



Hematological and Biochemical Alterations in Doxorubicin-Induced Toxicity and the Protective Role of *Persea americana* Seed Extract

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Abstract	Article History
Doxorubicin (DOX) is a common chemotherapy drug, which causes dose-dependent toxicity affecting multiple systems like heart, blood, liver, and kidneys. This study assessed the hematological and biochemical changes caused by DOX and explored the protective effects of <i>Persea americana</i> seed extract in an experimental animal model. Forty-two Wistar rats were divided into six groups: G1, control rats; G2, received 5mg/kg of DOX alone; G3, received 100mg/kg reference drug, vitamin C; G4, received 5mg/kg DOX + 500mg/kg extract; G5 received 5mg/kg DOX + 1000mg/kg extract; G6 received 5mg/kg DOX + 1500mg/kg extract. Dox (5 mg/kg) was given intraperitoneally, and treatments lasted four weeks. Blood parameters (RBC, Hb, PCV, WBC, platelets), liver function markers (ALT, AST, ALP, total protein, albumin, bilirubin), and kidney function markers (urea, creatinine, electrolytes) were evaluated using standard methods. DOX treatment led to significant reductions ($p < 0.05$) in RBC, Hb, PCV, and platelets, along with an increase in WBC levels. It also raised liver enzymes and bilirubin while lowering total protein and albumin, indicating liver damage. Kidney impairment was shown by higher levels of urea and creatinine, as well as an electrolyte imbalance. Treatment with <i>Persea americana</i> seed extract significantly reduced these changes in a dose-dependent manner. The highest dose (1500 mg/kg) provided the most consistent improvement, similar to vitamin C. These results suggest that <i>Persea americana</i> seed extract may protect against DOX-related toxicity, likely through antioxidant effects. However, not all parameters completely normalized, showing partial recovery instead of full restoration. This study highlights the potential of <i>Persea americana</i> as a natural aid in reducing chemotherapy-induced toxicity and encourages more research into its therapeutic uses. Keywords: Protective, Toxicity, Natural, Treatment, Dose-dependent, Restoration, Extract	Received: 15 Mar 2026 Accepted: 16 Apr 2026 Published: 22 Apr 2026
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1. Introduction

Doxorubicin (DOX) is a powerful anthracycline antibiotic often used to treat various cancers, including breast cancer, lymphomas, and solid tumors. Its effectiveness primarily comes from its ability to intercalate DNA, inhibit topoisomerase II, and produce free radicals that interfere with cell replication (Wang et al., 2021; Carvalho et al., 2014). However, DOX's clinical use is greatly limited due to its cumulative and dose-related toxicity, especially its potential to cause heart problems that can lead to lasting heart damage and failure (Octavia et al., 2012; Kong et al., 2022). Besides affecting the heart, DOX can cause widespread toxicity impacting the liver, kidneys, and blood system, disrupting the body's overall balance (Carvalho et al., 2014; Radeva et al., 2025).

The mechanisms behind DOX-induced toxicity are complex, with oxidative stress identified as a key factor. DOX undergoes redox cycling in mitochondria, producing excessive reactive oxygen species (ROS), such as superoxide anions and hydroxyl radicals. This overload can overwhelm the body's natural antioxidant systems (Kong et al., 2022; Wang et al., 2021; Wang and Zhang, 2024). The resulting oxidative stress leads to damage in lipids, proteins, and DNA, which can trigger cell death and inflammation (Wang et al., 2021; Carvalho et al., 2014). Additionally, DOX affects iron balance, which can lead to reactions that further increase ROS and damage cells (Radeva et al., 2025). These biochemical changes often result in blood parameter alterations, showing suppressed white blood cells, decreased platelets, and anemia, which reflect damage to bone marrow and the entire system.

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Given the significant role of oxidative stress in DOX toxicity, there has been a focus on using natural antioxidants as protective treatments. Compounds from plants can scavenge free radicals, influence inflammatory pathways, and boost the body's natural antioxidant enzymes, helping to lessen damage from chemotherapy (Bhuyan et al., 2019; Pal et al., 2024). *Persea americana* (avocado) has gained attention due to its rich content of bioactive compounds like flavonoids, phenolic acids, and carotenoids, which have strong antioxidant effects (Bhuyan et al., 2019). Notably, the seed of *P. americana*, often seen as waste, is a significant source of these beneficial compounds and shows pharmacological effects.

Recent studies suggest that *Persea americana* seed extracts can help reduce toxicity caused by oxidative stress. Evidence from experiments indicates that these extracts can lessen the heart damage caused by DOX by reducing lipid damage, improving antioxidant activity, and preserving cell health (Shamlan et al., 2020; Chibueze et al., 2025). Furthermore, avocado seed extracts can improve lipid levels and lower cardiovascular risk in animals treated with DOX, reinforcing their protective role (Chibueze et al., 2025). The rich phytochemical content of avocado seed, including polyphenols and flavonoids, supports its ability to combat ROS and protect cell membranes, reducing tissue damage (Dabas et al., 2013; Nascimento et al., 2025). Despite these promising results, there are still not enough comprehensive studies looking at both blood and biochemical changes related to DOX toxicity and the effects of *P. americana* seed extract.

This study aims to examine the blood and biochemical changes linked to DOX toxicity and to assess the protective effects of *Persea americana* seed extract. By providing a complete evaluation of systemic toxicity and natural treatment, this study hopes to contribute to developing safer strategies for chemotherapy, especially in areas with limited access to advanced heart-protective treatments.

2. Methodology

2.1 Study Area

The study took place in the Medical Biochemistry Laboratory at Imo State University in Owerri, Nigeria. Some biochemical tests were done at the Biochemistry Laboratory of Michael Okpara University of Agriculture in Umudike.

2.2 Preparation of Plant Extract

Avocado seeds were cleaned, air-dried, and ground into powder. Extraction used cold soaking in 90% ethanol (1:2 w/v), based on Egbonu's method (2018). The filtrate was concentrated using a water bath at 60°C and then dried in an oven at 50°C to obtain the crude extract.

2.3 Experimental Animals and Ethical Approval

Forty-two adult Wistar rats (both males and females) were used for the study. The rats were kept for two weeks under standard lab conditions, with unlimited access to food and water. Males and females were housed separately. All experiments adhered to international guidelines for the care and use of laboratory animals (OECD, 1995; National Research Council, 2011).

2.4 Acute Toxicity Study

The median lethal dose (LD₅₀) of the extract was determined using Lorke's method (Lorke, 1983), further modified by Orieki et al., (2019). Tests involved two phases. In first phase, 9 animals assigned to 3 groups were given 10, 100 and 1000 mg/kg oral doses of the extract. Death or survival records in first phase determined doses used for second phase. In second phase, another set of 9 animals also assigned to 3 groups of 3 animals each were given 1600, 2900 and 5000 mg/kg of extract, respectively. The treated animals were observed for 24 hours for signs of toxicity and lethality. With no mortality observed after 24 hours, 5000 mg/kg body of the extract was given to yet another set of 3 animals as confirmatory tests. The animals were observed for 24 hours and a further 7 days. Acute toxicity of the extract was calculated using the expression below:

$$LD_{50} = \sqrt{A \times B}$$

A = Maximum dose that produced no mortality

B = Minimum dose that killed all animals in a group

2.5 Experimental Design

Animals were randomly assigned to six groups (n = 7):

Group I: Normal control

Group II: Doxorubicin (5 mg/kg, i.p., weekly)

Group III: Vitamin C + doxorubicin

Group IV: Doxorubicin + extract (500mg/kg)

Group V: Doxorubicin + extract (1000mg/kg)

Group VI: Doxorubicin + extract (1500 mg/kg)

Treatment lasted four weeks. Animals were fasted overnight before sample collection.

2.6 Sample Collection

Blood samples were taken via cardiac puncture. Serum was separated for biochemical analysis. Organs were collected for further evaluation.

2.7 Laboratory Analyses

2.7.1 Hematological Parameters

Blood indices, including red blood cell count (RBC), hemoglobin concentration (Hb), packed cell volume (PCV), total white blood cell count (WBC), and platelet count, were measured using an automated hematology analyzer (Mindray BC-2300, China) as per the manufacturer's guidelines.

2.7.2 Liver Function Parameters

Serum alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP) were measured using standard colorimetric methods with commercial kits (Randox Laboratories, UK). Total protein and albumin levels were also assessed using standard biochemical methods following manufacturer instructions.

2.7.3 Renal Function Parameters

Serum urea and creatinine levels were evaluated using enzymatic colorimetric methods with commercial kits (Randox Laboratories, UK). Electrolyte levels (sodium, potassium, chloride, and bicarbonate) were measured using standard diagnostic kits based on accepted biochemical methods (Teco Laboratories).

2.8 Statistical Analysis

Data were analyzed using IBM SPSS version 20.0. Results are expressed as mean $\pm$ standard deviation. One-way ANOVA was used to compare groups, followed by Duncan's multiple range test for post hoc analysis. Statistical significance was set at $p < 0.05$.

3 Results

3.1 Hematological Parameters

DOX treatment caused significant reductions ($p < 0.05$) in RBC, Hb, PCV, and platelets, while WBC count increased compared to the control (Table 1), indicating blood toxicity. Treatment with *Persea americana* seed extract improved RBC, Hb, PCV, and platelet counts in a dose-dependent fashion, although not all values returned to normal. Elevated WBC levels decreased after treatment, especially at the higher doses. The effect at 1500 mg/kg was comparable to vitamin C.

Table 1: Effects of *Persea americana* (PA) ethanolic seed extract on haematological parameters in DOX treated rats.

Treatments	Normal control	DOX, 5 mg/kg body weight.	Vitamin C (100 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (500 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (1000 mg/kg BW) + DOX, 5 mg/kg BW	P. A seed extract (1500 mg/kg BW) + DOX, 5 mg/kg BW
RBC ($\times 10^6/\text{mm}^3$)	7.72 $\pm$ 0.47 ^d	6.38 $\pm$ 0.07 ^a	7.33 $\pm$ 0.38 ^{c,d}	6.96 $\pm$ 0.26 ^{b,c}	6.57 $\pm$ 0.14 ^{a,b}	7.32 $\pm$ 0.28 ^{c,d}
PCV (%)	48.33 $\pm$ 2.89 ^c	40.67 $\pm$ 1.16 ^a	45.67 $\pm$ 3.31 ^{b,c}	43.67 $\pm$ 1.53 ^{a,b}	41.33 $\pm$ 1.16 ^a	45.00 $\pm$ 1.00 ^{b,c}
Hb (g/dl)	18.13 $\pm$ 1.33 ^c	15.60 $\pm$ 0.20 ^a	17.47 $\pm$ 1.10 ^{b,c}	16.13 $\pm$ 0.31 ^b	15.60 $\pm$ 0.20 ^a	17.00 $\pm$ 0.87 ^{a,b,c}
WBC ($\times 10^3/\text{mm}^3$)	9.82 $\pm$ 0.18 ^a	14.02 $\pm$ 0.18 ^c	10.40 $\pm$ 0.60 ^{a,b}	11.10 $\pm$ 0.89 ^b	13.55 $\pm$ 0.13 ^c	10.92 $\pm$ 0.28 ^b
PLT ($\times 10^3/\text{mm}^3$)	400.67 $\pm$ 19.66 ^b	350.67 $\pm$ 6.11 ^a	373.33 $\pm$ 14.01 ^{a,b}	379.33 $\pm$ 20.55 ^{a,b}	394.67 $\pm$ 42.71 ^{a,b}	376.67 $\pm$ 19.60 ^{a,b}
MCV (fl)	62.64 $\pm$ 0.51 ^{a,b}	63.77 $\pm$ 1.21 ^b	62.28 $\pm$ 0.41 ^a	62.71 $\pm$ 0.19 ^{a,b}	62.91 $\pm$ 0.45 ^{a,b}	61.53 $\pm$ 1.01 ^a
MCH (pg)	23.49 $\pm$ 0.32 ^a	24.46 $\pm$ 0.27 ^b	23.81 $\pm$ 0.41 ^a	23.18 $\pm$ 0.42 ^a	23.75 $\pm$ 0.27 ^a	23.23 $\pm$ 0.37 ^a
MCHC (g/dl)	37.50 $\pm$ 0.56 ^a	38.37 $\pm$ 0.70 ^a	38.23 $\pm$ 0.53 ^a	36.96 $\pm$ 0.60 ^a	37.75 $\pm$ 0.69 ^a	37.76 $\pm$ 1.20 ^a

Values are presented as mean $\pm$ standard deviation ($n = 3$); and values different letter superscripts are significantly ($P < 0.05$) different from paired mean across the row.

3.2 Liver Function Parameters

DOX significantly ($p < 0.05$) increased ALT, AST, ALP, and bilirubin levels while decreasing total protein and albumin (Table 2), indicating liver dysfunction.

The administration of *Persea americana* extract reduced these changes in a dose-dependent manner, with the highest dose showing the most significant improvement, similar to vitamin C.

Table 2: Effects of *Persea americana* (PA) seed extract on hepatic function parameters in DOX treated rats

Treatments	Normal control	DOX, 5 mg/kg body weight.	Vitamin C (100 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (500 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (1000 mg/kg BW) + DOX, 5 mg/kg BW	P. A seed extract (1500 mg/kg BW) + DOX, 5 mg/kg BW
Total protein (g/dl)	7.43 $\pm$ 0.09 ^c	5.33 $\pm$ 0.09 ^a	6.84 $\pm$ 0.59 ^{b,c}	6.58 $\pm$ 0.39 ^b	6.51 $\pm$ 0.21 ^b	7.12 $\pm$ 0.73 ^{b,c}
Albumin (g/dl)	4.02 $\pm$ 0.11 ^d	2.93 $\pm$ 0.14 ^a	3.30 $\pm$ 0.11 ^{a,b}	3.49 $\pm$ 0.37 ^{b,c}	3.53 $\pm$ 0.04 ^{b,c}	3.86 $\pm$ 0.43 ^{c,d}
Globulin (g/dl)	3.41 $\pm$ 0.05 ^{b,c}	2.40 $\pm$ 0.16 ^a	3.54 $\pm$ 0.49 ^c	3.10 $\pm$ 0.03 ^{b,c}	2.98 $\pm$ 0.22 ^b	3.25 $\pm$ 0.30 ^{b,c}
ALT (u/l)	37.00 $\pm$ 2.65 ^a	51.33 $\pm$ 3.51 ^c	42.67 $\pm$ 2.08 ^b	43.33 $\pm$ 1.16 ^b	43.67 $\pm$ 1.53 ^b	41.33 $\pm$ 0.58 ^b
AST (u/l)	43.67 $\pm$ 1.53 ^a	98.00 $\pm$ 3.61 ^d	68.67 $\pm$ 5.77 ^b	81.00 $\pm$ 7.00 ^c	70.33 $\pm$ 1.53 ^b	72.67 $\pm$ 3.06 ^b
ALP (u/l)	75.00 $\pm$ 3.00 ^a	108.00 $\pm$ 9.85 ^c	89.67 $\pm$ 11.59 ^b	86.67 $\pm$ 6.66 ^{a,b}	85.00 $\pm$ 5.29 ^{a,b}	77.67 $\pm$ 4.04 ^{a,b}
Total Bilirubin (mg/dl)	0.45 $\pm$ 0.04 ^a	0.88 $\pm$ 0.13 ^c	0.65 $\pm$ 0.06 ^b	0.60 $\pm$ 0.06 ^b	0.63 $\pm$ 0.06 ^b	0.58 $\pm$ 0.05 ^b

Values are presented as mean $\pm$ standard deviation ($n = 3$); and values different letter superscripts are significantly ($P < 0.05$) different from paired mean across the row.

3.3 Renal Function Parameters

DOX treatment significantly increased urea and creatinine levels and changed electrolyte balance, indicating impaired kidney function. Treatment with *Persea americana* extract reduced urea and creatinine levels and improved electrolyte

balance in a dose-dependent manner, although some parameters did not return to normal levels compared to the control. The highest dose provided the most consistent improvement, similar to vitamin C.

Table 3: Effect of *Persea americana* (PA) seed extract on renal function parameters in DOX treated rats

Treatments	Normal control	DOX, 5 mg/kg body weight.	Vitamin C (100 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (500 mg/kg BW) + DOX, 5 mg/kg BW	P.A seed extract (1000 mg/kg BW) + DOX, 5 mg/kg BW	P. A seed extract (1500 mg/kg BW) + DOX, 5 mg/kg BW
Urea (mg/dl)	20.20 $\pm$ 1.30 ^a	26.92 $\pm$ 1.03 ^d	21.69 $\pm$ 0.83 ^{a,b}	23.02 $\pm$ 1.23 ^{b,c}	23.70 $\pm$ 0.30 ^c	21.60 $\pm$ 0.67 ^{a,b}
Creatinine (mg/dl)	0.80 $\pm$ 0.03 ^a	1.90 $\pm$ 0.14 ^b	1.22 $\pm$ 0.03 ^b	1.28 $\pm$ 0.09 ^b	1.24 $\pm$ 0.06 ^b	1.19 $\pm$ 0.04 ^c
Na ⁺ (mEq/L)	128.70 $\pm$ 1.95	136.430 $\pm$ 1.06 ^c	132.00 $\pm$ 1.28 ^b	132.83 $\pm$ 2.41 ^b	133.37 $\pm$ 1.60 ^b	132.23 $\pm$ 1.08 ^b
K ⁺ (mEq/L)	4.79 $\pm$ 0.10 ^c	4.20 $\pm$ 0.17 ^a	4.43 $\pm$ 0.07 ^b	4.32 $\pm$ 0.13 ^{a,b}	4.30 $\pm$ 0.09 ^{a,b}	4.25 $\pm$ 0.08 ^{a,b}
Cl ⁻ (mEq/L)	87.23 $\pm$ 1.50 ^a	91.77 $\pm$ 0.97 ^b	91.27 $\pm$ 2.20 ^b	92.90 $\pm$ 0.62 ^b	90.50 $\pm$ 0.36 ^b	91.30 $\pm$ 1.31 ^b
HCO ₃ ⁻ (mmol/L)	19.83 $\pm$ 0.15 ^a	20.37 $\pm$ 0.15 ^b	20.13 $\pm$ 0.21 ^{a,b}	20.27 $\pm$ 0.12 ^b	20.07 $\pm$ 0.15 ^{a,b}	20.07 $\pm$ 0.23 ^{a,b}
Uric acid (mg/dl)	4.41 $\pm$ 0.07 ^a	7.10 $\pm$ 0.21 ^d	5.31 $\pm$ 0.32 ^b	5.80 $\pm$ 0.21 ^c	5.45 $\pm$ 0.26 ^{b,c}	5.12 $\pm$ 0.22 ^b

Values are presented as mean $\pm$ standard deviation ($n = 3$); and values different letter superscripts are significantly ($P < 0.05$) different from paired mean across the row.

4. Discussion

This study showed that doxorubicin (DOX) caused significant changes in blood, liver, and kidney function, while *Persea americana* seed extract lessened these effects in a dose-dependent way, with the highest dose providing the most reliable protection. This pattern matches current evidence that DOX toxicity affects more than just the heart; it also causes damage throughout multiple systems due to oxidative stress, mitochondrial dysfunction, inflammation, and cell death (Adeneye et al., 2024; Radeva & Yoncheva, 2025; Arozal et al., 2025).

The significant drops in red blood cells (RBC), hemoglobin, packed cell volume (PCV), and platelet counts seen after DOX treatment indicate blood toxicity, likely due to oxidative damage to red blood cell membranes and a reduction in blood cell production (Radeva & Yoncheva, 2025; Millat et al., 2025). This finding aligns with recent reports showing that DOX generates reactive oxygen species (ROS), which contributes to anemia and low platelet counts by suppressing bone marrow function and shortening red blood cell lifespan (Radeva & Yoncheva, 2025; Millat et al., 2025). Similarly, Alwaili et al. (2025) reported marked reductions in RBC and hemoglobin in rats treated with DOX.

The increase in white blood cell (WBC) count noted in this study suggests an inflammatory response to tissue damage caused by DOX. This aligns with reports that DOX activates inflammatory signaling and leads to the release of signaling molecules under oxidative stress (Arozal et al., 2025). However, this contrasts with other studies that found a decrease in white blood cell counts following DOX exposure (Alwaili et al., 2025; Mohammed Hegab et al., 2025). These differences may be due to variations in dose, treatment duration, and assessment timing; early inflammatory responses can raise WBC counts, while prolonged exposure may lower blood cell production.

Treatment with *Persea americana* seed extract significantly improved blood parameters, indicating it helped maintain red blood cell and platelet health. This protective effect likely results from antioxidant compounds like flavonoids and phenols, which reduce oxidative damage and aid blood cell recovery. Similar improvements have been reported where plant-based antioxidants restored blood parameters after DOX toxicity (Alwaili et al., 2025; Paternina-Ricardo et al., 2025). Nonetheless, the incomplete return to normal in some groups suggests partial recovery, consistent with other antioxidant treatments (Nascimento et al., 2025).

Hepatic findings confirm that DOX causes liver damage, as shown by increased ALT, AST, ALP, and bilirubin levels, alongside decreased total protein and albumin concentrations. These changes reflect liver cell injury, membrane damage, and impaired functioning, which are common consequences of oxidative stress and mitochondrial dysfunction (Savas et al., 2025; Saleh et al., 2022). The reduced protein and albumin levels indicate that the toxicity affected not just enzyme leakage but also the liver's ability to produce proteins.

While these findings support several recent studies, some reports noted slight changes in albumin levels after short-term

exposure, implying that the level of liver damage may vary based on how long and how severely the liver is affected (Nwosu et al., 2025).

Administering *Persea americana* extract significantly improved liver function, suggesting it has protective potential. This effect likely comes from its antioxidant abilities, including reducing lipid damage and enhancing natural defense systems (Savas et al., 2025; Nascimento et al., 2025). Similar findings were reported where plant antioxidants reduced liver injury caused by DOX.

Renal dysfunction in this study, marked by high urea and creatinine levels and electrolyte imbalance, fits established evidence of DOX's kidney toxicity. These changes indicate poor kidney filtering and tubular function due to oxidative stress, inflammation, and cell death in the kidneys. Similar increases in kidney markers have been widely documented in DOX toxicity studies.

The drop in urea and creatinine levels after treatment with *Persea americana* extract suggests some level of kidney protection, likely by reducing oxidative and inflammatory damage. This supports recent findings indicating that antioxidant-rich treatments can preserve kidney function in models treated with DOX (Arozal et al., 2025; Mohammed Hegab et al., 2025). However, some persistent changes from control values hint at incomplete recovery, reinforcing that the extract can help but does not fully reverse kidney damage (Adeneye et al., 2024).

Electrolyte imbalances observed in this study further indicate kidney dysfunction, reflecting poor tubular reabsorption and ion regulation (Arozal et al., 2025). Although the pattern observed here shows higher sodium and chloride levels with lower potassium, which differs from some studies reporting the opposite, such discrepancies are common and may result from differences in experimental design, dosage, and measurement timing (Arozal et al., 2025). Despite these variations, there is strong agreement that DOX disrupts electrolyte balance through kidney injury (Adeneye et al., 2024; Arozal et al., 2025).

Overall, these findings are consistent with current research showing that oxidative stress plays a key role in DOX-induced multi-system toxicity. The protective effects of *Persea americana* seed extract, especially at higher doses, make biological sense given its rich antioxidant composition and align with growing evidence supporting plant-based approaches to reduce chemotherapy-induced toxicity (Paternina-Ricardo et al., 2025; Nascimento et al., 2025).

However, the incomplete normalization of some parameters shows that while the extract offers significant protection, it does not fully reverse DOX damage. This points to the complexity of anthracycline toxicity and suggests that antioxidant treatment may be most effective as a complementary strategy rather than the only protective measure.

5. Conclusion

This study shows that doxorubicin causes significant blood, liver, and kidney issues, consistent with its known profile of

multi-system toxicity driven by oxidative stress and inflammation. The noted reductions in blood indices and platelets, increases in liver enzyme levels and bilirubin, and impairments in kidney function markers confirm the broad impact of doxorubicin beyond its cancer-fighting properties. Administering *Persea americana* seed extract significantly lessened these changes in a dose-dependent manner; the highest dose showed the most reliable protective effects across all parameters. The extract improved blood indices, restored liver function markers, and eased kidney problems, with effects comparable to a standard antioxidant treatment. These results suggest that the protective role of *Persea americana* likely comes from its antioxidant and cell-protective properties, which help reduce oxidative damage and support cell health. However, incomplete normalization of some parameters indicates that while the extract provides substantial protection, it does not completely reverse doxorubicin-induced harm. This underscores the complexity of anthracycline toxicity and suggests that antioxidant interventions may work best when combined with other therapies.

Overall, this study provides evidence supporting the potential of *Persea americana* seed extract as a natural agent for reducing doxorubicin toxicity. Future studies should include molecular analyses, tissue evaluations, and clinical applications to better understand its mechanisms and optimize its therapeutic use.

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