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Pharmacological and phytochemical biodiversity of *Corchorus olitorius*

Marwa A. M. Abdel-Razek, *[a] Miada F. Abdelwahab, [a] Usama Ramadan Abdelmohsen [b] and Ashraf N. E. Hamed [a]

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Corchorus olitorius L. is a nutritious green leafy vegetable that is eaten as a viscous soup in African and Middle Eastern cultures. The purpose of this review is to highlight the nutritional and nutraceutical potential of this plant. The leaves of *C. olitorius* are rich providers of minerals as calcium and iron in addition to vitamins B1, B2, folic acid C and E. The leaves contain numerous compounds having several biological effects including antidiabetic and antioxidant properties. Besides, the leaves comprise other phytochemicals such as cardiac glycosides, terpenes, flavonoids, fatty acids, hydrocarbons and phenolics. Various extracts of *C. olitorius* were shown to exhibit antioxidant, anti-inflammatory, hepatoprotective, antihyperlipidemic, immunostimulant, antitumor, antimicrobial, antidiabetic, analgesic, wound-healing properties and cardioprotective activities.

1. Introduction

C. olitorius, belonging to the family Malvaceae, is an annual herbaceous plant with a thin stem. It can be found in all tropical and sub-tropical regions because it is used as a popular leafy soup.[1] It is considered as a nutritious vegetable attributed to its high content of vitamins, minerals, and phenolic compounds.[2] *C. olitorius* is a stiff and fibrous annual herb that grows up to 4 m tall, it is also known as bush okra, wild okra, Jew's mallow, tossa jute, long fruited jute, Meloukia, Moroheia, Moroheiya, Mulukhiyah (and other spelling variations), nalta jute, and Tasso.[3] It is utilized as a herbal remedy for fevers, chronic cystitis, dysentery and aches, in addition to its cooking purposes. In some parts of Nigeria, the leaf decoction is used for the treatment of iron deficiency as well as folic acid deficiency, in addition to the use of leaves in ascites, dysuria, pectoral pain and female infertility.[4–6] Furthermore, typhoid and malarial fevers are treated with the leaves as a herbal medication.[7] Leaf twigs are used to treat heart issues, while the leaf infusion is utilized as an appetite enhancer. In Tanzania, the leaves are used to alleviate constipation.[5,8,9] Additionally, leaves are used as emollient, diuretic and in treatment of infantile malnutrition in Benin (Fig. 1).[9]

2. Methodology

From 2000 to 2022, a systematic research was carried out for the previous literature (66 peer-reviewed articles) in databases such as Pubmed, Google Scholar, El Sevier and Science Direct for reported compounds and biological activities of *C. olitorius*.

3. Pharmacological biodiversity

C. olitorius has been shown to have wide spectrum of biological activities, which is certainly related to its phytochemical

Fig. 1 *C. olitorius* leaves.

[a]*Department of Pharmacognosy, Faculty of Pharmacy, Minia University, 61519 Minia, Egypt. E-mail: drmarwaali33@gmail.com*

[b]*Department of Pharmacognosy, Faculty of Pharmacy, Deraya University, Universities Zone, 61111 New Minia City, Egypt*

Table 1 A list of previously reported compounds from *C. olitorius*

No.	Compound	Molecular weight	Molecular formula	Part used	References
(1) Phenolic acids					
1	Protocatchuic acid	154.12	$C_7H_6O_4$	Leaves	55
2	Coumaric acid	164.15	$C_9H_8O_3$	Leaves	55
3	1,2-Benzenedicarboxylic acid	166.14	$C_{10}H_{10}O_4$	Flowers	56
4	Vanillic acid	168.14	$C_8H_8O_4$	Flowers	57
5	Caffeic acid	180.16	$C_9H_8O_4$	Flowers	58
6	Quinic acid	192.17	$C_7H_{12}O_6$	Flowers	55
7	Ferulic acid	194.18	$C_{10}H_{10}O_4$	Flowers	58
8	Chlorogenic acid	354.31	$C_{16}H_{18}O_9$	Flowers	59
9	Isochlorogenic acid	354.31	$C_{16}H_{18}O_9$	Flowers	59
10	Rosmarinic acid	360.31	$C_{18}H_{16}O_8$	Flowers	55
11	3,4-Di-*O*-caffeoylquinic acid	516.45	$C_{25}H_{24}O_{12}$	Flowers	55
(2) Terpenes					
(2i) Monoterpenes					
12	Piperonal	150.13	$C_8H_6O_3$	Leaves	55
13	Limonene	136.23	C_9H_{13}	Leaves	56
14	Camphene	136.23	$C_{10}H_{16}$	Leaves	56
15	Sabinene	136.23	$C_{10}H_{16}$	Leaves	56
16	α-Phellandrene	136.23	$C_{10}H_{16}$	Leaves	56
17	α-Pinene	136.23	$C_{10}H_{16}$	Leaves	56
18	α-Terpinene	136.23	$C_{10}H_{16}$	Leaves	56
19	β-Myrcene	136.23	$C_{10}H_{16}$	Leaves	56
20	Menthone	154.25	$C_{10}H_{18}O$	Leaves	55
21	Dihydroterpineol	156.26	$C_{10}H_{20}O$	Leaves	60
22	Carvacrol methyl ether	164.24	$C_{11}H_{16}O$	Leaves	55
(2ii) Sesquiterpenes					
23	Germacrene D	204.35	$C_{15}H_{24}$	Flowers	56
24	β-Cedrene	204.35	$C_{15}H_{24}$	Flowers	56
25	Nerolidol	222.27	$C_{15}H_{26}O$	Flowers	56
(2iii) Diterpenes					
26	Phytol	296.53	$C_{20}H_{40}O$	Seeds	61
(2iv) Triterpenes					
27	β-Amyrin	426.72	$C_{30}H_{50}O$	Seeds	60
28	Ursolic acid	456.7	$C_{30}H_{48}O_3$	Seeds	8
29	Corosolic acid	472.69	$C_{30}H_{48}O_4$	Seeds	6
30	Corrosion	518.68	$C_{30}H_{46}O_7$	Seeds	6
(3) Fatty acids					
31	Methyl tiglate	114.14	$C_6H_{10}O_2$	Leaves	56
32	Isoamyl butyrate	158.24	$C_9H_{18}O_2$	Leaves	60
33	Phenyl ethyl tiglate	204.26	$C_{13}H_{16}O_2$	Leaves	60
34	Palmitic acid	256.42	$C_{16}H_{32}O_2$	Leaves	60
35	Linoleic acid	280.4	$C_{18}H_{32}O_2$	Leaves	60
36	Oleanolic acid	456.7	$C_{30}H_{48}O_3$	Leaves	61
(4) Ionones					
37	Betulabuside A	332.36	$C_{16}H_{28}O_7$	Roots	62
38	Corchoiononside C	386.44	$C_{19}H_{30}O_8$	Roots	6
39	6*S*,9*R*-Roseoside	386.44	$C_{19}H_{30}O_8$	Roots	6
40	Corchoiononside A	388.42	$C_{19}H_{32}O_8$	Seeds	6
41	Corchoiononside B	400.42	$C_{19}H_{28}O_9$	Seeds	6
(5) Flavonoids					
(5i) Flavones derivatives					
42	Apigenin	270.24	$C_{15}H_{10}O_5$	Flowers	55
43	Luteolin	286.24	$C_{15}H_{10}O_6$	Flowers	55
44	Cirsiliol	330.29	$C_{17}H_{14}O_7$	Leaves	55
45	Cirsilineol	344.4	$C_{18}H_{16}O_7$	Leaves	55
46	Apigenin 7-*O*-glucoside	432.4	$C_{21}H_{20}O_{10}$	Leaves	55
(5ii) Flavonol derivatives					
47	Kaempferol	286.24	$C_{15}H_{10}O_6$	Flowers	55
48	Quercetin	302.24	$C_{15}H_{10}O_7$	Flowers	55

Table 1 (*Contd.*)

No.	Compound	Molecular weight	Molecular formula	Part used	References
49	Myricetin	318.24	$C_{15}H_{10}O_8$	Flowers	55
50	Juglanin (kaempferol 3*O*-α-L-arabinopyranoside)	418.38	$C_{20}H_{18}O_{10}$	Flowers	55
51	Astragalin	448.38	$C_{21}H_{20}O_{11}$	Flowers	59
52	Quercetin-3-galactoside	464.38	$C_{21}H_{20}O_{12}$	Flowers	55
53	Quercetin 3-*O*-(6″-*O*-malonyl)-β-D-glucoside	550.42	$C_{24}H_{22}O_{15}$	Flowers	55
54	Rutin	610.52	$C_{27}H_{30}O_{16}$	Flowers	55
(5iii) Flavanone derivatives					
55	Naringenin	272.25	$C_{15}H_{12}O_5$	Flowers	55
56	Naringin	580.53	$C_{27}H_{32}O_{14}$	Flowers	55
(6) Coumarins					
57	4,7-Dihydroxycoumarin	178.14	$C_9H_6O_4$	Leaves	6
58	Scopoletin	192.17	$C_{10}H_8O_4$	Leaves	63
59	Scopolin	354.31	$C_{16}H_{18}O_9$	Leaves	64
(7) Steroidal derivatives					
60	Canarigenin	372.49	$C_{23}H_{32}O_4$	Seeds	6
61	Cannogenol	390.49	$C_{23}H_{32}O_5$	Seeds	6
62	Campesterol	400.68	$C_{28}H_{48}O$	Seeds	60
63	Strophanthidin	404.52	$C_{23}H_{32}O_6$	Seeds	65
64	Stigmasterol	412.68	$C_{29}H_{48}O$	Seeds	61
65	β-Sitosterol	414.17	$C_{29}H_{50}O$	Seeds	61
66	Fusidic acid	516.7	$C_{31}H_{48}O_6$	Seeds	63
67	Corchoroside A	534.6	$C_{29}H_{42}O_9$	Roots	66
68	Helveticoside (strophanthidin-3-*O*-β-D-digitoxopyranoside)	534.61	$C_{29}H_{42}O_9$	Seeds	65
69	Coroloside (digitoxigenin-3-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-boivinopyranoside)	666.76	$C_{35}H_{54}O_{12}$	Seeds	65
70	Glucoevatromonoside (digitoxigenin-3-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-digitoxopyranoside)	666.76	$C_{35}H_{54}O_{12}$	Seeds	65
71	Erysimoside (strophanthidin-3-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-digitoxopyranoside)	696.77	$C_{35}H_{52}O_{14}$	Seeds	65
72	Olitoriside (strophanthidin-3-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-boivinopyranoside)	696.77	$C_{35}H_{52}O_{14}$	Seeds	65
(8) Miscellaneous					
73	Cyclohexane	84.16	C_6H_{12}	Leaves	56
74	2-Hexanone	100.16	$C_6H_{12}O$	Leaves	56
75	Benzaldehyde	106.12	C_7H_6O	Leaves	56
76	Tetradecane	198.39	$C_{14}H_{30}$	Leaves	61
77	Geranyl propionate	210.31	$C_{13}H_{22}O_2$	Leaves	56
78	Hexenyl benzoic acid	204.29	$C_{16}H_{18}O_2$	Leaves	56
79	2-Methylanthraquinone	222.24	$C_{15}H_{10}O_2$	Leaves	63
80	Geranyl isobutyrate	224.33	$C_{14}H_{24}O_2$	Leaves	56
81	Fraxinellone	232.28	$C_{14}H_{16}O_3$	Leaves	56
82	Octadecane	254.49	$C_{18}H_{38}$	Leaves	61
83	Nonadecane	268.52	$C_{19}H_{40}$	Leaves	61
84	Gingerol	294.39	$C_{17}H_{26}O_4$	Leaves	55
85	Monogalactosyldiacylglycerol	689	$C_{38}H_{72}O_{10}$	Leaves	8

composition. Table 1 lists some of the main constituents detected in *C. olitorius* leaves, flowers and seeds covering the literature from 2000 to 2022. Fig. 2 shows the chemical structures of these reported metabolites.

3.1. Antioxidant activity

Potential polyphenols of *C. olitorius* exhibited antioxidant activity *in vitro*, and the preliminary results indicated that the studied plant has an interesting free radical scavenging potential, detected by different assays.[10]

C. olitorius infusions and extracts with various polarities were examined for their polyphenolic content and antioxidant activity. The total phenolic content was estimated as gallic acid equivalents (GAE) using the Folin–Ciocalteu technique and spectrometric analysis. The antioxidant activity was investigated through measuring the absorbance of the samples in aqueous emulsion system of linoleic acid and carotene. The ability to scavenge free radicals was also tested against the 2,2-diphenyl-1-picryhydrazyl radical (DPPH). The findings were compared with the synthetic antioxidant, butylated

Fig. 2 Chemical structures of the reported compounds from *C. olitorius*.

hydroxytoluene (BHT). The overall quantity of phenolic components in the extracts was linked to their antioxidant properties. Samples with elevated phenolic content demonstrated stronger antioxidant activity.[11]

The presence of secondary metabolites including phenols, glycosides, steroids, terpenoids, and flavonoids was identified in the phytochemical screening of *C. olitorius* leaf extracts. DPPH radical scavenging assay was used to test the extracts for total phenolic, total flavonoids and antioxidant activity. The results confirmed that the ethanolic extract of *C. olitorius* leaves had higher antioxidant activity than the petroleum ether and aqueous extracts, due to its higher concentration of phytochemical constituents. The presence of hydroxyl groups in phenolic constituents could explicate the strong scavenging ability.[12]

When rats are exposed to radiation, their free radical levels rise from subtoxic (24 g mol^{-1}) to toxic (120 g mol^{-1}) levels in their systems. When free radical levels rise above 120 g mol^{-1}, Nf-κB and Nrf-2 are dysregulated, aggravating oxidative stress and cellular changes in rats. The effects of solvent fractions (*n*-hexane, ethyl acetate and *n*-butanol) of *C. olitorius* leaves in radiation-induced Nf-κB and Nrf-2 dysregulation in the cellular system of rats were examined. Irradiation boosted Nf-κB, alkaline phosphatase (ALP), and alanine transaminase (ALT) while decreasing Nrf-2 and antioxidant capacity considerably. The administration of solvent fractions of *C. olitorius* leaves at 1000 mg kg^{-1} lowered Nf-κB, ALP, and ALT, while significantly increasing Nrf-2 and antioxidant capacity in rats in the treated groups, indicating that the *n*-butanol fraction is the most beneficial. As a result, *n*-butanol fractions could be investigated as an oral treatment for cellular changes in rats.[13]

The amount of lycopene, a powerful antioxidant, was investigated in fresh, processed, and preserved jute leaves from the cultivated species *C. olitorius* and *C. capsularis*. The maximum concentration of lycopene was found in 45 day-old fresh leaves, which subsequently declined as the plant aged. Leaves steeped

in vinegar possessed the maximum lycopene for *C. olitorius*, on the other hand, leaves boiled with salt and water for fifteen minutes had the highest lycopene for *C. capsularis*. When compared to fresh leaves, all of the processing procedures enhanced the availability of lycopene. After drying and preservation at 20 °C, lycopene was maintained in preserved jute leaves. Cold dried preserved leaves at 4 °C and subsequently air dried leaves at 33–35 °C had the maximum lycopene concentration, whereas the leaves dried in oven at 100 °C had the lowest. The amount of lycopene in the leaves varied depending on the maturity of the plant. When compared to fresh red tomatoes, lycopene levels in 45 day-old plant *Corchorus* leaves were more than double.[14]

C. olitorius mucilage was extracted using hot water. Uronic acid made up the majority of the mucilage (34.24%, w/w). At 65 ° C, the solubility was 79.48 1.08%, the swelling index was 29.01 2.54%, the water-holding capacity was 28.66 1.48 g g^{-1}, and the oil-binding capacity was 8.423 0.23 g g^{-1}. The mucilage viscosity increased from 4.38 to 154.97 cP, in a concentration-dependent way. Due to the concurrent rise in surface tension and viscosity, the concentration increase resulted in a decrease in emulsion activity and an increase in emulsion stability. The *in vitro* radical scavenging activity of the mucilage increased with concentration. The study demonstrated the potential of *C. olitorius* as a new hydrocolloid source with potential applications in a variety of industries, including food, cosmetics, and pharmaceuticals.[15]

3.2. Anti-inflammatory activity

The inflammatory activity of *C. olitorius* was evaluated. Consequently, five fractions were generated, including crude phenolic extracts (using 80% aqueous acetone) of the whole plant, leaf, stem, washed leaf (WL) and dried water washing material (WW). On all fractions, linoleic acid autoxidation inhibition was higher than on α-tocopherol. All fractions, with the exception of WL and WW, showed DPPH radical scavenging efficiency. Moreover, all fractions, except WL and WW, demonstrated regulation of the inflammatory responses through suppression of lipopolysaccharide induced protein expression, nitric oxide and prostaglandin E2. The study showed that washing the leaves markedly influenced DPPH radical scavenging and inflammatory responses due to loss of leaf phenolics.[16] In a study investigating the therapeutic effect of *C. olitorius* on rat testicular tissue damage caused by cadmium (Cd), it was found that *C. olitorius* (given orally at a dose of 250 mg kg^{-1}) reduced the toxic effect of Cd on testicular tissue. The degeneration was still existing in the treated groups, however inflammatory cell numbers, oedema and apoptotic cells were reduced.[17]

3.3. Hepatoprotective activity

Alcohol intake causes gut microbial dysbiosis, which disturbs the gut–liver axis, resulting in the development and progression of alcoholic liver disease. Do *et al.* looked into the effects of a water-soluble extract from *C. olitorius* leaves (WM) on alcohol-induced gut–liver axis disruption in rats. The levels of blood indicators for liver injury were lowered when 50 and 100 mg kg^{-1} of WM were given. Furthermore, WM therapy reduced the effects of alcohol on hepatic inflammation and lipogenic protein levels. WM ameliorated lipid accumulation in liver and the gut barrier function. In addition, the gut microbial composition has been regulated.[18]

In another study, the ethanolic extract of leaves significantly lowered the levels of alanine aminotransferase (ALT), alkaline phosphatase (ALP) and aspartate aminotransferase (AST) at three dose levels of 50, 100, and 200 mg kg^{-1}. At 50 and 100 mg kg^{-1}, the extract also lowered total cholesterol levels and increased HDL levels in a dose-dependent manner. *C. olitorius* extract was thought to give hepatoprotection with a probable tendency to elevate total cholesterol levels because it increased cholesterol levels at 200 mg kg^{-1}.[19]

Interestingly, Iweala and Okedoyin demonstrated that the regular consumption of *C. olitorius* may exacerbate hepatotoxicity which could be attributed to the presence of some accumulated antinutrients in the plant *e.g.* oxalate, nitrate and cyanide. Nevertheless, the study showed the importance of processing this vegetable *via* cooking prior consumption in order to eliminate or reduce this hepatotoxic effect in humans. However, they emphasized the role of this plant in increasing the antioxidant potential of consumers through the significant increase in the reduced glutathione levels compared with the normal and negative groups. In addition, they suggested a hepatoprotective role of this plant due the elevated total plasma protein concentration that maintain protein synthesis efficiency in hepatocytes.[20]

The hepatoprotective property of *C. olitorius* ethanolic leaf extract on CCl_4-induced liver damage in rats was evaluated. The administration of the extract was oral at doses of 500 mg kg^{-1}, 750 mg kg^{-1} and 1 g kg^{-1} daily for 15 days period. The serum enzyme assay showed a marked reduction in the elevated activity of the hepatic enzymes ALT, ALP and AST, compared with the control group. Furthermore, the results revealed lowered serum albumin with no change in bilirubin but increased levels of total protein in all treated groups. Additionally, the white blood cell count and platelets were significantly decreased while the packed cell volume and hemoglobin were not changed.[21]

3.4. Prevention of obesity

Gut dysbiosis is a metabolic illnesses like obesity and leaky gut, it is caused by a high-fat diet (HFD). In HFD-induced C57BL/6J mice, the impact of a water-soluble extract from *C. olitorius* leaves (WM) on lipid accumulation in 3T3-L1 adipocytes, hormone levels, gut permeability, gut microbiota, and faecal enzyme activity of the intestinal microflora were investigated. In 3T3-L1 adipocytes, WM treatment dramatically reduced lipid buildup. Mice given 100 mg kg^{-1} WM had 13.1, 17.4, and 52.4% lower body weights, hepatic fat accumulation and intestinal permeability, respectively, than mice given HFD. WM also had an effect on gut health *via* reducing metabolic endotoxemia and colon inflammation. It also changed the gut microbiota's composition, increasing the number of bacteria in the gut.[22]

Diet-induced obesity was significantly reduced by *C. olitorius* leaf mucilage polysaccharide fraction (MPF), which also

modulated gut flora and inflammation. During an HFD, the administration of MPF for eight weeks reduced body weight, triglyceride levels, as well as adipocyte size, LDL-cholesterol levels and in the expression of lipid synthesis-related proteins. Furthermore, MPF delivery improved gut health by reducing leaky gut, inflammation and metabolic endotoxemia, in addition to enhancing tight junction protein expression. Findings demonstrated that *C. olitorius* MPF rich in rhamnogalacturonan-I attenuated HFD-induced obesity in mice through regulating the constitution of gut microbiota.[23]

3.5. Immune enhancing

Polysaccharides derived from plants have the potential to improve gut health and immune system. Mucilage polysaccharide is abundant in *C. olitorius* leaves. MPF's prebiotic and intestinal immune-enhancing actions were tested *in vitro* to investigate its bio-functional effects. MPF enhanced immunological function on Peyer's patches, as evidenced by significant increase in bone marrow cell proliferation activity as well as immunoglobulin A and cytokines production. These findings suggested that MPF could be a potentially helpful prebiotic and intestinal immune-enhancer.[24]

3.6. Antitumor activity

Dioxins are mostly ingested and produced a variety of toxicological consequences by attaching to the cytosolic aryl hydrocarbon receptor (AhR) and then transforming it. Certain natural substances have been proven to inhibit AhR transformation *in vitro*. Among 41 types of extracts from vegetables and fruits, Nishiumi *et al.* found that the ethanolic extract from *C. olitorius* had the most powerful suppressive effect on AhR transformation induced by TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) in a cell-free system utilizing rat hepatic cytosol. The extract also inhibited TCDD-induced AhR transformation in mice hepatoma cells and in intestinal permeability system established with human hepatoma (HepG2) and human colon adenocarcinoma (Caco-2) cells.[25]

The effects of the ethanolic extract of *C. olitorius* on the proliferation of human hepatocellular carcinoma (HepG2) cells and the underlying mechanisms of action were investigated. HepG2 cells treated for 24 hours with the extract at a concentration more than 12.5 μg mL^{-1} showed a significant decrease in cell viability, on the other hand, normal FL83B hepatocytes were unaffected. The study indicated that *C. olitorius* ethanol extract could be efficacious against hepatocellular carcinoma *via* apoptosis induction involving mitochondria-dependent pathway.[26]

Darcansoy şeri *et al.* investigated the cytotoxic and genotoxic effects of *C. olitorius* leaf extracts (LE) and seed extracts (SE) on multiple myeloma-derived ARH-77 cells. The total phenol content (TPC) and free radical scavenging activity (FRSA) of the extracts were also determined using the Folin–Ciocalteu and DPPH free radical techniques, respectively. The MTT test (4–2048 μg mL^{-1} range) was used to assess cytotoxicity, and the comet assay was used to assess DNA damage (at IC_{50} and 1/2 IC_{50}). The LE had much higher total phenol content (78 mg GAE per g extract) with pronounced FRSA (IC_{50}: 23 μg mL^{-1}) while SE total phenol was about 2 mg GAE per g extract and FRSA with IC_{50} SE: 10 401 μg mL^{-1}. Both LE and SE exhibited cytotoxicity after 48 hours, SE showed higher cytotoxicity on cells compared with LE with IC_{50} values of 17 μg mL^{-1} and 151 g mL^{-1}, respectively. In addition, the comet test demonstrated that both extracts caused genotoxic damage when applied at 17 and 8.5 μg mL^{-1} for SE and at 150 and 75 μg mL^{-1} for LE.[27]

Acrylamide is a compound formed when starchy foods are cooked at high temperatures. It is carcinogenic, genotoxic and neurotoxic. Short-term acrylamide exposure has also been proven to produce severe hepatic impairment in experimental animals, as well as disruption of antioxidant defense mechanisms due to increased reactive oxygen species generation. As a result, dietary antioxidants may be beneficial in reducing the harmful effects of acrylamide. *C. olitorius* is an antioxidant with strong organo-protective effects. The aqueous extract of *C. olitorius* leaves was administered to rats to study if it could protect them against acrylamide-induced liver damage. After three levels of dose, hepatic damage markers such as blood total protein, total bilirubin, ALT, ALP and AST were examined, as well as oxidative stress markers such as MDA, GSH, CAT, and SOD. The extracts significantly lowered high levels of bilirubin, ALT, AST, ALP, and MDA to normal levels. They also restored normal serum protein, GSH, CAT, and SOD levels. Owing to its high radical scavenging ability, *C. olitorius* leaves extract protects against acrylamide-induced liver damage.[28]

From the leaves of jute, two anticancer promoters, phytol and monogalactosyldiacylglycerol, were extracted (*C. capsularis* L.). Immunoblotting analysis was used to look for antitumor-promoting activities. The metabolites concentration in four cultivars of *C. capsularis* and *C. olitorius* varied depending on the cultivar. Treatment of the leaves with hot water increased the measurable amount of each active component.[8]

Taiwo *et al.* separated two polyphenolic metabolites namely, methyl-1,4,5-tri-*O*-caffeoyl quinate and *trans*-3-(4-hydroxy-3-methoxyphenyl) acrylic anhydride from the methanolic extract of *C. olitorius*. The isolated compounds were evaluated at a range of concentrations up to 1.6 mM. They were found to exhibit mild cytotoxic activity against HeLa cells at ≥800 μM. The compounds revealed high binding affinities to fibroblast growth factor receptor 2 and epidermal growth factor receptor. Therefore, the plant could be considered as a potential source of 'lead' drugs with anti-tumour activity.[29] *C. olitorius* extract in ethanol was used to make copper nano complexes. These metal complexes were found to have *in vitro* antitumor action against hepatocellular carcinoma (HepG-2) cells, with IC_{50} value of 30.9 μg mL^{-1}, using cis-platin as the standard anticancer drug.[30]

The methanolic extract of *C. olitorius* revealed the presence of flavonoids and phenolic compounds as main ingredients, with 699 g GAE per g and 1361.50 g QE per g, respectively. The methanolic extract of the plant demonstrated cytotoxic activity against L929 cell line with IC_{50} value of 227.84 g mL^{-1}. In addition, the cell viability in MTT experiment for methanol extract against the MCF-7 and A549 cell lines revealed significant activities with IC_{50} values of 20 g mL^{-1} and 12.45 g mL^{-1},

respectively. The extract was found to induce early and late apoptosis in the tested lung and breast cancer cell lines through activating caspase-3 and inhibiting Bcl-2 protein, it also caused cell death *via* DNA damage. Consequently, the results demonstrated that the methanolic extract of *C. olitorius* had significantly inhibited breast cancer and lung cancer cell lines.[31]

3.7. Antimicrobial activity

The antibacterial and antifungal properties of *C. olitorius* leaf extracts collected from various parts of the Turkish Republic of Northern Cyprus were investigated. Seven samples of dried plant material (*C. olitorius* leaves) were collected from different regions. Methanol, ethanol, chloroform, and hexane (1 : 10 [weight/volume]) were used to extract the leaves at room temperature for three days. Following evaporation, each sample was prepared at a concentration of 100 mg mL^{-1}. The disc diffusion method was used to assess antibacterial activity. Only hexane leaf extracts showed antibacterial action against *Bacillus subtilis* and *Staphylococcus aureus*, whereas methanol, ethanol, and chloroform extracts showed no antibacterial activity.[32]

Ilhan *et al.* investigated the *in vitro* antimicrobial activity of petroleum ether, methanol, and ethyl acetate–water extracts of *C. olitorius* leaves, using the agar-well diffusion method. The petroleum ether extract exerted antibacterial activity against *Staphylococcus aureus*, *Escherichia coli* and *Yersinia enterocolitica* with inhibition zones of 19, 20 and 19 mm, respectively. The ethyl acetate–water extract showed considerable efficacy against *Botrytis cinerea* and *Geotrichum candidum* with inhibition zones of 12 and 19 mm, respectively.[33]

The antimicrobial and antioxidant activities in addition to the total phenolic content of the dried leaf extracts of *C. olitorius* were studied. The extracts were tested for antibacterial activity, using the broth dilution technique, against *Bacillus subtilis*, *Bacillus cereus*, *Enterococcus faecalis*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli* and *Salmonella typhimurium*. The MIC values of ethanol and methanol extracts ranged from 50 to 6.25%, while water extract had no inhibitory effect. The methanol extract was significantly active against *L. monocytogenes*, *B. subtilis* and *E. faecalis* with MIC value of 6.25%. Ethanol extract had the highest phenolic content (24.61 mg GAE per g). Water, methanol and ethanol extracts suppressed the DPPH radical by 17.50, 86.00 and 87.10%, respectively. These investigations indicated that *C. olitorius* extracts are valuable sources of antibacterial and antioxidant activities.[34]

Strophanthidin, a compound present in *C. olitorius*, was found to be a promising drug candidate in treatment of brucellosis. The study demonstrated that the compound had potential to inhibit *Brucella melitensis* methionyl-tRNA synthetase using virtual screening and molecular docking. Strophandin bioavailability was as well confirmed through molecular dynamics modelling with the target protein. *In vivo* and *in vitro* studies are required in order to assess the efficacy and toxicity of this lead compound.[35]

C. olitorius leaves were air dried after collection, then extracted with distilled water, methanol, and diethyl ether. The crude extracts were assessed employing the agar well diffusion method against a number of pathogens. The positive control was chloramphenicol. The crude extracts of *C. olitorius* leaves exhibited antibacterial activity against *Staphylococcus aureus* (inhibition zone of 14 mm), *Streptococcus pneumoniae* (inhibition zone of 16 mm), and *E. coli* (inhibition zone of 11 mm). The positive control showed inhibition zone of 18 mm. The plant extract did not reveal any bioactivity against *Candida albicans* nor *Mycobacterium tuberculosis*.[36]

The antibacterial activity of *C. olitorius* leaves was assessed against the Gram-negative bacteria *E. coli*, using the agar well diffusion method. As a result, the aqueous extract exhibited stronger antibacterial activity (16.3 ± 1.7) against the studied bacteria *E. coli*, compared to the ethanolic extract (8.23 ± 0.7).[37]

3.8. Antidiabetic activity

C. olitorius contains a lot of mucilaginous polysaccharides that has been shown to have anti-diabetic properties in animal studies. Although the presence of phenolic and non-phenolic chemicals is also thought to be responsible for the anti-diabetic properties of this plant, the exact mechanism of action is unknown. *C. olitorius* leaves powder (at 2 and 4%) was tested *in vitro* for its capacity to modulate starch digestion and glucose diffusion. Results demonstrated that the powder bonded substantially more glucose than wheat bran (2%) and also decreased glucose diffusion over the dialysis membrane, as evidenced by a significantly higher glucose dialysis retardation index. In addition, the plant powder (4%) showed full suppression of starch digestion and glucose diffusion similar to acarbose in the starch-α-amylase system until 120 minutes. *C. olitorius* leaves powder (4%) slowed down glucose diffusion by 83.7% and 63.5% at 180 and 240 minutes, respectively. Whereas the plant powder (2%) slowed glucose diffusion by 96%, 65%, and 51% at 120, 180, and 240 minutes, respectively. Furthermore, *C. olitorius* leaf extract obviously increased glucose absorption by rat hemidiaphragm. These data convincingly showed that the antidiabetic activity of *C. olitorius* leaves is achieved by delaying starch digestion and physical adsorption of released glucose, reducing glucose diffusion across the intestinal lumen and increasing its uptake in peripheral tissues.[38]

The hypoglycemic and the hypolipidemic impact of the leaves of *C. olitorius* on alloxan-induced diabetic rats was determined. The diabetic rats were given *C. olitorius* leaves as food supplement for fourteen days. The post-treated rats were shown to have significant decrease in plasma glucose concentrations, total cholesterol, LDL—cholesterol and triglycerides. These findings suggested that *C. olitorius* leaf has anti-hyperglycemic and hypolipidemic effects that could be strongly attributed to the different phyto-constituents and the fiber content. Plant fibers may chelate with intestinal glucose therefore reducing blood glucose levels, in addition they contribute in the reduction of circulating plasma cholesterol because they trap bile in intestine leading to more bile production from cholesterol.[39]

Mahgoub *et al.* evaluated the effect of *C. olitorius* soup (prepared from *C. olitorius* leaves) on fasting blood glucose,

lipid profile, and hepatic oxidative status in STZ-induced diabetes in male albino rats. Treatment with *C. olitorius* soup (given at a dose of 4.80 g per kg body weight) showed encouraging antihyperglycemic, antihypertriglyceridemic as well as antioxidant properties. The serum levels of glucose, triglycerides and liver peroxidative products were significantly reduced in the treated animals. In the meantime, *C. olitorius* administration had led to increased glutathione, antioxidant enzymes catalase and superoxide dismutase. Hence, the plant could be considered a valuable candidate in the reversal of diabetes complications.[40]

C. olitorius leaves were serially extracted with methanol, diethyl ether, and water. 48 rats were separated into 8 groups of 6 for the assessment of the antihyperglycemic and antidiabetic effects, and each group received 500 mg kg^{-1} of each extract. Distilled water and glibenclamide (10 mg kg^{-1}) were used as controls. The methanolic extract showed the most antihyperglycemic efficacy.[41]

3.9. Analgesic activity

Methanolic *C. olitorius* extract was tested for analgesic efficacy against acetic acid-induced writhing in mice. The extract was given at doses of 50, 100, 200, and 400 mg per kg body weight. Writhing was induced by injecting acetic acid intraperitoneally. The reference doses of aspirin were 200 and 400 mg kg^{-1}. The plant extract inhibited acetic acid-induced abdominal contraction in a dose-dependent manner. At the dosage range studied, abdominal contractions were reduced by 20 to 58%. The extract had stronger analgesic effect at 100 mg kg^{-1} than aspirin at 200 mg kg^{-1}, showing that *C. olitorius* has significant analgesic characteristics.[42]

3.10. Wound healing property

In a rat excision wound model, the wound-healing effect of *C. olitorius* leaf powder and aqueous extract were tested. When compared to the control, both showed considerable wound healing activity. On the 18th day, a 5% powdered plant ointment or 100 mg mL^{-1} extract produced 100% wound contraction. *C. olitorius* was found to have powerful healing activity and it can be used as an alternative wound healing treatment since it effectively decreased microbial burden.[43]

Yokoyama *et al.* were interested in evaluating the skin barrier protection and the hydration efficacy of *C. olitorius* leaf extract without the polysaccharides. Their experiment demonstrated that the rats topically treated with the cream supplemented with *C. olitorius* extract had improved skin hydration and suppressed trans-epidermal water loss. This concluded that the plant may maintain the hydration of the skin and inhibit the disturbance of skin barrier function, therefore, it could be used as a complementary therapy in atopic dermatitis.[44]

An atopic dermatitis mouse model was used to assess the skin hydration capacity of *C. olitorius* extract. The extract was combined with a stable base cream and applied to the mice's dorsal skin. Following 14 days of therapy, the skin hydration was improved while the trans-epidermal water loss and atopic dermatitis symptoms were significantly reduced compared with control and untreated groups. The results of this study explicated that *C. olitorius* leaf extract could be a helpful therapeutic candidate for atopic dermatitis which may be attributed to its suppression of the plasma concentrations of immunoglobulin E and degranulation of mast cells.[45]

3.11. Cardioprotective activity

The cardioprotective activity of *C. olitorius* aqueous extract at 50 and 100 mg kg^{-1} against sodium arsenite-induced cardiotoxicity in rats was investigated. Rats exposed to sodium arsenite (10 mg kg^{-1}) for 10 days had a significant rise in plasma total cholesterol and arsenic levels in heart tissue, as well as a reduction in serum HDL. Through histological examinations, pretreatment with *C. olitorius* extract reverted all of these parameters in blood and cardiac tissues to normal values, indicating that *C. olitorius* extract may provide considerable protection against sodium arsenite-induced cardiotoxicity.[46]

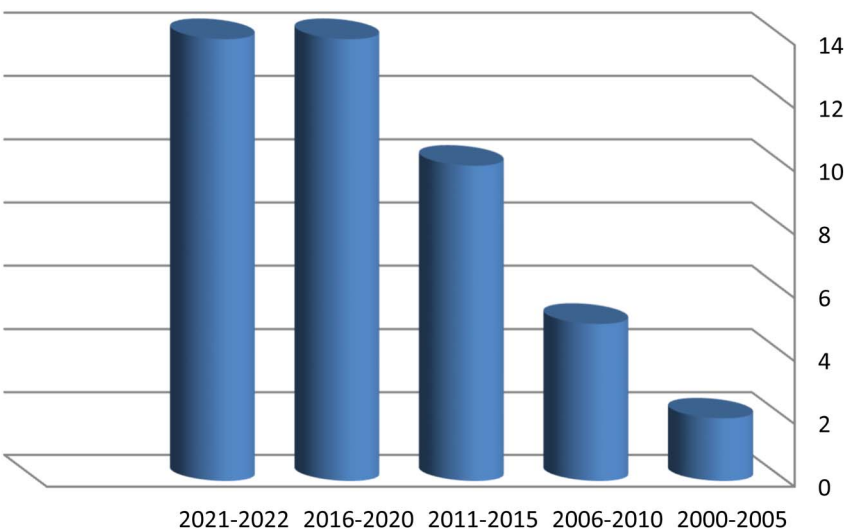

Fig. 3 Publication rate of *Corchorus olitorius*.

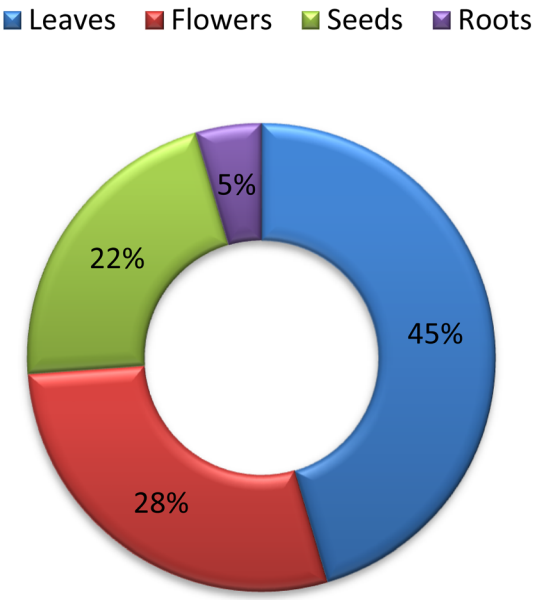

Fig. 4 Parts used of *Corchorus olitorius* published from 2000–2022.

3.12. Antiviral activity

Antioxidants and polyphenolics derived from the leaves of *C. olitorius* that can block the activity of the angiotensin converting enzyme 2 (ACE2), which is a key protein in the physiology of Covid-19 and necessary for the entry of the SARS-Cov-2 virus into the host's cells. Compared the co-crystallized inhibitor of the enzyme ACE2, chloroquine, hydroxychloroquine, captopril, and simerprevir antiviral drugs, the results of the docking simulation revealed that méthyl-1,4,5-tri-*O*-caféoyl quinate had a high affinity, stronger bond and gives the best docking scores. Hence, it could be regarded as a potential inhibitor of essential protease viral enzyme.[47]

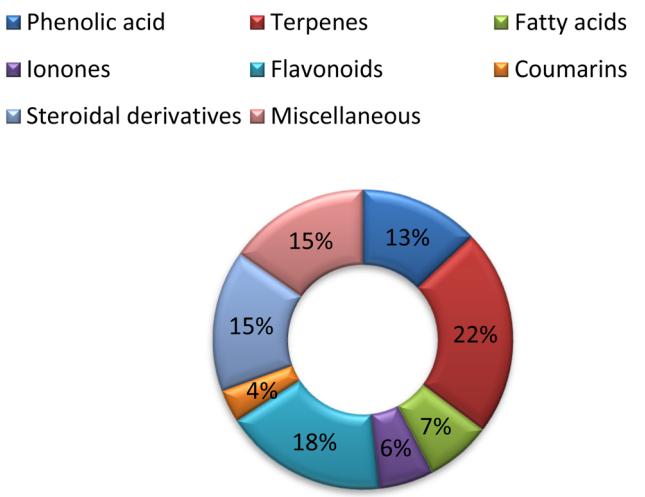

Fig. 5 Phytochemical diversity in *Corchorus olitorius* published from 2000–2022.

3.13. Treatment of aphthous ulcers

A bucco-adhesive fast-dissolving film that contains *C. olitorius* seed extract was created in order to treat recurrent minor aphthous ulceration. With special focus on wound healing molecular targets like TGF-, TNF-, and IL-1. An excision wound model was used to evaluate the *in vivo* wound healing capacity of *C. olitorius* L. seed extract. Interestingly, the wound healing data showed that *C. olitorius* seed extract increased wound closure rates, boosted TGF- levels, and dramatically downregulated TNF- and IL-1, when compared to the Mebo-treated group. Additionally, by applying *in silico* analysis, the study revealed the potential of *C. olitorius* seed extract in wound repair and identified the most likely mechanisms of action.[48]

4. Natural products from *C. olitorius*

Eleven phenolic acids were reported from *C. olitorius* that showed diverse biological activities. Caffeic acid and chlorogenic acid phenolic phytochemicals may be responsible for the antidiabetic and antihypertensive properties of *C. olitorius*.[49] Additionally, 3,4-dicaffeoylquinic acid had a powerful antioxidant activity besides neuroprotective action.[50] Terpenoids are widely distributed in *C. olitorius*, with 18 terpenoidal compounds have been reported. Phytol diterpenoidal compounds showed antimicrobial, antioxidant and anticancer activities.[51] Ionones are a class of compounds contains corchoionoside A, B and C which were isolated from *C. olitorius* showing antinociception (strong analgesia)[52] in addition to antiallergic activity.[53] Flavonoids showed diverse biological activities and 14 flavonoidal derivatives were reported including quercetin, kaempferol, and luteolin.[54] They know for their antioxidant and anti-inflammatory health benefits as well as the support of the cardiovascular and nervous systems.[54] *C. olitorius* also had several steroidal compounds including β-sitosterol and cardiac glycosides. Helveticoside for example showed strong cardiotonic activity.[53] Finally, there are uncategorized or miscellaneous group including 12 compounds. Monogalactosyldiacylglycerol had anticancer activity against different cell lines.[26]

5. Phytochemical biodiversity

Several studies have identified many compounds from different parts of *C. olitorius* as shown in Table 1. The chemical structures of the reported compounds are illustrated in Fig. 2.

6. Conclusion

Despite the fact that the leaves of *C. olitorius* are utilized in traditional medicine and have been known to have a variety of pharmacological effects, their use is restricted to a few cultures and widely employed in eating habits. Significant progress has been detected in publication rates of *C. olitorius* over the past 22 years (Fig. 3). Researchers have been investigating *C. olitorius* leaves, flowers as well as seeds and roots (Fig. 4). Investigation of *C. olitorius* has been shown to have a wide spectrum of

interesting bioactivities including antioxidant, hepatoprotective, anti-inflammatory, immunostimulant antitumor, antimicrobial, antidiabetic, analgesic and cardioprotective activities, in addition to the wound healing properties and its role in prevention of obesity and its antiviral activity against Covid 19. This biological diversity is certainly attributed to its diverse phytochemical composition. Flavonoids and terpenes are the most detected phytochemical classes in *C. olitorius*, followed by phenolic acids, cardiac glycosides and fatty acids (Fig. 5). *C. olitorius* is regarded as a valuable source for developing novel natural drug candidates for clinical application.

Although *C. olitorius* is used worldwide in complementary medicine, the knowledge about its phytopharmacological biodiversity is still being scanty. Detailed investigations are required to fully understand the relation between the active constituents and the proved biological activities. Analysis of the reported data indicated that the research was particularly limited to the total extracts or fractions, whereas the purified compounds have not received much interest. Additional investigations should be comprehensively performed in order to identify the secondary metabolites and their actual contribution to the medicinal activities of *C. olitorius*. Moreover, the mechanism of action and the probable synergistic interactions of the different phytoconstituents should be considered as well. This will control the safe and beneficial application of *Corchorus olitorius* in phytotherapy. From a therapeutic viewpoint, the anticancer and the antimicrobial potentials of *C. olitorius* represent indispensable future research themes involving the study of the pure compounds, their structure–activity relationship and the mechanisms of action *C. olitorius* is an interesting candidate for the development of alternative drugs beside its effective utilization as a functional food ingredient due to its prominent nutritional value.

Conflicts of interest

No conflicts to declare.

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