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Research Article

Effect of Nutrients and Phytochemical Compounds of *Solanum melongena* (Eggplants) on Cognitive Protection in Rats

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Abstract

Many factors among which life style and oxidative stress are implicated in the incidence of neurodegenerative diseases. One of the ways to prevent neurodegeneration is to supply the body with antioxidant molecules derived from food. The aim of this study is to evaluate the nutritional value and neuroprotective activities of eggplants on cognitive impaired rat model. Powder was made with the white and purple *Solanum melongena* and the nutritional value of each was determined. Total phenolic and flavonoid content, antioxidant activity by DPPH scavenging and reducing iron tests, were determined from aqueous, ethanolic and hydroethanolic fruit extracts. The powder and the most active extract of *Solanum melongena* were used to determine neuroprotective activity in rats. Male wistar rats were divided into 7 groups of 6 each. Morris water maze and radial maze tests were performed at the end of the experiment to assess behaviour in rats. After 28 days, the rats were sacrificed and biochemical investigations such as protein content, reduced glutathione, catalase activity, malondiadehyde and acetylcholinesterase activity were evaluated in brain homogenates. The purple *Solamun melongena* showed the highest ash (6.06%), calcium (10.50 mg/100 g of desiccated foods), phosphorus (25.75 mg/100 g of desiccated foods), potassium (218.00 mg/100 g of desiccated foods) and zinc (0.18 mg/100 g of desiccated foods) content. On the other hand, white *Solanum melongena* showed the highest fiber (3.61%) and iron (0.36 mg/100 g of desiccated foods) content. The greatest phenolic content (69.90 mg GAE /g) and flavonoid content (31.54 mg CATE / g) was observed with the purple *Solanum melongena*. It also presented the best scavenging DPPH activity (EC 50 = 41.91 µg/ml). The group Sm400 showed the best memory learning activity with radial maze tests (0.66 n/min), a significant decrease of malondialdehyde (15.26 µmole/g), acetylcholinesterase activity (0.13 nmol/min/mg protein) and an increase of protein content (43.71 µmole/g) ($P<0.05$). The group Sm10% showed the best memory capacity radial maze tests (0.73 n/min), the lowest malondialdehyde level and acetylcholinesterase activity (12.45 µmole/g and 0.11nmol/min/mg protein respectively) ($P<0.05$). Purple *Solanum melongena* could be used to protect neuron functions.

Keywords

Nutrients, Phytochemical Compounds, Cognitive Protection, *Solanum melongena*

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1. Introduction

Neurodegenerative diseases occur with ageing and many elderly people are more and more exposed. It affects the neurology system, then conducts to brain cell death [1]. The main symptoms are characterized by loss of autonomy, depression, anxiety, progressive memory loss, language disability, bradykinesia and muscular rigidity… [2]. According to Javaid et al. [3], about 49 million humans over the word are concerned and the number of patients is predicted to triple by 2050. Unfortunately, in Africa, the prevalence of these diseases is not well-known and documented. Besides, patients suffering from these pathologies are sometimes perceived as victims of witchcraft practices and thus left to fend for themselves [4]. Oxidative stress is widely implicated in the neurodegenerative diseases. The brain, the main organ concerned, is highly vulnerable to oxidative stress because it is essentially made up of polyunsaturated fatty acids, its function needs high oxygen consumption, possesses relatively weak endogenous antioxidant defense. [5, 6]. The consequence are oxidative damage of proteins, lipids and nucleic acids, thus activating cell death pathways. [7]. Many treatment or preventive method focus to reduce cellular reactive oxygen species (ROS) levels may offer neuroprotective effect for these diseases. Nevertheless, attempts to treat these diseases are not easy. Available treatments such as anticholinergics and antidopaminergics do not cure the disease, but slow down its progression by relieving symptoms, given that neuronal loss is irreversible. They have undesirable side effects and are also very expensive [8, 9]. Therefore, to counteract oxidative damage, therapeutic interventions are used to stimulate endogenous neuronal antioxidant defense pathways. Many works have shown the neuroprotective effect of natural product against neurodegenerative disorders [10]. This is why fruit and vegetables, with their wealth of exogenous antioxidants, are an ideal solution. Many studies have shown that fruit and vegetables are rich in nutrients and phytochemical compounds that can be used in the treatment of cancer, diabetes, cardiovascular and inflammatory diseases [11]. Furthermore, Doungue *et al.* [12] have shown antioxidant and neuroprotective activities of the powder and the aqueous extract of the mesocarp of *Raphia hookeri* in rats subjected to aluminum chloride neurotoxicity. Flavonoid has the ability to traverse the blood brain barrier and inhibit oxidative stress [11]. However, despite the large number of molecules already studied, their bioavailability is due to the capacity of the substances to travel the blood brain barrier. Moreover, very few food-derived products are found in our environment due to the seasonal nature, hence the need to explore new products. Therefore, some local plants were subjected to preliminary tests and *Solanum melongena* (*S. melongena*), commonly called eggplants, showed the best results. *S. melongena* is a vegetable in the *Solanaceae* family, cultivated for its fruit. It occurs in several varieties and the best known are green, white and purple. *S. melongena* can be grilled, baked, skewered or eaten raw [13, 14]. It contains selenium, zinc, vitamin A, C, E and bioactive compounds like chlorogenic acid, lanosterol, steroid alkaloids, glycoalkaloids, nasunin, oxalic acid, and can cure many diseases like cancer, diabetes, cardiovascular diseases and inhibit inflammation [15]. Futhermore, the leaves of *S. melongena* also showed neuroprotective effect on scopolamine-induced amnesia in mice [16] and in drosoplasts [17]. In view of these multiple benefits, given that the activity of plant changes according to the parts studied and the varieties, it would be important to assess the neuroprotective activity of the flesh of *S. melongena*. This works aims to the evaluation of the nutritional value and phytochemical compounds of eggplants on cognitive protection in rat model.

2. Materials and Methods

2.1. Raw Materials

Fresh mature white and purple *S. melongena* fruits were collected in the experimental field of the Faculty of Agronomic Sciences of the University of Dschang.

2.2. Methods

2.2.1. Production of Different Formulations of *S. melongena* (Sm5% and Sm10%) Powders and Extraction of Natural Antioxidants

The fresh fruits were cleaned, cut into small fraction and dried in an electric air-dried oven (*Venticell*) at 45 ℃ for 48 hours. The dried eggplant was ground in the blender machine (*moulinex*) and sieved (diameter of pore is 1 mm). The formulations were made as follows: Sm5% was produced with 95 g of food staple and 5 g of the powder of *S. melongena*; Sm10% was produced using 90 g of food staple and 10 g of the powder of *S. melongena* [18].

Phenolic compounds were extracted from the plant material by maceration, as described by Womeni *et al.* [19]. 20 g of powder was dissolved into 100 mL of ethanolic, aqueous and a hyhro-ethanolic extract (80:20) respectively. The mixture was regularly shook and was then filtered with a Wahtman N °1 filter paper and the filtrates were evaporated at 45 ℃. The products obtain were conserved at 4 ℃ for further analysis.

2.2.2. Determination of Nutrients Composition of *S. melongena*

Moisture, ash, fiber, fat, protein contain and micronutrient mainly calcium, phosphorus, iron, magnesium, manganese, potassium and zinc are determined by AOAC method [20]. 5 g of sample was diluted with acid and alkaline solution in order

to evaluate the crude fiber content [21]. The carbohydrate content was computed by difference via equation (1) as described by Mohammed Ahmed *et al*. [22].

% Carbohydrate = 100 - % (Moisture + Fat + Protein + Fiber + Ash)

2.2.3. Evaluation of the Phytochemical Composition of *S. melongena* Extract

(i). Evaluation of the Total Phenolic Content (TPC)

Folin-Ciocalteu colorimetric method was used to determine phenolic content, as described by Gao *et al.* [23] with slight modifications. 20 µL of extract 2000 µg/mL was poured, followed by the Folin-Ciocalteu reagent (200 µL) and distilled water (2000 µL) were added in each tube. 1000 µL of 20% sodium carbonate solution was added and the mixture incubated against for 20 min under the same conditions. The result solution was quantified using a Biomate brand spectrophotometer at 765 nm. The ethanolic solution of gallic acid (200 µg/L) was used as a standard and the results were expressed as milligrams equivalents gallic acid per gram of extract.

(ii). Evaluation of the Total Flavonoid Content (TFC)

Flavonoid content was determined as described by Quettier *et al.* [24]. 100 µL of each 2000 µg/mL extract was mixed with 1900 µL of distilled water, then 100 µL of 10 % aluminum chloride, 100 µL of potassium acetate (1M) and 2800 µL of distilled water were added. This solution was incubated at room temperature for 40 minutes. The Catechin (200 µg/mL) was used as a standard and the absorbance was read at 510 nm. The result was expressed as mg catechin /g of extract.

2.2.4. Evaluation of *in vitro* Antioxidant Activity of White and Purple *S. melongena* Extract

(i). Determination of Radical Scavenging Capacity of the Extracts

Braca *et al.* [25] method was used to determine of 4.5 mL radical scavenging capacity of different extracts of S. *melongena*. A concentration of 2.2-diphenyl-1-picrylhydrazyl (DPPH) at 0.002 % of ethanolic solution was added to 0.5 ml of different concentrations (125, 250, 500, 1000 and 2000 µg/mL) of extracts and standard solution (vitamin C) separately, in order to have final concentrations of products of 12.5 - 200 µg/ mL. The samples were kept at room temperature in the dark and after 30 min, the absorbance of the resulting solution was read at 517 nm. The antiradical activity (AA) was determined using the following formular:

$$AA\% = [(Abs\ control - Abs\ sample) \times 100/Abs\ control] \quad (1)$$

Where Abs control was the absorbance of DPPH solution and Abs sample the absorbance of the sample or standard.

The EC50 values (Efficient Concentration 50) were calculated from the antioxidant activity percentage, the logarithm of the concentrations by plotting the equation regression lines (2) and were expressed in µg/mL.

$$EC_{50} = a \log (C) + b \quad (2)$$

(ii). Determination of the Capacity of Extracts to Reduce Ferric Iron to Ferrous Iron

The capacity of extracts to reduce ferric iron was determined by Oyaizu [26] method. 500 µL of the two varieties of *S. melongena* extract (0.125, 0.25, 0.5, 1, 2 mg/ mL) was added to 1000 µL of phosphate buffer (200 mM, pH 6.6) and 1000 µL of 1 % aqueous $K_3Fe(CN)_6$, homogenized and put at 50 ℃ for 30 min. Then, 1000 µL of 10 % TCA solution was added to stop the reaction and the mixture was centrifuged at 3000 rpm for 10 min, 1500 µL of supernatant, 1500 µL of distilled water and 100 µL of 0.1 % $FeCl_3$ solution were homogenized, incubated for 10 min and the absorbance was read at 700 nm using a spectrophotometer against Vitamin C, which was used as a positive.

2.3. Evaluation of the Cognitive Effect of the Aqueous Extract of Purple *S. melongena* on Aluminum Chloride Induced Neurotoxicity

2.3.1. Experimental Animals

Male wistar rats weighting between 200 and 250 g were separated in seven groups of six animals. Rats were cared-for according to the guidelines of the OECD [27]. All groups, except the normal control group (NM) were administered daily by intraperitoneal route 4.2 mg/kg/ of $AlCl_3$ for 28 days. *S. melongena* was administered to four groups: group Sm200 which was induced and received 200 mg/kg body weight (bw) aqueous extract of purple *S. melongena*; group Sm400 which was induced and received 400 mg/kg bw aqueous extract of *S. melongena*; group Sm5% which was induced and received 5g of the powder of *S. melongena* + 95g of the staple food; group Sm10% which was induced and received 10 g of the powder of *S. melongena* + 90 g of staple food. The group VC200 (positive control group) was induced and received 200 mg of vitamin C per Kg of body weight. The negative control group was also induced without treatment (NC). All experiments were carried out during 28 days consecutively according to the Experimental Animal Welfare and Ethics Committee of the Institution (No. 2017/056).

2.3.2. Evaluation of Animal Behaviour During Treatment

(i). Morris Water Maze Procedure (MWM)

MWM was used to evaluate memory of rodents to rapidly remember and deposit upon a visible platform put in a wa-

terpool containing cold water, after several trainings. The waterpool was an apparatus of 300 mm in length with a diameter of 1800 mm. In the center, a platform was put at 10 mm below the water level. Each rat was given 60 s in the pool until it finds this platform. The time spent to find the platform were recorded by the aid of a camera as described by Morris *et al.* [28].

(ii). Radial Eight-Arm Maze Test Procedure (RAM)

It was based on locomotion and remembrance capacity of rats to visit targeted arms of the maze. The apparatus was a maze made up of eight arms (length: 60 cm; height: 50 cm). Each rat was given 5 min to explore the maze a day. Each session lasts until all 8 arms are seized. The 4 arms filled with rewards were always the same, in order to teach the animal to find the food only in the 4 arms during this 5 min. Rats were deprived from food for 12 hours and two trials were performed before the test [29].

Acquisition speed of food = number of rewards /times taken

2.3.3. Sacrifice of Animals

After 4 weeks of experiments, rats were deprived from food for 12 hours and sacrificed under anesthesia using diazepam and ketamin. Brains were removed by cervical dislocation. They were homogenized in ice-cold phosphate buffer (0.1 M, pH 7.4) at 10 % (m/v). The homogenate was used for determination of protein content, reduced glutathione (GSH), catalase activity, malondialdehyde (MDA) and acetylcholinesterase (AchE) activity.

2.3.4. Evaluation of Biochemical Investigations

(i). Total Protein Content

This was used according to Gornall [30]. 50 µL of homogenate, 2950 µL of 0.9 % sodium chloride and 3 mL of Biuret reagent were introduced in each tube, then homogenized and incubated at room temperature for 15 minutes. The optical density was read at 540 nm against that of the blank. The protein concentration (mg/g) was determined from the calibration curve.

(ii). Reduced Glutathione Level (GSH)

GSH was evaluated according to Ellman [31]. 100 µL of homogenate and 900 µL of 400 µg/mL Ellman's reagent prepared in tris-HCl buffer (100 mM, pH 6.5) were added to each tube and were homogenized. The mixture was incubated for 30 min at room temperature. Optical densities were read at 412 nm against the blank and the result was expressed in nmol/min/g.

(iii). Catalase Activity

It was evaluated according to the method of Sinha [32]. 50 µL of brain homogenate and 750 µL of phosphate buffer (0.01 M; pH 7.0) were introduced successively into the test tubes, 200 µL of hydrogen peroxide (0.2 M) was added to the mixture. The stopwatch was turned on after the addition of 2 mL of Dichromate/acetic acid solution (1: 3 v/v mixture of 5% potassium dichromate with concentrated acetic acid) and the reaction was stopped after 60 seconds. The tubes were heated to 100 ℃ for 10 min and after, they were cooling in an ice bath, the optical densities were read at 570 nm against the blank. The result was in nmol/min/g.

(iv). Malondialdehyde (MDA)

MDA was evaluated according to Yagi [33]. 100 µL of brain homogenate, 500 µL of 1 % thiobarbituric acid was prepared in 1 % trichloroacetic acid and 500 µL of 1% phosphoric acid were added to the tubes. The mixture was heated in a water bath at 100 ℃ for 15 minutes and then cooled down in cold water for 30 minutes. They were centrifuged at 3000 rpm for 10 minutes and the absorbance of the supernatant was read at 532 nm against the blank. Malondialdehyde level was expressed in µmole/g.

(v). Acetylcholinesterase Activity

This assay was performed according to Ellman *et al.* [34]. In each tube, 50 µL of brain homogenate was added 1 mL of phosphate buffer (100 mM, pH 7.4), 50 µL of 5-5'-Dithio-bis (2-nitrobenzoate) and 50 µL acetylthiocholine. These Tubes were clogged, shaken and absorbance were taken at 412 nm against blank solution. AChE activity was expressed in nanomoles per minute per milligram of protein (nmol/min/mg protein).

2.4. Statistical Analysis

Analyses were performed in triplicate. The results were reported as means ± standard deviation using Excel 2016. One-way analysis of variance with the post hoc turkey was used to evaluate the statistical difference among the samples using XLSTAT software version 2016. At $p < 0.05$ a probability value was considered statistically significant.

3. Results and Discussion

3.1. Results

3.1.1. Nutritional Value of Purple and White *S. melongena*

Table 1 below presents the nutritional value of the purple and white *S. melongena*. Purple *S. melongena* presented the highest values of ash content (6.06 %), calcium (10.50 mg/100 g of desiccated foods), phosphorus (25.75 mg /100 g of desiccated foods), potassium (218.00 mg /100 g of desiccated foods) and zinc (0.18 mg /100g of desiccated foods) while white *S. melongena* presented the highest values of fiber (3.61 g/100g of desiccated foods) and iron (0.36 g /100 g of desiccated foods).

Table 1. *Nutritional composition of white and purple S. melongena.*

Parameter	White Sm	Purple Sm
Moisture (%)	84.05 ± 0.28[a]	84.54 ± 0.59[a]
Carbohydrate (%)	5.77 ± 0.29[a]	5.89 ± 0.18[a]
Protein (%)	0.82 ± 0.11[a]	0.83 ± 0.06[a]
Fat (%)	0.18 ± 0.04[a]	0.2 ± 0.00[a]
Fiber (%)	3.61 ± 0.23[a]	2.48 ± 0.08[b]
Ash (%)	5.57 ± 0.23[b]	6.06 ± 0.53[a]
Energy (Kcal /100 g)	28.22 ± 1.96[a]	28.64 ± 0.96[a]
Calcium (mg)	7.40 ± 1.01[b]	10.50 ± 0.72[a]
Magnesium (mg)	14.04 ± 0.45[a]	14.20 ± 0.26[a]
Phosphorus (mg)	20.62 ± 2.38[b]	25.75 ± 1.94[a]
Potassium (mg)	127.00 ± 3.37[b]	218.00 ± 5.35[a]
Iron (mg)	0.36 ± 0.03[a]	0.25 ± 0.05[b]
Maganese (mg)	0.21 ± 0.08[a]	0.21 ± 0.04[a]
Zinc (mg)	0.10 ± 0.01[b]	0.18 ± 0.03[a]

At P<*0.05*, the means values in the same line carrying different superscript letters are significantly different*; Sm: solanum melongena*

3.1.2. Phytochemicals Content of Extracts of White and Purple *Sm*

Table 2 shows the phytochemicals content of different extracts of purple and white *S. melongena*. The TPC varied significantly between 32.91 and 69.90 mg GAE/g of extract. The aqueous extract of purple *S. melongena* showed the highest content (69.90 mg GAE/ g of extract) and the ethanolic extract of white *S. melongena* the lowest content (32.91 mg GAE/ g of extract). TFC was also evaluated and varied between 17.26 and 31.54 mg CATE/g of extract. The aqueous extract of purple *S. melongena* showed the highest content (31.54 mg CATE/g of extract) and the ethanolic extract of the same variety showed the lowest content (17.26 mg CATE/g of extract).

Table 2. *Total phenolic and flavonoid content of purple and white S. melongena.*

Extracts	TPC (mg GAE/ g of extract)	TFC (mg CATE / g of extract)
APSm	69.90 ± 0.42[a]	31.54 ± 0.84[a]
EPSm	63.63 ± 1.47[b]	17.26 ± 1.03[c]
HEPSm	46.39 ± 2.88[d]	30.95 ± 1.68[a]
AWSm	54.85 ± 2.21[c]	28.57 ± 2.68[a]
EWSm	32.91 ± 1.32[f]	24.40 ± 0.87[b]
HEWSm	38.55 ± 0.44[e]	29.16 ± 0.56[a]

At P<*0.05*, the mean values in the same colunm carrying different superscript letters are significantly different; TFC: total phenolic content; TFC: total flavonoid content; CATE: catechin equivalent; GAE*:* gallic acid equivalent; APSm*:* Aqueous extract of Purple *Solanum melongena*; HEPSm*:* hydro-ethanolic extract of Purple *Solanum melongena;* EPSm*:* ethanolic extract of Purple *Solanum melongena;* AWSm*:* Aqueous extract of white *Solanum melongena;* HEWSm*:* hydro-ethanolic extract of white *Solanum melongena;* EWSm*:* ethanolic extract of white *Solanum melongena*

3.1.3. *In vitro* Antioxidant Activities of Different Extracts of White and Purple *S. melongena*

(i). Efficient Concentration 50 (EC_{50}) of Different Extracts of Purple and White *S. melongena*

The efficient concentration 50 (EC 50) of different extracts of purple and white *S. melongena* are presented in Table 3. The hydro-ethanolic extract of white and the aqueous extract of purple *S. melongena* exhibited the highest DPPH scavenging capacity with the EC_{50} values at 41.85 µg/mL and 41.91 µg/mL respectively. However, the ethanolic extract of purple *S. melongena* showed the lowest capacity (203.26 µg/mL).

Table 3. *Efficient concentration 50 of different extracts of purple and white S. melongena.*

Extracts	Efficient concentration 50 (EC_{50} in µg/mL)
APSm	41.91 ± 2.51[c]
HEPSm	57.93 ± 9.12[c]
EPSm	203.26 ± 28.29[a]
AWSm	106.15 ±5.98[b]
HEWSm	41.85 ±2.09[c]
EWSm	111.59 ±1.54[b]

Extracts	Efficient concentration 50 (EC_{50} in µg/mL)
Vit C	4.78 ± 0.71^{d}

Mean values carrying different superscript letters are significantly different at P<*0.05*; APSm*:* Aqueous extract of Purple *Solanum melongena;* HEPSm*:* hydro-ethanolic extract of Purple *Solanum melongena;* EPSm*:* ethanolic extract of Purple *Solanum melongena;* AWSm*:* Aqueous extract of white *Solanum melongena;* HEWSm*:* hydro-ethanolic extract of white *Solanum melongena;* EWSm*:* ethanolic extract of white *Solanum melongena;* Vit C: Vitamin C

(ii). Ferric Reducing Antioxidant Power of Different Extract of Purple and White *S. melongena*

Figure 1 presents the ferric reducing antioxidant power of different extracts of *S. melongena*. The reducing power of extracts varied significantly (*P*<0.05) between the varieties, solvent and concentration. The ethanolic and aqueous extracts of purple *S. melongena* showed the highest ferric reducing power.

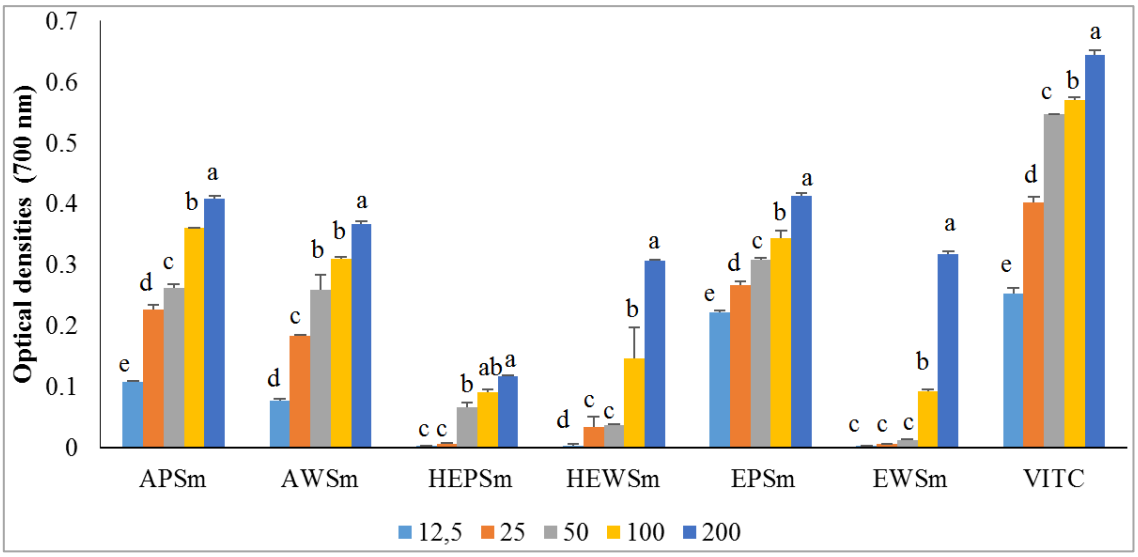

Figure 1. *Ferric reducing antioxidant power of different extract of purple and white S. melongena.*

At P<*0.05,* values with different letters are significantly different; APSm*:* Aqueous extract of Purple *Solanum melongena*; HEPSm*:* Hydro-ethanolic extract of Purple *Solanum melongena;* EPSm*:* Ethanolic extract of Purple *Solanum melongena;* AWSm*:* Aqueous extract of white *Solanum;* HEWSm*:* Hydro-ethanolic extract of white *Solanum melongena;* EWSm*:* Ethanolic extract of white *Solanum melongena;* VITC: Vitamin C

3.1.4. Effect of Purple *S. melongena* on the Cognitive Behaviour

(i). Effect of Purple *S. melongena* in the Acquisition Speed of Food

Figure 2 presents the effect of purple *S. melongena* in the acquisition speed of food. Neurotoxicity induction led to a significant decrease on food acquisition speed in induced non treated group (NC) compared to the non-induced and non-treated group. The administration of aqueous extract significantly increased (*P*<0.05) food acquisition speed in test groups compared to the negative control, and the groups Sm400 and Sm10% performed better.

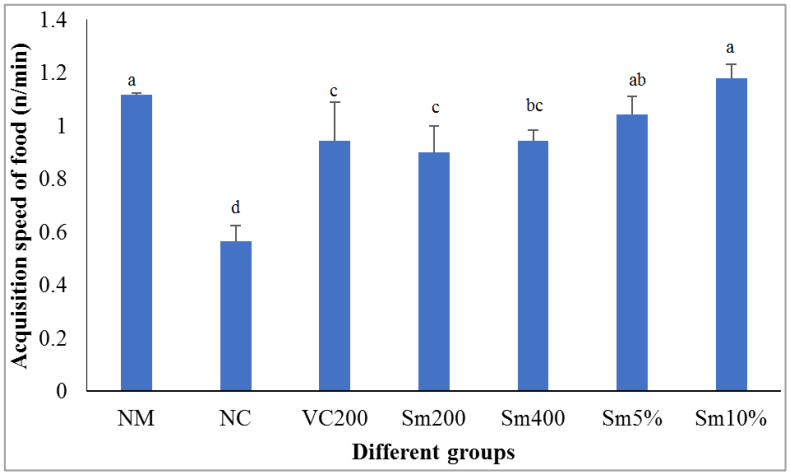

Figure 2. *Effect of purple S. melongena on the acquisition speed of food.*

At P<*0.05*, values with different letters are significantly different; NM: normal group was not induced and received only water; NC: negative control group was induced with 4.2mg/kg of bw of aluminum chloride and received water; Sm 200: induced rats with 4.2mg/kg of bw of aluminum chloride which received 200 mg/kg bw aqueous extract of *Solanum melongena*; Sm400: induced rats with 4.2mg/kg of bw of aluminum chloride received 400 mg/kg bw aqueous extract of *Solanum melongena*; VC 200: induced rats with 4.2mg/kg of bw of aluminum chloride which received 200 mg/kg bw of vitamin C; Sm5%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 5g of powder of *Solanum melongena* + 95 g of staple food; Sm10%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 10g of powder of *Solanum melongena* + 90 g of staple food.

(ii). Effect of the Powder and Aqueous Extract of Purple *S. melongena* on the Time Used to Find Platform

Aluminum administration led to a significant increase of the time spent to find the platform in the negative control group. The administration of the powder and aqueous extract of *S. melongena* significantly reduced (P<0.05) the time used to find the platform compared to the negative control. The best performances were observed in groups Sm200 and Sm10% (Figure 3).

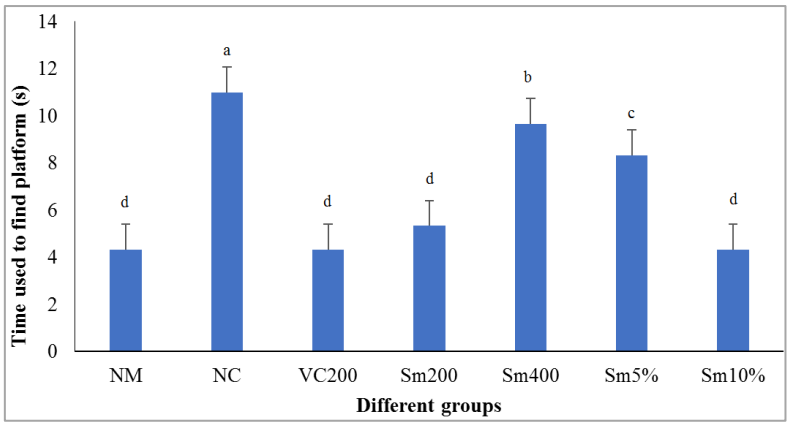

Figure 3. *Effects of purple S. melongena on the time used to find platform.*

At P<0.05 Values with different letters are significantly different; NM: normal group was not induced and received only water; NC: negative control group was induced with 4.2mg/kg of bw of aluminum chloride and received water; Sm 200: induced rats with 4.2mg/kg of bw of aluminum chloride which received 200 mg/kg bw of the aqueous extract of Solanum melongena; Sm400: induced rats with 4.2mg/kg of bw of aluminum chloride received 400 mg/kg bw of the aqueous extract of Solanum melongena; VC 200: induced rats with 4.2mg/kg of bw of aluminum chloride which received 200 mg/kg bw of vitamin C; Sm5%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 5g of powder of Solanum melongena + 95 g of staple food; Sm10%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 10g of powder of Solanum melongena + 90 g of staple food.

3.1.5. Effect of Purple *S. melongena* on Some Biochemical Investigations

Table 4 shows the effect of purple *S. melongena* on some biochemical investigations in the brain homogenates. Oxidative stress induction led to a significant decrease ($P<0.05$) of total protein level, reduced glutathione level and a significant increase ($P<0.05$) of malondialdehyde level and acetylcholinesterase activity in the brain homogenates of the negative control group compared to the normal group. However, the administration of the powder and aqueous extract of *S. melongena* significantly increased ($P<0.05$) the total protein level and catalase activity with the best value obtained in group Sm10%. The most reduced glutathione level was observed in group Sm200. It was also noted with significantly decreased ($P<0.05$) malondialdehyde level in group Sm5% and Sm10% compared to the negative control group. The best acetylcholinesterase activity was observed in groups Sm400 and Sm10%.

Table 4. *Effects of purple S. melongena in some biochemical investigations in the brain homogenates.*

Groups	Protein (µmole/g)	Glutathione (µmole/g)	Catalase (nmol/min/g)	MDA (µmole/g)	Ache (nmol/min/mg protein)
NM	36.86 ±2.45^{b}	624.97 ±37.32^{cde}	10.99 ±0.97^{abc}	10.99 ±0.9^{d}	0.07 ±0.01^{c}
NC	15.28 ±5.67^{d}	547.71 ±2.77^{e}	7.26 ±0.43^{c}	34.10 ±6.4^{a}	0.45 ±0.04^{a}
VC200	24.42 ±2.33^{c}	633.63 ±67.03^{cd}	12.65 ±3.41^{a}	18.57 ±3.4^{bc}	0.11 ±0.03^{c}
Sm200	23.52 ±3.42^{c}	886.82 ±39.62^{a}	11.40 ±0.35^{ab}	21.26 ±4.43^{b}	0.28 ±0.04^{b}
Sm400	43.71 ±2.18^{a}	561.37 ±14.06^{de}	9.21 ±1.98^{bc}	15.26 ±2.4^{bcd}	0.13 ±0.02^{c}
Sm5%	36.41 ±2.04^{b}	664.34 ±39.03^{c}	11.34 ±0.58^{ab}	12.06 ±4.28^{d}	0.24 ±0.05^{b}
Sm10%	40.31 ±1.05^{ab}	786.74 ±51.83^{b}	13.94 ±0.23^{a}	12.45 ±1.11^{cd}	0.11±0.02^{c}

At <0.05, values in the same colunm carrying different superscript letters are significantly different; NM: normal group was not induced and received only water; NC: negative control group was induced with 4.2mg/kg of bw of aluminum chloride and received water; Sm 200: induced rats with 4.2mg/kg of bw of aluminum chloride and 200 mg/kg bw of the aqueous extract of *Solanum melongena*; Sm400: induced rats with 4.2mg/kg of bw of aluminum chloride and received 400 mg/kg bw the aqueous extract of *Solanum melongena*; VC 200: induced rats with 4.2mg/kg of bw of aluminum chloride which received 200 mg/kg bw of vitamin C; Sm5%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 5g of powder of *Solanum melongena* + 95 g of staple food; Sm10%: induced rats with 4.2 mg/kg of bw of aluminum chloride and 10g of powder of *Solanum melongena* + 90 g of staple food

3.2. Discussion

Purple and white *S. melongena* contain both macronutrients and micronutrients. However, in this finding, purple *S. melongena* contained high amount of ash, phosphorus, potassium, zinc while white *S. melongena* has the highest fiber and iron content. The highest amount of fiber was obtained with white *S. melongena*. However, fibers have laxative effect and the daily intake of dietary fiber for males and females is 38 and 25 g / day, respectively [35]. The highest ash content was 6.06%. It provides information on the quantity of minerals present in the food [36]. Calcium content was 10.5 mg/100g of desiccated foods. However, FAO/WHO [36] recommended daily intake of 800 mg of calcium. It helps to the fortification of tooth and bones, transmission of nerve impulses and as cofactor in metabolic processes [36]. The results of this study were higher than those of Naeem and Ugur [38], who obtained a value of 9 mg/ 100g of dry matter. The difference observed could be due to climatic and genetic conditions. Phosphorus is vital for metabolic processes the also helps for the fortification of children and nursing mothers [39]. The highest content was 25.5 mg/100g of dry matter. This value is near to those of Gürbüz et *al*. [15] who obtained a value of 24 mg/100g of dry matter. Potassium helps to maintain acido-basic balance, osmotic pressure and nerve impulse conduction. The recommended value is 2.5 mg/day, and its deficiency leads to muscular weakness and paralexia [36]. The highest potassium content was 218 mg/100g dry of matter. Purple *S. melongena* present the highest iron content with the value of 0.36mg/100g of dry matter. The purple *S. melongena* present the highest zinc content (0.18 mg/100g dry matter). Zinc plays an essential role in human growth and development. It helps in the stabilization of macromolecular structure and synthesis [40]. The recommended daily intake is between 0.3 and 1mg/Kg for adults [37].

The two varieties of *S. melongena* are rich in phenolic compounds and the aqueous extract of purple *S. melongena* showed the highest TPC and TFC (Table 2). This could be due to the fact that water is one of the best solvents for extracting

these compounds. This is on line with the findings of Doungue *et al*. [12] who showed that aqueous extracts of *Raphia hookeri* have the best TPC and TFC amongst the three solvents used. Phenolic compounds have antioxidant which scavenging free radicals and oxidants to protect cell damage [41]. Jarerat *et al*. [42] showed that the total phenolic and the total flavonoid contents were considerably high in the peels of aqueous extract of *S. melongena* after irradiation under red-blue rays and the values were 821.86 mg GAE/100 g fresh water and 595.98 mg CE/100 g fresh water respectively. The difference between the amount of *S. melongena* extract and those of literature may be explained by genotypic and weather conditions between these plants, the choice of the part tested, the period of harvest [43].

Plant extracts which usually harbor large amount of phenolic compounds, are also doted with antioxidant properties. Ayouarz *et al*. [44] showed that there is a positive correlation between phenolic compounds and the DPPH radical scavenging activity of leaves and flowers of hydroalcoholic extracts of *Nerium oleander*. The lowest EC50 were obtained with the aqueous and hydro-ethanolic extracts of purple and white *S. melongena* and were 41.85 and 41.91 µg/ml respectively (Table 3). Nevertheless, these concentrations were higher than those of vitamin C, thus these extracts showed a moderate antioxidant capacity. Souri *et al*. [45], showed that, the antioxidant activity is moderate when the EC50 is between 20 and 75 µg/ml. This activity can be attribute to phytochemicals contain of *S. melongena* such as flavonoid and chlorogenic acid. Furthermore, the findings of Young *et al*. [46] showed that chlorogenic acid is the most phenolic compound contained in *S. melongena* which can be responsible for its antioxidant activity. The best activity was observed in the aqueous extract of purple *S. melongena*. Since the powder and the aqueous extract of purple *S. melongena* showed the best nutrients content and antioxidant activities, they were used for the *in vivo* tests.

Aluminum chloride administration increase the speed of food acquisition and reduce the time used to find the platform in induced non treated group (Figure 2 and Figure 3). This could be firstly due to the neurotoxic effect of aluminum which can bind to negatively charged phospholipids, making them susceptible to oxidation with a great chance to generate reactive oxygen species that affect the brain and consequently the memory [11]. Secondly, aluminum has the ability to interfere with effector molecules, like cyclic guanosine monophosphate, and reduce the learning capacity of the spatial memory task [5]. The administration of the aqueous extract of purple *S. melongena* led to an increase in food acquisition speed and reduction of the time used to find the platform. Many reports have shown the relationship between consumption of fruits and vegetables which have many varieties of polyphenols in the prevention of cognitive decline dementia [9]. Angeloni *et al*. [11] have shown the benefit effect of polyphenols, vitamins and polyunsaturated fatty acid on the cognitive performance. This cognitive performance is associated to the antioxidant activities of these compounds which can trap reactive oxygen species in the brain and prevent the oxidation of polyunsaturated fatty acids. The nutrients and phytochemicals compounds present in *S. melongena* protect the memory function of the brain.

The decrease in the brain protein level, reduced glutathione activity and the increase in malondialdehyde level and acetylcholinesterase activity in non-treated group compared with the treated groups could be explained by the fact that aluminum can bind to different metal binding proteins such as Ca, Fe, Cu, Zn and affects homeostasis of other molecules [5, 6]. Aluminum neurotoxicity is also explained by free radical production that leads to lipid peroxidation and protein damage [7]. The consumption *S. melongena* increased the level of total protein with the best significance in group Sm400 and Sm10%. The powder and extract of *S. melongena* contain some bioactive compounds including alkaloids, steroids, vitamins C, zinc, selenium, chlorogenic acid and caffeic acid which reduce oxidative stress and cognitive impairments in rats [47]. These bioactive compounds are reported to act through several mechanisms including expression of genes responsible for the secretion of compounds with benefit effect, reduction of oxidative stress incidence by neutralizing free radicals through oxidoreduction reactions [48]. Catalase protects cells by detoxification of the generated hydrogen peroxide and plays an important role in the acquisition of tolerance of oxidative stress. It also maintains the concentration of oxygen either for repeated rounds of chemical reduction or for direct interaction with toxin [49]. The best activity of catalase in group Sm10% can be explained by the presence of zinc which is an essential metal that increases the activation of enzymatic antioxidants. Zinc inhibits NADPH oxidase, and regulates oxidant production and metal-induced oxidative damage [42]. Acetylcholine is an important neurotransmitter involved in muscle contraction and memory process. During neurodegenerative diseases, this acetylcholine was destroyed by the enzyme called acetylcholinesterase [50]. The best anti acetylcholinesterase activity was obtained in group Sm10%. It can be explained by the presence some nutrients like calcium and zinc which play an important role in synapse plasticity. Calcium regulates numerous cellular processes such as transduction, muscle contraction and neurotransmitter release. Zinc is required for synaptic plasticity, learning and memory [40]. According to Watanabe *et al*. [51], this reduction in AchE activity is due to the fact that the polyphenols present in *S. melongena* stimulated the expression of transthyretin, a natural chemical that protects neurons by removing oxidized β-amyloids. It also inhibits AchE, thus blocking acetylcholine degradation. The polyphenolic compounds had scavenging activity against ROS and the ability to activate key antioxidant enzymes in the brain, protecting it from neurological disorders.

4. Conclusion

Purple *S. melongena* showed the highest value of ash (6.06%), calcium (10.5 mg), phosphorus (25.75 mg), potassium (218 mg) and zinc content (0.18 mg). Aqueous extract of purple *S. melongena* showed the highest total phenolic (69.90 mg GAE / g), flavonoid content (31.54 mg CATE / g) and also presented the best efficient concentration 50 (41.912 µg / ml). Groups Sm10% and Sm400 enhanced antioxidant activities, cognitive functions by reducing the time use to find the platform in the water maze, and increased the food acquisition speed in the radial aim maze. It also increased proteins, reduced glutathione levels and decreased malondialdehyde level and acetylcholinesterase activity. Therefore, purple *S. melongena* could be used for its healthy potential to protect the brain against oxidative damage and protect neuron functions. To complete this work, it will be necessary to characterize the bio-actives molecules present in eggplants and evaluate the neuroprotective activity of each of them.

Abbreviations

AchE: Acetylcholinesterase
bw: Body Weight
CATE*:* Catechin Equivalent
GAE: Gallic Acid Equivalent
GSH: Reduced Glutathione
MDA: Malondialdehyde
RAM: Radial Eight-Arm Maze
MWM: Morris Water Maze
TFC: Total Flavonoid Content
TPC: Total Phenol Content

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Conflicts of Interest

The authors declare no conflicts of interest.

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