Investigational
Medicinal Chemistry & Pharmacology

Research Article Open Access

Pharmacological and molecular insights into β-glucan-rich *Saccharomyces cerevisiae var. boulardii*: *In vivo* and *in silico* protection against arsenic-induced redox and hematologic imbalance

Moses Blessing Thomas[1], Muankang Junior Tegha Kum[2], Orhonigbe Innocent[3], Ozougwu Vincent[4], Ogara Amaechi[5], Ugwuene Francis[6], Agwu Linus[7], Uhuo Emmanuel[8], Achi Ngozi[9], Onoyima Samson[10,11], Onoja Remiguis[12], Ike Mmesoma[13], Parker Elijah Joshua[14]*

Abstract

Background: Arsenic toxicity remains a major environmental and pharmacological concern in sub-Saharan Africa, with limited safe antidotes. Chronic exposure induces oxidative stress, hematologic dysfunction, and multi-organ injury through redox imbalance. *Saccharomyces cerevisiae* var. *boulardii* (SCb), a β-glucan-rich probiotic yeast, possesses antioxidant and immunomodulatory properties that may mitigate arsenic toxicity. This study combined *in vivo* and *in silico* approaches to elucidate the protective mechanisms of SCb against sodium arsenate-induced oxidative and hematologic alterations.

Methods: Thirty male Wistar rats were randomized into five groups (n = 6): control, arsenic only (100 mg/L), arsenic + SCb (500 mg/kg), arsenic + sodium thiosulfate (25 mg/kg), and SCb only. Treatments were administered orally for 28 days. Oxidative stress markers (malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT)) and hematologic indices (hemoglobin (Hb), Red blood cell (RBC), packed cell volume (PCV)) were evaluated. Major SCb bioactive compounds were docked against antioxidant enzymes (superoxide dismutase (SOD) and glutathione peroxidase (GPx)) using AutoDock Vina, while pharmacokinetic and drug-likeness properties were assessed using SwissADME.

Results: SCb exhibited no acute toxicity up to 6500 mg/kg. Arsenic significantly increased MDA and reduced CAT, SOD, PCV, and Hb (all $p < 0.05$). SCb co-treatment significantly improved CAT, SOD, PCV, and Hb when compared with arsenic alone ($p < 0.05$). Docking revealed strong binding affinities of 2,4-bis(1,1-dimethylethyl)-phenol and vanillic acid (–5.0 and –5.3 kcal/mol) with SOD and GPx, comparable to ascorbic acid. ADMET profiling demonstrated favorable pharmacokinetic properties.

Conclusion: β-glucan-rich SCb confers significant protection against arsenic-induced oxidative and hematologic toxicity via antioxidant enzyme modulation and stable ligand–protein interactions.

Keywords: Arsenic toxicity; β-glucan; molecular docking; oxidative stress; *Saccharomyces cerevisiae var. boulardii*

*Correspondence: Tel.: +2348037804687; E-mail address: parker.joshua@unn.edu.ng (Parker Elijah Joshua), E-mail: juniorkum@yahoo.com (Muankang, Junior Tegha Kum).

[1,2,4,10,13,14]Department of Biochemistry, University of Nigeria, Nsukka; [5]Department of Science Laboratory Technology, University of Nigeria, Nsukka; [6]Department of Medical Laboratory Science, Faculty of Allied Health Sciences, ESUT College of Medicine, ESUT, Enugu State; [3]Department of Biochemistry, Delta State University, Abraka, Delta State; [7]Department of Biochemistry, Federal University of Technology, Owerri, Imo State; [8,9]Department of Biochemistry, Michael Okpara University of Agriculture, Umidike, Abia State; [11]Department of Agricultural and Bio-system Engineering, Makerere University, Kampala, Uganda; [12]Veterinary Pathology and Microbiology, Faculty of Veterinary Medicine, University of Nigeria, Nsukka, Enugu State, Nigeria. Postal code (410001).

Other authors
E-mail: blessingumoh7809@gmail.com (Moses Blessing Thomas); E-mail: juniorkum@yahoo.com (Muankang, Junior Tegha Kum); E-mail: innocentorhonigbe@gmail.com (Orhonigbe Innocent); E-mail: Vincent.ozougwu@unn.edu.ng (Ozougwu Vincent); E-mail: Amaechi.ogara@unn.edu.ng (Ogara Amaechi); E-mail: fugwuene@yahoo.com (Ugwuene Francis); E-mail: linus.agwu@futo.edu.ng (Agwu Linus); E-mail: Emmanuel.uhuo@mouau.edu.ng (Uhuo Emmanuel);E-mail: achi.ngozi@mouau.edu.ng (Achi Ngozi); E-mail: samson.onoyima.pg90826@unn.edu.ng (Onoyima Samson); E-mail: Remigius.onoja@unn.edu.ng (Onoja Remiguis); E-mail: makuo.ike.2369947@unn.edu.ng (Ike Mmesoma Makuo).

Citation on this article: Thomas, MB, Tegha Kum, MJ, Innocent O, Vincent O, Amaechi O, Francis U, Linus A, Emmanuel U, Ngozi A, Samson O, Remiguis O, Mmesoma I, Joshua PE. Pharmacological and molecular insights into β-glucan-rich Saccharomyces cerevisiae var. boulardii: In vivo and in silico protection against arsenic-induced redox and hematologic imbalance. Investigational Medicinal Chemistry and Pharmacology (2026) 9(1):126; Doi: https://dx.doi.org/10.31183/imcp.2026.00126

Background

Arsenic contamination of drinking water is a pervasive global health challenge, affecting over 137 million people across more than 70 countries, with significant impacts in Asia and sub-Saharan Africa [1]. In Nigeria, arsenic is frequently detected in surface and groundwater, often exceeding WHO permissible limits, largely due to mining activities, agricultural runoff, and industrial waste disposal especially from major industrial zones [2,3]. Arsenic (As) contamination of drinking water is a public-health burden, and chronic exposure is often associated with multisystem toxicity, hepatic fibrosis, nephropathy, cardiovascular dysfunction, and anemia, primarily mediated through oxidative stress and disruption of antioxidant defense mechanisms [4, 5]. The pharmacologic hallmark of arsenic toxicity involves the overproduction of reactive oxygen species (ROS), leading to lipid peroxidation, DNA damage, and Suppression of enzymes such as superoxide dismutase (SOD) and catalyze (CAT) [6, 7, 8]. These biochemical alterations compromise erythropoiesis and hematologic balance [9, 10]. Current chelation therapies though effective for acute exposure are limited by nephrotoxicity, cost, and incomplete efficacy [11]. This necessitates exploration of safer, natural pharmacologic alternatives with both antioxidant and detoxifying capacities. These changes impair organ function and hematological stability, often leading to anemia and compromised immune competence [9]. Arsenic exposure is also known to harm blood, leading to significant changes in various blood parameters, including Packed Cell Volume (PCV), Red Blood Cell (RBC) count, and Hemoglobin (Hb) concentration [9,12]. Consequently, there is increasing interest in natural alternatives with antioxidant and detoxifying capacities. *Saccharomyces cerevisiae* var. *boulardii* (SCb) is a probiotic yeast containing β-1,3/β-1,6-glucans known for immunomodulatory and metal-binding properties [13]. β-glucans enhance antioxidant enzyme expression through Nrf2/HO-1 signaling, stabilize cellular membranes, and promote erythropoietic recovery [14]. Despite extensive biological studies, there is scarce molecular evidence explaining how SCb bioactive components interact with antioxidant proteins to mitigate arsenic-induced oxidative damage. The present study bridges this knowledge gap by combining *in vivo* physiological evaluation with *in silico* molecular docking analysis. Using sodium arsenite-exposed rats, we investigated the antioxidant and hemato-protective effects of β-glucan-rich SCb and computationally characterized the ligand–receptor interactions of its bioactive compounds with SOD and GPx. This integrated pharmacologic framework provides mechanistic insight into SCb's dual antioxidant–cytoprotective actions and identifies potential lead compounds for drug development against heavy-metal toxicity.

Methods

Chemicals and reagents

Sodium arsenite ($NaAsO_2$) was purchased from Merck & Co. (USA). β-glucan-rich *Saccharomyces cerevisiae* var. *boulardii* (FloraNorm®, Prisma Pharmaceutical Ltd., Nigeria) contained 250 mg of 5 billion live yeast cells with at least 19 mg β-1,3/β-1,6-glucans per capsule. Sodium thiosulfate was sourced from INEOS Group (London, UK). All other chemicals were of analytical grade

Experimental animals and study location

Thirty healthy male Wister rats (10-12 weeks, 120 – 140 g) were obtained from the University of Nigeria Nsukka. The rats were housed under controlled temperatures (25 ± 4°C) and humidity (65 ± 5%) with a 12-hour light/dark cycle, fed with standard growers` diet (Top Feed Ltd, Nigeria), and given water ad libitum. A total of thirty (30) adult male Wistar rats weighing (120 – 140 g) were used for this study. The animals were kept in rat cages and maintained under standard laboratory conditions. The animals were acclimatized for two weeks, fed on rat pellets and allowed free access to clean water *ad libitum*. The weights of the experimental rats were measured before and after the treatment. The study was conducted in compliance with institutional ethical guidelines Ethical clearance (RF Nº: UNN/FBS/25/PG/MSC/22/95988) was obtained from the University of Nigeria Nsukka ethical review board.
Body weight gain = $Final\ body\ weight\ (g) - Initial\ body\ weight\ (g)$

Acute toxicity studies

Acute oral toxicity was assessed following OECD (2008) guidelines. Eighteen (18) rats were divided into six groups (n = 3). Phase I groups received SCb at 130, 650, and 1300 mg/kg b.w for 14 days. Phase II groups received single doses of 2900, 3250 and 6500 mg/kg b.w. the animals were monitored for mortality, clinical signs, and weight changes for 14 days.

Experimental design

After an acclimatization period of two weeks, the animals were separated randomly into 5 groups (n = 6 rats). Group 1 (normal control): received distilled water; Group 2 (Toxic control): 100 mg/L of Sodium arsenate; Group 3 (Arsenic + SCb): 100 mg/L of Sodium arsenate and 500 mg/kg b. w. SCb; Group 4 (Arsenic + STS): 100 mg/L of Sodium arsenate and 25 mg/kg b.w. of Sodium thiosulphate, and Group 5 (SCb only): (administered 500 mg/kg b.w. SCb. All treatments were given orally for 28 days and body weights of the different groups measured at the beginning and end of the experiment.

Sample collection

At the end of the experimental period, the rats were fasted overnight and about 4 mL of blood samples were collected from the retro orbital plexus of each rat into a plain tube and Ethylenediaminetetraacetate (EDTA) tubes, centrifuged at 10000rmp for 10 minutes and aliquoted to obtain serum for biochemical analysis. Serum was stored at 2 – 8ºC. Subsequently, the rats were sacrificed by cervical dislocation under ketamine (60 mg/kg, i.m) and xylazine (10 mg/kg, i.m) anesthesia. Then the liver and kidneys of the rats were collected, washed in phosphate buffer and wrapped in aluminum foil then placed in polyethylene bags for further analysis. The tissues were kept at temperature −20°C for analysis.

Biochemical analysis

Antioxidant analysis

Tissues were weighed, homogenized in 1/10 volumes of cold Tris buffer (pH 7.4) using an utra Turrax T-25, and centrifuged at 3500 rmp for 15 minutes at 4°C (Nuve NF 800R, Turkey). The supernatant was collected and used for antioxidant/oxidant analysis as described by Sarlsilmaz et al. (2000).

MDA, a marker of lipid peroxidation, was quantifies using the thiobarbituric acid reactive substances (TBARS) method of [15] with Elabscience® MDA kit (Elabscience®– Houston, Texas, USA). Briefly, in the blank tube 0.2ml mL of absolute ethanol was added into test tubes T1. For the standard 0.2 mL of 10 nmol/mL standard was added into test tubes T2. while the sample tubes were added 0.2 mL of supernatant of test samples into numbered test tubes T3. For the control, 0.2 mL of tested sample was added into numbered test tubes T4. A 0.2 mL of clarification was added into each test tube followed by the addition of 3 mL of acid reagent. Thereafter, 1 mL of chromogenic application solution was added into blank test tube T1, standard tube (T2) and test sample tubes (T3) while 1 mL of 50% acetic acid was added to the control tubes (T4). The tubes were vortexed, and their mouth fastened with plastic film, pricked with a needle, then incubated at 95-100℃ for 40 min. the tubes were then cooled to room temperature with running water, and centrifuged at 10000 rmp for 10 min. After that, 3 mL of the supernatant from each tube was measured into a cuvette and read with the spectrophotometer nm (Spectrum Lab 23A, HME Global Ltd, England) at 532 nm.

Catalase activity was determined by Elabscience® catalase (CAT) assay kit which measures the decomposition of hydrogen peroxidation, with residual H_2O_2 reacting with ammonium molybdate to form a yellow complex [16]. Briefly, 1 ml of reagent 1 working solution was added to all sample test tubes and the control test tube, followed by 50 µl of serum added to the sample test tubes followed by 50 µl of distilled water to the control test tube and incubated at 37°C for 5 minutes. A 0.1ml volume of reagent 2 was added to sample test tubes and the control test tube and allowed to stand for 1 minute. A 1 mL and 0.1 mL of Reagent 3 and reagent 4, respectively, were then added to all test tubes. And incubated for 10 minutes at 37°C. The absorbance of the samples and control against distilled water blank was read at 405 nm (Spectrum Lab 23A, HME Global Ltd, England).

SOD activity was assayed with the Elabscience kit, based on inhibition of nitrite formation by superoxide radicals generated in the xanthine-xanthine oxidase system [17]. Serum samples incubated with reagents were processed at 37ºC, reacted with chromogenic solution, and the absorbance was recorded at 550 nm (Spectrum lab 23A). Briefly, A clean 5 ml glass test tubes for samples and a control were labelled and then a 50 µl of reagent 1 working solution was added to all sample test tubes and the control test tube, followed by 50 µl of serum added to the sample test tubes and 50 µl of distilled water added to the control test tube and incubated at 37°C for 5 minutes. A 50 µl of reagent 2 was added to sample test tubes and the control test tube and was allowed to stand at 37°C for 1 minute. A 50 µl Reagent 3 and reagent 4 were then added step wise to all sample test tubes and the control test tube and incubated for 40 minutes at 37°C. After incubation period, 1 ml of chromogenic agent working solution was added to all the all-sample test tubes, vortex mixed properly and left to stand at room temperature for 10 minutes. The absorbance of the samples and control was read against blank at the 550 nm (Spectrum Lab 23A, HME Global Ltd, England).

Hematologic assays

Packed cell Volume (PCV) was measured using the microhematocrit method [18], a well-mixed anticoagulated whole blood was allowed to enter capillary hematocrit tubes until it was approximately 2/3 filled with blood. and centrifuge at 1000 rpm (NF 800R, Nuve, Turkey) for 15 minutes. The space occupied by the RBCs is measured and expressed as percentage of the whole blood volume.

Hemoglobin concentration was measured by the cyanmethemoglobin method [18]. EDTA- treated blood (0.02 mL) was diluted with Drabkin`s reagent, incubated at 25ºC for 10 min to form cyanmethemoglobin, and the absorbance was read at 540 nm (Spectrum lab 23A)

Erythrocyte count (Red blood cell counts) was performed by diluting whole blood with isotonic solutions (Hayem`s solution, Gower`s solution, or 0.85% NaCl) to prevent hemolysis and counting erythrocytes in a hemocytometer under light microscopy [18].

Molecular docking

Molecular Docking studies were carried out to further investigate the protective effects of SCb against oxidative stress (antioxidant properties). The bioactive compounds of *Saccharomyces cerevisiae* var. *boulardii* reported by [19] alongside an antioxidant standard drug (ascorbic acid), were downloaded from Pubchem data base in SDF file. These SDF files were converted to PDB using Pymol software prior to molecular docking studies. Similarly, the crystal structure of the antioxidant implicated proteins [20], superoxide dismutase (SOD: 1CB4) and glutathione peroxidase (GPx 2P31), were obtained from the Protein Data Bank (PDB). The protein structures were refined using Discovery studio software. The 3D format of the bioactive compounds (ligands) and standard drugs were downloaded from Pubchem data base in SDF file. These SDF files were converted to PDB using Pymol software prior to molecular docking studies. The 3D structure of Beta-glucan (Figure 1) as ligand downloaded via PubChem with file format sdf. Ligands are minimized through open babel [21].

To know the types of chemical bonds formed, we analyzed molecular interactions on the molecular complexes generated by docking simulations using Discovery Studio software version 16. 1. 0. Numerous chemical bonds, including hydrogen, hydrophobic, PiAlkyl, Van der Waals, and electrostatic, were depicted in two-dimensional structures. The complex 3D structure of the mooring simulation results was illustrated using the PyMol structural selection and coloring software. Sticks, cartoons, ribbons, spheres, and surfaces formed the structure displayed by the software [21].

Binding affinity energy

The target (protein) and the ligands were prepared prior to molecular docking using AutoDock tools and this involved, addition of charges, polar hydrogen and generation of grid boxes. The active site investigation was performed using Site finder of Molecular Operating Environment. A site-specific molecular docking was performed using AutoDock Vina Software [22], targeting key active site residues with the following grid coordinates, SOD (center_x = 15.003, center_y = 84.041, center_z = 16.757) and GPx (center_x = -7.740, center, y = -1.697, center_z = -42.952). The 2D diagrams and the 3D (surface) views of the protein-ligand interactions renderings were done using Discovery studio software and Pymol software [23] respectively, While the Pharmacokinetic and Drug likeness (ADMET) properties, were predicted using SWISSADME.

Statistical analysis

Data were entered into Microsoft excel and analyzed using SPSS version 23. One-way ANOVA was used to test group differences, followed by followed by Duncan multiple range Post hoc test. Results were expressed as mean ± standard deviation and significant differences were considered at $p < 0.05$.

Results

Acute toxicity for β- glucan saccharomyces cerevisiae var. boulardii (SCb)

Based on the results obtained presented Table 1, Group 1, 2 and 3 experienced no cases of mortality, behavioral changes or body weight changes upon administration of 130, 650, and 1300 mg/kg b.w. the pure *Saccharomyces cerevisiae* var. *boulardii* in Phase I. Similar results were obtained in phase II upon administration of 2900, 3250 and 6500 mg/kg b.w. *Saccharomyces cerevisiae* var. *boulardii* to Group 1, 2 and 3 respectively (Table 1).

Effect of β-glucan macrofungal (Saccharomyces cerevisiae var. boulardii) on body weight

Arsenic exposure (Group 2) significantly reduced final body weight compared with controls (142.90 + 4.26 Vs. 144.37 + 3.76 g, $p < 0.05$). SCb co-treatment (Group 3) preserved body weight (141.00 + 1.35 g), while SCb alone (Group 5) promoted significant weight gain (145.70 + 4.51 g, $p < 0.05$) as shown in Table 2.

Effects of β-glucan-rich macrofungi (saccharomyces cerevisiae var. boulardii) on arsenic-induced changes in oxidative stress status in Wistar rats

Arsenic significantly increased MDA and reduced CAT and SOD relative to control group ($p < 0.05$). SCb restored CAT (57.05 + 16.88 U/g vs. 55.05 + 7.18 in arsenic group, $p < 0.05$) and SOD (6.61 + 1.38 vs 6.29 + 0.65, $p < 0.05$), with partial normalization of MDA as shown in Table 3.

Effects of beta-glucan-rich macrofungi (Saccharomyces cerevisiae var. boulardii) on arsenic-induced packed cell volume, red blood counts and hemoglobin changes in Wistar rats

Arsenic reduced PCV (35.33 + 2.52%), Hb (8.15 + 0.96 mcL), and RBC (6.60 + 0.61 g/dL). SCb co-treated Group 3 significantly improved (39.33 + 1.16%, Hb (9.74 + mcL) and RBC (6.78 + 0.47 g/dL) compared with arsenic alone ($p < 0.05$) as shown in Table 4.

Binding energies of bioactive compounds of Saccharomyces cerevisiae var. boulardii against antioxidant implicated proteins (superoxide dismutase (SOD) and glutathione peroxidase (GPx))

Bioactive compounds of *Saccharomyces cerevisiae* var. *boulardii* demonstrated great binding affinities against targeted antioxidant implicated proteins (SOD and GPx), when compared to the standard drug ascorbic acid. From the study, 2,4-bis(1,1-dimethylethyl)-phenol and Vanillic acid exhibited highest binding affinity against SOD and GPx respectively with binding energies of -5.0 and -5.3 kcal/mol when compared to ascorbic acid standard drug -5.2 and -5.5 kcal/mol for SOD and GPx respectively as shown in Table 5.

2D and 3D interaction of bioactive compounds of Saccharomyces cerevisiae var. boulardii against antioxidant implicated proteins (SOD and GPx)

The compound 2,4-bis(1,1-dimethylethyl)-phenol, was the top scoring bioactive compound of *Saccharomyces cerevisiae* var. *boulardii* against Superoxide dismutase showed strong interactions through hydrogen bonding amongst other forces of attraction with key active site residues such as His 78, Pro 60, Thr 133, Asn 63, His 61, and Lys 68. Ascorbic acid standard drug was also found in interaction with same residues. Similarly, vanillic acid being the top scoring compound against glutathione peroxidase, equally interacted strongly alongside ascorbic acid standard drug with Arg 105, Tyr 43, Lys 42, Arg 34, Met 114, Phe 112, and Val 38. On the other hand, the 3D structures of the targets in surface view highlighted the nature of the binding pocket/active sites as highlighted in white colour (Figure 2).

Pharmacokinetic and drug likeness properties (ADMET) of studied compounds drug

The phamacokinetics and drug likeness properties (ADMET) of the studied compounds of *Saccharomyces cerevisiae* var. *boulardii* are presented in Table 6. All studied compounds demonstrated great features such as obeying Lipinski rule, exhibiting high gastrointestinal absorption rate, bioavailability, high water solubility and acceptable molar refractivity index.

Discussion

The findings demonstrate a robust pharmacologic role of β-glucan-rich *S. cerevisiae* var. *boulardii* in mitigating oxidative and hematologic damage caused by sodium arsenite. The absence of mortality up to 6500 mg/kg confirms SCb's high safety margin, consistent with prior probiotic toxicology reports [24]. This study demonstrates that β-glucan-rich SCb exerts strong protective effects against sodium arsenite-induced oxidative and hematological toxicity in Wistar rats. Consistent with previous research which demonstrates arsenic exposure significantly elevated MDA and suppressed CAT and SOD activity, reflecting oxidative stress-induced cellular damage [6,8]. The concomitant reduction in PCV, Hb, and RBC confirms arsenics hematotoxic effects, largely mediated by oxidative injury to erythrocyte membranes and impaired hematopoiesis [25]. Importantly, SCb supplementation restored antioxidant defenses and hematological indices. B-glucans are known to activate Nrf2/HO-1 signaling pathway, which upregulates antioxidant enzymes, and modulates immune responses [26]. Our findings align with reports that β-glucans enhance catalase and SOD activities, thereby neutralizing ROS and mitigating lipid peroxidation. The Partial elevation of MDA in treated groups may reflect increased lipid turnover during repair processes, a phenomenon requiring further mechanistic investigation [27]. The haemato-protective effects of SCb likely derived from both its antioxidant activity and its immunomodulatory properties, which enhance erythropoiesis and protect red blood cell integrity [28,29]. Restoration of Hb and PCV suggests improved oxygen transport capacity, crucial for mitigating arsenic-induced hypoxia. Compared with sodium thiosulphate, a conventional chelating agent, SCb showed comparable or superior effects in restoring antioxidant enzyme activity and hematological function. This highlights SCb`s potential as a safe, natural adjunct or alternative for managing chronic arsenic toxicity. Molecular docking studies complemented physiological data by revealing strong interactions between SCb-derived compounds and antioxidant enzymes [30]. 2,4-bis(1,1-dimethylethyl)-phenol and vanillic acid exhibited binding affinities comparable to ascorbic acid, forming hydrogen and hydrophobic bonds with catalytic residues of SOD (His78, Thr133) and GPx (Arg105, Tyr43, Phe112). These interactions suggest stable ligand-protein complexes capable of enhancing enzymatic stability and redox cycling [24, 30, 31]. The

ADMET profiling indicated high gastrointestinal absorption, water solubility, and compliance with Lipinski's rule of five, supporting oral bioavailability and favorable pharmacokinetics, key features for nutraceutical or drug development. Such properties strengthen SCb's candidacy as a natural pharmacologic agent with multi-target antioxidant potential. Integrating *in vivo* and *in silico* results suggest that SCb exerts protection through: (i) direct ROS scavenging via β-glucan and phenolic constituents, (ii) upregulation of antioxidant enzymes through receptor-ligand stabilization of SOD and GPx, and (iii) enhancement of erythropoietic signaling to counter anemia. These pharmacologic mechanisms collectively attenuate oxidative burdens and restore hematologic homeostasis, providing a mechanistic rationale for SCb's therapeutic promise in chronic heavy-metal exposure

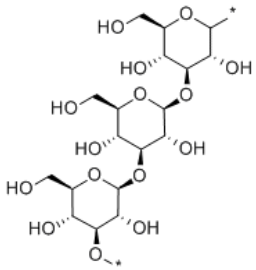

Figure 1. Chemical Structure of Beta-glucan.

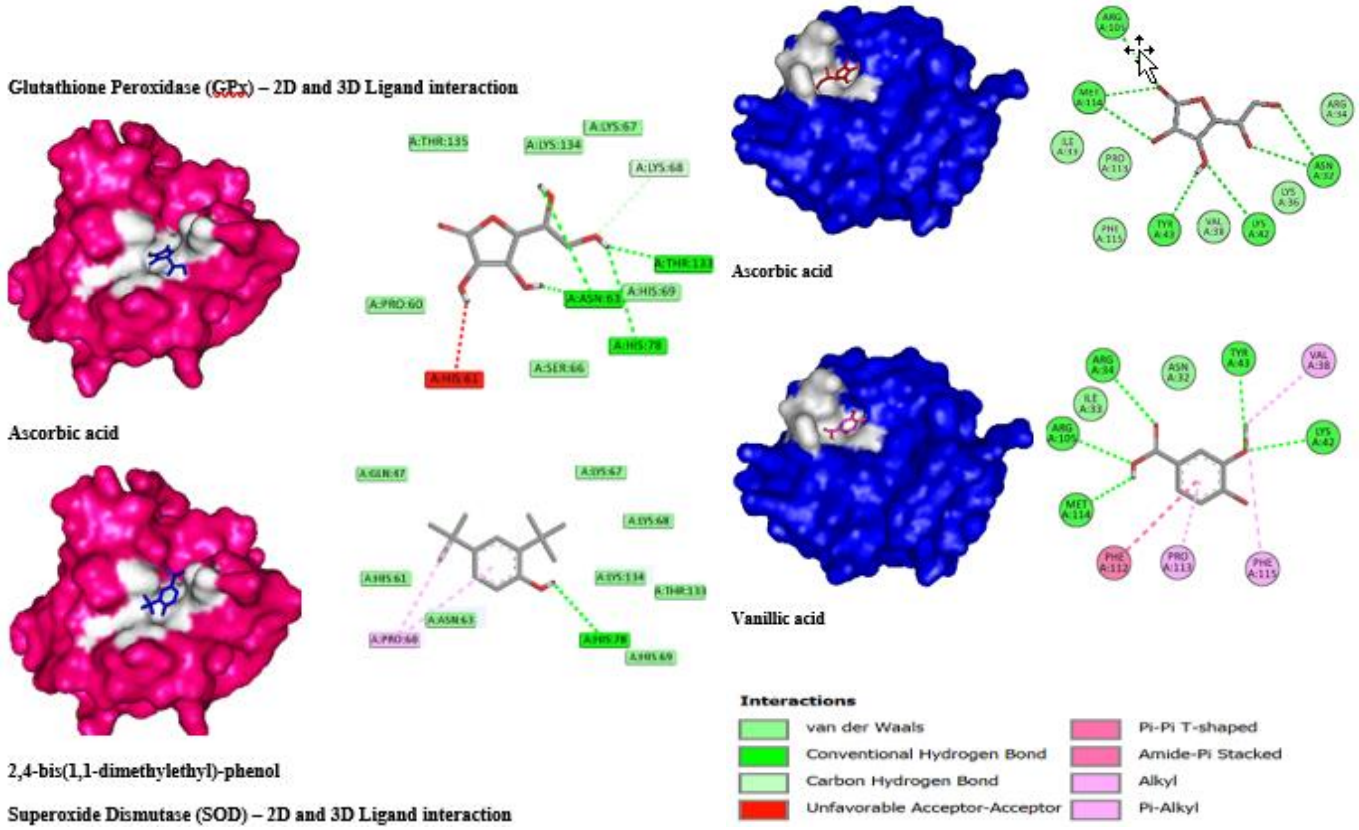

Figure 2. 2D and 3D interaction of bioactive compounds of *Saccharomyces cerevisiae* var. *boulardii* against antioxidant implicated proteins (SOD and GPx)

Table 1. Acute toxicity test results for *Saccharomyces cerevisiae* var. *boulardii*: mortality, behavioral changes, and body weight effects in phases I and II.

Groups	Dose (mg/kg b.w.)	Mortality	Behavioral changes	Body weight changes
Phase I				
Group 1	130	0/3	Nil	NS
Group 2	650	0/3	Nil	NS
Group 3	1300	0/3	Nil	NS
Phase II				
Group 1	2900	0/3	Nil	NS
Group 2	3250	0/3	Nil	NS
Group 3	6500	0/3	Nil	NS

*NS = not significant

Table 2. Effects of β-glucan-rich macrofungi (*Saccharomyces cerevisiae var. boulardii*) and distilled water on body weight of sodium arsenite-induced Wistar rats.

Treatment Group	Body Weight (g)	
	Initial Body Weight (g)	Final Body Weight (g)
Group 1 (Normal Control)	123.17 ± 3.26^{a}	144.37 ± 3.76^{b}
Group 2 (Toxic Control 100 mg/L Sodium Arsenite)	123.50 ± 0.95^{a}	142.90 ± 4.26^{ab}
Group 3 (100 mg/L Arsenic + 500 mg/kg SCb)	123.37 ± 2.97^{a}	141.00 ± 1.35^{a}
Group 4 (100 mg/L Arsenic + 25 mg/kg b.w Sodium thiosulphate)	123.97 ± 3.40^{a}	142.63 ± 4.70^{ab}
Group 5 (500 mg/kg SCb)	123.73 ± 3.27^{a}	145.70 ± 4.51^{b}

Results are expressed as means ± standard deviation (n = 3). Mean values with different superscript a, b down a column (Groups) are considered significant ($p < 0.05$).

Table 3. Oxidative stress markers in Wistar rats following arsenic exposure and β-glucan-rich macrofungi (*Saccharomyces cerevisiae* var. *boulardii*) treatment

Treatment Group	Oxidative Stress Parameters		
	MDA (nmol/mg)	Catalase Activity (U/g/Tissue/min)	SOD Activity (U/g/Tissue/min)
Group 1 (Normal Control)	18.43 ± 0.57^{a}	83.01 ± 14.50^{cb}	8.57 ± 1.03^{b}
Group 2 (Toxic Control 100 mg/L Sodium Arsenite)	22.17 ± 1.12^{ab}	55.05 ± 7.18^{ab}	6.29 ± 0.65^{a}
Group 3 (100 mg/L Arsenic + 500 mg/kg SCb)	25.74 ± 3.18^{b}	57.06 ± 16.88^{b}	6.61 ± 1.38^{a}
Group 4 (100 mg/L Arsenic + 25 mg/kg b.w Sodium thiosulphate)	25.15 ± 6.10^{b}	54.92 ± 11.37^{a}	6.48 ± 1.31^{a}
Group 5 (500 mg/kg SCb)	25.51 ± 5.19^{b}	56.04 ± 8.21^{b}	6.24 ± 0.99^{a}

Results are expressed as means ± standard deviation (n = 3). Mean values with different superscript a, b down a column (Groups) are considered significant ($p < 0.05$).

Table 4. Effects of β-glucan-rich microfungi (*Saccharomyces cerevisiae var. boulardii*) on arsenic induced changes in some hematological indices in Wistar rats

Treatment Group	Hematological Indices		
	PCV (%)	Hb (mcL)	RBC (g/dL)
Group 1 (Normal Control)	43.33 ± 1.53^{b}	12.33 ± 2.26^{b}	7.21 ± 2.22^{b}
Group 2 (Toxic Control 100 mg/L Sodium Arsenite)	35.33 ± 2.52^{a}	8.15 ± 0.96^{ab}	6.60 ± 0.61^{a}
Group 3 (100 mg/L Arsenic + 500 mg/kg SCb)	39.33 ± 1.16^{ab}	9.74 ± 1.79^{ab}	6.78 ± 0.47^{a}
Group 4 (100 mg/L Arsenic + 25 mg/kg b.w Sodium thiosulphate)	39.33 ± 1.53^{ab}	9.82 ± 1.62^{a}	6.23 ± 1.10^{a}
Group 5 (500 mg/kg SCb)	39.67 ± 1.53^{ab}	9.25 ± 0.89^{b}	7.02 ± 1.44^{b}

Results are expressed as means ± standard deviation (n = 3). Mean values with different superscript a, b down a column (Groups) are considered significant ($p < 0.05$).

Table 5. Binding energies of bioactive compounds of Saccharomyces *cerevisiae* var. *boulardii* against antioxidant implicated proteins (SOD and GPx)

Compounds	Binding Energies SOD (PDB ID: 1CB4)	Binding Energies GPx (PDB ID: 2P31)
2,4-bis(1,1-dimethylethyl)-phenol	-5.0	-5.1
Citric acid	-4.6	-5.0
Hydroxycinnamic acid	-4.7	-4.8
Malic acid	-4.2	-4.5
Fumaric acid	-3.9	-4.1
Hydroxylamine	-2.5	-2.8
Vanillic acid	-4.4	-5.3
Vitamin B6	-4.9	-5.2
Ascorbic acid (Standard Drug)	-5.2	-5.5

Table 6. Pharmacokinetic and drug likeness properties (ADMET) of studied compounds drug

Parameters	Ascorbic acid (Std drug)	Citric acid	Hydroxycinnamic acid	Malic acid	Fumaric acid	Hydroxylamine	2,4-bis(1,1-dimethylethyl)-phenol	Vanillic acid	Vitamin B6
Phytochemical Properties									
Molecular formular	C6H8O6	C6H8O7	C9H8O3	C4H6O5	C4H4O4	-	-	C8H8O4	C8H10NO5P--
Molecular weight(g/mol)	176.12	192.12	164.16	134.09	116.07	-	-	168.15	231.14
Num. H-Bond acceptor	6	7	3	5	4	-	-	4	6
Num. H-Bond donor	4	4	2	3	2	-	-	2	1
Molar refractivity	35.12	37.47	45.13	26.05	24.41	-	-	41.92	50.17
Lipophilicity $CLogP_{o/w}$ value	-1.42	-1.51	1.26	-1.00	-0.35	-	-	1.08	0.17
Water solubility	Highly Soluble	Highly Soluble	Soluble	Highly Soluble	Very Soluble	-	-	Soluble	Very Soluble
Druglikeness									
Obeys Lipinski rule?	Yes	Yes	Yes	Yes	Yes	-	-	Yes	Yes
No Verber violations	Yes	Yes	Yes	Yes	Yes	-	-	Yes	Yes
Bioavailability score	0.56	0.56	0.85	0.56	0.85	-	-	0.85	0.56
Pharmacokinetics									
GI absorption	High	Low	High	High	High	-	-	High	High
BBB permeant	No	No	Yes	No	No	-	-	No	No
P – gp substrate	No	No	No	No	No	-	-	No	No
CYP1A2 inhibitor	No	No	No	No	No	-	-	No	No
CYP2C19 inhibitor	No	No	No	No	No	-	-	No	No
CYP2A9 inhibitor	No	No	No	No	No	-	-	No	No
CYP2A6 inhibitor	No	No	No	No	No	-	-	No	No
CYP3A4 inhibitor	No	No	No	No	No	-	-	No	No
Log K_p (cm/s)(skin permeation)	-8.54	-8.69	-6.26	-8.01	-7.25	-	-	-6.31	2.40

Conclusion

This study provides experimental and preclinical evidence that β-glucan-rich *Saccharomyces cerevisiae var. boulardii* through the bond interaction between Beta-glucan and sodium arsenite which was strong, showing its protective effect against sodium arsenite-induced oxidative stress and hematological dysfunction in Wister rats. By enhancing antioxidant enzyme activities and restoring hematological indices, SCb offers a promising natural intervention for populations at risk of arsenic exposure. Future research should explore molecular mechanisms, dose optimization, and translational applicability in human populations.

Abbreviations

As: Arsenic
b.w: Body weight
CAT: Catalase
EDTA: Ethyline Diamine Tetra-Acetic Acid
GPx: Glutathione peroxidase
Hb: Hemoglobin
MDA: Malondialdehyde
PCV: Packed cell volume
PDB: Protein Data Base
RBC: Red Blood Cell
SCb: *Saccharomyces cerevisiae var boulardii*
SOD: Superoxide Dismutase
STS: Sodium thiosulphate
TBARS: Thiobarbituric reactive substances

Authors' Contribution

MB participated in designing and carrying-out the experiment, MJTK, participated in writing and reviewing of the manuscript, OIO, OVEO, OAL, UFO participated in review and following up the writing of the manuscript, ALO, UEN, ANK, OSE participated in molecular analysis and review of the manuscript, RI and IMI participated in carrying out the experiment, PEJ contributed in designing and carrying out the experiment and in revision of the manuscript.

Acknowledgments

None

Conflict of interest

The authors declare no conflict of interest

Article history:

Received: 18 January 2026
Received in revised form: 4 March 2026
Accepted: 17 March 2026
Available online: 17 March 2026

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