73.
16. Maria Immaculata Esteria, N.; Novrina, S.; Sanggam, H. The Effect of Giving Moringa Leaf Extract (Moringa Oleifera) and Orlistat on the Body Weight of Mice Induced with D-Galactose. Proceedings of the 1st International Conference on Lifestyle Diseases and Natural Medicine (ICOLIFEMED 2024); Atlantis Press: **2025**; pp. 239-244, https://doi.org/10.2991/978-94-6463-664-2_22.
17. Farajdokht, F.; Sadigh-Eteghad, S.; Mahmoudi, J. Chapter 42 - d-galactose-induced aging and brain mitochondria. In Assessments, Treatments and Modeling in Aging and Neurological Disease, Martin, C.R., Preedy, V.R., Rajendram, R., Eds.; Academic Press: **2021**; pp. 471-480, https://doi.org/10.1016/B978-0-12-818000-6.00042-1.
18. Taylor-LaPole, A.M.; Cunny, H.C.; Shockley, K.R. Statistical Analysis of Rodent Body Weight Data is Robust to Departures from Normality in Historical National Toxicology Program Studies Dated 1980-2013. *J. Young. Investig.* **2022**, *25*, 1-12.
19. Pujimulyani, D.; Santoso, U.; Luwihana, D.S.; Maruf, A. Orally administered pressure-blanched white

saffron (*Curcuma mangga* Val.) improves antioxidative properties and lipid profiles *in vivo*. *Heliyon* **2020**, *6*, e04219, https://doi.org/10.1016/j.heliyon.2020.e04219.
20. Wittig, F.; Pannenberg, L.; Schwarz, R.; Bekeschus, S.; Ramer, R.; Hinz, B. Antiangiogenic Action of JZL184 on Endothelial Cells via Inhibition of VEGF Expression in Hypoxic Lung Cancer Cells. *Cells* **2023**, *12*, 2332, https://doi.org/10.3390/cells12192332.
21. Rahayu, R.F.; Prayitno, A.; Purwanto, B.; Soewondo, W.; Nurwati, I.; Pamungkasari, E.P.; Dirgahayu, P. Combination of Metformin and Magnesium Citrate Reduces TNF-α, NF-κB p65, IL-6, CD4, and MMP-9 Expressions in Diabetic Model Rats. *Indones. Biomed. J.* **2024**, *16*, 546-552, https://doi.org/10.18585/inabj.v16i6.3360.
22. Kocaadam, B.; Şanlier, N. Curcumin, an active component of turmeric (*Curcuma longa*), and its effects on health. *Crit. Rev. Food Sci. Nutr.* **2017**, *57*, 2889–2895, https://doi.org/10.1080/10408398.2015.1077195.
23. Susiloningrum, D.; Sari, D.E.M. Uji Aktivitas Antioksidan Dan Penetapan Kadar Flavonoid Total Ekstrak Temu Mangga (*Curcuma mangga* Valeton & Zijp) Dengan Variasi Konsentrasi Pelarut. *Cendekia. J. Pharm.* **2021**, *5*, 117–127, https://doi.org/10.31596/cjp.v5i2.148.
24. Ramírez-Mendoza, A.A.; Ramírez-Herrera, M.A.; Cortez-Álvarez, C.R.; Nery-Flores, S.D.; Tejeda-Martínez, A.R.; Romero-Prado, M.M.d.J.; Mendoza-Magaña, M.L. Curcumin Modifies the Activity of Plasmatic Antioxidant Enzymes and the Hippocampal Oxidative Profile in Rats upon Acute and Chronic Exposure to Ozone. *Molecules* **2022**, *27*, 4531, https://doi.org/10.3390/molecules27144531.
25. Pujimulyani, D.; Suryani, L.; Setyawati, A.; Amalia, A.; Qodaniah, R.L.; Kusuma, H.S.W.; Widowati, W. Elastase, Hyaluronidase and Tyrosinase inhibitor activities antiaging of *Curcuma mangga* Val. extract and its fractions. *IOP Conf. Ser.: Earth Environ. Sci.* **2019**, *379*, 012004, https://doi.org/10.1088/1755-1315/379/1/012004.
26. Abdel-Diam, M.M.; Samak, D.H.; El-Sayed, Y.S.; Aleya, L.; Alarifi, S.; Alkahtani, S. Curcumin and quercetin synergistically attenuate subacute diazinon-induced inflammation and oxidative neurohepatic damage, and acetylcholinesterase inhibition in albino rats. *Environ. Sci. Pollut. Res.* **2019**, *26*, 3659-3665, https://doi.org/10.1007/s11356-018-3907-9.
27. Memarzia, A.; Khazdair, M.R.; Behrouz, S.; Gholamnezhad, Z.; Jafarnezhad, M.; Saadat, S.; Boskabady, M.H. Experimental and clinical reports on anti-inflammatory, antioxidant, and immunomodulatory effects of *Curcuma longa* and curcumin, an updated and comprehensive review. *BioFactors* **2021**, *47*, 311-350, https://doi.org/10.1002/biof.1716.
28. Alizadeh, M.; Kheirouri, S. Curcumin reduces malondialdehyde and improves antioxidants in humans with diseased conditions: a comprehensive meta-analysis of randomized controlled trials. *BioMedicine* **2019**, *9*, 23.
29. Barbalho, S.M.; de Sousa Gonzaga, H.F.; de Souza, G.A.; de Alvares Goulart, R.; de Sousa Gonzaga, M.L.; de Alvarez Rezende, B. Dermatological effects of *Curcuma* species: a systematic review. *Clin. Exp. Dermatol.* **2021**, *46*, 825-833, https://doi.org/10.1111/ced.14584.
30. Fuloria, S.; Mehta, J.; Chandel, A.; Sekar, M.; Rani, N.N.I.M.; Begum, M.Y.; Subramaniyan, V.; Chidambaram, K.; Thangavelu, L.; Nordin, R.; Wu, Y.S.; Sathasivam, K.V.; Lum, P.T.; Meenakshi, D.U.; Kumarasamy, V.; Azad, A.K.; Fuloria, N.K. A Comprehensive Review on the Therapeutic Potential of *Curcuma longa* Linn. in Relation to its Major Active Constituent Curcumin. *Front. Pharmacol.* **2022**, *13*, 820806, https://doi.org/10.3389/fphar.2022.820806.
31. Farzaei, M.H.; Zobeiri, M.; Parvizi, F.; El-Senduny, F.F.; Marmouzi, I.; Coy-Barrera, E.; Naseri, R.; Nabavi, S.M.; Rahimi, R.; Abdollahi, M. Curcumin in Liver Diseases: A Systematic Review of the Cellular Mechanisms of Oxidative Stress and Clinical Perspective. *Nutrients* **2018**, *10*, 855, https://doi.org/10.3390/nu10070855.
32. Mukhlisa, N.; Sudibyo, R.S.; Murwanti, R. Uji Sitotoksitas dan Hambatan Ekspresi VEGF pada Sel 4T1 Minyak Atsiri Rimpang Curcuma mangga Val. *J. Penelit. Saintek* **2021**, *26*, 122-130, https://doi.org/10.21831/jps.v26i2.41386.
33. Cui, J.; Li, H.; Zhang, T.; Lin, F.; Chen, M.; Zhang, G.; Feng, Z. Research progress on the mechanism of curcumin anti-oxidative stress based on signaling pathway. *Front. Pharmacol.* **2025**, *16*, 1548073, https://doi.org/10.3389/fphar.2025.1548073.
34. Li, X.; Fang, Q.; Tian, X.; Wang, X.; Ao, Q.; Hou, W.; Tong, H.; Fan, J.; Bai, S. Curcumin attenuates the development of thoracic aortic aneurysm by inhibiting VEGF expression and inflammation. *Mol. Med. Rep.* **2017**, *16*, 4455-4462, https://doi.org/10.3892/mmr.2017.7169.
35. Zhang, R.; Zhao, T.; Zheng, B.; Zhang, Y.; Li, X.; Zhang, F.; Cen, J.; Duan, S. Curcumin Derivative Cur20

Attenuated Cerebral Ischemic Injury by Antioxidant Effect and HIF-1α/VEGF/TFEB-Activated Angiogenesis. *Front. Pharmacol.* **2021**, *12*, 648107, https://doi.org/10.3389/fphar.2021.648107.
36. Kasprzak-Drozd, K.; Niziński, P.; Hawrył, A.; Gancarz, M.; Hawrył, D.; Oliwa, W.; Pałka, M.; Markowska, J.; Oniszczuk, A. Potential of Curcumin in the Management of Skin Diseases. *Int. J. Mol. Sci.* **2024**, *25*, 3617, https://doi.org/10.3390/ijms25073617.
37. Pujimulyani, D.; Suryani, C.L.; Setyowati, A.; Handayani, R.A.S.; Arumwardana, S.; Widowati, W.; Maruf, A. Cosmeceutical potentials of *Curcuma mangga* Val. extract in human BJ fibroblasts against MMP1, MMP3, and MMP13. *Heliyon* **2020**, *6*, e04921, https://doi.org/10.1016/j.heliyon.2020.e04921.
38. Jiang, W.; Xu, J. Immune modulation by mesenchymal stem cells. *Cell Prolif.* **2020**, *53*, e12712, https://doi.org/10.1111/cpr.12712.
39. Rani Safitri, C.; Sidharta, W.; Kusumaningsih, A.; Wicaksono, F.M.; Aljunaid, M.; Krismariono, A. The effect of curcumin 1% methanolic extract on the expression of Matrix Metalloproteinase-1, Matrix Metalloproteinase-8, Matrix Metalloproteinase-13, neutrophil, macrophage, lymphocyte counts in *Porphyromonas gingivalis* induced periodontitis: a randomized controlled trial. *Saudi Dent. J.* **2024**, *36*, 1339-1343, https://doi.org/10.1016/j.sdentj.2024.08.002.
40. Araki, Y.; Mimura, T. Matrix Metalloproteinase Gene Activation Resulting from Disordred Epigenetic Mechanisms in Rheumatoid Arthritis. *Int. J. Mol. Sci.* **2017**, *18*, 905, https://doi.org/10.3390/ijms18050905.
41. Rinnerthaler, M.; Bischof, J.; Streubel, M.K.; Trost, A.; Richter, K. Oxidative Stress in Aging Human Skin. *Biomolecules* **2015**, *5*, 545-589, https://doi.org/10.3390/biom5020545.
42. Júnior, A.S.S.; Aidar, F.J.; Santos, J.L.D.; Estevam, C.D.S.; dos Santos, J.D.M.; de Oliveira e Silva, A.M.; Lima, F.B.; De Araújo, S.S.; Marçal, A.C. Effects of resistance training and turmeric supplementation on reactive species marker stress in diabetic rats. *BMC Sports Sci. Med. Rehabil.* **2020**, *12*, 45, https://doi.org/10.1186/s13102-020-00194-9.
43. Bao, X.; Chen, M.; Yue, Y.; Liu, H.; Yang, Y.; Yu, H.; Yu, Y.; Duan, N. Effects of Dietary Nano-Curcumin Supplementation on Growth Performance, Glucose Metabolism, and Endoplasmic Reticulum Stress in Juvenile Largemouth Bass, *Micropterus salmoides*. *Front. Mar. Sci.* **2022**, *9*, 924569, https://doi.org/10.3389/fmars.2022.924569.
44. Mohiti-Ardekani, J.; Asadi, S.; Ardakani, A.M.; Rahimifard, M.; Baeeri, M.; Momtaz, S. Curcumin increases insulin sensitivity in C2C12 muscle cells via AKT and AMPK signaling pathways. *Cogent Food Agric.* **2019**, *5*, 1577532, https://doi.org/10.1080/23311932.2019.1577532.
45. Kumar, H.; Bhardwaj, K.; Valko, M.; Alomar, S.Y.; Alwasel, S.H.; Cruz-Martins, N.; Dhanjal, D.S.; Singh, R.; Kuča, K.; Verma, R.; Kumar, D. Antioxidative potential of *Lactobacillus* sp. in ameliorating D-galactose-induced aging. *Appl. Microbiol. Biotechnol.* **2022**, *106*, 4831-4843, https://doi.org/10.1007/s00253-022-12041-7.
46. Liu, S.; Chen, Z.; Cai, X.; Sun, Y.; Zhao, C.; Liu, F.; Liu, D. Effects of Dimethylaminoethanol and Compound Amino Acid on D-Galactose Induced Skin Aging Model of Rat. *Sci. World J.* **2014**, *2014*, 507351, https://doi.org/10.1155/2014/507351.
47. Kaban, V.E.; Nasri, N.; Rani, Z.; Suci, N.; Karo Sekali, E.S.; Sagala, H.U.B. The effect of turmeric parent extract gel (*Curcuma longa* Linn) on incision wound healing in male white rats (*Rattus norvegicus*). *J. Pharm. Sci.* **2024**, *7*, 616-627, https://doi.org/10.36490/journal-jps.com.v7i4.590.
48. Lee, H.; Hong, Y.; Kim, M. Structural and Functional Changes and Possible Molecular Mechanisms in Aged Skin. *Int. J. Mol. Sci.* **2021**, *22*, 12489, https://doi.org/10.3390/ijms222212489.
49. Wang, Z.; Xu, R.; Yang, H.; Li, R.; Ding, J.; Chang, Y.; Zuo, R. Vitamin E Regulates the Collagen Contents in the Body Wall of Sea Cucumber (*Apostichopus japonicus*) via Its Antioxidant Effects and the TGF-β/Smads Pathway. *Antioxidants* **2024**, *13*, 847, https://doi.org/10.3390/antiox13070847.

Publisher's Note & Disclaimer

information before relying on it, and the publisher assumes no responsibility for any consequences arising from the use of materials contained in this publication.