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Potential Therapeutic Phytochemicals from *Putranjiva roxburghii* Leaf Targeting Glucose-6-Phosphate Dehydrogenase in Cancer

Lubna Kanwal[1*], Saba Asghar[2], Arooj Haer[3], Vishal Haer[4]

[*1,2,3,4]*Department of Zoology, University of Okara, Okara, Pakistan*

[*1]lubna.kanwal@uo.edu.pk

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Corresponding Author: *
Lubna Kanwal

Abstract

Putranjiva roxburghii is a medicinal plant that has good anti-inflammatory, anticancer, antimicrobial and antioxidant effects. The focus of the current research was to identify the biologically active constituents of the methanolic leaf extract of P. roxburghii, and to determine the modulatory capacity of these components on glucose-6-phosphate dehydrogenase (G6PD), which is one of the key enzymes, which contributes to the development of cancer. The identification of phytocompounds in the P. roxburghii methanolic leaf extract was carried out by gas chromatography-mass spectrometry (GC-MS). The Swiss ADME web tool was used to determine the pharmacokinetics of each compound. The findings indicated complete compliance with Lipinski Rule of Five devoid of violation, and good oral bioavailability and drug-like properties. Moreover, the virtual screening tool PyRx was used to discover the binding affinity with glucose-6-phosphate dehydrogenase by molecular docking. Discovery Studio viewer was used to analyze interactions. The docking outcomes indicated that a number of phytochemicals possess very high affinities to the active site of G6PD. Having a docking score of -6.9 kcal/mol, 20-acetoxy was the compound that had the highest binding affinity on the screened compounds, followed by 2,2'-methylene bis / Dichlorophene (-6.8 kcal/mol), Phthalic acid (-6.7 kcal/mol), Phytol (-6.4 kcal/mol), Sinapyl alcohol (-6.3 kcal/mol), and Benzeneacetic acid (-6.1 kcal/mol). The findings show that the leaf extract of Putranjiva roxburghii contains bioactive constituents which may regulate glucose-6-phosphate dehydrogenase with a high probability of application in cancer control, but additional experimental research is required to establish the therapeutic effect of the identified compounds.

1. Introduction

Plants are the major source of numerous medicines and they are very essential to the health of the human being and other animals. There is a great number of herbs and plants that are popular in terms of their healing and therapeutic properties. Medicinal plants are on the rise in the healthcare system to treat human beings and animals (Ur Rehman *et al.*, 2021). There is a tendency among scientists to focus on the healing properties of plant extracts in reducing inflammation that is significant in chronic disorders such as arthritis, heart disease, and cancer (Alajeeli *et al.*, 2023). *Putranjiva roxburghii* is a traditional medicine that is part of the treatment of common diseases such as fever, cold, cough, headache, and inflammation (Naik *et al.*, 2023). *Putranjiva roxburghii* is used in herbal remedies, Unani medicine, and Ayurvedic medicine, particularly the leaf extract and seed oil. Its extract is used traditionally as a treatment of elephantiasis (Sudha Bai *et al.*, 2019).

P. roxburghii seed extract demonstrated high-level antibacterial actions and great glycemic control

capabilities (Joy *et al.,* 2022). Phytocompounds refer to universal chemical compounds found in herbs, which are bioactive and benefit human health as antioxidants, antimicrobials, anti-inflammatory, and anti-cancer targets (Aleman *et al.,* 2022). The many varieties of phytonutrient sources are also renewable to investigate food and biological actions (Xiao *et al.,* 2019). The *Putranjiva roxburghii* plant is a source of alkaloids, flavonoids, triterpenoids, phenols, phytosterols, saponins, fats, and fixed oil, as well. The alkaloids are present in all extracts other than the petroleum extract (Dar *et al.,* 2018).

Cancer is a disease that is brought about when the genes or the environment causes the cells to grow in abnormal ways. Such cells may occasionally reach other areas of the body (Saini *et al.,* 2020). This occurs when some genes that enable the growth of the cell are switched on or those that prevent tumor are switched off. Consequently, the cancer cells escape the normal processes that regulate the cell division and death (Sarkar *et al.,* 2013). The growth of the tumors can be slowed down by attacking the proteins being influenced by the major mutations. Such issues as DNA repair such as BRCA1 and BRCA2 proteins predispose certain organs to cancer (Gatenby *et al.,* 2017). The cancer may also use the immune cells by sending signals to the immune cells which may lead to the growth of the tumor cells (Lu *et al.,* 2006). There is a complex association between the immune system and tumors where the system is able to both combat and promote cancer. The variations that occur in tumors and the dissemination (metastasis) of the tumor significantly influence the development of cancer (Paul *et al.,* 2019). A significant role is played by DNA methylation; decreased DNA methylation triggers the expression of some genes which contribute to the development of cancer. With p53, it is crucial in cancer since its inactivation is associated with stress and aging (Olivier *et al.,* 2010).

Glucose-6-phosphate dehydrogenase is a cytoplasmic enzyme which is involved in the production of NADPH in metabolism. G6PD leads to the production of glutathione that has the potential to diminish the extent of harm done by reactive oxygen species (ROS) (Li *et al.,* 2020). G6PD has an influence on proteins that regulate cell cycle, which influences cell growth and survival. The G6PD activity was elevated in the colon cancer cells in particular phases of the cell cycle, particularly in the later stages of G1 and S (Yang *et al.,* 2021). The overexpression of G6PD may also affect the repair of DNA and the proliferation of cells, as well as cancer development, such as the invasive and metastatic events (Song *et al.,* 2022). Unusual cell proliferation and excessive pentose phosphate pathway (PPP) are typical of cancer of the lung and liver, pancreas and leukemia. It is the oxidative arm of PPP that is critical towards redox equilibrium by generating NADPH to synthesize fatty acids, cholesterol, and reduced glutathione (GSH) (Hong *et al.,* 2018). PPP is essential to help cancer cells grow rapidly to synthesize DNA material, and to balance their redox (Song *et al.,* 2022). Therefore, to find natural G6PD modulators would be an acceptable intervention towards cancer treatment.

Even though research has been performed on the phytochemistry and bioactivity of *P. roxburghii* seed (Joy *et al.,* 2022; Dar *et al.,* 2018), not much research has been done on the chemical constituents of methanolic *P. roxburghii* leaf extract and how it can interact with cancer targets like glucose-6-phosphate dehydrogenase. The current study was aimed at filling this research gap by providing an in-silico investigation of *Putranjiva roxburghii* methanolic leaf extract. The main objectives of GC-MS analysis include discovering phytocompounds of the extract, model the drug-likeness and pharmacokinetic properties with SwissADME tool, and quantify the binding affinities and lead molecules to treat cancer by means of molecular docking with glucose-6-phosphate dehydrogenase. The results demonstrate that leaves of *P. roxburghii* can serve as new source of treatment against cancer.

2. Materials and Methods

2.1. Plant collection and identification

Leaves of *Putranjiva roxburghii* were collected from different areas of the University of Okara (Punjab,

Pakistan). The plant material was identified by a taxonomist at the Department of Botany, and a voucher specimen has been deposited in the departmental herbarium for future reference.

2.2. Extract preparation

Fresh leaves were washed thoroughly, then air dried in a shady area until they completely dried out. After drying, the leaves were ground using an electric grinder until they formed a coarse powder, then sieved to remove any large pieces. A portion (50 g) of the leaf powder was weighed and dissolved in 75% methanol to create a solution of 1 g of leaf powder per 10 ml of methanol. The resulting solution was placed into a conical flask and then mixed on an orbital shaker at 250 RPM at room temperature (24 °C), for a period of 72 hours. After mixing, the solution was filtered through Whatman filter paper No. 1. After drying the extract was stored at 4 °C until required (Nauroze *et al.*, 2023).

2.3. Gas Chromatography-Mass Spectrometry (GC-MS) analysis

The gas chromatography-mass spectrometry analysis of the methanolic leaves extract of *P. roxburghii* showed diverse bioactive compounds. The GC-MS instrument used Agilent model GC 7890B and MS 5977A together with a nonpolar DB 5MS column. The column dimensions measured 30 mm length and 0.25 mm diameter and 0.25 µm film thickness. The system used helium as carrier gas while the mobile phase operated at a flow rate of 1 mL per minute. The oven temperature increased at a rate of 10 °C until it reached 280 °C. The system operated at an injection volume of 1 microliter. The GC-MS analysis used an electron ionization energy system which operated at 70 eV voltage. The analysis required a duration of 65 minutes (Saravanan *et al.*, 2022).

2.4. Pharmacokinetics profile

The phytocompounds that have been detected during the GC-MS analysis of the *Putranjiva roxburghii* were profiled by the Swiss ADME, through the input of the SMILES formula of each active compound. The drug-likeness parameters of these phytocompounds were assessed. Also, the Rule of Five (LR5) analysis of Lipinski was performed to assess the pharmacokinetic potential of compounds.

2.5. Ligand-protein docking study.

To determine the ability of the compounds in *P. roxburghii* to inhibit the targeted protein, molecular docking of the compounds with the G6PD was done. PyRx 0.8 was used to perform docking studies to ascertain the binding interactions of the ligand and the protein. The 3D structure of the receptor protein was obtained in the Protein Data Bank (RCSB-PDB). The chemical structures of the plant compounds were retrieved in PubChem as secondary data files. The target protein was then structured by the removal of water molecules and bound ligands and then polar hydrogen atoms were added. Then, two- and three-dimensional models of the interactions between the target protein and the selected plant compounds were produced with the help of the BIOVIA Discovery Studio version 21.1.0.20298 (Arif *et al.*, 2024).

3. Results

3.1. Detection of bioactive compounds in *P. roxburghii* leaf extract via GC-MS

The gas chromatography-mass spectrometry (GC-MS) chromatogram of *Putranjiva roxburghii* revealed 35 peaks, indicating the presence of 35 distinct chemical compounds (Fig. 1). The identification of phytocompounds was based on molecular formula, peak area, and retention time. Table 1 enumerates these phytocompounds, detailing their structures, names, classes, retention times (RT), and the percentage of their peak areas. The compound with the largest peak area was Serylserine, exhibiting a peak area of 9.33% at a retention time of 12.610 minutes. This was followed by D-Glucopyranoside, with a peak area of 5.90% at RT 11.351 minutes; 1,3-Dioxane, with a peak area of 5.21% at RT 12.878 minutes; 3-Hexanol, with a peak area of 4.89% at RT 12.735 minutes; and Thiophene, with a peak area of 4.10% at RT 12.677 minutes.

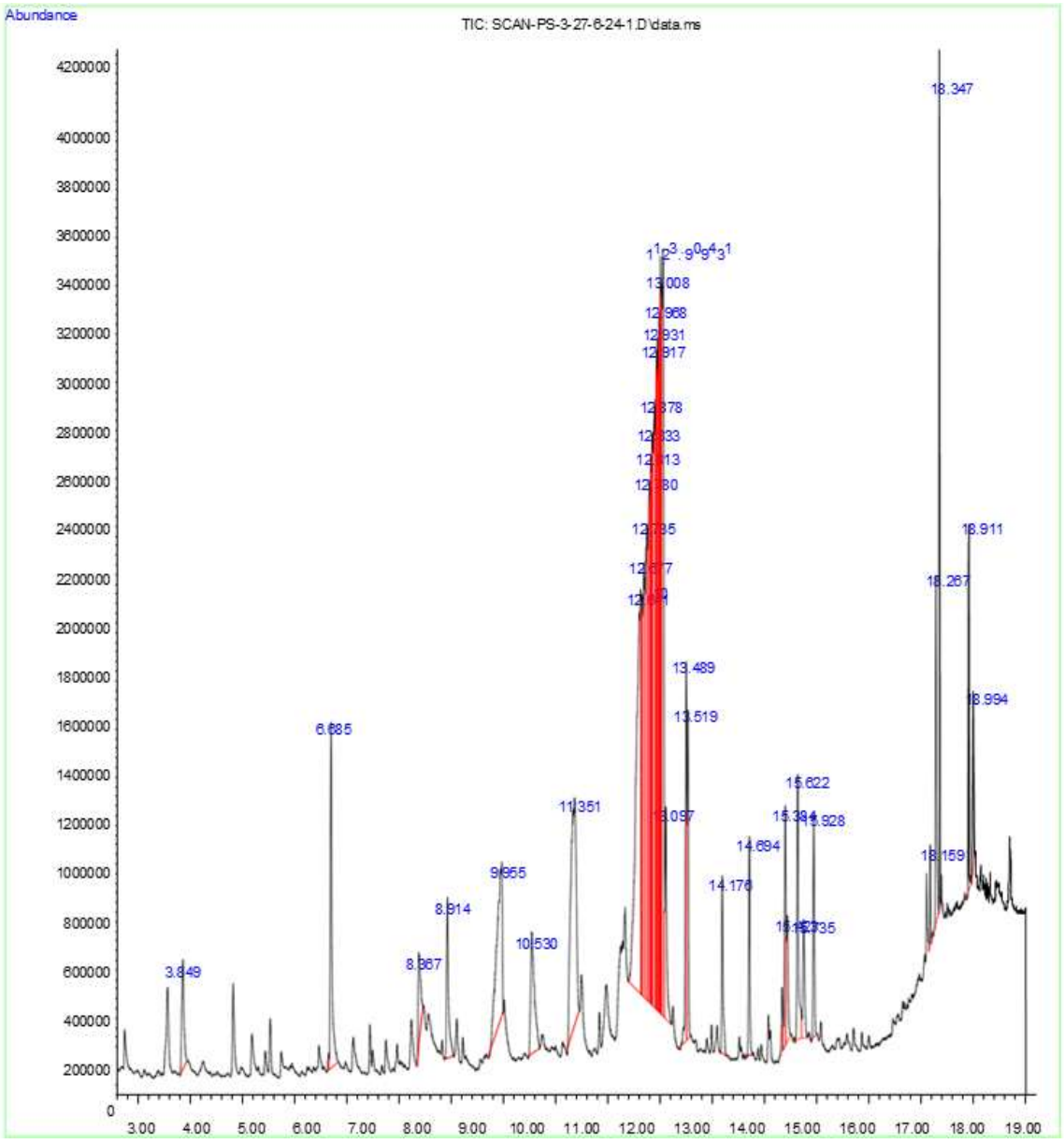
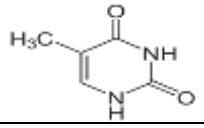
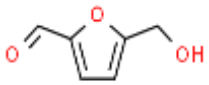
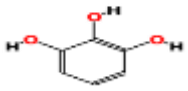
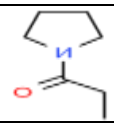
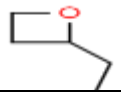
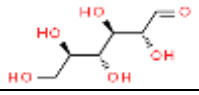
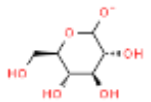
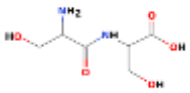
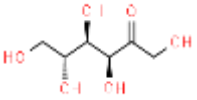
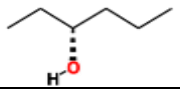
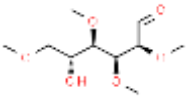
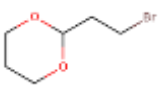
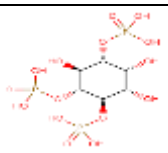
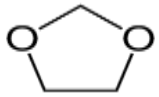
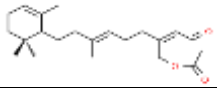
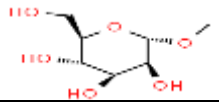
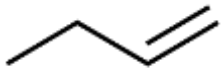
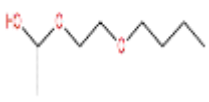
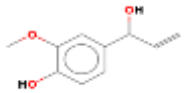
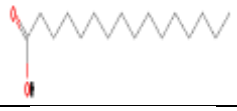
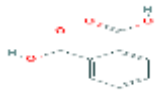
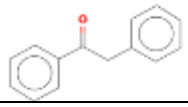
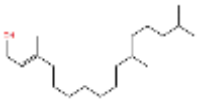
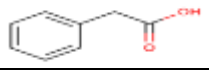
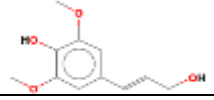


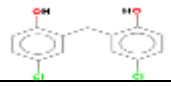
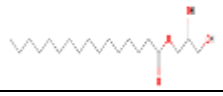
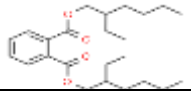
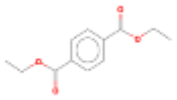
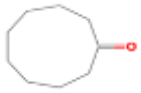
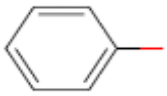
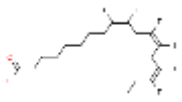
Figure 1: GCMS chromatogram of a methanolic leaf extract of *Putranjiva roxburghii*

Table 1: Bioactive compounds derived from the methanolic leaf extract of *P. roxburghii* using GC-MS.

Sr. No.	Compound name	Class name	RT	Peak area (%)	Structure
1.	Thymine	Pyrimidine	1.14	3.849	

2.	5-Hydroxymethyl-Furfural	Furans	2.75	2.75	
3.	1,2,3-Benzenetriol	Organic Compounds	1.04	8.367	
4.	Pyrrolidine	Tetrahydropyrrole	1.47	8.914	
5.	2-Ethyl-oxetane	Alkene	4.01	9.955	
6.	D-Allose	Aldo-Hexose- Sugar	2.08	10.530	
7.	D-Glucopyranoside	O-Glycosyl	5.90	11.351	
8.	Seryl-serine	Dipeptides	9.33	12.610	
9.	D-Fructose	Monosaccharide	1.79	12.641	
10.	Thiophene	Heteromonocyclic	4.10	12.677	
11.	3-Hexanol	Alcohol /Hexanol	4.89	12.735	
12.	4-O-Methylmannose	Aldehyde	3.68	12.780	
13.	2-(2-Bromoethyl)-1,3-dioxane	Ethyl Acetal	3.21	12.813	
14.	Inositol	Cyclohexane	2.65	12.833	

15.	1,3-Dioxane	Diethylene ether	5.21	12.878	
16.	20-Acetoxy	Alkaloid	4.39	12.917	
17.	3-Methylmannoside	Methyl Alpha-D-Mannopyranoside	4.39	12.917	
18.	1-Butene	Alkene	4.11	12.931	
19.	2-Butoxyethoxy	2-Butoxyethoxy	1.79	12.641	
20.	4-(1-Hydroxyallyl)-2-methoxy phenol	Phenol	1.55	13.097	
21.	N-Hexadecanoic Acid	Fatty Acid	2.57	13.489	
22.	Phthalic Acid	Dibasic Acid	1.76	13.519	
23.	Ethanone	Aldehyde	1.11	14.176	
24.	Phytol	Acyclic diterpenoid	1.25	14.694	
25.	Octadecanoic acid / Oleic Acid	Mono-Unsaturated Omega-9 Fatty Acid	1.60	15.384	
26.	9,12-Octadecadienoic Acid	Fatty Acid	0.91	15.423	
27.	Benzeneacetic Acid / Phenylacetic Acid	Acetate Ester	0.96	15.735	
28.	Sinapyl Alcohol	Phenols	1.31	15.928	

29.	2,2'-Methylene Bis / Dichlorophene	Synthetic organic chemical	0.36	18.159	
30.	Glycerol 1-Palmitate	Acyl Group	1.74	18.267	
31.	Bis(2-ethylhexyl) phthalate	Organic Compound	2.40	18.347	
32.	1,4-Benzenedicarboxylic Acid	Benzene-Dicarboxylic Acid	1.30	18.911	
33.	Cyclononanone	Cycloalkane	0.88	18.994	
34.	Phenol	Carbolic acids	0.36	18.159	
35.	9,12,15-Octadecatrienoic acid	linolenic acid	1.95	15.622	

3.2. Pharmacokinetic profile

The SwissADME web tool was to conduct pharmacokinetic studies by entering all compounds' SMILES formulas to analyze their biological system effects over time. The drug-like properties of phytocompounds were assessed, while conducting Lipinski's Rule of Five analysis to evaluate the compounds' pharmacokinetic properties. The results are shown in table 2.

Table 2. Pharmacokinetic analyses of extracted compounds

Sr. No.	Compound	Molecular Mass	Acceptor H	Donor H	Lipinski	Log P
1	Thymine	126.11	3	1	Yes	0.15
2	5-Hydroxymethylfurfural	126.11	3	1	YES	0.19
3	1,2,3-Benzenetriol	126.11	3	3	YES	0.58
4	Pyrrolidine	71.12	1	1	YES	0.77
5	2-Ethyl-oxetane	86.13	1	1	YES	1.32
6	D-Allose	180.16	6	5	YES	-2.26
7	D-Glucopyranoside	180.16	6	5	YES	-2.26
8	Serylserine	192.17	6	5	YES	-2.55
9	D-Fructose	180.16	6	5	YES	-2.15
10	Thiophene	84.14	0	0	YES	1.51
11	3-Hexanol	102.17	1	1	YES	1.60
12	4-O-Methylmannose	194.18	6	4	YES	-1.91

13	2-(2-Bromoethyl)-1,3-dioxane	195.05	2	0	YES	1.67
14	Inositol	180.16	6	6	YES	-2.67
15	1,3-Dioxane	88.11	2	0	YES	0.62
16	20-acetoxy	396.48	5	1	YES	2.77
17	3-Methylmannoside	194.18	6	4	YES	-1.63
18	1-Butene	56.11	0	0	YES	1.85
19	2-Butoxyethoxy	338.44	5	0	YES	4.01
20	n-Hexa-decanoic acid	256.42	2	1	YES	5.20
21	Phthalic acid	166.13	4	2	YES	0.84
22	Etha-none	44.05	1	0	YES	0.07
23	Phytol	296.53	1	1	YES	6.22
24	Octadecanoic acid	282.46	2	1	YES	5.71
26	9,12-Octadecadienoic acid	280.45	2	1	YES	5.45
27	Benzene-acetic acid	136.15	2	1	YES	1.43
28	Sinapyl alcohol	210.23	4	2	YES	1.47
29	2,2'-methylene bis	269.12	2	2	YES	3.68
30	Glycerol 1-palmitate	330.50	4	2	YES	4.64
31	Bis(2-ethylhexyl) phthalate	390.56	4	0	YES	6.17
32	1,4-Benzenedicarboxylic acid	166.13	4	2	YES	1.13
33	Cyclononanone	140.22	1	0	YES	2.45
34	Phenol	94.11	1	1	YES	1.41

3.2. In silico screening of *Putranjiva roxburghii* for G6PD inhibitors

The methanolic leaf extract of *Putranjiva roxburghii*, containing bioactive compounds, was analyzed through molecular docking against glucose-6-phosphate dehydrogenase (G6PD) using the PyRx docking tool. The results of this study are detailed in Table 3.

Table 1: Bioactive compounds with docking score and biological activities.

Sr. No.	Ligands	CID	Docking score (kcal/mol)	Biological activity
1.	Thymine	1135	-5.3	Anti-cancer, antibacterial, Antimicrobial. (Kumar *et al.*, 2012).
2.	5Hydroxymethylfurfural	237332	-5.2	Antioxidant. anti proliferated (Zhao *et al.*, 2013).
3.	1,2,3-Benzenetriol	1057	-5.2	Antibacterial, antioxidant, Anti-inflammatory, antimicrobial, antiviral (Bozyel *et al.*, 2023).
4.	Pyrrolidine	31268	-3.4	Antimicrobial, anti-fungal (Raj *et al.*, 2023).

5.	2-Ethyl-oxetane	521218	-3.8	Antibiotic (Santoni *et al.*, 2022).
6.	D-Allose	439507	-5.5	Anticancer, antioxidant (Sakoguchi *et al.*, 2016).
7.	D-Glucopyranoside	5793	-5.3	Antimicrobial, antifungal (Islam *et al.*, 2019).
8.	Serylserine	138784	4.8	Anti-oxidant, anti-cancer, antibacterial (Igarashi *et al.*, 2012).
9.	D-Fructose	2723872	-4.7	Antifungal, antibacterial (Jasim *et al.*, 2018).
10.	Thiophene	8030	-3.2	Anticancer (Mishra *et al.*, 2020).
11.	3-Hexanol	12178	-4.3	Antibacterial, antifungal, (Kyoui *et al.*, 2023).
12.	4-O-Methylmannose	345716	-5.2	Antimicrobial, antifungal, antioxidant (Bouali *et al.*, 2024).
13.	2-(2-Bromoethyl)-1,3 dioxane	520656	-4.5	Antibacterial, anticancer, antioxidant, anti-viral, anti-fungal (Yang *et al.*, 2013).
14.	Inositol	892	-5.8	Antioxidant, anticancer (Bizzarri *et al.*, 2016).
15.	1,3-Dioxane	10450	-3.9	Antibacterial, anti-staphylococcal (Li *et al.*, 2019)
16.	20-acetoxy	443402	-6.9	Anti-tumor, antiviral, antibiotic, antibacterial, antituberculosis, anti-inflammatory (Savchenko *et al.*, 2022).
17.	3-Methylmannoside	247323	-4.8	Antibacterial, antioxidant, antimicrobial, anti-inflammatory (Sánchez *et al.*, 2023).
18.	1-Butene	7844	-3.7	Antimicrobial, antioxidant antiestrogenic, antibacterial (Kawuri *et al.*, 2021).
19.	2-Butoxyethoxy	5794	-4.3	Antioxidant, antimicrobial, anti-inflammatory (Jimoh *et al.*, 2023)
20.	4-(1-Hydroxyallyl)-2-methoxy phenol	14008907	-5.9	Antibacterial, antifungal, anticancer, antioxidant (Hadi *et al.*, 2024)
21.	n-Hexa-decanoic acid	985	-4.4	Antioxidant, antimicrobial, anti-inflammatory antifungal, antibacterial, (Ogbuagu *et al.*, 2021)
22.	Phthalic acid	1017	-6.7	Anti-inflammatory,

				anti-depressant, anti-cancer (Kalinichenko *et al.*, 2023)
23.	Ethanone	177	-2.8	Antifungal, antimicrobial, anti-cancer, antibacterial, anti-plasmodial (Darekar *et al.*, 2022)
24.	Phytol	5280435	-6.4	Anticancer, antioxidant, antimicrobial, anti-pathogenic, antiradical, anti-inflammatory (Islam *et al.*, 2020)
25.	Octadecanoic acid / Oleic Acid	445639	-4.4	Antibacterial, antioxidant, antimicrobial (Muflihunna *et al.*, 2021)
26.	9,12-Octadecadienoic acid	3931	-4.6	Anti-microbial. antibacterial (Abdel *et al.*, 2021).
27.	Benzene-acetic acid / Phenylacetic Acid	999	-6.1	Anti-tumor, antibacterial, antifungal (Atallah *et al.*, 2023)
28.	Sinapyl alcohol	5280507	-6.3	Antimicrobial, antifungal, antitumor (Barakate *et al.*, 2011)
29.	2,2'-methylene bis / Dichlorophene	3037	-6.8	Antioxidant, antimicrobial, anti-tumor, anti-cancer. (Li *et al.*, 2006).
30.	Glycerol 1-palmitate	14900	-5.6	Anti-cancer, antimicrobial, antibacterial, anti-meningitis, anti-viral, anti, sars-coV-2-action, anti-HIV, anti-oxidant (Wasilah *et al.*, 2021)
31.	Bis(2-ethylhexyl) phthalate	8343	-5.7	Anti-tumor, antibacterial activity, antimicrobial, antiviral, anti-leukemic, anti-mutagenic (Lotfy *et al.*, 2018)
32.	1,4-Benzenedicarboxylic acid	7489	-6	Antibacterial, antifungal, antimicrobial, anti-tumor (Du *et al.*, 2011)
33.	Cyclononanone	76877	-5.4	Antifertility, antimicrobial, anticoccidial (Firdosi *et al.*, 2023)
34.	Phenol	996	-4.8	Antioxidant, antigenotoxic, antithrombotic (Stasiuk *et al.*, 2010)

3.4. Molecular docking of phytocompounds with glucose-6-phosphate dehydrogenase

Most identified bioactive compounds in the methanolic leaf extract of *Putranjiva roxburghii* had good binding energy. Interactions of key compounds with the target protein as revealed by the Discovery Studio software are depicted in Figures 2-6. The compound with the highest binding score was 20-acetoxy which had a score of -6.9 kcal/mol (Fig. 2). This was followed by 2,2'-

methylene bis, which had a binding score of -6.8 kcal/mol (Fig. 3), Phthalic acid which had a binding score of -6.7 kcal/mol (Fig. 4), Phytol which had a binding score of -6.4 kcal/mol (Fig. 5), Sinapyl alcohol which had a binding score of -6.3 kcal/mol (Fig. 6).

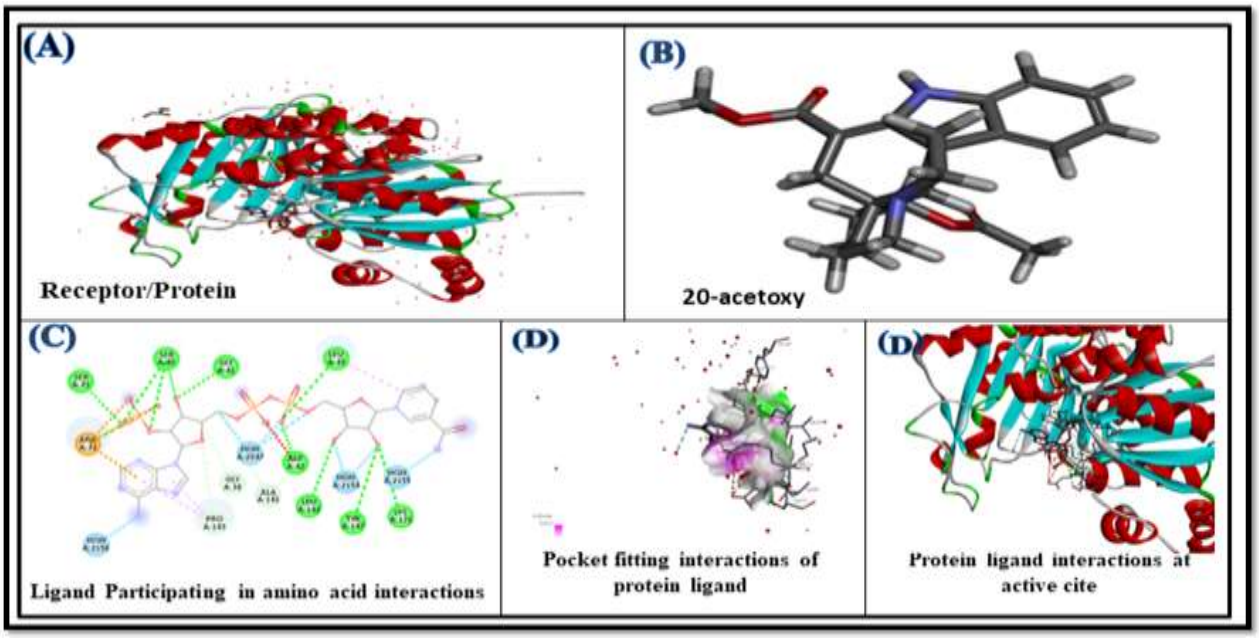


Figure 2: Interaction of 20-acetoxy with Glucose-6-phosphate dehydrogenase

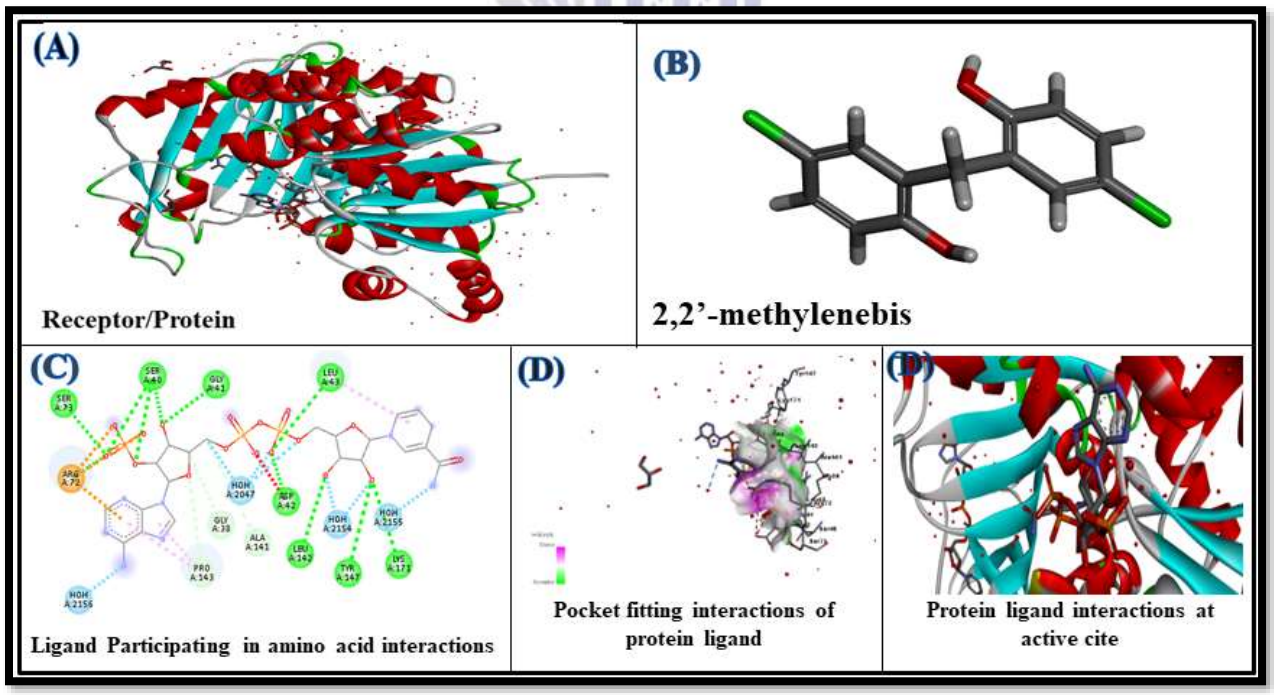


Figure 3: Interaction of 2,2'-methylene bis with Glucose-6-phosphate dehydrogenase

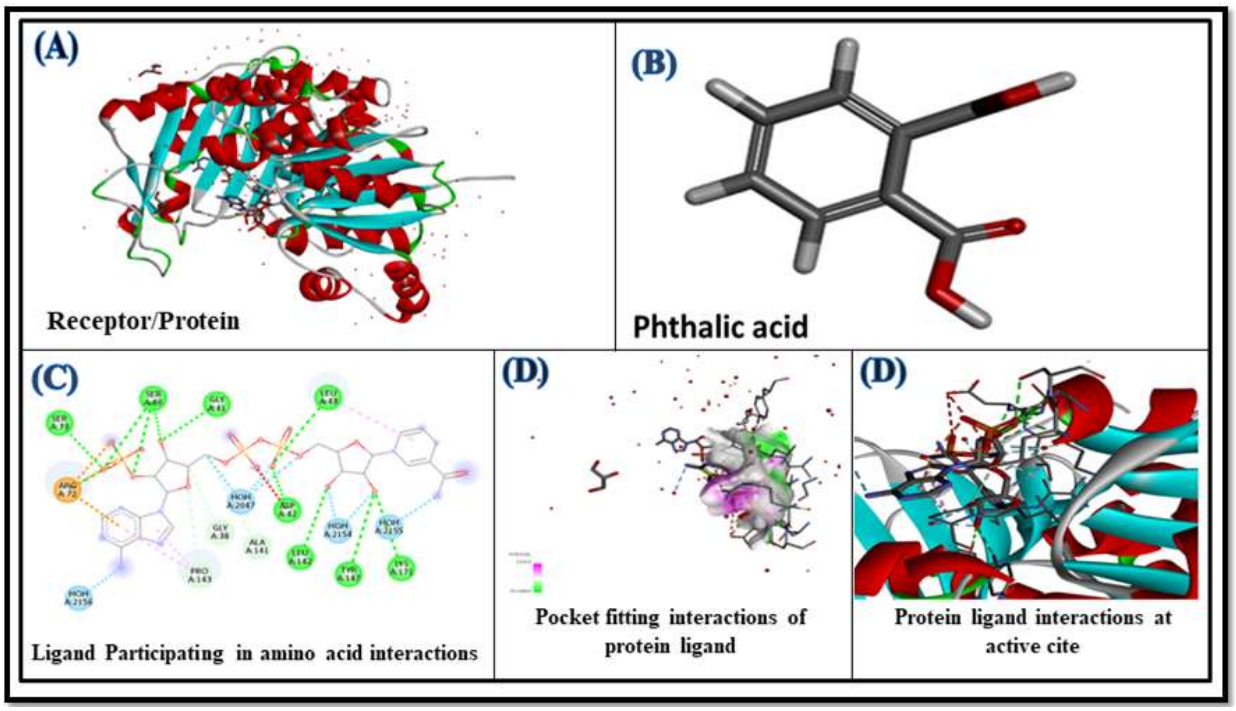


Figure 4: Interaction of Phthalic Acid with Glucose-6-phosphate dehydrogenase

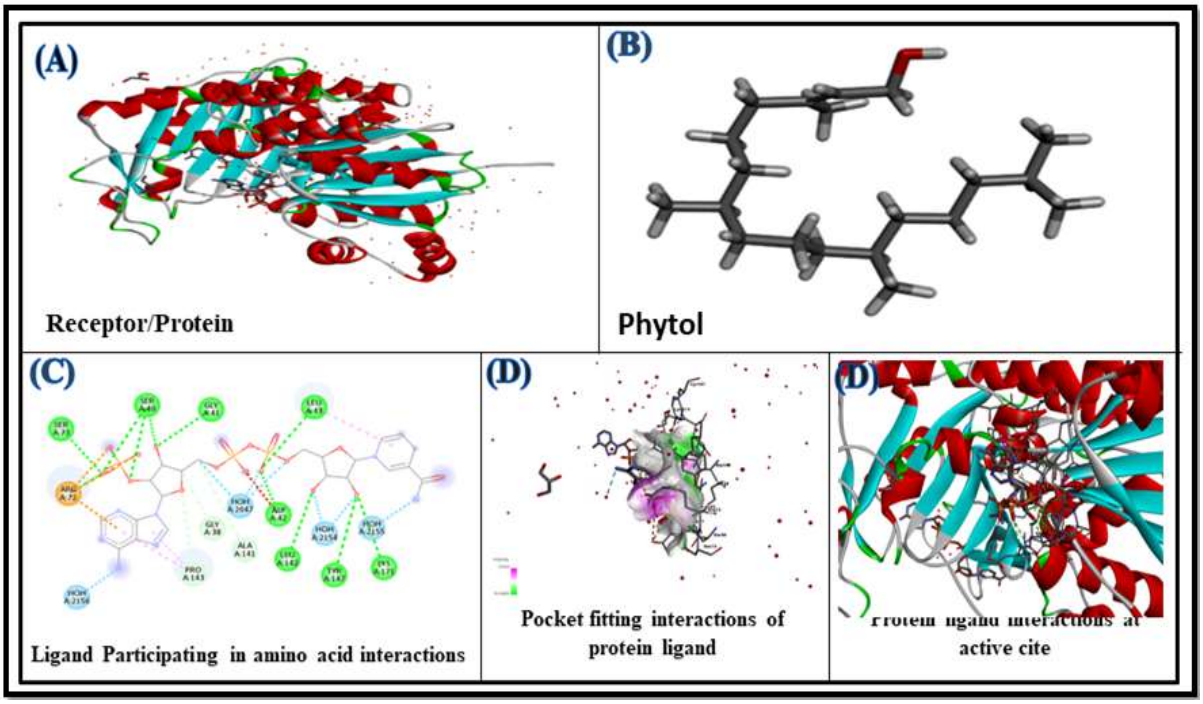


Figure 5: Interaction Phytol with Glucose-6-phosphate dehydrogenase

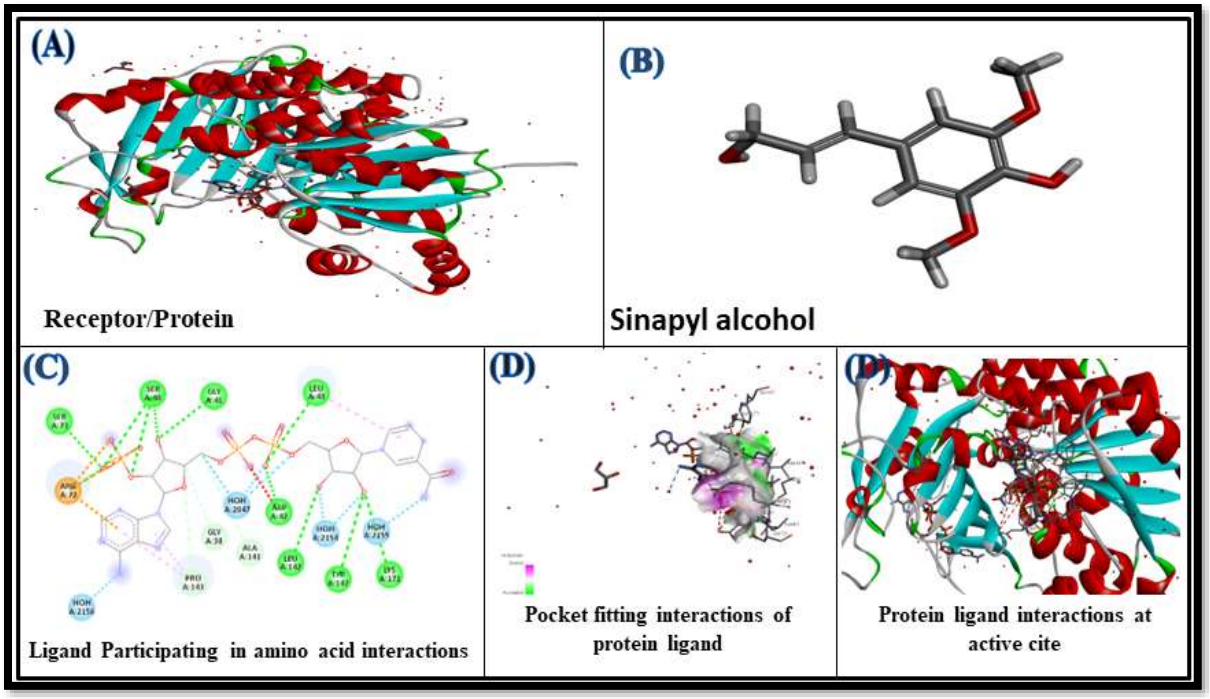


Figure 6: Interaction of Sinapyl Alcohol with Glucose-6-phosphate dehydrogenase

5. Discussion

An integrated *in-silico* method was used in the present study to explore the medicinal properties of bioactive compounds extracted using methanol as a solvent in the leaves of *Putranjiva roxburghii*. The study provides the computational data of the therapeutic capability of the *P. roxburghii* leaves through the combination of GC-MS profiling, drug-likeness prediction, and molecular docking against glucose-6-phosphate dehydrogenase (G6PD). The GC-MS analysis of the methanolic extract of the leaf extract has detected 35 phytocompounds. The connection between environment and health is increasingly being recognized and plant-based drugs are a significant ingredient. Even though synthetic drugs have been useful, their excessive use leads to side effects (Sen *et al.,* 2011). Herbal medicines are also good in curing different health conditions such as diabetes, cancer and infections. The most important medications such as digoxin and penicillin are natural derivatives (Ara *et al.,* 2020). Plants provide about 50 percent of the highest selling drugs and more than 60 percent of cancer and infection therapies (Khan *et al.,* 2019).

Based on molecular docking analysis, most of the molecules have a strong binding affinity to glucose-6-phosphate dehydrogenase (G6PD). These results indicate effective and long-lasting contacts with the active site of the enzyme. The second most common cause of death after the heart disease is cancer which initiates with mutation of genes that lead to abnormal cell growth. The cells increase uncontrollably and enter tissues (Kooti *et al.,* 2017). The abnormal epigenetic mechanisms, such as hypermethylation of tumor-suppressor genes, are associated with cancer development, as well as, they inhibit tumor prevention (Greenwell *et al.,* 2015). It is also found that cancer growth is promoted by abnormal glucose metabolism and that it decreases the efficacy of certain treatments (Varghese *et al.,* 2020). There is a network of interconnected pathways of glucose metabolism, and the most important points are G-6-P, pyruvate, and acetyl- CoA. After the G-6-P, which is the product of hexokinase, is formed by the conversion of glucose into G-6-P in the cell, it can travel either the glycolysis or the pentose phosphate pathway (PPP) (Cho *et al.,* 2018). Other important functions of oncogenic signals are

maintenance of NADPH balance and regulation of PPP flow. p53 activates the fructose-2, 6-bisphosphatase-like protein TIGAR which accelerates PPP activity and decelerates glycolysis. But p53 itself suppresses an important PPP enzyme, G6PD, and in the absence of p53, additional glucose is channeled into the PPP (Kim *et al.,* 2017). Enzyme inhibition studies play a central role in drug development, and most drugs are enzyme-based such as G6PD which is usually abundant in cancer cells. The cancer cells can be killed by inhibiting G6PD. One research study has associated the high G6PD based on the poor liver cancer results (Cao *et al.,* 2021).

As results of molecular docking tests, it was established that glucose-6-phosphate dehydrogenase (G6PD) strongly bound several molecules namely, 20-acetoxy with binding affinity of -6.9 kcal/mol, 2-methoxyphenyl with binding affinity of -6.8 kcal/mol, Phytol with binding affinity of -6.4 kcal/mol, Sinapyl alcohol with binding affinity of -6.3 kcal/mol, and Benzeneacetic acid These data show that there are excellent and durable enzyme-active site interactions. We discovered that thymine is one of the known compounds that are capable of binding to G6PD and is anticancer. Studies have revealed that a complex of ruthenium-thymine is able to kill cancer cells by interacting with DNA (Onabote *et al.,* 2022). Another bioactive compound that we analyzed, phytol, is promising against gastric and liver cancers. We have simulated its interaction with G6PD and its impacts on the lung cancer A549 cells (Thakor *et al.,* 2017). Similar studies have already been done to support this investigation since it demonstrates that the side effects of using phytol on lung cancer in animals do not exist (Sakthivel *et al.,* 2019). Finally, we detected sinapyl alcohol within the extract that binds to G6PD. Scientists have developed analogs of sinapyl alcohol which were applied to cancerous cells in human beings. Wahyuni *et al.* (2022) have confirmed this finding by showing that sinapyl alcohol is anti-metastatic against triple-negative breast cancer. When compared to the past studies, the results of our study show that these compounds could possess anticancer properties, which is probably explained by the capability to inhibit G6PD (Tselepi *et al.,* 2011).

Oral bioavailability of all compounds was high, and drug-like properties had been shown using Swiss ADME pharmacokinetic tool. This is because Lipinski Rule of Five was followed in every compound. This result is as well important because majority of the natural products with high in-vitro potency fail to undergo clinical development process because of low absorption rate or metabolism rate (Khan and Ahmad, 2019). The compounds found in *P. roxburghii* leaves should be investigated as oral medicinal agent as they obey the rule of Lipinski. The future research must be done on the inhibitory effect of these compounds against G6PD using the experimental studies. These advancements can be done through the modifications of the best leads to enhance their binding specificity and selectivity.

Conclusion

The present study has demonstrated that the methanolic leaf extract of *Putranjiva roxburghii* contains several bioactive phytochemicals with potential *in-silico* anticancer properties. Through GC-MS analysis, 35 distinct compounds were identified, many of which were found to be effective modulators of the key anticancer target, glucose-6-phosphate dehydrogenase (G6PD). Notably, eighteen of these compounds exhibited promising binding energies, with 20-acetoxy showing the highest binding affinity at -6.9 kcal/mol, followed by 2-methoxyphenyl (-6.8 kcal/mol), Phytol (-6.4 kcal/mol), and Sinapyl alcohol (-6.3 kcal/mol). The drug-likeness of these lead compounds was confirmed by their adherence to Lipinski's Rule of Five and favorable pharmacokinetic properties. These findings highlight the untapped potential of *P. roxburghii* leaves as a source of nutraceutical compounds and provide computational evidence supporting the anticancer properties of this medicinal plant. Nonetheless, further experimental investigations are warranted to elucidate the mechanisms by which these compounds exert their therapeutic effects. Such research could potentially lead to the

development of novel herbal therapies for cancer treatment.

References

Abdel Karim, M., Hamid, A. M., & Hagr, T. E. (2021). Gas Chromatography/Mass Spectroscopy Analysis, antibacterial Activity of Fixed Oil from Acacia Polyacantha (Sudanese Kakamout) Seeds. *Sudan Online Research Journal*, 21-7.

Alajeeli, F. S., Al-Karawi, A. S., & Ali, M. M. (2023). The Immunological Significance of

Medicinal Plants in Disease Control and Prevention in Humans. *Al-Salam Journal for Medical Science*, *2*(2), 13-19.

Alemán, A., Marín-Peñalver, D., de Palencia, P. F., Gómez-Guillén, M. D. C., & Montero, P. (2022). Anti-inflammatory properties, bioaccessibility and intestinal absorption of sea fennel (Crithmum maritimum) extract encapsulated in soy phosphatidylcholine liposomes. *Nutrients*, *14*(1), 210.

Ara, I., Maqbool, M., Bukhari, B., Ara, N., & Hajam, T. A. (2020). Present status, standardization, and safety issues with herbal drugs. *International Journal of Research in Pharmaceutical Sciences and Technology*, *1*(3), 95-101.

Arif, R., Bukhari, S. A., Mustafa, G., Ahmed, S., & Albeshr, M. F. (2024). Network Pharmacology and Experimental Validation to Explore the Potential Mechanism of Nigella sativa for the Treatment of Breast Cancer. *Pharmaceuticals*, *17*(5), 617.

Atallah, B. M., Haroun, S. A., & El-Mohsnawy, E. (2023). Antibacterial activity of two actinomycetes species isolated from black sand in North Egypt. *South African Journal of Science*, *119*(11-12), 1-8.

Barakate, A., Stephens, J., Goldie, A., Hunter, W. N., Marshall, D., Hancock, R. D., ... & Halpin, C. (2011). Syringyl lignin is unaltered by severe sinapyl alcohol dehydrogenase suppression in tobacco. *The Plant Cell*, *23*(12), 4492-4506.

Bozyel, M. E., Canli, K., Benek, A., Turu, D., Simsek, O., & Altuner, E. M. (2023). In vitro Antimicrobial, Antioxidant Activity, and Biochemical Composition of Parasitic Plant Cytinus hypocistis from Turkiye. *Fresenius Environmental Bulletin*, *32*(3), 1266-1273.

Bizzarri, M., Dinicola, S., Bevilacqua, A., & Cucina, A. (2016). Broad spectrum anticancer activity of myo-inositol and inositol hexakisphosphate. *International Journal of Endocrinology*, *2016*(1), 5616807.

Blackadar, C. B. (2016). Historical review of the causes of cancer. *World journal of clinical oncology*, *7*(1), 54.

Bouali, N., Ahmad, I., Patel, H., Alhejaili, E. B., Hamadou, W. S., Badraoui, R., ... & Noumi, E. (2024). GC–MS screening of the phytochemical composition of Ziziphus honey: ADME properties and in vitro/in silico study of its antimicrobial activity. *Journal of Biomolecular Structure and Dynamics*, *42*(3), 1368-1380.

Cao, F., Luo, A., & Yang, C. (2021). G6PD inhibits ferroptosis in hepatocellular carcinoma by targeting cytochrome P450 oxidoreductase. Cellular Signalling, 87, 110098.

Cho, E. S., Cha, Y. H., Kim, H. S., Kim, N. H., & Yook, J. I. (2018). The pentose phosphate pathway as a potential target for cancer therapy. *Biomolecules & therapeutics*, *26*(1), 29

Dar, P., Faisal, M., Dar, A., & Waqas, U. (2018). Journey describing biological activities and chemical constituents in the leaves, stem bark, and seed of Putranjiva roxburghii. Current Traditional Medicine, 4(4), 263-278.

Darekar, N. R., Takate, S. J., Akolkar, H. N., Shaikh, M. H., Khedkar, V. M., Karale, B. K., & Mhaske, S. D. (2022). Synthesis, Biological Activity, and Computational Study of 1-[5-(4-Methylthiazol-5-yl)-2-phenyl-1, 3, 4-oxadiazol-3 (2 H)-yl]

ethanone Derivatives. *Russian Journal of General Chemistry*, *92*(8), 1511-1518.

de Souza Oliveira, M., De Santana, Á. A. D., Correa, R. S., Soares, M. B. P., Batista, A. A., & Bezerra, D. P. (2018). Ru (II)-thymine complex causes cell growth inhibition and induction of caspase-mediated apoptosis in human promyelocytic leukemia HL-60 cells. *International Journal of Molecular Sciences*, *19*(6), 1609.

Du, D., Jiang, Z., Liu, C., Sakho, A. M., Zhu, D., & Xu, L. (2011). Macrocyclic organotin (IV) carboxylates based on benzenedicarboxylic acid derivatives: Syntheses, crystal structures and antitumor activities. *Journal of Organometallic Chemistry*, *696*(13), 2549-2558.

Ekor, M. (2014). The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety. *Frontiers in pharmacology*, *4*, 177.

Gatenby, R. A., & Brown, J. (2017). Mutations, evolution, and the central role of a self-defined fitness function in the initiation and progression of cancer. *Biochimica et Biophysica Acta (BBA)-Reviews on Cancer*, *1867*(2), 162-166.

Ferdosi, M. F., Naseem, M. K., Afzal, A., Khan, I. H., & Javaid, A. (2023). Potential antimicrobial compounds in flower extract of Plumeria alba. *Arabian Journal of Chemistry*, *16*(6), 104719.

Greenwell, M., & Rahman, P. K. S. M. (2015). Medicinal plants: their use in anticancer treatment. *International journal of pharmaceutical sciences and research*, *6*(10), 4103.

Hadi, A. A., Seeewan, A. N., Jawad, Z. A., Naoom, A. Y., & Abdulmahdi, R. R. Screening of Phytochemical Constituents in Ethanolic Extract from Astragalus spinosus Roots and Assessment of Its Anticancer, Antioxidant, and Antibacterial Activities. *Journal of the Turkish Chemical Society Section A: Chemistry*, *11*(1), 149-160.

Hong, W., Cai, P., Xu, C., Cao, D., Yu, W., Zhao, Z., ... & Jin, J. (2018). Inhibition of glucose-6-phosphate dehydrogenase reverses cisplatin resistance in lung cancer cells via the redox system. *Frontiers in Pharmacology*, *9*, 43.

Igarashi, Y., Iida, T., Fukuda, T., Miyanaga, S., Sakurai, H., Saiki, I., & Miyanouchi, K. (2012). Catechoserine, a new catecholate-type inhibitor of tumor cell invasion from Streptomyces sp. *The Journal of Antibiotics*, *65*(4), 207-209.

Islam, M. T., Ayatollahi, S. A., Zihad, S. N. K., Sifat, N., Khan, M. R., Paul, A., ... & Sharifi-Rad, J. (2020). Phytol anti-inflammatory activity: Pre-clinical assessment and possible mechanism of action elucidation. *Cellular and Molecular Biology*, *66*(4), 264-269.

Islam, M., Arifuzzaman, A., Rahman, M., Rahman, M. A., & Kawsar, S. M. A. K. (2019). Novel Methyl 4, 6-O-Benzylidene-α-D-Glucopyranoside Derivatives: Synthesis, Structural Characterization and Evaluation of Antibacterial Activities. *Hacettepe Journal of Biology and Chemistry*, *47*(2), 153-164.

Jasim, A. O., Ali, K. F., & Tomma, J. H. (2018). Synthesis and biological activity of new esters derived from D-fructose-containing isoxazole moiety. *Journal of Pharmaceutical Sciences and Research*, *10*(12), 3233.

Jimoh, T. A., Tukur, A., Musa, N. M., Muhammad, R., & Obansa, M. I. (2023). Phytochemical and Gas Chromatography-Mass Spectrometry (GC-MS) Analysis of Ethyl Acetate Root Extract of Indigofera Diphylla.

Joy, A., Appavoo, R. M., & Wilsy, I. J. Antibacterial Activity of Putranjiva Roxburghii Wall: A Medicinal Plant. *International Journal of Health Sciences*, (III), 3032-3037.

Kalinichenko, E., Faryna, A., Bozhok, T., Golyakovich, A., & Panibrat, A. (2023). Novel Phthalic-Based Anticancer Tyrosine Kinase Inhibitors: Design, Synthesis and Biological Activity. *Current Issues in Molecular Biology*, *45*(3), 1820-1842.

Kawuri, R., Darmayasa, I. B. G., & Sukmaningsih, A. A. S. A. (2021, March). Determination of Chemical Components and Analysis. In Silico Streptomyces drozdowiczii against Acinobacter baumanii. In *IOP Conference Series: Earth and Environmental Science* (Vol. 709, No. 1, p. 012072). IOP Publishing.

Khan, M. S. A., & Ahmad, I. (2019). Herbal medicine: current trends and future prospects. In *New look to phytomedicine* (pp. 3-13). Academic Press.

Kooti, W., Servatyari, K., Behzadifar, M., Asadi-Samani, M., Sadeghi, F., Nouri, B., & Zare Marzouni, H. (2017). Effective medicinal plant in cancer treatment, part 2: review study. *Journal of evidence-based complementary & alternative medicine*, *22*(4), 982-995.

Kumar, H., Mishra, A., & Bajpai, P. A Review Article of Pharmacognostic Study, Botanical Description and Therapeutic Uses of Putranjiva Roxburghii. *Journal of Advances in Pharmacy Practices*, *1*(2).

Kumar, H., Mishra, A., & Bajpai, P. A Review Article of Pharmacognostic Study, Botanical Description and Therapeutic Uses of Putranjiva Roxburghii. Journal of Advances in Pharmacy Practices

Kumar, S., Koh, J., Kim, H., Gupta, M. K., & Dutta, P. K. (2012). A new chitosan–thymine conjugate: Synthesis, characterization and biological activity. *International journal of biological macromolecules*, *50*(3), 493-502.

Li, F. H., Zhao, G. H., Wu, H. X., Lin, H., Wu, X. X., Zhu, S. R., & Lin, H. K. (2006). Synthesis, characterization and biological activity of lanthanum (III) complexes containing 2-methylene–1, 10-phenanthroline units bridged by aliphatic diamines. *Journal of inorganic biochemistry*, *100*(1), 36-43.

Li, H., Li, L., Xue, C., Huang, R., Hu, A., An, X., & Shi, Y. (2021). A novel ferroptosis-related gene signature predicts overall survival of breast cancer patients. *Biology*, *10*(2), 151

Li, L., Okumu, A. A., Nolan, S., English, A., Vibhute, S., Lu, Y., ... & Mitton-Fry, M. J. (2019). 1, 3-Dioxane-linked bacterial topoisomerase inhibitors with enhanced antibacterial activity and reduced hERG inhibition. *ACS infectious diseases*, *5*(7), 1115-1128.

Li, R., Wang, W., Yang, Y., & Gu, C. (2020). Exploring the role of glucose-6-phosphate dehydrogenase in cancer. *Oncology reports*, *44*(6), 2325-2336.

Lotfy, W. A., Mostafa, S. W., Adel, A. A., & Ghanem, K. M. (2018). Production of di-(2-ethylhexyl) phthalate by Bacillus subtilis AD35: Isolation, purification, characterization and biological activities. *Microbial pathogenesis*, *124*, 89-100.

Lu, H., Ouyang, W., & Huang, C. (2006). Inflammation is a key event in cancer development. *Molecular cancer research*, *4*(4), 221-233.

Mishra, R., Kumar, N., Mishra, I., & Sachan, N. (2020). A review on anticancer activities of thiophene and its analogs. *Mini Reviews in Medicinal Chemistry*, *20*(19), 1944-1965.

Muflihunna, A., Mu'Nisa, A., & Hala, Y. (2021, February). Gas chromatography-mass spectrometry (GC-MS) analysis and antioxidant activity of sea-cucumber (Holothurian atra and Holothurian edulis) from Selayar Island. In *Journal of Physics: Conference Series* (Vol. 1752, No. 1, p. 012057). IOP Publishing.

Naik[1], A. N., Pandya, P. N., & Mankad, A. U. (2023). A comprehensive review on phytochemicals and medicinal properties of putranjiva roxburghii wall. *Int Assoc Biol Comput Digest*, *2*(1), 234-240.

Naik[1], A. N., Pandya, P. N., & Mankad, A. U. (2023). A comprehensive review on phytochemicals and medicinal properties of putranjiva roxburghii wall. Int Assoc Biol Comput Digest, 2(1), 234-240.

Nauroze, T., Ali, S., Kanwal, L., Ara, C., Mughal, T. A., & Andleeb, S. (2023). Ameliorative effect of Nigella sativa conjugated silver nanoparticles against chromium-induced hepatotoxicity and renal toxicity in mice. Saudi journal of biological sciences, 30(3), 103571.

Olayode, O. A., Daniyan, M. O., & Olayiwola, G. (2020). Biochemical hematological and histopathological evaluation of the toxicity potential of the leaf extract of Stachytarpheta cayennensis in rats. Journal of Traditional and Complementary Medicine, 10 (6), 544-554

Olivier, M., Hollstein, M., & Hainaut, P. (2010). TP53 mutations in human cancers: origins, consequences, and clinical use. *Cold Spring Harbor perspectives in biology*, *2*(1), a001008.

Onabote, O., Hassan, H. M., Isovic, M., & Torchia, J. (2022). The role of thymine DNA glycosylase in transcription, active DNA demethylation, and algorithms for the assessment of global cardiovascular risk in women: The Reynolds Risk Score JAMA 297: 611– 619,2007

Paul, P., Malakar, A. K., & Chakraborty, S. (2019). The significance of gene mutations across eight major cancer types. *Mutation Research/Reviews in Mutation Research*, *781*, 88-99.

Raj, A. A., Raghunathan, R., SrideviKumari, M. R., & Raman, N. (2003). Synthesis, antimicrobial and antifungal activity of a new class of spiro pyrrolidines. *Bioorganic & medicinal chemistry*, *11*(3), 407-419.

Saini, A., Kumar, M., Bhatt, S., Saini, V., & Malik, A. (2020). Cancer causes and treatments. *Int. J. Pharm. Sci. Res*, *11*(7), 3121-3134.

Sakoguchi, H., Yoshihara, A., Izumori, K., & Sato, M. (2016). Screening of biologically active monosaccharides: growth inhibitory effects of D-allose, D-talose, and L-idose against the nematode Caenorhabditis elegans. *Bioscience, Biotechnology, and Biochemistry*, *80*(6), 1058-1061.

Sakthivel, R., Sheeja Malar, D., Archunan, G., & Pandima Devi, K. (2019). Phytol ameliorated benzo (a) pyrene-induced lung carcinogenesis in Swiss albino mice via inhibition of oxidative stress and apoptosis. *Environmental toxicology*, *34*(4), 355-363.

Santoni, A., Arifin, B., Ferdinal, N., Salim, E., Amelia, A., Zein, L., ... & Lestari, I. P. (2022). Analysis of Chemical Content, Cytotoxic and Anti-Bacterial Activity Essential Oil of Lantana Camara Linn Leaves from Various Regions. *Molekul*, *17*(2), 156-164.

Saravanan, R., Raja, K., & Shanthi, D. (2022). GC–MS Analysis, molecular docking and pharmacokinetic properties of phytocompounds from Solanum torvum unripe fruits and its effect on breast cancer target protein. Applied biochemistry and biotechnology, 194(1), 529-555.

Sarkar, S., Horn, G., Moulton, K., Oza, A., Byler, S., Kokolus, S., & Longacre, M. (2013). Cancer development, progression, and therapy: an epigenetic overview. *International journal of molecular sciences*, *14*(10), 21087-21113.

Sánchez-Hernández, E., González-García, V., Palacio-Bielsa, A., Lorenzo-Vidal, B., Buzón-Durán, L., Martín-Gil, J., & Martín-Ramos, P. (2023). Antibacterial activity of Ginkgo biloba extracts against Clavibacter michiganensis subsp. michiganensis, Pseudomonas spp., and Xanthomonas vesicatoria. *Horticulturae*, *9*(4), 461.

Savchenko, R. G., Veskina, N. A., Odinokov, V. N., Benkovskaya, G. V., & Parfenova, L. V. (2022). Ecdysteroids: Isolation,

chemical transformations, and biological activity. *Phytochemistry Reviews*, *21*(5), 1445-1486.

Sen, S., Chakraborty, R., & De, B. (2011). Challenges and opportunities in the advancement of herbal medicine: India's position and role in a global context. *Journal of Herbal medicine*, *1*(3-4), 67-75.

Song, J., Sun, H., Zhang, S., & Shan, C. (2022). The multiple roles of glucose-6-phosphate dehydrogenase in tumorigenesis and cancer chemoresistance. *Life*, *12*(2), 271.

Song, J., Sun, H., Zhang, S., & Shan, C. (2022). The multiple roles of glucose-6-phosphate dehydrogenase in tumorigenesis and cancer chemoresistance. *Life*, *12*(2), 271.

Stasiuk, M., & Kozubek, A. (2010). Biological activity of phenolic lipids. *Cellular and Molecular life sciences*, *67*, 841-860.

Sudha Bai, R., & Sarath, P. (2019). Screening and Evaluation of Bioactivity of Methanolic Extract of Leaf of Putranjiva roxburghii Wall. (Putranjivaceae). *International Journal of Pharmaceutical Biology Sciences*, *9*(1), 1148-1156.

Thakor, P., Subramanian, R. B., Thakkar, S. S., Ray, A., & Thakkar, V. R. (2017). Phytol induces ROS mediated apoptosis by induction of caspase 9 and 3 through activation of TRAIL, FAS and TNF receptors and inhibits tumor progression factor Glucose 6 phosphate dehydrogenase in lung carcinoma cell line (A549). *Biomedicine & Pharmacotherapy*, *92*, 491-500.

Tselepi, M., Papachristou, E., Emmanouilidi, A., Angelis, A., Aligiannis, N., Skaltsounis, A. L., Kouretas, D., & Liadaki, K. (2011). Catalytic inhibition of eukaryotic topoisomerases I and II by flavonol glycosides extracted from Vicia faba and Lotus edulis. Journal of Natural Products, 74 (11), 2362-2370.

Ur Rehman, F., Kalsoom, M., Adnan, M., Fazeli-Nasab, B., Naz, N., Ilahi, H., ... & Toor, M. D. (2021). Importance of medicinal plants in human and plant pathology: A review. *Int. J. Pharm. Biomed. Res*, *8*, 1-11.

Varghese, E., Samuel, S. M., Líšková, A., Samec, M., Kubatka, P., & Büsselberg, D. (2020). Targeting glucose metabolism to overcome resistance to anticancer chemotherapy in breast cancer. Cancers, 12(8), 2252.

Wahyuni, W., Diantini, A., Ghozali, M., Subarnas, A., Julaeha, E., Amalia, R., ... & Sahidin, I. (2022). In-vitro anticancer activity of chemical constituents from etlingera alba poulsen against triple-negative breast cancer and in silico approaches towards matrix metalloproteinase-1 inhibition. *Indonesian Journal of Science and Technology*, *7*(2), 251-278.

Wasilah, S., Sari, A. N., Nasution, R. S., & Diningrat, D. S. (2021, May). Anti-meningitis agent potentially of Syzigium Cumini Essential oil by GC-MS. In *IOP Conference Series: Earth and Environmental Science* (Vol. 753, No. 1, p. 012051). IOP Publishing.

Xiao, J., & Bai, W. (2019). Bioactive phytochemicals. *Critical reviews in food science and nutrition*, *59*(6), 827-829.

Yang, H. C., Stern, A., & Chiu, D. T. Y. (2021). G6PD: A hub for metabolic reprogramming and redox signaling in cancer. *Biomedical journal*, *44*(3), 285-292.

Zhao, L., Chen, J., Su, J., Li, L., Hu, S., Li, B., ... & Chen, T. (2013). In vitro antioxidant and antiproliferative activities of 5-hydroxymethylfurfural. *Journal of agricultural and food chemistry*, *61*(44), 10604-10611.