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Evaluation of Protective Activity of Potato Peel Extracts on Liver and Brain Against Oxidative Stress.

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ABSTRACT

The objective of the present study was to evaluate the protective activity of potato peel extracts (PPEs) on liver and brain cells against oxidative stress *in vitro*. Protective effects against ethanol induced cytotoxicity in liver cells and Fe^{2+}-induced lipid peroxidation in brain were assayed. The results showed that the pre-treatment or treatment along of liver slices with water and ethanol potato peel extracts prevented the ethanol-induced oxidative stress in the liver by decreasing the lipid peroxidation and protein carbonylation. Also, the PPEs reduced the LDH leakage from liver cells and maintaining the levels of antioxidant enzymes. In addition, PPEs prevented Fe^{2+}-induced lipid peroxidation in mouse brain tissues in a dose dependent manner. The ethanol potato peel extract (EPPE) was more effective than water potato peel extract (WPPE) in protection of liver and brain cells from oxidative stress. Finally, it can be concluded that potato peel extracts have protective effects on liver and brain cells against oxidative stress.
Keywords: Protective, potato peels, liver, brain, oxidative stress.

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INTRODUCTION

Reactive oxygen species (ROS) have important physiological roles in living organisms and are actively participated in cellular signal transduction, cell proliferation and apoptosis [1,2]. The ROS production is balanced by antioxidant defense systems which include reducing compounds and different enzymes. The biological mode where the imbalance between pro-oxidants and antioxidant is disrupted in favor of the former can lead to a process known as oxidative stress [3]. ROS, which are potent oxidant, can damage various bio-significant molecules ranging from DNA damage to protein carbonylation and lipid peroxidation. The generation of ROS could be due to several factors one of which is environmental factors such as exposure to pollutants, alcohol, medications, infections, poor diet, toxins, radiation etc [4,5]. The participation of ROS has been implicated in a set of pathological manifestations such as cancer, liver diseases, neurodegenerative diseases and aging etc. [6,7]. The field of antioxidant therapy is exploding in the literature and different classes of chemical compounds have been examined for potential antioxidant therapy. However, very less success has been done with the later because of the complex pharmacological and toxicological processes [8,9]. One of the most important planning could be the use of dietary antioxidant intake; which may prevent or retard the oxidation of susceptible cellular substrates and ultimately can help in reducing the risk of different diseases. In this regard flavonoids, phenolic acids, tannins and tocopherols have received interest for their high antioxidant activity [10] and less toxicity problems which may arise from the use of synthetic antioxidants [8,9,11]. It could be summarized that plants have many phytochemicals which are potential sources of natural antioxidants and can be useful against a variety of oxidative stress related diseases.

Potato (*Solanum tuberosum*) is a main food for humans and the fourth largest crop in the world after rice, wheat, and maize [12]. Though there is increasing interest, relatively little is known about the important phytochemicals contained in this most-consumed vegetable and its processing by-products. Potato peels (PPs) are a good source of phenolic compounds which may potentially be used in food formulations or when extracted can be used as natural antioxidants to prevent oxidation of selected foods [13-15]. PPs are by-products of the potato processing industry and are an excellent source for the recovery of phenolics because almost 50% of phenolics are found in the peel and adjoining tissues and their concentration decreases towards the centre of the tuber [16,17]. Thus, value added use of this by-product is of interest to the potato industry [18,19]. The literature was poor concerning in the data of protective effects of potato peel extracts (PPEs). Singh and Rajini [20] found that freeze-dried aqueous extract of potato peels possessed strong inhibitory activity in the direction of lipid peroxidation of rat liver homogenate produced by the $FeCl_2$-H_2O_2 system. Singh *et al*. [21] proposed the likelihood that PP waste could be effectively used as an ingredient in health and functional food to improve particular disease states such as diabetes. Singh and Rajini [22] pointed out that potato peel extract (PPE) is effective of protecting erythrocytes against oxidative damage perhaps by acting as a strong antioxidant. Singh *et al*. [23] revealed that PPE pretreatment significantly compensates CCl_4 induced liver damage in rats, which may be due to its strong antioxidant tendency.

The present study was aimed to investigate the protective effects of potato peel extracts on liver and brain cells against oxidative stress *in vitro*.

MATERIALS AND METHODS

Materials

Plant material

Potato tubers (*Solanum tuberosum* cv Diamond) was purchased from a local market at Giza, Egypt.

Animals

Male Swiss albino mice, weighing about 28-30 g were obtained from Research Institute of Ophthalmology, Giza, Egypt.

Chemicals

Guaiacol and 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid (HEPES) were obtained from Sigma Chemical Co., USA. Lactate dehydrogenase (LDH) kit was purchased from Centronic GmbH, Germany. All other chemicals were of analytical reagent grade.

Methods

Preparation of potato peel extracts

Two various extracts were prepared from potato peels using the method described by Singh and Rajini [20] with some modifications as follows:

Potato tubers were washed with tap water and peeled manually using a kitchen vegetable peeler. The peels were air dried (in shade, 25-30°C) for one week and crushed by using a kitchen blender. The potato peel powder (0.5 g) was soaked in 10 ml of distilled water (DW) for 24 h at room temperature and was blended three times. The mixture was centrifuged at 5000 rpm for 10 min. The supernatant was filtered through filter paper (Whatman No.1). The obtained filtrate was utilized as water potato peel extract (WPPE). The same method was used for the extraction of potato peels with ethanol 80%. After extraction with ethanol, the solvent was evaporated from the obtained extract. The residue was redissolved in the DW. The obtained solution was utilized as ethanol potato peel extract (EPPE).

Assay against ethanol cytotoxicity of liver cells *in vitro*

Liver slice culture

Liver slice culture was preserved following the protocol progressed by Wormser *et al*. [24] as described by Naik *et al*. [25] as follows:

The mice were dissected open after decapitation, and liver lobes were removed and transported to pre-warmed Krebs-Ringer-HEPES (KRH) buffer solution (HEPES 2.5 mM pH 7.4, NaCl 118 mM, KCl 2.85 mM, CaCl$_2$ 2.5 mM, KH$_2$PO$_4$ 1.5 mM, MgSO$_4$ 1.18 mM and glucose 4.0 mM). Liver was then cut into thin slices utilizing acute scalpel blades. After weighting the slices, the slice weighing between 7 and 10 mg was utilized in this experiment. Each experimental system included 15-17 slices weighing together 120–150 mg. Slices of each system were washed with 10.0 ml KRH buffer solution every 10 min over interval of 1 h. Each system was then pre-incubated for 60 min in small closed beaker containing 2.0 ml of KRH buffer on a shaker water bath at 37°C. In the experiments of potato peel extracts, each medium contained 12.5 mg/ml potato peel extract during the second half of the pre-incubation period. At the end of pre-incubation, the medium was replaced by fresh 2.0 ml of KRH buffer solution and incubated for 2 h at 37°C with ethanol solution (1.37 M) or both ethanol and potato peel extract. Four different experimental conditions were used for treatment with potato peel extracts as follows: WPPE + Eth-1: Water potato peel extract was present for 0.5 h only during pre-incubation; WPPE + Eth-2: Water potato peel extract was present for 0.5 h during pre-incubation and also for next 2 h with ethanol; EPPE + Eth-1: Ethanol potato peel extract was present for 0.5 h only during pre-incubation; EPPE + Eth-2: Ethanol potato peel extract was present for 0.5 h during pre-incubation and also for next 2 h with ethanol. At the termination of incubation, each set of slices was homogenized in suitable volume of chilled potassium phosphate buffer solution (100 mM, pH 7.8) in an ice bath to yield a concentration of tissue 100 mg/ml. The culture medium was obtained and utilized for determination of LDH, which was used as a cytotoxicity indication. The homogenates were centrifuged at 10,000 rpm for 10 min at 4°C. The obtained supernatants were used to estimate the LDH, catalase, peroxidase activities and protein content. Lipid peroxidation and protein carbonyl content were also determined in obtained homogenates.

Estimation of protein content

Protein content was determined according to the method of Lowry-Folin as described by Dawson *et al*. [26].

Assay of lipid peroxidation

Thiobarbituric acid-reactive species (TBARS) formation was used to evaluate lipid peroxidation according to the method of Draper and Hadley [27] as described by Rudnicki *et al*. [28] as follows: 600 µl of trichloroacetic acid solution (TCA; 10%, w/v) were mixed with 300 µl of the liver slices homogenate in centrifuge tube then centrifuged at 10,000 rpm for 10 min. 400 µl of supernatant were mixed well with 400 µl of thiobarbituric acid solution (TBA; 0.67%, w/v). After 30 min in a boiling water bath, the mixture was cooled to room temperature. The absorbance (A) of solution was measured at 532 nm. The malondialdehyde (MDA) content (µmol/ml) was calculated using molar extinction coefficient (156,000 M/cm). The data are expressed as MDA equivalents (µmol/mg protein).

Assay of protein carbonyl content

Protein carbonyl content was assayed by the method of Levine *et al*. [29] with some modification of Srivastava and Shivanandappa [30] as follows:

In centrifuge tube, 600 µl of the liver slices homogenate were centrifuged at 10,000 rpm for 15 min. 200 µl of obtained supernatant were mixed with 200 µl of 2,4-dinitrophenylhydrazine solution (DNPH; 10.0 mM in 2 M HCl solution) then incubated at room temperature for 1 h. After incubation, 100 µl of TCA (20%, w/v) were added then centrifuged at 5000 rpm for 3 min. The protein pellets were washed three times with 500 µl of acetone and 1.0 ml of sodium dodecyl sulphate solution (2% SDS in 20 mM Tris–HCl and 0.1 M NaCl, pH 7.4) was added to solublize the pellet. The absorbance of the solution was measured at 360 nm. The protein carbonyl content (µmol/ml) was calculated using molar extinction coefficient (22,000 M/cm). The data are expressed as µmol of carbonyls/mg protein.

Assay of lactate dehydrogenase activity

Lactate dehydrogenase (LDH) was estimated by the method of Weibhaar *et al*. [31]. Percent release of enzyme from liver slices was calculated as the ratio of LDH activity found in the supernatant to the total LDH (supernatant + homogenate) activity [25].

Assay of catalase activity

Catalase (CAT) activity was estimated using the method of Sinha [32] as described by Murugan and Pari [33] as follows:

In the clean test tube, 1.0 ml of phosphate buffer solution (0.01 M, pH 7), 0.1 ml of liver homogenate and 0.4 ml of H_2O_2 solution (2 M) were mixed well. The reaction was stopped by the addition of 2.0 ml of dichromate-acetic acid reagent (5% potassium dichromate solution with glacial acetic acid, 1:3). The absorbance of solution was measured at 620 nm. CAT activity was expressed as µM of H_2O_2 consumed/min/mg protein.

Assay of peroxidase activity

Peroxidase (POX) activity was determined using the method of Bergmeyer [34] as follows:

In a clean test tube, 0.1 ml of liver homogenate was added to 3.0 ml of phosphate buffer solution (0. 1 M, pH 7), 0.05 ml of guaiacol solution (20.1 mM), and 0.03 ml of H_2O_2 solution (12.3 mM). The mixture was mixed thoroughly and incubated for 1 min at 37°C. The absorbance was measured at 1 min intervals thereafter for 3 min against blank at 436 nm. The activity unit was defined as the amount of enzyme that produced an increase of an absorbance unit per minute under the assay conditions.

Assay against Fe^{2+}-induced lipid peroxidation in brain

Fe^{2+}-induced lipid peroxidation in brain was carried out using the method of Ohkawa *et al*. [35] as described by Oboh *et al*. [36] as follows:

Preparation of brain homogenate

Mice were decapitated under mild diethyl ether anaesthesia and the cerebral tissue (whole brain) was rapidly dissected, weighed and then placed in ice. The tissues were subsequently homogenized in cold saline solution (1% NaCl, w/v) by ultrasonic probe (frequency at 10 kHz) for 30 s. The homogenate was centrifuged at 7,000 rpm for 10 min to yield a pellet that was discarded and a supernatant containing mainly water, proteins and lipids (cholesterol, galactolipid, individual phospholipids, gangliosides), DNA and RNA was kept and collected for lipid peroxidation assay [37].

Procedure

100 µl of obtained supernatant were mixed with a mixture containing 30 µl of Tris–HCl buffer solution (0.1 M, pH 7.4), different volumes of potato peel extract (40, 80 or 100 µl) and 30 µl of $FeSO_4$ solution (250 µM) and the volume was completed to 300 µl by DW before incubation at 37°C for 1 h. The colour reaction was developed by adding 300 µl of SDS (8.1%, w/v) and followed by addition of 600 µl of acetic acid/HCl mixture (0.1 M, pH 3.4) and 600 µl of TBA (0.8%, w/v). This mixture was incubated at 100°C for 1 h. Thiobarbituric acid reactive species produced were measured at 532 nm. Control was prepared by the same procedure without sample. The inhibition percent of Fe^{2+}-induced lipid peroxidation was calculated using the following equation:

$$\text{Inhibition } (\%) = \frac{\text{Acontrol} - \text{Asample}}{\text{Acontrol}} \times 100$$

Statistical analysis

The results were presented as mean ± standard error (SE) and analysed by an analysis of variance ($P<0.05$). The means compared by Duncan's multiple range test. CoStat computer program (1986) was used for statistical analyses.

RESULTS

Protection of liver cells from ethanol induced cytotoxicity

In this study, liver slice culture system was used to quantitate the cytotoxic effects of ethanol and their reversal by potato peel extracts. The liver slice culture is an *in vitro* technique consisting of highly organized cellular community in which different cell types are subject to mutual contact. It provides desirable complexity of structurally and functionally intact cells (25,38). Oxidative stress was induced by adding cytotoxic ethanol to the liver slice culture. The ethanol toxicity was measured in terms of lipid peroxidation, protein carbonyls, the release of lactate dehydrogenase (LDH) by the cells into the medium and the cellular levels of the antioxidant enzymes (AOEs), catalase and peroxidase.

Lipid peroxidation and protein carbonyls in liver slice culture

Lipid peroxidation levels in the liver slice culture medium were assessed by thiobarbaturic acid reactive substances assay. Lipid peroxidation was measured in terms of thiobarbituric acid reactive substances and was expressed as µmol of malondialdehyde (MDA)/mg protein. The results presented in Table 1 showed that the amount of lipid peroxidation increased in ethanol-treated liver cells (4.35 µmol MDA/mg protein) compared to control (2.18 µmol MDA/mg protein). The pre-treatment of liver cells with WPPE or EPPE resulted in reduction of lipid peroxidation to 4.17 and 3.18 µmol MDA/mg protein, respectively. Extent of lipid peroxidation was reduced to near control levels when liver cells were treated either with WPPE and EPPE along with ethanol (3.37 and 3.04 µmol MDA/mg protein, respectively).

On the other hand, protein carbonyls were measured in liver slice culture and are expressed as protein carbonyl formed/mg protein. The results revealed that the levels of protein carbonyls were significantly reduced when liver cells were pre-treated with WPPE and EPPE or when WPPE and EPPE were added along with ethanol in comparison with ethanol treated slices (Table 1). In ethanol treated liver slices, the value of

protein carbonyls recorded 6.32 µmol/mg protein compared with control (1.44 µmol/mg protein). The protein carbonyl contents were also reduced when liver cells pre-treated with WPPE and EPPE (5.35 and 4.33 µmol/mg protein, respectively). Additional reduction in protein carbonyl (4.56 and 2.73 µmol/mg protein, respectively) was reported when liver cells treated along, individually with WPPE and EPPE. From the obtained results, it could be concluded that EPPE was more effective than WPPE in reduction of lipid peroxidation and protein carbonyls in liver cells.

Table 1: Effect of water potato peel extract (WPPE) and ethanol potato peel extract (EPPE) on the lipid peroxidation and protein carbonyl in liver slice culture *in vitro* against ethanol-induced cytotoxicity

Treatment*	Lipid peroxidation (µmol MDA/mg protein)	Protein carbonyl (µmol/mg protein)
Control (KRH)	2.18[f]±0.02	1.44[e]±0.09
Ethanol	4.35[a]±0.03	6.32[a]±0.32
WPPE1+ethanol	4.17[b]±0.02	5.35[b]±0.07
WPPE2+ethanol	3.37[c]±0.03	4.56[c]±0.20
EPPE1+ethanol	3.18[d]±0.03	4.33[c]±0.34
EPPE2+ethanol	3.04[e]±0.03	2.73[d]±0.10
L.S.D	0.083	0.669

- Values are means of three replicates ± SE. Numbers in the same column followed by the same letter are not significantly different at *P*<0.05. KRH: Krebs-Ringer-HEPES buffer solution; MDA: malondialdehyde.
*WPPE1+ethanol: WPPE was present for 0.5 h during pre-incubation; WPPE2+ethanol: WPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol; EPPE1+ethanol: EPPE was present for 0.5 h during pre-incubation; EPPE2+ethanol: EPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol.

LDH leakage in liver slice culture

Release of LDH was used as a marker of cytotoxicity in liver slice culture. Ethanol was highly toxic to the treated cells, which increased LDH leakage (%) four times higher (73.81%) as compared to control (Table 2). The pre-treatment of liver cells with WPPE or EPPE for 0.5 h resulted in reduction of LDH leakage to 58.09% and 53.37%, respectively. When WPPE or EPPE presented along with ethanol incubation, further reduction in LDH leakage was recorded (46.67% and 40.31%, respectively). Therefore, EPPE was more potent than WPPE in prevention of LDH leakage from liver cells.

Table 2: Effect of water potato peel extract (WPPE) and ethanol potato peel extract (EPPE) on the LDH leakage% in liver slice culture against ethanol-induced cytotoxicity

Treatment*	LDH leakage%
Control (KRH)	18.37[d]±1.78
Ethanol	73.81[a]±1.19
WPPE1+ethanol	58.09[b]±0.95
WPPE2+ethanol	46.67[c]±3.84
EPPE1+ethanol	53.37[b]±1.82
EPPE2+ethanol	40.31[c]±1.72
L.S.D	6.486

- Values are means of three replicates ± SE. Numbers in the same column followed by the same letter are not significantly different at *P*<0.05. KRH: Krebs-Ringer-HEPES buffer solution.
*WPPE1+ethanol: WPPE was present for 0.5 h during pre-incubation; WPPE2+ethanol: WPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol; EPPE1+ethanol: EPPE was present for 0.5 h during pre-incubation; EPPE2+ethanol: EPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol.

Antioxidant enzymes in liver slice culture

Ethanol induces oxidative stress in the cells by generation of ROS. Antioxidant enzymes (AOEs) CAT and POX protect cells from oxidative stress of highly reactive free radicals. CAT and POX are known enzymes to prevent damage by directly scavenging the harmful active oxygen species. Activities of two AOEs were checked

in liver slice cultures treated with ethanol alone or ethanol and potato peel extracts. The results presented in Table 3 revealed that the activities of CAT and POX were decreased in the liver tissue treated with ethanol (5.36 and 0.011 U/mg protein, respectively) in comparison with control (6.32 and 0.066 U/mg protein, respectively). The liver tissue pre-treated with WPPE or EPPE for 0.5 h showed significantly increased the activities of CAT (5.68 and 5.93 U/mg protein, respectively) and POX (0.029 and 0.033 U/mg protein, respectively). When liver tissue treated with WPPE or EPPE along with ethanol, further increased in the activities of CAT (5.82 and 6.12) and POX (0.034 and 0.044) was recorded. Therefore, the effect of PPEs was better when it was present continuously with ethanol compared to when it was added only for 0.5 h during pre-incubation period.

Table 3: Effect of water potato peel extract (WPPE) and ethanol potato peel extract (EPPE) on the activity of catalase and peroxidase in liver slice culture against ethanol-induced cytotoxicity

Treatment*	Catalase activity (U/mg protein)	Peroxidase activity (U/mg protein)
Control (KRH)	$6.32^a\pm0.010$	$0.066^a\pm0.002$
Ethanol	$5.36^f\pm0.017$	$0.011^d\pm0.002$
WPPE1+ethanol	$5.68^e\pm0.010$	$0.029^c\pm0.003$
WPPE2+ethanol	$5.82^d\pm0.010$	$0.034^c\pm0.001$
EPPE1+ethanol	$5.93^c\pm0.006$	$0.033^c\pm0.001$
EPPE2+ethanol	$6.12^b\pm0.006$	$0.044^b\pm0.002$
L.S.D	0.032	0.0064

- Values are means of three replicates ± SE. Numbers in the same column followed by the same letter are not significantly different at $P<0.05$. KRH: Krebs-Ringer-HEPES buffer solution.
*WPPE1+ethanol: WPPE was present for 0.5 h during pre-incubation; WPPE2+ethanol: WPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol; EPPE1+ethanol: EPPE was present for 0.5 h during pre-incubation; EPPE2+ethanol: EPPE was present for 0.5 h during pre-incubation and also for the next 2 h with ethanol.

Protection of brain cells from Fe^{2+}-induced lipid peroxidation

The results of the inhibitory effect of potato peel extracts on Fe^{2+}-induced lipid peroxidation in mouse brain are shown in Table 4. Three concentrations of WPPE or EPPE were used (1111.1, 2222.2, and 2777.8 ppm) in this experiment. The results demonstrated that there was positive relationship between the concentration of potato peel extract and inhibition of Fe^{2+}-induced lipid peroxidation in mouse brain. The maximum inhibitory effect (46.97%) was observed with WPPE at higher concentration (2777.8 ppm). However, the inhibition of Fe^{2+}-induced lipid peroxidation in mouse brain reached 68.18% with EPPE at the same concentration. Therefore, EPPE was also more effective than WPPE. The increased lipid peroxidation in the presence of Fe^{2+} could be attributed to the fact that Fe^{2+} can catalyze one-electron transfer reactions that generate reactive oxygen species, such as the reactive hydroxyl radical (OH·), which is formed from H_2O_2 through the Fenton reaction. Iron also decomposes lipid peroxides, thus generating peroxyl and alkoxyl radicals, which favors the propagation of lipid oxidation [39].

Table 4: Inhibitory effect of water potato peel extract (WPPE) and ethanol potato peel extract (EPPE) on Fe^{2+}-induced lipid peroxidation in mouse brain

Treatment	Conc. (ppm)	Inhibition%
WPPE	1111.1	$5.15^e\pm0.61$
	2222.2	$21.21^d\pm1.52$
	2777.8	$46.97^b\pm4.01$
EPPE	1111.1	$5.30^e\pm0.76$
	2222.2	$28.79^c\pm1.52$
	2777.8	$68.18^a\pm2.62$
L.S.D	-	6.714

-Values are means of three replicates ± SE. Numbers in the same column followed by the same letter are not significantly different at $P<0.05$.

DISCUSSION

Potato peel extracts were subjected to test their protective effects of liver and brain cells against oxidative stress. The hepatotoxic effects of ethanol are attributed to oxidative stress. Metabolism of ethanol is associated with generation of free radicals especially hydroxyethyl radicals which induce lipid peroxidation [40,41]. The polyunsaturated fatty acids of cellular membranes are particularly susceptible to this oxidative attack leading to membrane lesions and loss of cellular homeostasis. Lipid peroxidation in liver slices was found to be doubled in presence of ethanol and PPEs reduced it significantly (Table 1). Increased lipid peroxidation has earlier been reported in the liver of animals fed with ethanol [42] and in hepatocytes exposed to ethanol *in vitro* [43]. However, Ethanol-induced protein carbonylation in the liver cells which is consistent with earlier reports [44]. Pre-treatment or treatment along with potato peel extracts (WPPE and EPPE) prevented lipid peroxidation and protein carbonyls which could be attributed to their antioxidant and free radical scavenging activities [14,18,20,45]. Ethanol-induced hepatic damage is characterized by the raised level of LDH which reflects the severity of liver injury [46]. The leakage of the LDH into the medium is attributed to the hepatic damage. However, ethanol-induced increase leakage of this enzyme was considerably reduced by pretreatment or treatment along with PPEs, implying that the extracts protected the liver against ethanol-induced damage. It has been shown that plant extracts having antioxidant activity exhibit protection against ethanol-induced hepatotoxicity [47,48]. The defense of cells against oxidative stress includes both antioxidant enzymes like catalase and peroxidase which scavenge free radicals as well as non-enzymatic antioxidants such as glutathione, ascorbic acid and alpha-tocopherol which directly react with free radicals. Treatment of liver cells with ethanol lowered the antioxidant capacity of the mouse liver as reflected in the decreased activity of the antioxidant enzymes which is in agreement with earlier reports [49]. Pretreatment or treatment along with PPEs restored the antioxidant enzyme activities in the liver slices. Induction of antioxidant enzymes in the liver by plant-derived polyphenols has been reported [50]. The results of Singh *et al*. [23] and Abd El-baky and Ahmed [51] supported the hepatoprotective effect of potato peel extracts against carbon tetrachloride. The results demonstrated that PPE pretreatment significantly offsets CCl_4 induced liver injury in rats, which may be attributable to its strong antioxidant propensity. On the other hand, the protective action of the potato peel extracts on brain against oxidative stress could be attributed to the presence of antioxidants, especially phenolic compounds. The redox properties of phenolic compounds allow them to act as reducing agents, hydrogen donors, free radical scavenger, singlet oxygen quenchers and metal chelators [14,52].

Finally, the protective effects of potato peel extracts may be due to their antioxidant and free radical scavenging properties and their ability to enhance antioxidant defenses [20,22,23,51]. The higher protective effect of ethanol potato peel extract in comparison with water potato peel extract was associated with its antioxidant activity and its content of types of phenolic compounds especially flavonoids [14]. The bioactive antioxidant principles of the potato peel extracts, phenolic compounds could be responsible for the observed protective effects [53,54].

CONCLUSIONS

The results of this study showed that potato peel extracts possess protective effects of liver and brain cells against oxidative stress. Additional comprehensive pharmacological examination will be necessary to prove the ethnobotanical claims and to explain the mechanism of these protective effects.

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