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REVIEW

Purple sweet potato antioxidants for oxidative stress caused by intense physical exercise

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Abstract

Background: Intense exercise increases ROS and reactive nitrogen species, leading to oxidative stress and potential health issues. Balancing free radical production and antioxidant defence is crucial. Endogenous antioxidants help neutralise ROS, but additional supplementation is required to prevent cell damage. **Objective:** This literature review explores the potential of purple sweet potato (Ipomoea batatas L.) as an antioxidant source to counteract exercise-induced oxidative stress. **Method:** Scientific articles from various platforms were collected using keywords such as "*Physical exercise*," "*Oxidative stress*," "*Purple sweet potato*," and "*Antioxidant*". **Result:** Purple sweet potato, rich in anthocyanins and vitamin C, exhibits potent free radical scavenging properties. Consumption of purple sweet potato enhances superoxide dismutase (SOD) levels, reduces lipid peroxidation (MDA), inhibits the NF-kB signalling pathway, and prevents increased heat shock protein 72 (HSP72) expression. These findings suggest that purple sweet potato consumption promotes cellular health and mitigates oxidative stress caused by intense physical exercise. **Conclusion:** In conclusion, incorporating purple sweet potato into the diet shows promise in countering exercise-induced oxidative stress, promoting overall well-being, and preventing chronic diseases. Further research is needed to fully understand the mechanisms and optimal dosage for combating oxidative stress during rigorous physical training.

Introduction

High-intensity exercise can increase oxygen use 10-20 times in various tissues. Oxygen use causes an increase in reactive oxygen species (ROS) in mitochondria (Hadi *et al.,* 2017). High-intensity physical exercise without following existing rules causes increased production of oxidative stress in the body (Dewangga *et al.,* 2022). Accumulated fatigue, which can occur if physical exercise lasts for an extended period, will reduce short-term (non-functional overreaching) or long-term (overtraining) performance capacity (Slattery *et al.,* 2015). Sudden increases in physical exercise load, hypoxia, strenuous exercise over a long time, and low intake of foods containing antioxidants can reduce tolerance to oxidative stress (Slattery *et al.,* 2015), causing oxidative damage. Besides, excessive production of oxidative stress induces the formation of oxidation of cellular macromolecules such as lipids, proteins, and DNA, which can cause the pathogenesis of various degenerative and chronic diseases (Yavari *et al.,* 2015). This effect needs to be treated quickly, one of which is by consuming foods rich in antioxidants. (Dewangga *et al.,* 2022).

Antioxidants have been shown to have benefits in restoring muscle strength production. Antioxidants to treat muscles can inhibit ROS production from key cellular sites during high-intensity exercise and do not affect the decrease in contractile strength due to fatigue (Cheng *et al.,* 2020). Anthocyanin, a natural pigment that gives blue, red, or purple colour to fruit and vegetables, can fight oxidative stress. One plant that is rich in anthocyanins is purple sweet potato. It contains the main anthocyanins, including peonidin 3-sophoroside-5-glucoside and cyanidin 3-sophoroside-5-glucoside, which are mono-or di-acylated with caffeic, ferulic, or p-hydroxybenzoic acids (Im *et al.,* 2021).

Purple sweet potatoes' antioxidant benefits can treat oxidative stress caused by excessive physical activity. The availability of hypercaloric foods and the increasing consumption of processed foods call for the promotion of fresh foods that contain bioactive compounds, among them sweet potato anthocyanins (Im *et al.,* 2021).

Methods

The study is a narrative review of previous research on the antioxidant potential of purple sweet potato against oxidative stress from physical exercise. Scientific papers published between 2018 and 2023 were collected from several platforms, such as PubMed, ResearchGate, Google Scholar, MDPI, and others. The keywords used were physical exercise, oxidative stress, purple sweet potato, anthocyanin, and antioxidant.

Results and Discussion

Physical exercise causes oxidative stress

Cognitive decline in the body can affect daily activities. However, the level of decline is different for each individual and is influenced by many factors. One proven factor is physical activity and exercise (Pastor *et al.,* 2022). The first research to demonstrate that physical activity could cause oxidative stress was published in 1978. This study observed an increase in expired pentane levels following 60 minutes of endurance exercise. Since then, many researchers have reported that physical exercise can increase oxidative damage in the blood and skeletal muscles. Continuous or intense contractile activity affects skeletal muscles by increasing ROS production beyond normal levels. For example, increased demand for oxygen during exercise can lower intracellular oxygen pressure, resulting in increased ROS production. Additionally, high levels of CO2, increased muscle temperature, and decreased cellular pH further exacerbate oxidative stress. The surge in ROS during physical exercise is attributed to the upregulation of mRNA expression of the NADPH oxidase subunit, an enzyme complex responsible for generating ROS, which, in turn, suppresses the expression and regulation of enzymatic antioxidants (Ji, 2002). As shown in Table I, several studies demonstrated that physical activity could increase oxidative stress in animals and humans.

Table I: Some studies that outlined the effects of oxidative stress

No	Object of research	Type of training given	Identified compounds	References
1.	20 football athletes	Plyometric jump and strength resistance set to exhaustion	Increased lipid peroxidation, total lipid peroxidation	(de Oliveira et al., 2019)
2.	20 high level swimmers	High-intensity interval training consisting of 4 sets of 50 meters	Diene conjugates (DC), Schiff bases (SB), Creatine kinase (CK)	(Ovchinnikov et al., 2022)
3.	54 swimmers	Divided into 4 groups: (1) Practice at moderate depths for 3 weeks (2) Practice at medium depths for 4 weeks (3) Practice at high and low depths (4) Practice at sea level	Nitrite, carbonyl, and lipid peroxidation (LPO) levels	(León-López et al., 2018)
4.	15 elite female water polo and 19 football players	Aerobic exercise	Lipid peroxidation (MDA), total antioxidant status (TAS), superoxide anion radicals (O^{2-}), hydrogen peroxide (H_2O_2), reduced glutathione (GSH), oxidised glutathione (GSSG), nitrite, superoxide dismutase activity (SOD), catalase activity (CAT) and glutathione-peroxidase (GPx) activity.	(Arsic et al., 2016)
5.	14 handball players	Graded exercises on cycle ergometers and handball training	Superoxide anion radicals (O^{2-}), hydrogen peroxide (H_2O_2), nitrites (NO_2) as nitric oxide markers, lipid peroxidation index (TBAR), glutathione (GSH), superoxide dismutase (SOD), and catalase (CAT)Superoxide anion radicals (O^{2-}), hydrogen peroxide (H_2O_2), nitrite (NO_2) as a marker of nitric oxide, lipid peroxidation index (TBAR), glutathione (GSH),	(Djordjevic et al., 2012)

No	Object of research	Type of training given	Identified compounds	References
			superoxide dismutase (SOD), and catalase (CAT)	
6.	21 untrained male students	Lower extremity plyometric exercises	Increased MDA levels, increased CK and LDH enzyme levels	(Cao et al., 2020)
7.	19 healthy and physically active men	Physical exercise: 15 minutes sitting continuously with one leg at a height of 42cm with an aerobic step bench. Followed by 15 sit-to-stand repetitions per minute for a total of 225 repetitions	Significant increase in MDA levels, significant increase in TNF-α	(Basham et al., 2020)
8.	Fisher's Rat	Trained exercise on the treadmill	Increased mitochondrial SOD, Catalase, and glutathione peroxidase by 167%, 358%, and 129%, respectively	(Somani et al., 1995)
9.	20 parents	Aquatic training for 12 weeks	Decreased protein carbonylation (46%) and nitric oxide (60%) and increased glutathione (170%) and superoxide dismutase (160%) in the depression group ($p<0.005$).	(da Silva et al., 2019)
10.	2 groups of teenagers aged 12-16 years, both men and women	The first group of swimmers trained more than 20 hours/week. The second group of teenagers exercised 2-4 hours/week	Increased ROS levels by looking at plasma lipid peroxidation via TBA	(Santos-Silva et al., 2001)

Increased oxidative stress is seen during heavy physical exercise due to the high demand for ATP production. The continuous synthesis of ATP requires oxygen; oxygen drives the increased generation of free radicals. The oxygen that binds to single electrons during oxidative phosphorylation forms ROS (Ji, 2002), causing lipid peroxidation of unsaturated fatty acids (Chang *et al.,* 2010).

In the data collected, many studies showed that lipid peroxidation is the indicator that determines oxidative stress induced by physical exercise. Malonaldehyde (MDA), a byproduct of lipid peroxidation, has long been used as a marker for free radical activity and oxidative damage. Cell membranes, rich sources of polyunsaturated fatty acids (PUFA), are particularly vulnerable to oxidative damage by free radicals during maximal physical exercise or endurance training. In 2009, researchers measured oxidative stress indicators with different markers, mainly thiobarbituric acid reactive substances (TBARS), which indicate oxidative stress (Ristow *et al.,* 2009). Their findings revealed that oxidative stress more than doubled after physical exercise without antioxidants, suggesting that high-intensity physical activity increases ROS production levels, potentially damaging the vascular endothelium (Santos-Silva *et al.,* 2001). However, this finding does not rule out that exercise with appropriate intensity can increase antioxidant responses, reduce oxidative stress, and promote the activity of anabolic and mitochondrial biogenesis pathways in skeletal muscles (El Assar *et al.,* 2022).

Purple sweet potato anthocyanin

Purple sweet potato (Ipomoea batatas (L.) Lam.) is a member of the Convolvulaceae family. As a dicotyledonous angiosperm, it can produce nutritious tubers rich in carbohydrates, serving as a source of non-rice staples. In Indonesia, the use of non-rice food remains relatively low, at just 5%. However, purple sweet potatoes hold great promise for development, production, and use as they align with Indonesia's diversified food programme. The country's output of purple sweet potato has been steadily increasing, reaching 2,628,807 tonnes with a productivity of 196.12 quintals/hectare in 2019 and 2,715,825 tonnes with a productivity of 206.46 quintals/hectare in 2020. Approximately 89% of this production is used as food, while the remainder serves as industrial raw materials and animal feed (Pelealu *et al.,* 2019). This abundant production of sweet potatoes needs to be utilised adequately to become a resource in the future.

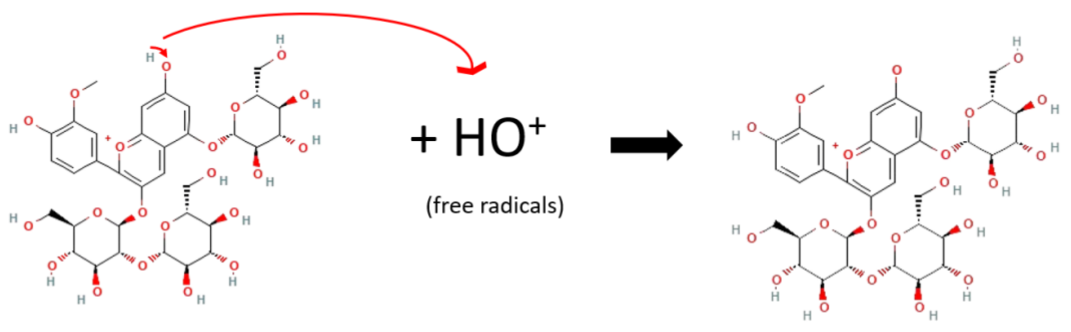
Sweet potatoes are rich in dietary fibres, minerals, vitamins, and antioxidants such as phenolic acids, anthocyanins, tocopherols and B-carotene. Based on its phytochemistry, sweet potato exhibits antioxidant activity and promotes several human health functions (Kurnianingsih *et al.,* 2021). Several studies have demonstrated the antioxidant activity of purple sweet potatoes, measured using the ORAC test and yielding values of 14.7–29.2 μmol TE/g fresh weight (Teow *et al.,* 2007). Further analysis through UHPLC identified three main anthocyanin contents, i.e., cyanidin, cyanidin-3-O-glucoside, and peonidin-3-O-glucoside (Teow *et al.,* 2007). In 2013, researchers investigated the antioxidant potential of four purple leafy vegetables, confirming their abundance of antioxidants and robust protective activity of lymphocyte DNA against oxidative damage. One of the four purple leafy vegetables is purple sweet potato. The antioxidants identified were flavonoids, anthocyanins, and flavonols (Chao *et al.,* 2013). Another anthocyanin content, peonidin 3-caffeoyl-p-hydroxybenzoyl sophoroside-5-glucoside, was previously discovered in purple sweet potatoes, further affirming the antioxidant profile of purple sweet potatoes (Truong *et al.,* 2010).

Antioxidant activity of purple sweet potato in overcoming oxidative stress in intense physical exercise

Experiments on house mice subjected to maximum physical exercise revealed increased oxygen use beyond normal levels (Elvana *et al.,* 2016), consistent with findings among humans (Hadi *et al.,* 2017). This excess use of oxygen releases free radicals in the mitochondria. Consequently, the activity of the GPx enzyme, an endogenous free radical fighter, increases until the body's GPx levels decline. This process is accompanied by an increased activity of SOD, CAT, and reduced GSH levels. Administering antioxidants from purple sweet potato to one group of mice resulted in increased GPx levels. However, the test group was subjected to the same maximum physical exercise as the control group (Elvana *et al.,* 2016). Further experiments examining the antioxidant activity of purple sweet potatoes involved 24 Sprague Dawley rats divided into four groups, where one group was administered purple sweet potato antioxidant supplements. This group exhibited 79.61% antioxidant activity, as determined by the DPPH test. A compound is considered an antioxidant if it can donate its hydrogen atom to DPPH free radicals. The hydrogen atoms in anthocyanins will bond with unpaired free radicals so that the free radicals become less reactive (Montilla *et al.,* 2010). Consequently, MDA levels, which initially increased during hyperglycemia in test animals, decreased following purple sweet potato consumption (Herawati *et al.,* 2020).

Anthocyanins have phenol groups, which can neutralise free radicals as a source of H+ and conjugated bonds as a source of electrons. After neutralising the existing free radicals, the anthocyanin will also become a radical. However, because of its conjunctive bond structure, the anthocyanin can be neutralised again, thereby delocalising electrons and forming a neutral structure. Several tests evaluating free radical scavenging abilities involved 19 types of sweet potatoes, including white, light yellow, yellow, orange, and purple sarcocarp parts. These tests showed that purple sweet potato could reduce the proliferation process, oxidative stress markers, and nitric oxide levels. In this study, purple sweet potato demonstrated a higher free radical scavenging ability than purple cabbage, grape skins, elderberry, purple corn extract, and ascorbic acid (Li *et al.,* 2019).

There are two mechanisms by which antioxidants can neutralise free radicals, including hydrogen atom transfer (HAT) and single electron transfer (SET). The first antioxidant mechanism of purple sweet potato, namely anthocyanin, donates hydrogen atoms to free radicals and neutralises them. In the second mechanism, anthocyanins donate electrons to free radicals, stabilising them and preventing damage. Anthocyanins have a conjugated double-bond system that gives them antioxidant properties (Figure 1).



Peonidin 3-sophoroside 5-glucoside

Figure 1: Mechanism of purple sweet potato anthocyanin donating hydrogen atoms to free radicals

Multiple tests highlight the potential of purple sweet potato anthocyanins in mitigating oxidative stress induced by muscle fatigue. These anthocyanins can reduce MDA levels by preventing oxidative stress in the blood and organs. Supplementation with anthocyanins can also increase antioxidant function, inhibiting the oxidation of low-density lipoproteins in a concentration-dependent manner. Lipoprotein oxidation is often used to indicate oxidative stress resulting from excessive exercise (Herawati *et al.,* 2020).

Conclusion

Consumption of purple sweet potatoes increases superoxide dismutase (SOD) levels, reduces lipid peroxidation (MDA), inhibits the NF-kB signalling pathway, and prevents increased expression of heat shock protein 72 (HSP72). Incorporating purple sweet potatoes into the diet holds promise in fighting exercise-induced oxidative stress, improving overall well-being, and preventing chronic disease. Further research is needed to elucidate the mechanisms and determine the optimal dosage to combat oxidative stress during rigorous physical exercise.

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