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Institute of Genetics and Animal Biotechnology
of the Polish Academy of Sciences, Jastrzębiec, Poland

Syringic acid as a pivotal component in reducing oxidative stress parameters in the civilization diseases - a review

Iga Bartel[1]*, Izabela Mandryk[2], Magdalena Koszarska[1]*

[1] Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences, Jastrzębiec, Postępu 36A, 05-552 Poland

[2] Faculty of Medicine and Health Sciences, University of Applied Sciences in Nowy Sącz, 33-300 Nowy Sącz, Poland

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Oxidative stress is defined as a biological balance between the amount of reactive oxygen species, especially free oxygen radicals, and the action of antioxidant systems, including the so-called repair mechanisms. Disturbance of this balance causes damages in proteins, fats and nucleic acids in healthy cells. This, in turn, gives rise to many diseases, especially those that are classified as civilization diseases e.g.: diabetes, cancer, atherosclerosis, neurodegenerative processes and many others. Syringic acid (SA) is a naturally occurring phenolic compound. Numerous in vitro and in vivo studies on SA have investigated its significant impact on oxidative stress in human. This review focuses on the SA as a potential compound reducing oxidative stress parameters in civilization diseases.

KEY WORDS: phenolic acids / antioxidants / oxidative stress / inflammation / civilization diseases

*Corresponding author: m.koszarska@igbzpan.pl; i.bartel@igbzpan.pl

Over the last few decades, a significantly change in daily dietary patterns and lifestyle has been noticed, especially in developing and developed countries. The model of consumption known as Western diet has become popular worldwide, being one of the causes of deteriorating health of millions people. As the result, it is noticeable deficiency intake of bioactive substances and at the same time high consumption of compounds acting as prooxidants. Low-caloric plant food being a source of vitamins, minerals, fiber and other beneficial substances is replaced by high-processed caloric products rich in saturated acids, including industrial trans fatty acids and monosaccharides [Azzam *et al*. 2021]. The use of herbs or plant ingredients is considered the oldest branch of medicine]. Nature provides a source of bioactive compounds that has been exploited through use for centuries [Cragg and Newman 2001]. Much research has been carried out on natural products to search for and develop new therapeutic agents that are beneficial to human health or with the least side effect. Natural product, including bioactive compounds, are used in the pharmaceutical and cosmetic industries and for the production of nutraceuticals. The relative study of natural products inspires scientists to isolate, identify and characterize active compounds from natural plants and further use them for the development of pharmacologically active molecules [Mir *et al*. 2023]. In recent years, the Food and Drug Administration (FDA) has approved an impressive number of modern drugs that are also natural products or derived directly from it [Thomford *et al*. 2018]. Additionally, unhealthy habits such as smoking, drinking alcohol and insufficient physical activity influence on public health. These transformations are strongly correlated with an excess of reactive oxygen species (ROS) and oxidative stress. In turn, these parameters are positively linked to civilization diseases, which currently represent a global problem [Mazzoli *et al*. 2019]. Alarming reports show that non-communicable diseases are main reason of premature deaths. Therefore, the researchers still intensively investigate the particular food ingredients and compounds that are able to reduce the effect of unbalanced lifestyle behaviors. One of the most prominent compounds are phenolic acids belonging to polyphenols [Wai *et al*. 2021] . They are present in plant kingdom such as vegetables, fruits, seeds and beverages, including coffee, tea and yerba mate. Including them to the diet is pivotal due to their properties such as antioxidant, anti-inflammatory, anti-cancer, antidiabetic and many more [Yeung *et al*. 2019, Sajadimajd *et al*. 2020, Bartel *et al*. 2023]. This knowledge provides an opportunity to prevent and mitigate negative symptoms related to cardiovascular diseases (CVDs), diabetes type 2, obesity, neurodegenerative diseases, etc. The phenolic acid account for wide subgroup divided into hydroxybenzoic and hydroxycinnamic acid. Although, the number of them is high, this review paper concentrates on the role of syringic acid as a crucial component in pathophysiological states such as oxidative stress that are risk factor of civilization diseases. The highest content of this phenolic acid is found in grapes and products based on them such as red wine, pumpkin, olives, blueberry, nuts (especially walnut), floral honey. Unfortunately, bioavailibity of SA is on unfavorable level to obtain valuable effects.

Therefore, scientists still try to find some alternatives to enhance prominent properties in human body by using carrier systems such as liposome forms or micelles [Yu *et al.* 2010, Liu *et al*. 2019].

Civilization diseases

Civilization diseases called as non-communicable diseases are the type of chronic diseases that develop for long period. Various factors have impact on appearing civilization diseases and it is difficult to indicate only one cause. Therefore, they are consequence of combination of genetic predisposition, physiological, environmental and daily habits as well [Kopp 2019]. The list of civilization diseases are constantly spread, but the most common are cardiovascular diseases (CVDs), cancers, chronic respiratory diseases, diabetes and many more (Fig. 1).

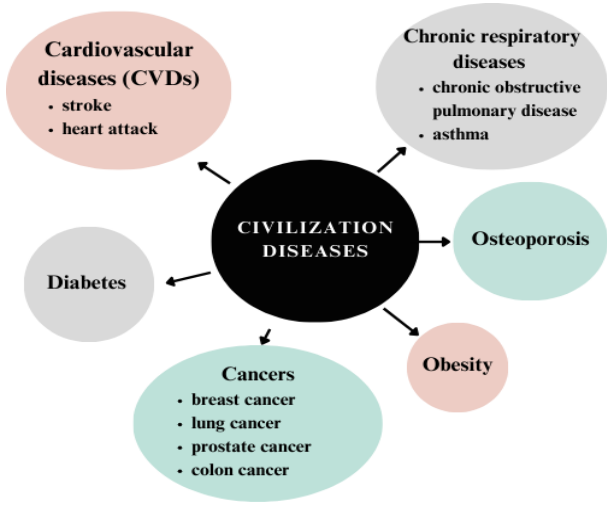

Fig. 1. Most common civilization diseases.

An increase in the prevalence of civilization diseases has been observed especially since the beginning of the 21st century. These diseases are typical for developing and developed countries [Malakar *et al*. 2019]. At the same time separately problem account for regions in low-income. There is noticed a strong correlaction between poverty and civilization diseases. It is caused by a few reasons, such as exposing for destructive behaviors (e.g., smoking), insufficient nutrition education as well as lack or limitation in health services [Kones and Rumana 2017]. Nevertheless, in the low and middle-income countries both children, adults and the elderly are all affected by these diseases due to many risk factors such as unbalanced diet poor in beneficial compounds, insufficient physical activity, air, water pollution, and negative

habits, including smoking and high intake of alcohol. Some of them are modifiable, mainly providing a nutritional food. In contest of the metabolic risk factors, the most significant are [Gupta and Xavier 2018, Martinez *et al*. 2019):

− elevated blood pressure;
− overweight or obesity;
− too high level of blood glucose (hyperglycemia);
− excess of fat in the blood (hyperlipidemia).

The most dangerous metabolic factor is raised blood pressure, which is responsible for 19% of premature deaths worldwide. Furthermore, according to the World Health Organization (WHO), civilization diseases are mainly reason of 74% global death. Approximately 17.9 milion people die every year due to cardiovascular diseases, 9.3 milion on cancers and 4.1 milion on chronic respiratory diseases (Fig. 2)

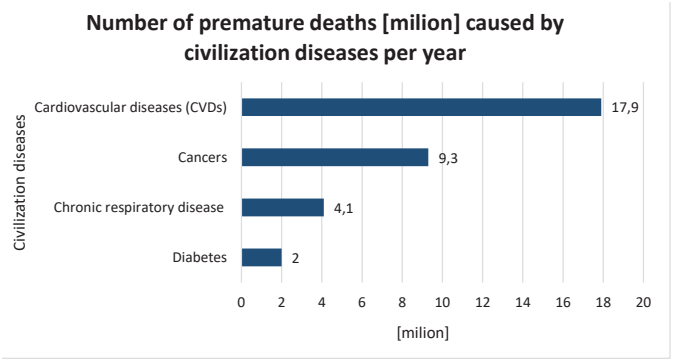

Fig. 2. Number of premature deaths (milion) per year depend on civilization diseases [WHO 2023].

Oxidative stress

Free radicals play a pivotal role in numerous biological processes in human body. Some of these are crucial for proper functioning of organism to eliminate the bacteria by scavenger cells, including granulocytes and macrophages. Many studies also suggest that free radicals are a significant agent in signaling process such as redox signaling [Bhattacharyya *et al.* 2014, Forman 2016]. Generally, the low or mediocre amount of ROS is pivotal to maintain the homeostasis. However, the high production of ROS has a negative influence on health status leading to many changes in functioning of body. It concerns the protein, lipid as well as DNA damage [Martemucci *et al.* 2022]. For instance, ROS are able to changing the protein functions due to transformation their structures [Hawkins and Davies 2019] and causing various modification, e.g., splitting bonds, changing the nucleotides order or removing them in DNA [Juan *et al.* 2021]. Free radicals are one of the reason of cell damage and apoptosis. It is positive correlated with many non-communicable diseases such as diabetes, cardiovascular diseases, and cancers [Sharifi-Rad *et al*. 2020]. Organism assess the ability to neutralize excess

of ROS by antioxidants, but when there is no balance between them, homeostasis is disturbed. Therefore, this state is known as oxidative stress. There are many factors leading to production of free radicals, including endogenous an exogenous (Fig. 3).

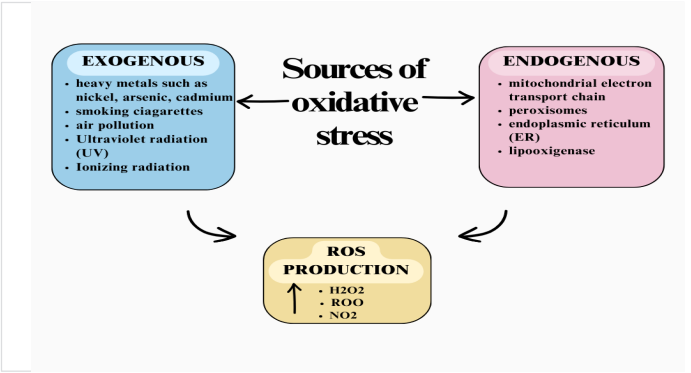

Fig. 3. Sources of oxidative stress.

Part of exogenous factors are linked to chemical pollutants, which result from human activities such as agriculture, household actions, industry, transport, etc., and also due to daily unhealthy behaviors, for example smoking tobacco. These toxic wastes get into the water, soil, air as well as food. Presence of heavy metals around account for a serious problem due to increasing amount of ROS leading to among others lipid peroxidation and disturbances in heart rate [Tan *et al.* 2020]. Some studies have shown, that metals such as arsenic enhance insulin resistance, which subsequently lead to development of diabetes [Provvisiero *et al*. 2016]. Furthermore, many investigations confirmed that ionizing radiation increase a number of ROS due to transforming forms such as hydroxyl radical, superoxides and organic radicals into organic hydroperoxides and hydrogen peroxide. Afterwards, the redox reaction between peroxides and metal ions of iron (Fe) and copper (Cu) at the cellular level manifesting secondary oxidative activity [Szumiel 2015, Nuszkiewicz *et al*. 2020]. In turn, ultraviolet radiation (UV) act on porphyrins, riboflavin, and NADPH-oxidase causing the oxidative chain due to diminishing level of intracellular glutathione (GSH) form [Varma *et al.* 2011]. Among the endogenous sources the most significant is mitochondrial electron transport chain, endoplasmic reticulum (ER) and peroxisomes. Presence of ROS is caused by aerobic metabolism in mitochondria. In turn, immune cells (macrophages, neutrophils) are capable to produces ROS through their oxygen-dependent processes as part of the defense against microorganisms [Curi *et al*. 2016]. The amount of ROS is regulated by numerous defense mechanisms. The human antioxidant system comprises both antioxidant and enzymes capable of detoxification (Fig. 4).

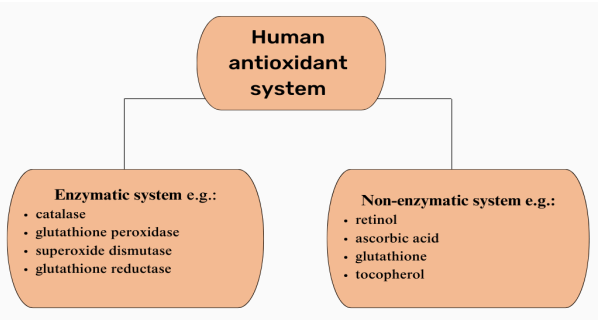

Fig. 4. Division of human antioxidant system.

Antioxidants are involved in diminishing or protecting against the oxidation of macromolecules. They decrease or terminate oxidation reactions by removing free radicals or blocking chain reactions through their own oxidation. Polyphenols serve as notable examples of these antioxidants [Duarte and Lunec 2005]. The enzymatic system is represent by three significant classes of antioxidant enzymes such as catalase, superoxide dismutase (SOD), and glutathione peroxidases (GPx) [Bartel et al. 2022]. Although, they are pivotal to ensure homeostasis, the mechanism of action is slightly different. For instance, SOD scavenges superoxide radicals, transforming them into hydrogen peroxide (H2O2), while GPx reduces not only H2O2, but also other organic hydroperoxides [Elsayed Azab *et a*l. 2019]. In turn, non-enzymatic system consists of antioxidants such as ascorbic acid, which has to provided with the diet. Neither animals nor humans have ability to synthetize it [Linster and Van Schaftingen 2007]. Tocopherol is involved in protecting the cell membranes due to reactions with lipid radicals, and the glutathione is pivotal cellular compound to maintain the cells redox status [Diaz-Vivancos *et al.* 2015].

Syringic acid

Phenolic acids belong to the wide group of strong antioxidants such as polyphenols, which are a secondary plant's metabolites [Yeung *et al*. 2021, 2022]. Providinga significant amount of polyphenols in the diet has been demonstrated to lower the likelihood of developing civilization diseases e.g. cancer [Zhou *et al.* 2016, Bhosale *et al*. 2020, Cháirez-Ramírez *et al.* 2021], stroke [Pacifici *et al*. 2021, Abdelsalam *et al*. 2023], heart diseases [Khurana *et al.* 2013, Alotaibi *et al*. 2021] or osteoporosis [Đudarić *et al*. 2015, Niwano *et al*. 2022]. Syringic acid (SA) has hydroxybenzoic acids properties. It is posses one benzene ring with two methoxy (-OCH3) groups, one hydroxyl (-OH), and one carboxyl (-COOH) group (Fig. 5). Due to presence of hydroxyl group, SA is a potent antioxidant being involved in scavenging free radicals [Vo *et al*. 2020]. It is produced by shikimic acid pathway in plants. SA is great soluble

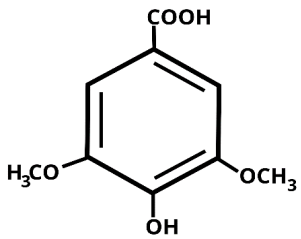

Fig. 5. Chemical structure of syringic acid (SA).

in alcohols such as ethanol and methanol and ethyl ether as well. In contrast its solubility in water is low [Ma *et al*. 2022]. Many studies have confirmed the strong antioxidant effects of SA, which suggests its possible therapeutic use [Srinivasulu *et al*. 2018, Bartel *et al.* 2024].

Reactive oxigen species and civilization diseases

Over the past two decades, there has been a shift in the perspective on ROS. They are now recognized not only as potentially harmful entities but also as essential for cellular communication and homeostasis across diverse organisms. In mammalian cells ROS can be produced, among others, in: membranes, cytoplasm, mitochondria, endoplasmic reticulum (ER), lysosomes and peroxisomes [Görlach *et al.* 2015]. In normal physiological circumstances, the generation of low levels of ROS serves a crucial role in cellular signaling and function and corresponds to their effective detoxification [Tsutsui *et al.* 2009]. This phenomenon is referred to as redox signaling, characterized by the targeted and reversible oxidation/reduction modifications of cellular signaling components. These modifications have the capacity to regulate various processes e.g. apoptosis, migration or gene expression and many others [Sack *et al*. 2017, Dubois-Deruy *et al*. 2020] . Various kinases and transcription factors participate in redox signaling. For example, H2O2 can trigger the activation of Ca/calmodulin-dependent kinase II (CAMKII), p38 mitogen-activated protein kinase (p38 MAPK) or c-Jun N-terminal kinase (JNKs) [Burgoyne *et al.* 2012]. The activation of nuclear factor-kappa beta (NFκB) occurs when ROS damage its inhibitor (IkB), thereby regulating the inflammatory process [Moris *et al.* 2017]. In addition, lipid peroxidation has the potential to induce the nuclear factor erythroid 2-related factor 2 (Nrf2) [Lismont *et al*. 2019]. Under pathological conditions, ROS have the capability to bring about oxidative modifications in crucial cellular macromolecules, including lipids, proteins, and DNA [Steinberg 2013]. The first change that can be observed is endotelial activation, characterized by an abnormal proinflammatory and pro-thrombotic phenotype in endotelial cells in blood vessels. As a consequence, there is lower bioavailability of nitric oxide (NO), which results in endotelial dysfunctions. This dysfunction is associated with the emergence of development of chronic

conditions like: cardiovascular diseases (CVDs), type 2 diabetes (T2D), obesity, aging, cancer or chronic respiratory diseases. Increased ROS levels may be caused by various factors, including: weakening of antioxidant defense or dysregulation of mitochondrial complexes [Incalza *et al.* 2018]. The generation of ROS within mitochondria is also implicated in numerous cardiovascular complications associated with diabetes. Jeong *et al.* [2016] and Jimenez-Gonzles *et al*. [2020] presented the correlation between the occurance of metabolic syndrome characterized by diabetes and obesity with left venticular hypertrophy and metabolic and diastolic disorders. Sverdlov *et al*. [2016] showed that mitochondrial ROS play a pathogenic role in metabolic heart disease (MHD) and contribute to mitochondrial dysfunction, partly through inducing oxidative posttranslational modifications of proteins in complex I and II. This includes reversible oxidative posttranslational modifications of complex II subunit B at Cys100 and Cys103. They fed mice for 4 months with high-fat high-sucrose (HFHS) diet. After that time mice developed MHD with cardiac diastolic and mitochondriual dysfunction. The finding of Anderson *et al*. [2009] revealed specific impairments in the maximal capacity to oxidize fatty acids and glutamate in mitochondria within diabetic human hearts. Despite this, they observed increase in mitochondrial H2O2 emission, offering valuable insights into the connection between mitochondrial dysfunction, oxidative stress, and the development of heart failure in diabetic patients. The degree of oxidative stress and apoptosis is elevated in cardiomyocytes from the right atrium in patients with obesity [Niemann *et al.* 2011]. Oxidative stress, caused by an imbalance between excessive production of reactive oxygen species (ROS) and inadequate antioxidant defenses, has been linked to cardiovascular and inflammatory diseases, cancer, and neurodegenerative disorders such as Alzheimer's disease. Growing evidence also suggests that oxidative stress may play a role in the pathophysiology of epileptogenesis and the development of epilepsy [Łukawski **et al.** 2023].

Within the realm of ROS, the superoxide anion radical ($O2\cdot-$) is a pivotal redox signaling molecule. It is produced mainly by the NOX enzyme family and the mitochondrial electron transport chain. Seven isoforms belong to the human NOX enzyme family (NOX1, NOX2, NOX3, NOX4, NOX5, DUOX1 and DUOX2) [Katsuyama 2010]. Each of them has a different activation mechanism, and all of them are expressed in various tissues.

The family of Nox and Duox enzymes plays a role in generating ROS across various tissues as part of normal physiological functions such as: innate immunity, signal transduction or biochemical reactions [Lambeth 2007]. Both in patients with various cancers and in cancer cell lines cultured at different stages increased NOX expression was observed [Juhasz *et al*. 2009, Meitzler *et al*. 2014]. Disturbances in the redox balance play an important role not only in the development of malignant tumors but also in resistance to therapies [Vermot et al. 2021, Pecchillo Cimmino *et al*. 2023]. Although, the generation of ROS in blood vessel is important for the vascular homeostasis, it also plays a role in the progression of many cardiovascular

diseases among others: cardiac arrest and diabetes. NOX plays an important role in stimulating and regulating the functions of downstream enzymes [Konior *et al.* 2014, Zhang et al. 2020, Vermot et al. 2021]. Similarly, to the diseases described above, also in diabetes (both in humans and animals) an increased level of ROS was found during hyperglycemia. This results in numerous endothelial dysfunctions, which cause vascular pathologies associated with diabetes [Pham-Huy *et al*. 2008, Asmat *et al*. 2016]. The increase in ROS levels in diabetes is associated with differences in the levels of enzymes such as catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GPx), as a result of which tissues are more susceptible to diabetic complications [Asmat *et al.* 2016].

Syringic acid and oxidative stress

Syringic acid has proven use in supporting the treatment and prevention of many civilization diseases. It also shows antioxidant, anti-inflammatory, neuro and hepatoprotective properties [Cikman *et al.* 2015, Ham *et al*. 2016, Li *et al*. 2019, Srinivasulu *et al*. 2018]. Srivastava *et al*. [2014] conducted HPTLC determination on antioxidant potential of monomeric phenolic acids, isolated from Bergenia species. The assessment of the antioxidant effect was made on the basis of 3 analyses; total phenolic contents (TPC), free radical scavening activity (FRSA) and β-carotene bleaching assay. Based on this experiment, it was demonstrated that SA had a free radical scavenging effect with 2,2-diphenyl-1-picrylhydrazyl (DPPH) and beta-carotene. The aim of another study was to check the protective role of SA on L-arginine-induced acute pancreatitis (AP). Rats were divided into 3 groups; control, the AP group and AP-SA group. The AP-SA rats first got AP (3.2 g/kg body weight L-arginine), later also received SA (50 mg/0.1 kg) in 2 parts within 24 hours. The results showed that SA mitigates oxidative stress markers and protects against L-arginine-induced acute pancreatitis in rats [Cikman *et al*. 2015]. Rashedini et al. showed that diabetic rats treated with 100mg/kg SA demonstrated significantly enhanced learning, memory as well as movement deficiency. The same study proved also that SA in dosage of 100 mg/kg upregulated the brain mRNA expression of PGC-1α and NRF-1, known as the regulators of energy metabolism, oxidative phosphorylation, and mitochondrial biogenesis [Rashedinia *et al*. 2020]. Another study conducted on diabetic rats proved that SA had a positive effect in rats with diabetic cardiomyopathy by reducing lipid peroxidation and protein carbonylation. SA was administrated in a dose of 50 and 100mg/kg [Sabahi *et al*. 2021]. Based on [Karamać *et al.* 2005] a study that analyzed the potential of selected phenolic acids to scavenge free radicals, it was confirmed that SA has greater free radical scavenging activity compared to other acids due to the presence of two methoxy groups attached to the aromatic ring in positions 3 and 5. The antioxidative activity of SA, sinapic and caffeic acids were investigated under different temperatures (22-90°C) in sunflower oil. As the result, the antioxidant activity of sinapic and caffeic acids were higher than of SA. This is

even more interesting because both SA and sinapic acid belong to phenolic acids and as is commonly known, the activity of phenolic acids in removing free radicals depends on the presence of the number of hydroxyl groups attached to the aromatic ring of the benzoic or cinnamic acid molecule [Kumar and Goel 2019]. Syringic acid exerted anti-asthmatic effects by preventing the accumulation of inflammatory cells (eosinophil, neutrophil, macrophage, lymphocyte) and inflammatory markers (IL-4, IL-5, IL-13, and TNF-α) as well as by enhancing antioxidant markers, suppressing ROS, and controlling airway hyperresponsiveness in asthmatic mice model (doses: 25mg/kg and 50mg/kg, oral administration). Syringic acid treatment led to elevated levels of enzymatic and nonenzymatic antioxidants, including SOD, CAT, and GSH (doses: 25mg/kg and 50mg/kg, oral administration) [Li *et al*. 2019]. Belkheiri *et al.* [2010] investigated antioxidant and carbonyl scavenger capacities of a new syringic hydrazones using 3 assays: 1,1-diphenyl-2-picrylhydrazyl (DPPH), Trolox equivalent Antioxidant Capacity (TEAC) and inhibition of LDL oxidation and of superoxide anion generation. It has been shown that the tested new hydrazone drugs fulfill the role of both radical scavengers and carbonyls, and additionally prevent oxidative and carbonyl stress in the pathophysiology of aterosclerosis. Another study demonstrated antioxidant and anti-inflammatory effects of SA and syringaldehyd (SYD) on peripheral blood mononuclear cells (PBMCs) isolated from myocardial infarction patients (MI). PBMCs treated with SA and SYD of the following concetrations: 5μM, 25μM, 50μM, 100μM, had lower level of TNF-α, IL-6, NO, ROS, lipid level and also protein oxidation was decreased. An augmented antioxidant defense was also noted, in proportion to the concentrations of SA and SYD [Shahzad et al. 2020]. Adeyi *et al*. [2023] proved that SA and ascorbic acid (AA) potentially treat DMN-induced hepatic injury in rats when administrated orally at the following doses: 50mg/kg and 100mg/kg. After treating DMN-induced rats with SA and AA a significant reduction of ALT, AST, GPx, CAT, and SOD, as well as MDA, GSH, TNF-α, IL-1β, and NFkB levels was observed. Although both compounds were effective, SA had a better therapeutic outcome when compared to AA. SA has been also studied for its cytotoxic effect against human hepatoma HepG2 cell line. ROS level and apoptotic markers expression (caspase 3 and 9, cytochrome c, Apaf-1, Bax and p53) in HepG2 cells after SA (100μM) treatment were significantly lower [Gheena and Ezhilarasan 2019]. SA inhibited the activation of Nrf2 and ARE-dependent genes in methyl cellosolve (MCE)-induced rats. The level of endogenous antioxidants was also maintained thanks to the protective effect of SA (doses: 25, 50 and 75 mg/kg, oral administration). In MCE-induced rats treated with SA the levels of: NO, GSH, and activities of GPx, GST, SOD, and CAT were significantly increased. MDA and mRNA expressions of Keap1, NQO1, Nrf2, and HO-1, on the hand, were significantly decreased [Somade *et al.* 2023]. The pleiotropic nature of bioactive substances contained in plant raw materials, in addition to having a positive biological effect, also carries a certain risk of negative effects on the organism. The unfavorable effects are mainly attributed to compounds that are so-called secondary metabolites, which are

largely part of the defense mechanism of many plants [Maag *et al*. 2015]. Unfavorable risk probably worsens with pharmacological doses in prevention/treatment and supplementation and in genetic situations polymorphisms or drug interactions that increase bioavailability of the tested compounds. An important aspect are also genetic factors that directly determine the composition and content of the compounds in plant [Lambert *et al.* 2007]. The toxicity of bioactive substances contained in plants may affect many systems - respiratory, nervous, musculoskeletal or circulatory, leading to their paralysis, as well as on organs, for example, the liver [Galati *et al.* 2006] Natural products are rarely toxic to humans and animals, although sometimes their widespread use may cause toxic effects. Syringic acid does not have toxic effects in animals, but cases where it is toxic to other organisms have been reported [Srinivasulu *et al.* 2018]. High concentrations of SA have a toxic effect on the growth of cucumber seedlings by disturbing the homeostasis of rhizome microorganisms. Studies have shown that SA has a toxic effect on yeast cell growth [Yu and Matsui 1994, Zhou *et al*. 2014]. Bioactive plant ingredients should be the subject of future extensive animal studies. It is necessary to clearly understand the potential adverse effects of bioactive ingredients in the diet, including syringic acid. Only when such data are available, weighed against evidence of beneficial health effects, should a balanced assessment be made of the potential usefulness of these compounds in the prevention and treatment of disease.

Another limitation is that most of the studies discussed present short-term effects of SA. The results also show effects on selected disease entities. Further studies are needed to examine the long-term effects of SA. Extended studies on this compound should be conducted both on specific disease entities and on healthy organisms.

Conclusions

One of the basic causes of the development of civilization diseases is the current lifestyle, including diet. The current way of consuming is characterized, on the one hand, by a high intake of meat products, products of grain origin, sugar and dairy products, and on the other hand by a low consumption of vegetables, fruit, fish and meat from animals raised on pastures. Polyphenols constitute a group of the most common antioxidants, protecting our body against many diseases related to oxidative stress. Despite the fact that there is no research confirming that polyphenols in the diet are essential for humans, a growing number of studies suggest that consuming foods rich in polyphenols, such as fruits and vegetables, provide significant health benefits. One example of bioactive compounds, which has preventive properties is SA. It occurs naturally in many fruits and vegetables, e.g. olives, current, pumpkin pulp etc. It has a free radical scavenger, which results in antioxidant properties. Additional research is required to comprehensively explore the molecular mechanisms of natural compounds, both in treating and preventing lifestyle-related diseases. At the same time, it has to be mentioned that there is no recommendation for what dose of SA has

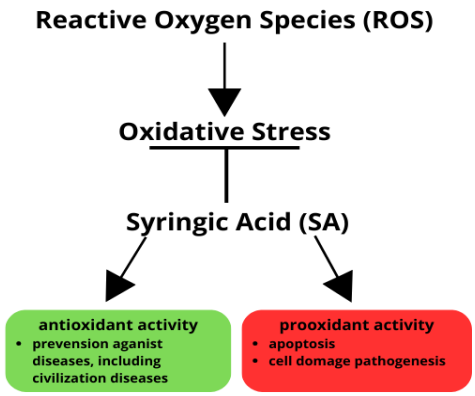

Fig. 6. Potentially influence of SA on oxidative stress.

a beneficial influence on the human body. The excess of SA may have adverse effects, such as a prooxidant impact (Fig. 6), but further investigations are necessary to extend current knowledge.

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