DOI: https://doi.org/10.4314/njbmb.v40i3.1 NJBMB (2025) 40(3) 250-257

e-ISSN: 2659-0042

Nigerian Journal of Biochemistry and Molecular Biology

The Official Publication of the Nigerian Society of Biochemistry & Molecular Biology (NSBMB). Journal homepage: https://www.nsbmb.org.ng/journals/

Research Article

Hypoglycemic and Antioxidant Potentials of *Amaranthus caudatus* Seed and Oil in Type-2 Induced Diabetes Model of *Drosophila melanogaster*

Almustapha Lawal[1], Fatima B. Alkali*[,1], Ochoechi Dorcas[1], Muhammad Y. Umar[1]

[1]*Department of Biochemistry and Molecular Biology, Faculty of Chemical Life Sciences, Usmanu Danfodiyo University, Sokoto, Nigeria*

OPEN ACCESS

***CORRESPONDENCE**
Alkali, F. B.
bashirfatimaalkali@gmail.com
+234-810-891-3809

ARTICLE HISTORY
Received: 25/01/2024
Reviewed: 03/06/2025
Revised: 25/06/2025
Accepted: 09/09/2026
Published: 09/09/2026

CITATION
Lawal A., Alkali F. B., Dorcas O. and Umar M. Y. (2025). Hypoglycemic and antioxidant potentials of *Amaranthus caudatus* seed and oil in type-2 induced diabetes model of *Drosophila melanogaster*. *Nigerian Journal of Biochemistry and Molecular Biology*. 40(3), 250-257
https://doi.org/10.4314/njbmb.v40i3.1

ABSTRACT

Amaranthus caudatus (*A. caudatus*) is a pseudo-cereal with potential therapeutic effects. The work aims to study the hypoglycaemic and antioxidant potentials of *A. caudatus* seeds in type 2 diabetes using *Drosophila melanogaster* model. Thirty (30) *Drosophila melanogaster* flies of 3 - days old were induced with type 2 diabetes using high sucrose diet prepared with 30% sucrose for 7 days. The flies were grouped into six of six flies each. Group A, positive control, fed on regular diet (non-diabetic); Group B, negative control (non-diabetic and untreated), Group C, positive control (induced and treated with standard drug), while Groups D, E and F were induced, and fed with 500 mg, 250 mg and 125 mg of *A. caudatus* seeds incorporated in a 5 g normal diet for seven days. The result obtained showed non-significant ($P > 0.05$) variation in negative geotaxis, bodyweight, and locomotion between non-diabetic and diabetic groups. On the other hand, glucose level was significantly ($P < 0.05$) reduced in group D fed with 500 mg of *A. caudatus* seeds. Triacylglycerol level (TAG) showed non-significant difference ($P > 0.05$) between the control group and diabetic group treated with *A. caudatus* seeds. Furthermore, antioxidant activity on the extracted oil of *A. caudatus* seeds showed significant scavenging activity against the DPPH radicals. The antioxidant vitamins (A, C and E) were found to be 51.50 ± 0.7, 18.34 ± 0.2 and 95.93 ± 0.4 mg%, which are quite significant in *A. caudatus* seeds. Phytochemical analysis of the seeds residuals after oil extraction indicated the presence of Flavonoids, alkaloids and tannins. Similarly, proximate analysis revealed % Ash (3.35 ± 0.01 %), lipids (6.21 ± 0.02 %) and carbohydrate (76.09 ± 0.08 %) contents, respectively. The presences of these phytochemicals and antioxidants are associated with hypoglycemic effect. In conclusion, the novel findings are; that despite high carbohydrates content, *A. caudatus* seeds reduced glucose levels at 500 mg.

Keywords: *Amaranthus caudatus; Antioxidant and hypoglycemic effects; Antioxidant vitamins*

INTRODUCTION

Amaranthus caudatus (*A. caudatus*) belongs to the family of Amaranthaceae, commonly known as African spinach in Nigeria. It is considered as pseudo-cereal and multipurpose crop. The research has shown that it can supply higher nutritional seeds in large quantities (Wouyou *et al*., 2017). The grains of *A. caudatus* are reported to be a good source of proteins, β-carotene, vitamins, minerals, and dietary fibre (Wouyou *et al*., 2017). It is also composed of starch, which was described as of high quality against other grains like wheat, rice and oats due to its highly soluble and digestible starch (Martinez-Lopez *et al*., 2020). The grains are also described as gluten-free and have protein content of about 30% (Martinez-Lopez *et al*., 2020). It has been reported that the grains

***Copyright © 2025** Alkali et al. This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

showed complete set of amino acids, which could provide new opportunities for food processing, pharmaceuticals, and cosmetics industries (Martinez-Lopez *et al*., 2020). It has high nutritional value; and many studies have shown the potential of *A. caudatus* grains as a good source of biologically active compounds in the treatment of diabetes mellitus, high cholesterol level, hypercholesterolemia, oxidative stress and antimicrobial activities (Olokoa *et al*., 2012). Diabetes mellitus causes oxidative stress leading to generation of reactive oxygen species (ROS) which subsequently manifested in metabolic and systemic problems (Olokoa *et al*., 2012). These complications are of major concern in public health system, causing economic and life loss in the affected people across the globe (Brownlee, 2005; Olokoa *et al*., 2012).

Drosophila melanogaster is increasingly being used as a model organism for studying metabolic diseases, including diabetes, due to its genetic and physiological parallels with mammalian insulin signalling pathways. The fruit fly's insulin-producing cells are functionally similar to mammalian pancreatic β-cells, making it an efficient model for studying type 2 diabetes mechanisms and potential therapeutic interventions (Apidianakis and Rahman, 2011; Nässel *et al*., 2013). Studies also demonstrated the used of *Drosophila melanogaster* in modelling metabolic disorders, such as obesity and insulin resistance, making it an ideal for testing the effects of natural hypoglycemic agents (Musselman *et al*., 2011; Chen *et al*., 2021).

Furthermore, researches on secondary metabolites of plant origin such as flavonoids, terpenes and alkaloids have been given more attention due to their diverse pharmacological properties, such as cytotoxic and anti-carcinogenic effects (Wouyou *et al*., 2017). Additionally, numerous plant-derived substances, such as flavonoids and alkaloids, have been shown to exert hypoglycemic effects in *Drosophila melanogaster* models (Prasad and Ashadevi, 2018; Gunther *et al*., 2021). Due to concerns on high cost and problems associated with counterfeits synthetic antioxidants, more attention is now being devoted to plantbased antioxidants, which led to accelerated research on vegetables and grains sources such as *A. caudatus* grains. Nutritional and pharmaceutical research is increasingly focusing on nutraceuticals (Katan, 1999; Zeisel, 1999).

While several studies have identified the nutritional and bioactive properties of *A. caudatus*, limited research has been conducted on its hypoglycemic effects using in vivo models of type 2 diabetes. In addition, it's potential as a natural antioxidant source for managing diabetes related oxidative stress has to be fully explored. Introduction of *A. caudatus* seeds in the diet and as nutraceuticals could be cost saving and associated with health promotion and prevention of diseases. We hypothesise that *A. caudatus* seeds, owing to their high content of bioactive compounds and antioxidants; will demonstrate significant hypoglycemic effects and antioxidant activity in a diabetes-induced Drosophila. Therefore, this work reports a study on the hypoglycemic and antioxidant potentials of *A. caudatus* seeds and oils in type-2 induced diabetes in *Drosophila melanogaster* flies.

MATERIALS AND METHODS

Study collection

A. caudatus seeds were sourced from the local market in the Sokoto metropolis, Nigeria and identified at the herbarium unit in the Faculty of Pharmacy and Pharmacognosy, Usmanu Danfodiyo University Sokoto with a voucher number assigned (*A. caudatus*0002).

Preparation of plant sample

The grains were mashed into powder using a pestle and mortar and then sieved through a fine muslin cloth and the resultant dried particles were packed and preserved in a sterilised airtight container at 25 ^{0}C.

Soxhlet extraction of *A. caudatus* seed oil

Dried seeds of *A. caudatus* (14 g) were pounded into a powdered form using a mortar and pestle, to improve the surface area. The powdered seeds rapped in a cleaned muslin cloth inserted into a thimble containing the extraction solvent (100 ml). The Soxhlet extractor was set up at 60 ^{0}C and allowed to run for 2 -3 hrs. The extracted oil was collected after simple distillation.

Sourcing of *drosophila melanogaster* flies

Adult flies of F1-generation (offspring generation) of 3-5 day old were generated at the *Drosophila* bank at the Centre for Advanced Medical Research and Training (CAMRET) and cultured at 21–25 °C. They were fed with a unique diet prepared using yeast agar, methyl-paraben, and maize flour. In this investigation, female *Drosophila melanogaster* fruit flies were used. Fruit flies are sexually dimorphic, and the males were easily identified from the females using their morphological differences: size and the pigment's colour in their abdominal region.

Composition and preparation of *drosophila* flies' diet

Methylparaben was dissolved in 100% ethanol, and 1300 ml of distilled water was poured into a pot and placed on the gas boiler to boil. 20 ml of the boiled water was used to dissolve yeast in a separate container. Agar-Ager was added to the boiled water and mixed for 10 minutes. Corn flour was dissolved in the 500ml of cold water and added to the mixture. The mixture was stirred for another 10 minutes. The already dissolved yeast was then added to the mixture and stirred for another 10 minutes after which, the gas heater was turned off as described by Musselman *et al*. (2011).

Induction of type 2 diabetes

Diabetes was induced in 3-day old *Drosophila melanogaster* as described by Chen *et al.* (2021). Briefly, high sucrose diet (30% Sucrose) was prepared and fed the *Drosophila melanogaster* for 7 days to induced diabetes.

Dose determination and treatment design

Due to the non-toxic nature of *A. caudatus* as reported by Jimoh *et al*. (2020), the mode of feeding systems on the *D.*

melanogaster flies was designed based on the lower dosages from 500, 250 and 125 mg of *A. caudatus* was adopted from the feeding protocol (not published) at Usmanu Danfodiyo University Centre for Advanced Medical Research and Training, Nigeria (CAMRET), and used in designing the treatment. The treatment design consists of six groups as presented in Table 1, and each group was replicated three times, which consist of 30 flies per vial. Thus, 18 vials were used for the experiment, making 540 flies.

Table 1. Treatment Design for *Drosophila melanogaster* Flies

Group	Description	Treatment	Status
A	Healthy flies	10g of normal diet	Normal control
B	Diabetic flies	10g of sucrose diet	Negative control
C	Diabetic flies treated	8 mg of standard drug (metformin)	Positive Control
D	Diabetic flies	500 mg of amaranth grain powder	Diabetes
E	Diabetic flies	250 mg of amaranth grain powder	Diabetes
F	Diabetic flies	125 mg of amaranth grain powder	Diabetes

Negative geotaxis assay

The ability of the flies to climb in coordinated speed was assessed after seven days of treatment using the rapid iterative negative geotaxis (RING) technique described by Gargano *et al*. (2005). Briefly, the groups with a sample size of approximately of 30 flies per group were used. The RING assay measures the average height climbed by a cohort of flies in a given time following induction of the negative geotaxis behaviour. Flies in each diet treatment were subjected to the RING assay three times. For each cohort, flies were transferred to polypropylene vials in groups of 10 per vial. The vials were quickly tapped four times to knock flies to the bottom and induce the negative geotaxis response; the flies were monitored while allowed to climb per minute. This procedure was carried out three consecutive times. The average distance climbed by flies was calculated and the mean taken per vials, and the daily average climbing distance was calculated by averaging the three means together. The calculated daily averages were charted to assess the decline in climbing ability with diet treatment. Negative geotaxis results were analysed using one-way ANOVA analysis and Tukey multiple comparison test using GraphPad Prism (version 8.0.1) software.

Weight determination and sample collection for biochemical analysis

At the end of the experiment, weight per group fed with different concentrations of *A. caudatus* was obtained using an analytical balance. Initially, the flies were incapacitated by placing the culture vials into a deep freezer until the flies were not moving and quickly placed in weighing balance and measured in milligrams. After the flies were weighed, they were digested in 100 µl of phosphate buffer saline (PBS). The supernatant obtained and stored at 20 ^{0}C was used for biochemical analysis.

Glucose determination

Glucose was determined using glucose oxidase (GOD-POD) method.

Triglycerides determination

Triglycerides determination was carried out using glycerol phosphate oxidase (GOD-PAP) method as reported by Bhanja *et al*. (2022).

Antioxidant properties of *A. caudatus* seed oil

The antioxidant properties of *A. caudatus* seeds oil was evaluated using DPPH as described by Brand-Williams *et al*. (1995), with little modification. Briefly, extracted oil was serially diluted in methanol in concentrations between 0.2 – 1.0 mg/ml. The test tubes were made up to 4ml of methanol and 1ml of DPPH radical (1Mmol) added to each test tube. The mixture was gently mixed and allowed to stand for 20 minutes and absorbance was read at 517 nm.

Proximate Analysis of the *A. caudatus* Seed

The total carbohydrate, moisture content, ash, crude protein, lipid and fibre were determined according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2000).

Qualitative phytochemical screening

The Flavonoids, tannins, saponins, alkaloids, glycosides and steroid content were determined as described by Harbone, (1998).

Determination of antioxidant vitamins (a and e in oil) and vitamin c in seed

Vitamins A, E and C were determined using methods described by Rutkowski *et al.* (2006); Rutkowski *et al.* (2005) and Rutkowski *et al.* (1998), respectively.

Statistical analysis

Values were expressed as mean ± standard deviation. The results were analysed using one-way analysis of variance (ANOVA) followed by Tukey multiple comparison test using GraphPad Prism (version 8.0.1) software to compare between groups. Results were considered statistically significant at $P < 0.05$.

RESULTS

Bodyweight and negative geotaxis

The result on bodyweight of the diabetes induced *D. melanogaster* treated with *A. caudatus* shows non-significant decrease (P > 0.05) as compared to the normal control groups

(Figure 1). Also, locomotive and negative geotaxis behaviours of the diabetes induced D. melanogaster treated with *A. caudatus* were non-significant (P > 0.05) compared within the groups (Figure 2) indicating non-toxic effect of *A. caudatus* on the *D. melanogaster*.

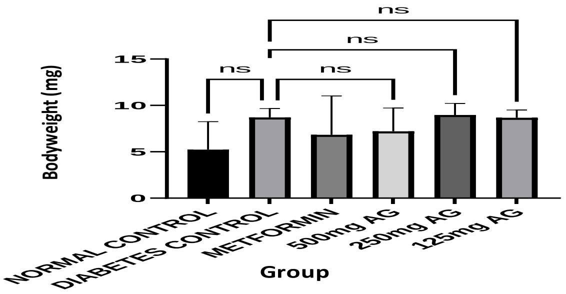


Figure 1. The bodyweight Loss or Gain on Diabetes Induced *D. melanogaster* Fed with Concentrations of *A. caudatus* Grains. Values are Mean of three replicates (*n = 3*) and error bars are Standard deviation, ns = non-significant (P > 0.05).

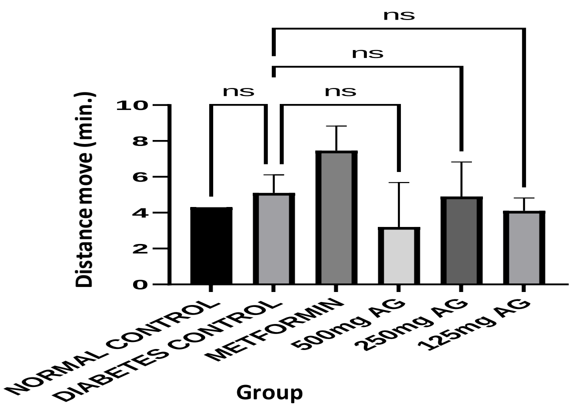


Figure 2. Effect of *A. caudatus* on negative geotaxis performance on Diabetic Induced *D. melanogaster*.
Values are Mean of three replicates (*n = 3*) and error bars are Standard deviation, ns = non-significant (P >0.05).

Glucose and triglycerides

Glucose and triglyceride levels were determined in diabetes induced *D. melanogaster* fed with different dosages of 500, 250 and 125 mg of *A. caudatus* seeds, respectively. The result indicated variation in glucose levels in response to the treatment in treated groups as compared to control groups. Non-significant reduction in glucose level was observed in groups E and F fed with 250 and 125 mg compared to the control groups (P > 0.05). In group D, fed with 500 mg, the result showed a significant decrease (P < 0.05) when compared to the normal control group and diabetes control (Figure 3**).** This indicates that at higher dose *A. caudatus* has the ability to lower glucose level in *D. melanogaster*. The *A. caudatus* seed was able to non-significantly reduced the triglyceride levels in all the diabetes induced groups (D - F) fed with 500, 250 and 150 mg (P > 0.05) as compared to the control groups. This could suggest that *A. caudatus* seeds can lower triglyceride level, which is good in the management diabetes.

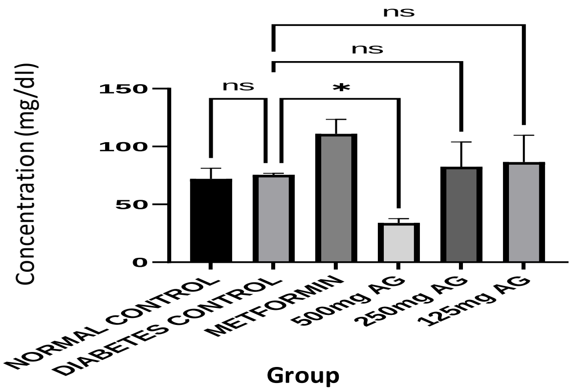


Figure 3. Glucose Level in Diabetes Induced *D. melanogaster* fed with different Concentration of *A. caudatus.* Values are Mean of three replicates (*n = 3*) and error bars are Standard deviation, * = Significant different (P <0.05), ns = non-significant (P >0.05) in Multiple Comparison.

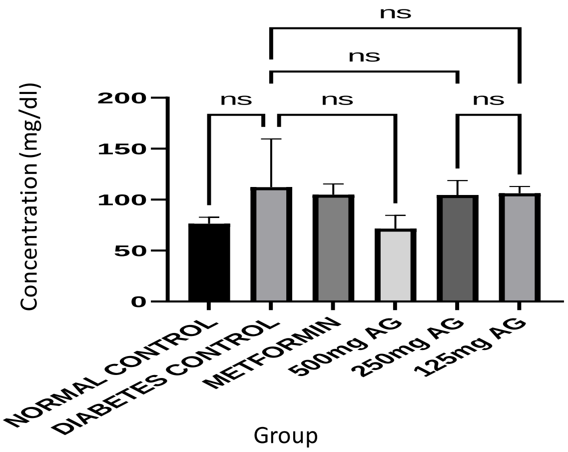


Figure 4. Triglyceride level in Diabetes Induced *D. melanogaster* Fed with *A. caudatus* Seeds. Values are Mean of three replicates (*n = 3*) and error bars are Standard deviation, ns = non-significant (P >0.05).

Antioxidant activity and antioxidant vitamins

Result of the antioxidant activity of *A. caudatus* seeds oil showed an increase in scavenging activity against the DPPH radicals at lower concentrations of *A. caudatus* (from 0.2 mg/dl with 63 % activity to 0.4 mg/dl with 58% activity) as compared to the ascorbic acid standard, which served as a positive control (Figure 5). The ascorbic acid has high scavenging activity at 1.0 mg/dl which is 94.21% against the DPPH radicals compared to *A. caudatus* 67.32% obtained at 1.0 mg/ml. Although the activity observed was less than the vitamin C standard at higher concentrations, it shows that *A. caudatus* seeds, which are not readily consumed as food, have comparable antioxidant potential than vitamin C at lower concentrations.

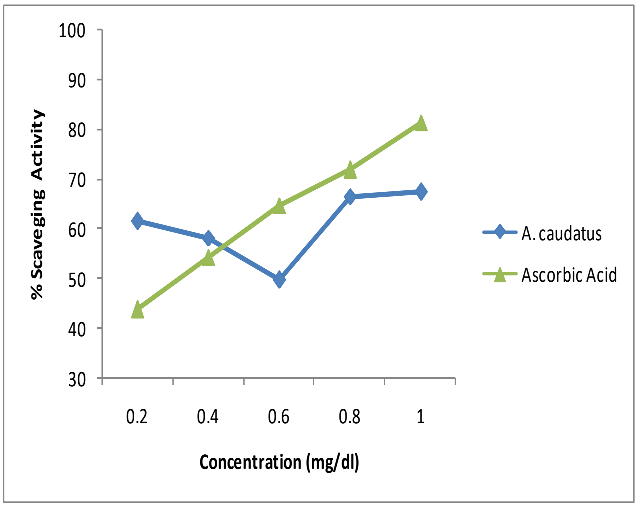


Figure 5. Scavenging Activity of *A. caudatus* Seeds Oil against DPPH Radicals

The study also assessed the antioxidant vitamins present in *A. caudatus* seed oil, which was analysed on the content of antioxidant vitamins (A & E). The result obtained showed significant presence of vitamins A (over 45%) and E (85%) in the oil from the *A. caudatus* seeds and vitamin C (over 10%) in the seeds (Figure 6). This result is vital because the oil could also be used in the management of oxidative stress associated diseases and diabetes.

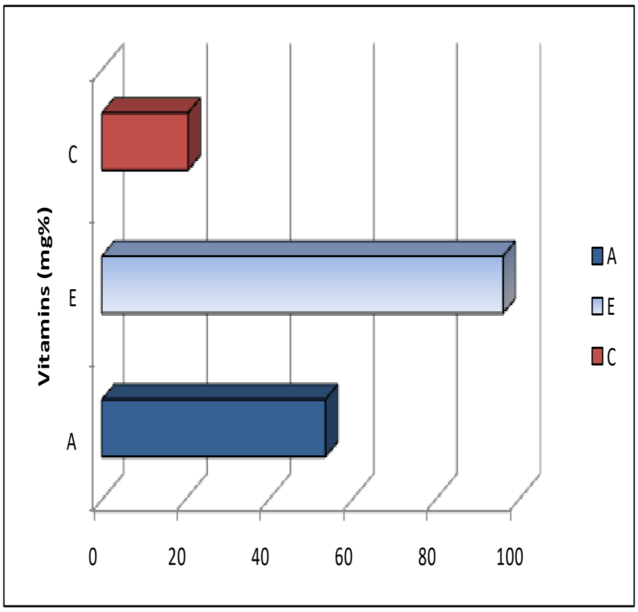


Figure 6. Proportion of Antioxidant vitamins (A & E) in extracted oil and vitamin C in the *A. caudatus* Seed

Phytochemicals

Phytochemical analysis of *A. caudatus* seed (Table 2) revealed the presence of metabolically important secondary metabolites such as alkaloids, flavonoids, saponins, steroids, tannins and glycosides as presented in the Table 2. These active metabolites are associated with many metabolic functions associated oxidative stress and metabolic syndromes.

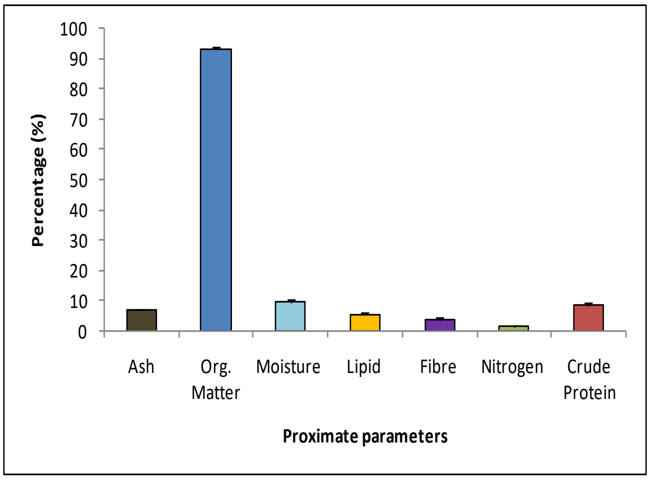
Table 2. Phytochemicals in *A. caudatus* Seeds Residues after Oils extractions

Compounds	Status
Flavonoids	+
Tannins	+
Saponins	+
Glycosides	+
Cardiac Glycoside	+
Saponin Glycosides	+
Steroids	+
Balsams	+
Anthraquinones	ND
Alkaloids	+
Volatile oil	+

Keys: + = Trace amount and ND = Not detected

Proximate composition

The research also evaluated the proximate composition of *A. caudatus* seed to unravel its suitability as a food supplement for diabetes management. The result showed that the seed has moisture content (9.36%), ash content (6.83%), crude fibre (3.42%), crude protein (8.4%), total lipids (5.35%) and 70.05% carbohydrates (Figure 7). The result showed that *A. caudatus* could be a good source of minerals, protein, and fibre and can be stored in a dry place for a longer period due to its lower moisture content.



DISCUSSION

The current study investigates the hypoglycemic and antioxidant potentials of *A. caudatus* seed and oil in *Drosophila melanogaster* model organism. The model flies have been reported to share some common biological signalling pathways with higher animals (Apidianakis and Rahme, 2011; O'Kane, 2011). It also possesses specialised insulin-producing cells in the brain which secret insulin-like peptides (Nässel *et al.,* 2013) and are shown to mimic pancreatic β-cells from mammals (Broughton *et al.,* 2005; Garelli *et al.,* 2012). The result obtained showed that *A. caudatus* did not significantly reduced bodyweight in groups treated with *A. caudatus* as compared the control group ($P > 0.05$) (Figure 1), suggesting that *A. caudatus* seed may possesses ability to improve the body's physiological functions such as absorption and digestion of the groups fed with *A. caudatus* in diabetic condition. This finding on bodyweight was contrary to the studies reported by Musselman *et al*. (2011) and Elbrense *et al*. (2021) that reported significant decrease in the bodyweight of diabetic infected flies. Brogiolo *et al*. (2001) also observed bodyweight reduction in insulin receptor mutants, and the decrease in the bodyweight of the diabetic infected *D. melanogaster* flies has been linked to a deficiency in the insect's physiological functions. According to Chen *et al.* (2021), diabetic flies had difficulty in the absorption and utilisation of carbohydrates. Also, the results demonstrated a significant improvement in negative geotaxis performance among the groups fed with *A. caudatus* at different dosages compared to the normal control group indicating non-toxic effect of *A. caudatus* as supported by Jimoh *et al*. (2020) (Figure 2). The result was also supported by studies of Phoswa and Mokgalaboni, (2023); Showkat, (2020) and Yang *et al*. (2020) that showed the potential protective effects of *A. caudatus* against diabetes-associated locomotion deficits.

The glucose level of diabetic *D. melanogaster* after treated with the *A. caudatus* showed significant decrease ($P < 0.05$) at 500mg as compared with the diabetic control group (Figure 3). This shows that *A. caudatus* seed may possess the ability to lower glucose level in a dose-depended pattern. Many researchers have reported on anti-diabetic effect of *A. caudatus* using animal model and showed significant reduction in glucose levels in different extractions. For instance, an investigation of anti-diabetic activities of some medicinal plants have revealed the high inhibitory effects of hexane, methanol and ethylacetate extracts of two varieties of *A. caudatus* on α-amylase; and effect of isolated squalene from the plant extract was recognised as the major component of hexane extracts (Girija *et al*., 2011). Also, Conforti *et al*. (2005) have reported similar finding using a dose of 400 mg/kg of the methanol extract of *A. caudatus* and found to show high anti-diabetes activity when administered to normal and streptozotocin-induced diabetic rats. Also, Zambrana *et al*. (2018) reported that hydroethanolic extract of *A. caudatus* improves glucose tolerance in Goto-Kakizaki Rats and Wister rats by increasing serum insulin levels. From these reported studies, it could be suggested that *A. caudatus* may have effect on the activity of α-amylase by inhibiting its activity and other dietary benefits (Girija *et al*., 2011). Furthermore, the triglycerides levels were non-significantly decrease ($P > 0.05$) in diabetic induced *D. melanogaster* both at 250 and 125 mg as compared to the control groups, but there is noticeable decrease in triglycerides level at 500 mg (Figure 4). This result has corroborated with the studies by Gunther *et al*. (2021) that reported significant decline in triglyceride levels in dietary starch-induced *D. melanogaster*. On the contrary, Prasad and Ashadevi, (2018) have reported significantly high triglyceride levels in diabetes induced *D. melanogaster* following the use of *Withania somnifera* (WS) at high concentration.

The results of phytochemical analysis and antioxidant activity of *A. caudatus* suggested that *A. caudatus* seeds are good source of phytochemicals and antioxidants. The result showed the presence of flavonoids, tannins, saponins, glycosides, steroids and alkaloids, respectively (Table **2**). These phytochemicals are shown to scavenged excess electrons, reducing the effects of free radicals generated because of oxidative stress in diabetes condition due to their chemical structures. Studies that show the anti-diabetic effect of phytochemicals revealed that flavonoids improve glycemic levels and lipid profiles in rats fed with hyper-caloric diet (Stankovic, 2011; Chuffa *et al*., 2014). Alkaloids and triterpenoids reduced the blood sugar by increasing insulin secretion from pancreatic β-cells (Murali and Saravanan, 2012; Ponnulakshmi *et al.,* 2019). On the other hand, flavonoids help in glucose uptake by peripheral tissues (Cazarolli *et al.,* 2008). Olayaki *et al*. (2015) recorded that active components of *M. oleifera* inhibits soluble epoxide hydrolase. The suppression of this enzyme has been reported to improve Diabetes treatment (Minaz *et al.,* 2018).

The result of the antioxidant activity of *A. caudatus* seed oils indicated an increase in scavenging activity seed oils against the DPPH radicals at lower concentrations of the extract from 0.2 mg/dl with 63 % activity to 0.4 mg/dl with 58% activity. This result corroborated well with reported studies by Rjeibi *et al.* (2016) that showed the scavenging activity of amaranths seed extracts against DPPH and H_2O_2 indicating concentration-dependent activity.The significance of this finding is that, as food supplements it could be useful in the management of type 2 diabetes to ameliorate the risk of over generation of reactive oxygen species and its downstream associated metabolic effects. Also, result obtained revealed presence of high antioxidants vitamins E and A in the oils extracted from the seeds, which constituted higher percentage and vitamin C from the seed grains of *A. caudatus*. These vitamins play important role in improving the immune system response against pathogens, especially vitamin C. Other studies have also shown that vitamin C supplementation causes reduction in blood glucose and HbA1c and thereby improving hyperglycaemia conditions (Eriksson and Kohvakka, 1995). Frequent intake of vitamin C from dietary sources has shown to reduce the risk of type 2 diabetes in a population-based study (Williams *et al.,* 1999). Ihara *et al.* (2000) have also shown that vitamin E has hyperglycaemic lowering effect and can lower HbA1c by inhibiting the sequence of oxidative stress in diabetic rats.

CONCLUSION

Our results show that *A. caudatus* grain has an anti-diabetes effect by decreasing the glucose level significantly at 500 mg and triglycerides in diabetes induced *Drosophila melanogaster*. In addition, the *A. caudatus* seeds constitute phytochemicals, rich in antioxidant vitamins and have good scavenging activity against DPPH radicals at lower concentration. These important markers have shown to have direct effect on hyperglycaemia, lipid metabolism and oxidative stress. Therefore, *A. caudatus* seeds as a food supplement have the potential to improve glucose utilisation in patients diagnosed with type 2 diabetes, because of its rich content of phytochemicals and antioxidant vitamins. Further study is recommended on use of *A. caudatus* in the management of type 2 diabetes mellitus.

AUTHORS' CONTRIBUTIONS

FBA, OD and MYU conceived the idea, designed and conducted the study, while AL wrote the manuscript and made final corrections.

FUNDING STATEMENT

CONFLICT OF INTEREST

There is no conflict of interest in this work

ACKNOWLEDGEMENT

Not applicable

REFERENCES

AOAC International Methods Committee guidelines for validation of qualitative and quantitative food microbiological official methods of analyses. *Journal of AOAC International*, *85*(5), 1187-1200.

Apidianakis, Y., Rahme, L. G. (2011). *Drosophila melanogaster* as a model for human intestinal infection and pathology. *Disease Models & Mechanisms*, 4(1): 21-30.

Bhanja, A., Nayak, N., Mukherjee, S., Sutar, P. P. and Mishra, M. (2022). Treating the onset of diabetes using probiotics along with prebiotics from pachyrhizuserosus in high-fat diet-fed drosophila melanogaster. *Probiotics and Antimicrobial Proteins*, *14*(5), 884-903.

Brand-Williams, W., Cuvelier, M. E., and Berset, C. L. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology*, *28*(1), 25-30.

Brogiolo, W., Stocker, H., Ikeya, T., Rintelen, F., Fernandez, R., Hafen, E. (2001). An evolutionarily conserved function of the *Drosophila* insulin receptor and insulin-like peptides in growth control. *Current Biology*, 11(4): 213-221.

Broughton, S. J., Piper, M. D., Ikeya, T., Bass, T. M., Jacobson, J., Driege, Y., Martinez, P., Hafen, E., Withers, D. J, Leevers, S.J. (2005). Longer lifespan, altered metabolism, and stress resistance in *Drosophila* from ablation of cells making insulin-like ligands. *Proceedings of the National Academy of Sciences*, 102(8): 3105-3110.

Brownlee, M. (2005). The pathobiology of diabetic complications: A unifying mechanism. *Diabetes*, 54, 1615–1625.

Cazarolli, L. H., Zanatta, L., Alberton, E. H., Reis-Bonorino, F. M. S., Folador, P., Damazio, R. G., Pizzolatti, M. G., Mena-Barreto, S. F. R. (2008). Flavonoids: cellular and molecular mechanism of action in glucose homeostasis. *Mini Reviews in Medicinal Chemistry*, 8(10): 1032-1038.

Chen, D., Yang, J., Xiao, Z., Zhou, S., Wang, L. (2021). A diet-induced type 2 diabetes model in Drosophila. *Science China Life Sciences*, 64: 326-329.

Chuffa, L.G.A., Fioruci-Fontanelli, B.A., Bordon, J.G., Pires, R.B., Braga, C.P., Seiva, F.R., and Fernandes, A.A.H. (2014). Rutin ameliorates glycemic index, lipid profile and enzymatic activities in serum, heart and liver tissues of rats fed with a combination of hypercaloric diet and chronic ethanol consumption. *Indian Journal of Biochemistry and Biophysics*, 51: 215-222.

Conforti, F., Statti, G., Loizzo, M.R., Sacchetti, G., Poli, F. & Menichini, F. (2005). In vitro antioxidant effect and inhibition of α-amylase of two varieties of Amaranthus caudatus seeds. *Biological and Pharmaceutical Bulletin* 28(6): 1098-1102.

Elbrense, H., Montaser, O., El-Aasr, M., &Meshrif, W. S. (2021). Potential anti-diabetic effect of certain plant extracts from the Egyptian flora on type II diabetes using Drosophila melanogaster as an animal model. *International Journal of Cancer and Biomedical Research*, *5*(4), 121-133.

Eriksson, J., Kohvakka, A. (1995). Magnesium and ascorbic acid supplementation in diabetes mellitus. *Annal of Nutrition and Metabolism*, 39:217-23.

Fedele, G., Green, E.W., Rosato, E., and Kyriacou, P.C. (2014) An electromagnetic field disrupts negative geotaxis in Drosophila via a CRY-dependant pathway. *Nature Communications*, 5(1), 4391.

Garelli, A., Gontijo, A. M., Miguela, V., Caparros, E., & Dominguez, M. (2012). Imaginal discs secrete insulin-like peptide 8 to mediate the plasticity of growth and maturation. *Science*, 336(6081), 579-582.

Girija, K., Lakshman, K., Chandrika, Udaya, Ghosh, S. S., Divya, T. (2011). Anti–diabetic and anti–cholesterolemic activity of methanol extracts of three species of Amaranthus, *Asian Pacific Journal of Tropical Biomedicine*, 1(2): 133-138, https://doi.org/10.1016/S2221-1691(11)60011-7.

Gunther, I., Rimbach, G., Nevermann, S., Verana, C.N (2021) Avens root (Geum Urbanum L.) extract discovered by target-based screening exhibits antidiabetic activity in the hen's egg test model and Drosophila melanogaster. *Frontier in Pharmacology,* 12, 794404

Harborne, A. J. (1998). Phytochemical methods a guide to modern techniques of plant analysis. *Springer Science & Business Media*.

Ihara Y, Yamada Y, Toyokuni S, Miyawaki K, Ban N, Adachi T. (2000). Antioxidant alpha-tocopherol ameliorates glycemic control of GK rats, a model of Type 2 diabetes. *FEBS Lett*er 473:24-6

Jimoh, M. O., Afolayan, A. J., Lewu, F. B. (2020). Toxicity and antimicrobial activities of *amaranthus caudatus* l. (amaranthaceae) harvested from formulated soils at different growth stages. *Journal Evidence-Based Integrative Medicine.;* 25:2515690X20971578. doi: 10.1177/2515690X20971578.

Katan, T., & Primo, P. D. (1999). Current status of vegetative compatibility groups in Fusarium oxysporum: Supplement. *Phytoparasitica*, *27*, 273-277.

Martínez-López, A. L., Pangua, C., Reboredo, C., Campión, R., Morales-Gracia, J., andIrache, J. M. (2020). Protein-based nanoparticles for drug delivery purposes. *International Journal of Pharmaceutics*, *581*, 119289.

Minaz, N., Razdan, R., Hammock, B.D., Goswami, S.K. (2018). An inhibitor of soluble epoxide hydrolase ameliorates diabetes-induced learning and memory impairment in rats. *Prostaglandins & Other Lipid Mediators*, 136: 84-89.

Mukherjee, S., Nayak, N., Mohapatra, S., Sahoo, J. K., Sahoo, H., & Mishra, M. (2022). Strontium ferrite as a nontoxic nanomaterial to improve metabolism in a diabetic model of Drosophila melanogaster. *Materials Chemistry and Physics*, *281*, 125906.

Murali, R., and Saravanan, R. (2012). Antidiabetic effect of d-limonene, a monoterpene in streptozotocin-induced diabetic rats. *Biomedicine and Preventive Nutrition*, *2*(4), 269-275.

Musselman, L. P., Fink, J. L., Narzinski, K., Ramachandran, P. V., Hathiramani, S. S., Cagan, R. L., Baranski, T. J. (2011). A high-sugar diet produces obesity and insulin resistance in wild-type Drosophila. *Disease Model Mechanism*; 4(6):842-9. doi: 10.1242/dmm.007948.

Nässel, D. R, Kubrak OA, Liu Y, Luo J, Lushchak OV. (2013). Factors that regulate insulin-producing cells and their output in *Drosophila*. *Frontiers in Physiology*, 4: 252.

O'Kane, C. J. (2011). Drosophila as a model organism for the study of neuropsychiatric disorders. *Curr Top Behav Neurosci*.;7:37-60. doi: 10.1007/7854_2010_110.

Olayaki, L.A, Irekpita, J.E, Yakubu, M.T, Ojo, O.O. (2015). Methanolic extract of *Moringa oleifera* leaves improves glucose tolerance, glycogen synthesis and lipid metabolism in alloxan-induced diabetic rats. *Journal of Basic and Clinical Physiology and Pharmacology*, 26(6): 585-593.

Olokoba, A.B., Obateru, O.A., Olokoba, L.B., (2012). Type 2 Diabetes mellitus: *A Review of Current Trends, Oman Medical Journal*, 27(4): 269-273

Phoswa, W. N. and Mokgalaboni, K. (2023). Comprehensive Overview of the Effects of Amaranthus and Abelmoschus esculentus on markers of oxidative stress in diabetes mellitus. *Life* 13(9), 1830. DOI: http://dx.doi.org/10.3390/life13091830.

Ponnulakshmi, R., Shyamaladevi, B., Vijayalakshmi, P., Selvaraj, J. (2019). *In silico* and *in vivo* analysis to identify the antidiabetic activity of beta-sitosterol in adipose tissue of high-fat diet and sucrose-induced type-2 diabetic experimental rats. *Toxicology Mechanisms and Methods Journal*, 29(4): 276-290.

Prasad, B. R., andAshadevi, J. S. (2018). Withaniasomnifera promotes stress-resistant activity in Drosophila melanogaster. *Journal of Drug Delivery and Therapeutics*, *8*(6-s), 83-88.

Rjeibi, I., Saad, A.B., Hfaiedh, N. (2016). Oxidative damage and hepatotoxicity associated with deltamethrin in rats: The protective effects of *Amaranthus spinosus* seed extract. *Biomedicine and Pharmacotherapy* 84, 853–860.

Rutkowski, M., Grzegorczyk, K. (1998). Kolorymetryczne oznaczanie stężenia witaminy C w osoczu krwi przy użyciu odczynnika fosforowolframianowego – modyfikacja metody Kyawa [Colorimetric determination of vitamin C concentration in blood plasma with phosphotung state reagent – a modification of Kyaw method]. *Diagnostic Laboratory*. 34, 243

Rutkowski, M., Grzegorczyk, K., Gendek, E., Kędziora, J. (2006). Laboratory convenient modifica tion of Bessey method for vitamin A determination in blood plasma. *Journal Physiol. Pharm.* 57 (Suppl. 2), 221.

Rutkowski, M., Grzegorczyk, K., Paradowski, M.T. (2005). Kolorymetryczna metoda oznaczania całkowitej witaminy E w osoczu krwi – modyfikacja własna metody Tsena [Colorimetric method of blood plasma total vitamin E determination – the own modification of Tsen met hod]. *Diagnostic Laboratory*. 41, 375

Sgro, C. M., & Partridge, L. (2000). Evolutionary responses of the life history of wild-caught Drosophila melanogaster to two standard methods of laboratory culture. *The American Naturalist*, *156*(4), 341-353.

Showkat, S. (2020). Antioxidant and anti-diabetic potential of nutraceutical rich amaranthus caudatus. *Indian Journal of Pure & Applied Biosciences* 8(3); 140–148. DOI: http://dx.doi.org/10.18782/2582-2845.8078.

Stankovic, M. S. (2011). Total phenolic content, flavonoid concentration and antioxidant activity of Marrubiumperegrinum L. extracts. *Kragujevac Journal of Science*, *33*(2011), 63-72.

Williams, D. E., Wareham, N.J, Cox, B.D., Bryne, C.D, Hales, C.N, Day, N.E. (1999). Frequent salad vegetable consumption is associated with a reduction in the risk of diabetes mellitus. *Journal of Clinical Epidemiology* 52:329-35.

Wouyou, A., Gandonou, C., Komlan, F., Montcho, D., Zanklan, A., Lutts, S. and Gnancadja, S. (2017). Salinity resistance of five amaranths (Amaranthus cruentus) cultivars at the young plants stage. *International Journal of Plant & Soil Science*, *14*(3), 1-11.

Yang, Y. C., Mong, M. C., Wu, W. T., Wang, Z. H. and Yin, M. C. (2020). Phytochemical profiles and anti-diabetic benefits of two edible Amaranthus species. *CyTA - Journal of Food* 18(1); 94–101. http://dx.doi.org/10.1080/19476337.2020.1716850.

Zambrana, S., Lundqvist, L. C. E., Veliz, V., Catrina, S. B., Gonzales, E., & Östenson, C. G. (2018). Amaranthus caudatus stimulates insulin secretion in goto-kakizaki rats, a model of diabetes mellitus type 2. *Nutrients*, *10*(1). https://doi.org/10.3390/nu10010094

Zeisel, S. H. andSalganik, R. I. (1999). Antioxidants and nutrition support. *Current Opinion in Clinical Nutrition and Metabolic Care*, *2*(1), 1-3.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher. The publisher remains neutral with regard to jurisdictional claims.

Submit your next manuscript to NJBMB at
https://www.nsbmb.org.ng/journals