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Original article

Comparative assessment of biological activities of different parts of halophytic plant Tamarix *articulata* (T. *articulata*) growing in Saudi Arabia

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ABSTRACT

Owing to extremely high salinity and harsh environmental conditions, T. *articulata* is one of the most abundant wild plants growing in the deserts of Saudi Arabia. Such plants may contain novel compounds to display promising biological activities. Here, in this study, we evaluate the biological activities of methanolic extracts of fresh leaves, dry leaves, stem, and roots of T. *articulata.* The antioxidant activity was determined by 2, 2-diphenyl-1-picrylhydrazyl (DPPH) and total phenolic and flavonoid content were determined using standard colorimetric methods. Whereas antimicrobial and ant-proliferative activities were determined by standard well-diffusion and 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) methods, respectively. Our results demonstrate that all methanolic extracts of T. *articulata* showed antioxidant activity, however, the methanolic extract of dry leaves exhibits promising antioxidant effect with IC_{50} value 49.08 ± 1.98, which was strongly supported by total phenolic (409.92 ± 6.03 mg GAE/g DW) and flavonoid (177.71 mg QE/g DW) content. Although, antimicrobial activity was also exhibited by all the methanolic extracts, however, methanolic extract of dry leaves exhibits promising antimicrobial activity in Gram-positive bacteria Staphylococcus *epidemidis.* Furthermore, MTT assay revealed that all methanolic extracts exhibit antiproliferative activity in MCF-7 (breast cancer) and RKO (colorectal cancer) cells with IC_{50} values ranges from 219 ± 5.112 μg/ml to 253 ± 5.231 μg/ml and 220 ± 4.330 μg/ml to 325 ± 6.213 μg/ml, respectively. However, the most promising antiproliferative effect was displayed by methanolic extract of dry leaves with IC_{50} values 219 ± 5.112 μg/ml and 220 ± 4.330 μg/ml, respectively. In summary, these findings provide evidence that T. *articulata* has promising biological activities and can be used for many pharmaceutical activities in the future.

1. Introduction

Plants are excellent sources of secondary metabolites including alkaloids, terpenoids, tannins, polyphenols, and flavonoids. Due to these secondary metabolites, the medicinal plants have great significance in the modern world. More than 30% of drugs in the modern world are derived from a plant source or derived from plant products (de Fátima et al., 2014; Patwardhan, 2005; Rah et al., 2012; Rah et al., 2015b). These valuable secondary metabolites possess numerous pharmacological activities including antioxidant, antimicrobial, anti-depressant, anti-lipidemic, anti-inflammatory, antitumor and other biological activities which can be of immense significance in therapeutics against different medical ailments (Alnuqaydan et al., 2020; Iwara et al., 2014; Ksouri et al., 2009; Mubashir et al., 2017; Nascimento et al., 2000). Attributable to nature's enormous diversity of plant species on this planet, these plants possess chemical substances and influence the biological processes of the human body because of their compatibility (Samy et al., 1999).

T. *articulata* is commonly called "Athal" in the Arabic region. It is a type of halophytic plant and grows much faster than other plants in extremely arid and harsh environmental conditions. T. *articulata* belongs to family *Tamaricaceae*. The plant is woody

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and can reach a height of 50 feet and a width of 6 feet (Alnuqaydan and Rah, 2019). A long time ago the plant was used by a tribal population called Tafilalet of the southeastern region of Morocco for its medicinal properties against various diseases such as heart disease, ulcers, hypertension, skin diseases, gastrointestinal disorders, and hair loss (Hebi and Eddouks, 2017; Hebi et al., 2017; Hebi et al., 2018; Tabet et al., 2018). Despite a few biological activities of T. *articulata* that have been reported from the Morocco region, but it is still not clear the phytochemical composition and the comprehensive analysis of biological activities of different parts of T. *articulata*. Therefore, the present study was conducted to evaluate the comparative analysis of biological activities of different methanolic extracts (fresh leave, dry leaves, stem, and root) of T. *articulata* found in Saudi Arabia.

2. Material and methods

2.1. Plant material and preparation of methanolic extracts

T. *articulata* plant specimens were collected from the desert areas of the Qassim region of Saudi Arabia in August 2019 along with dried leaves from the floor.

Methanolic extracts were prepared as per standard protocol (Wannes et al., 2010). The different parts of T. *articulata* were completely air-dried; the fine powder was obtained after grinding 100 g of each plant part (fresh leaves, dry leaves, stem, and root) in a kitchen blender. 12 g of each part was weighed, dissolved in 100% methanol, and were constantly stirring at room temperature for 3 days. Mixtures obtained were filtered through Whatman filter paper in a clean autoclaved glass beaker. The solvent was evaporated completely to get a fine powder of residue. The residue powder was stored at 4 °C and dissolved in 90% methanol for further experiments to evaluate the biological activities of the various residues of different parts of T. *articulata* plant.

2.2. Chemicals

Folin–Ciocalteu reagent (FCR), 3-(4,5-dimethylthiazol-2-yl)-2,5 -diphenyltetrazolium bromide (MTT), gallic acid (GA), 1,1-diphenyl-2-picryl-hydroxyl (DPPH), quercetin (QE), almunium chloride ($AlCl_3$), dimethyl sulfoxide (DMSO) and HPLC grade methanol were purchased from Sigma-Aldrich St. Louis, Mo., USA). Other analytical grade solvents and chemicals were procured locally.

2.3. Cell culture and treatments

MCF-7 (breast cancer) and RKO (colon cancer) cell lines were obtained from American Type Culture Collection (ATCC) and cultured in a humidified incubator with 5% CO_2. The cells were cultured in the Roswell Park Memorial Institute (RPMI)-1640 and Dulbecco's Minimal Essential Medium (DMEM) cell culture media respectively, which were supplemented with 10% fetal bovine serum (FBS) and 1% penicillin–streptomycin solution to avoid any bacterial contamination. Both the cell lines were free from Mycoplasma contamination.

2.4. Total phenolic content

The total phenolic content of all methanolic extracts of different parts of T. *articulata* was determined by FCR. GA was used as a reference phenolic compound for the determination of phenolic content in different methanolic extracts. As determined in previous studies (de Oliveira et al., 2009), 1.0 ml of FCR was mixed with 1.0 ml of methanolic extract from different parts of the plant having concentration (1.0 mg/mL). After proper mixing for at least 5 min, add 3.0 ml of 2% sodium carbonate solution and vortex the glass tubes to ensure complete mixing. Keep the glass tubes containing the mixture in the dark at room temperature for 3 h for proper mixing. Record the absorbance at 760 nm of each solution using a spectrophotometer. The absorbance recorded were analyzed and expressed the results in milligrams of GA equivalent per gram dry weight (mg GAE/g DW).

2.5. Total flavonoid content

The total flavonoid content of methanolic extracts of different parts of T. *articulata* was determined by using the $AlCl_3$ method (Eberle et al., 2018). Briefly, 2.0 ml of methanolic extract of different parts of T. *articulata* with concentration (1.0 mg/mL) were added to 2.0 ml of 10% $AlCl_3$ solution and vortex the solution to ensure complete mixing. After 10 min of incubation, record the absorbance of different extracts at 430 nm. Quercetin (0–40 μg/mL) was used as a reference for establishing standard curve (y = ax + b) and quantification of the flavonoid content of methanolic extracts from different parts of T. *articulata*. The concentration of total flavonoid content was expressed in milligrams of QE equivalent per gram dry weight (mg QE/g DW).

2.6. DPPH antioxidant assay

To determine the antioxidant activity of methanolic extracts of various parts of T. *articulata*, the DPPH assay was performed to estimate the scavenging ability of various extracts by quenching DPPH. As previously determined by Brand-Williams et al., in 1995 (Brand-Williams et al., 1995), the assay was performed in triplicates with slight modifications, and the mean absorbance was calculated and noted. Briefly, freshly prepared DPPH solution (0.3 mM) was prepared in 95% methanol, stored in an amber color bottle at 4–8 °C. All the T. *articulata* were dissolved in 95% methanol and make various concentrations (1000–0.976 μg/ml) of an extract as well as ascorbic acid (positive control) by applying serial dilution method. Add 500 μl of (0.3 mM) of DPPH working solution to each serial diluted 500 μl of extract as well as ascorbic acid as positive control under restricted light. Additionally, 500 μl of DPPH is mixed with 500 μl of 95% methanol as a control without extract or ascorbic acid. The mixtures of DPPH working solution and extract, ascorbic acid (positive control), or control are mixed well and incubated in dark for 30 min. The absorbance of different extracts, positive control and blank were measured by spectrophotometer at 517 nm after adjusting zero for 95% methanol. The change in coloration from dark blue to yellowish color of DPPH was recorded and percent inhibition of DPPH radical exhibited by extract samples and ascorbic acid as a positive control was calculated by using formula

$$\%\ \text{radical scavenging activity or } (\%\ \text{inhibition}) = [(A_b - A_s)/A_b] \times 100$$

A_b is the absorbance of blank, A_s is the absorbance of extract or ascorbic acid (positive control)

2.7. Antibacterial activity of plant extract

The antibacterial activity of various extracts of T. *articulata* was performed by Agar well diffusion method (Ahmad and Beg, 2001; Ramesh et al., 2002). Briefly, 0.1 ml of bacterial inoculum (10^5 colony forming units (CFU)/ml), was inoculated with a sterile cotton swab on plates containing Muller Hinton agar. 8.0 mm wells were made by punching into the solidified agar medium plate and seal the bottom of well with sterile melted agar. Add 100 μl extract (2.5 and 5 mg/ml) in each well separately, along with solvent blank

(95% methanol) and positive controls (gentamycin and ampicillin). Incubate plates overnight at 37 °C. The next day the antibacterial activity was analyzed by measuring the zone of inhibition of different concentrations against the test organism. The entire set of experiments was conducted in triplicates.

2.8. Cell viability assay

The proliferation of cells was analyzed by MTT assay as per the standard protocol (Rah et al., 2012). Briefly, MCF-7 and RKO cells were processed for trypsinization and plated at a density of 5×10^3 cells per well of 96-well plate. The cells seeded in triplicates were treated with varying concentrations of different extracts of T. *articulata* (100–10000 μg/ml) and control DMSO for 24 h, incubated in an incubator containing 5% CO_2. Subsequently, cells were saturated with MTT dye (2.5 mg/ml) for 3 h at 37 °C. The crystals formed of formazan were solubilized in DMSO, mixed properly by vortex and the optical density was measured at 570 nm by multi-plate reader. The percentage of cell proliferation was analyzed as the percent cell viability of treated cells compared with the control of DMSO cells.

2.9. Statistical analysis

All the experiments were accomplished for at least three independent times. The latest version of software Graph Pad Prism was used for statistical analysis of all independent unbiased experiments. The results obtained were denoted as the mean of ± SEM. Entire results were calculated by using the Student's unpaired *t*-test, wherein a p-value of less than 0.05 was reflected significant (* means $p < 0.05$. ** $p < 0.01$, and *** $p < 0.001$).

3. Results

3.1. Methanolic extracts of T. articulata exhibit promising antioxidant activity and possess abundant flavonoid and phenolic content

To evaluate the antioxidant potential of methanolic extracts of different parts of T. *articulata,* we accomplish the scavenging activity of DPPH radicals exhibited by methanolic extracts of different parts of T. *articulata* along with the standard compound ascorbic acid. As summarized in (Fig. 1a–d and Table 1) the higher concentrations of all methanolic extracts of T. *articulata* displays a promising scavenging activity by donating electrons to the purple-colored solution of DPPH, that results in decolorization of the purple color of DPPH to yellowish color, due to trapping of electrons donated by T. *articulata* extract to DPPH solution. The straight line obtained after recording optical density at 517 nm by spectrophotometer, revealed that the IC_{50} value of scavenging activity is 77.16 ± 1.02, 49.08 ± 1.98, 53.00 ± 1.08, 49.13 ± 1.46 μg/ml ($p < 0.5$) of methanolic extracts of T. *articulata* fresh leaves, dry leaves, stem, and root respectively. However, among all four methanolic extracts, dry leaves methanolic extract has maximum scavenging activity (49.08 ± 1.98 μg/ml) (Fig. 1b) followed by methanolic extract of root (49.13 ± 1.46 μg/ml) (Fig. 1d), indicates that methanolic extracts of T. *articulata* dry leaves and root had promising antioxidant activity.

The total phenolic content of T. *articulata* extracts was determined by colorimetric assay and the absorbance was measured at 760 nm. The phenolic content was expressed as mg of gallic acid equivalent per gram of dry weight of T. *articulata* extract. As summarized in (Table 2 and Fig. 2), T. *articulata* extracts showed the 137.12 ± 5.01, 409.92 ± 6.03, 141.75 ± 4.21, 387.08 ± 5.93 mg GAE/gDW ($p < 0.01$) for fresh leaves, dry leaves, stem, and root respectively, indicates that methanolic extract of dry leaves has highest polyphenolic content (409.92 ± 4.21) than other methanolic extracts of T. *articulata.* The total flavonoid content of methanolic extract of T. *articulata* was calculated by colorimetric assay, absorbance was measured at 430 nm and total flavonoid content was expressed as mg quercetin equivalent per g dry weight of T. *articulata* extract. As summarized in (Table 2 and Fig. 2) of each T. *articulata* extracts showed the 80.66 ± 3.54, 177.71 ± 3.76, 60.66 ± 2.88, 45.23 ± 2.13 mg QE/gDW ($p < 0.01$) for fresh leaves, dry leaves, stem, and root respectively, indicates that methanolic extract of dry leaves has high flavonoid content (177.71 ± 3.76) than other methanolic extracts of T. *articulata.* Collectively these results demonstrate methanolic extracts of different parts of T. *articulata* exhibits significant antioxidant activity, and have abundant total polyphenolic and flavonoid content; however, methanolic extract of dry leaves displays highest antioxidant activity and demonstrates that polyphenolic and flavonoid content, indicates promising biochemical activities among all extracts.

3.2. Methanolic extracts of T. articulata exhibits promising antibacterial activity

The antibacterial activity of all methanolic extracts of T. *articulata* was determined by using a well-known well-diffusion method. As summarized in Table 3, the methanolic extracts of different parts of T. *articulata* were significantly active against both Gram-positive and Gram-negative bacterial species. The highest antimicrobial activity was exhibited by methanolic extract of dry leaves of T. *articulata* (5 mg/ml) against both Gram-negative bacteria exhibit zone of inhibition (20.1 ± 0.30 mm, 19.9 ± 0.18 mm, 18.1 ± 0.18 mm against P. *aeruginosa*, K. *pneumonia*, E. *coli*) and Gram-positive bacteria (22.7 ± 0.23 mm, 25. 3 ± 0.34 mm, 19.4 ± 0.12 mm against S. *aureus*, S. *epidermidis*, S. *pneumonia*) respectively.

3.3. Methanolic extracts of T. articulata exhibits antiproliferative effect on cancer cells

To evaluate the antiproliferative effect of methanolic extracts of different parts of T. *articulata*, cancer cells (MCF-7 and RKO cells) were cultured in RPMI-1640 medium and exposed to increasing (100–10000 μM) concentrations of methanolic extracts of T. *articulata* for 24 h. As confirmed (Fig. 3a and b), all the four methanolic extracts of T. *articulata* reduces the cell viability of both MCF-7 and RKO cells as the concentrations increase above 100 μM and the effect is significant above 200 μM concentrations of T. *articulata.* Using GraphPad Prism the IC_{50} value of all the methanolic extracts of T. *articulata* on MCF-7 cells are (fresh leaves-220 ± 5.243 μg/ml, dry leaves-219 ± 5.112 μg/ml, stem-220 ± 5.643 μg/ml, root-253 ± 5.231 μg/ml) and RKO cells are (fresh laves-225 ± 2.39 μg/ml, dry leaves-220 ± 4.330 μg/ml, stem-266 ± 5.120 μg/ml, root-325 ± 6.213 μg/ml). Although the results reveal that all the extracts show promising antiproliferative activity against tumor cells, however, the methanolic extract of dry leaves exhibit maximum antiproliferative effect against both breast cancer (MCF-7) and colorectal cancer (RKO) cells.

4. Discussion

Recent advancements in alternative medicine and ethnopharmacological findings revealed that medicinal plants play an important role in the modern health care system. In recent past conservation of medicinal plants and their unrelenting supply is part of future global medical and health strategy (Sher et al., 2010). T. *articulata* is a halophytic, fork medicinal plant and has been used against various skin diseases in Saudi Arabia from long back. Although some biological activities including antidiabetic,

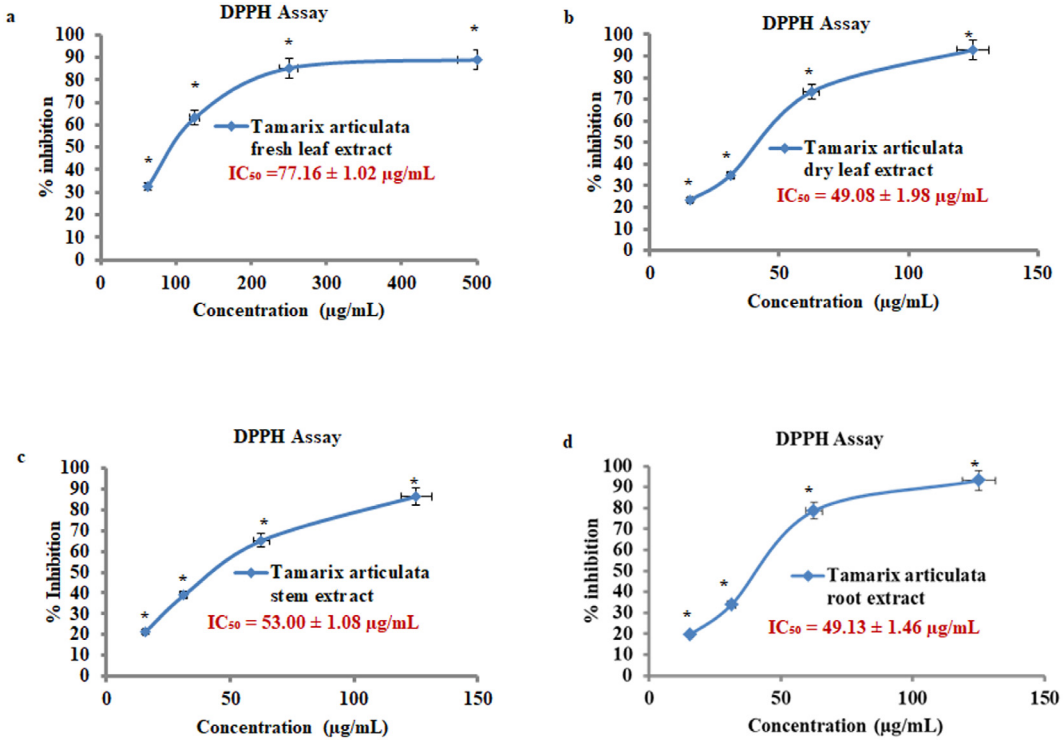

Fig. 1. (a–d) Antioxidant effect of methanolic extracts of T. *articulata* by DPPH radical scavenging assay. The data represent the mean value ± SE of 3 independent experiments. $^{*}p < 0.05$.

Table 1
The scavenging activity of DPPH radicals of methanolic extracts of different parts of T. *articulata*.

Concentration (µg/mL)	DPPH scavenging (%)				
	T. *articulata* (Fresh Leaves)	T. *articulata* (Dry Leaves)	T. *articulata* (Stem)	T. *articulata* (Root)	Quercetin
000	00.0	00.0	00.0	00.0	00.0
0.97	–	–	–	–	11.4 ± 1.41
1.95	–	–	–	–	22.6 ± 1.42
3.90	–	–	–	–	24.4 ± 1.83
7.81	–	–	–	–	45.9 ± 1.34
15.62	–	23.2 ± 1.38	27.4 ± 1.49	29.6 ± 1.41	90.4 ± 1.74
31.25	3.4 ± 1.21	34.8 ± 1.64	31.0 ± 1.30	30.9 ± 1.39	92.1 ± 1.35
62.50	32.59 ± 1.35	73.5 ± 1. 51	59.7 ± 1.28	71.7 ± 1.98	94.0 ± 1.62
125	63.0 ± 1.72	93.0 ± 1.91	86.3 ± 1.47	91.2 ± 1.72	94.8 ± 1.71
250	85.0 ± 1.43	94.3 ± 1.58	94.5 ± 1.56	94.1 ± 1.36	96.2 ± 1.32
500	88.74 ± 1.52	95.0 ± 1.71	94.7 ± 1.93	95.0 ± 1.39	96.3 ± 1.34
1000	91.5 ± 1.62	9.6 ± 1.65	95.9 ± 1.81	96.0 ± 1.32	96.4 ± 1.51
IC_{50}	**77.19 ± 1.02**	**49.08 ± 1.98**	**53.00 ± 1.08**	**49.13 ± 1.46**	**8.17 ± 1.11**

Table 2
Total polyphenolic, and flavonoid content of all the four methanolic extracts of T. *articulata* collected from Qassim region of Saudi Arabia. Values represent the mean value ± SE of 3 independent experiments.

	T. *articulata* (Fresh Leaves)	T. *articulata* (Dry Leaves)	T. *articulata* (Stem)	T. *articulata* (Root)
Total phenolic content (mg GAE/g DW)	137.12 ± 5.01	**409.92 ± 6.03**	141.75 ± 4.21	387.08 ± 5.93
Total flavonoid content (mg QE/g DW)	80.66 ± 3.54	**177.71 ± 3.76**	60.66 ± 2.88	45.23 ± 2.13

antiepileptic, anti-hair fall as well as antilipidemic activities have been reported from the southern region of Morocco (Hebi and Eddouks, 2017; Hebi et al., 2017; Hebi et al., 2018), however, it is yet to be evaluated and elucidated the biological activities of T. *articulata* plant of Saudi Arabian region. Therefore, the present study is based on the comparative analysis of biological activities of methanolic extracts of different parts of T. *articulata*.

Owing to environmental and other oxidative stress, plants produce secondary metabolites that decrease the production of free radicals and helps in the protection of cellular damage due to oxidative stress (Kasote et al., 2015). These secondary metabolites are most commonly polyphenolic compounds including flavonoids. The polyphenolic compounds exhibit antioxidant potential by reducing the level of reactive oxygen species and prevents lipid peroxidation (Ghasemzadeh and Ghasemzadeh, 2011). Previous studies revealed that the presence of polyphenolic compounds in plant extracts have promising antioxidant activity to neutralize free radicals (Alara et al., 2019; Kumaran, 2006; Rahmani et al.,

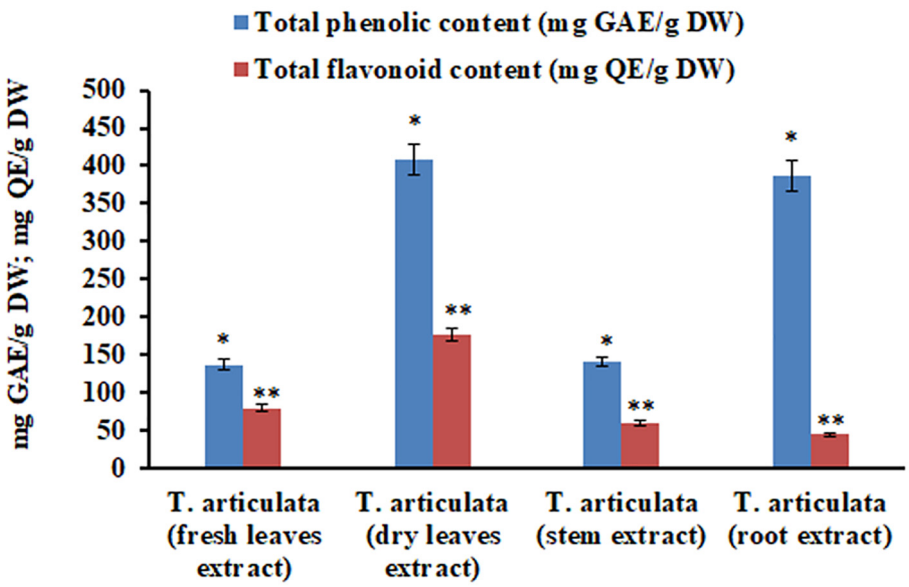

Fig. 2. Graphical representation of comparison of total phenolic and flavonoid content of methanolic extracts of different parts of T. *articulata*. The data represent the mean value ± SE of 3 independent experiments $^{*}p < 0.05$, $^{**}p < 0.01$.

Table 3
Antimicrobial activities of methanolic extracts of T. *articulata*. Values represent the mean value ± SE of 3 independent experiments.

T. *articulata*		**Gram Negative Bacteria Inhibition zone diameter (mm)**			**Standard**	**Gram Positive Bacteria Inhibition zone diameter (mm)**			**Standard**
Extracts	concentration (mg/mL)	P. *aeruginosa*	K. *pneumonia*	E. *coli*	Gentamycin	S. *aureus*	S. *epidermidis*	S. *pneumonia*	Ampicillin
Fresh Leaves	5 mg/mL	18.6 ± 0.44	17.7 ± 0.19	15.3 ± 0.35	21.3 ± 0.25	19.2 ± 0.44	19.2 ± 0.25	16.1 ± 0.35	29.3 ± 0.30
	2.5 mg/mL	15.3 ± 0.35	11.3 ± 0.58	12.0 ± 0.19		16.0 ± 0.44	16.2 ± 0.19	11.9 ± 0.19	
Dry Leaves	**5 mg/mL**	**20.1 ± 0.30**	**19.9 ± 0.18**	**18.1 ± 0.18**	**21.4 ± 0.14**	**22.7 ± 0.23**	**25. 3 ± 0.34**	**19.4 ± 0.12**	**26.9 ± 0.42**
	2.5 mg/mL	**16.3 ± 0.15**	**15.2 ± 0.14**	**14.7 ± 0.34**		**17.2 ± 0.19**	**18.1 ± 0.17**	**12.4 ± 0.18**	
Stem	5 mg/mL	19.3 ± 0.35	18.7 ± 0.32	18.7 ± 0.12	28.3 ± 0.45	19.3 ± 0.32	18.7 ± 0.32	16.9 ± 0.19	28.3 ± 0.34
	2.5 mg/mL	15.9 ± 0.30	14.7 ± 0.37	14.7 ± 0.44		15.2 ± 0.24	14.7 ± 0.43	13.2 ± 0.12	
Root	5 mg/mL	19.9 ± 0.24	18.2 ± 0.30	17.9 ± 0.33	21.7 ± 0.21	20.2 ± 0.22	22.1 ± 0.34	17.2 ± 0.18	28.1 ± 0.40
	2.5 mg/mL	16.2 ± 0.16	14.7 ± 0.22	13.8 ± 0.20		16.9 ± 0.23	17.3 ± 0.44	12.1 ± 0.19	

2014). Consistent with previous studies, methanolic extracts of different parts of *T. articulata has* abundant total phenolic as well as flavonoid content. Most importantly, among all four methanolic extracts, methanolic extract of dry leaves possesses the highest amount of total phenolic (409.92 ± 4.21 mg GAE/gDW) as well as flavonoid content (177.71 ± 3.76 mg QE/gDW). The considerably higher phenolic and flavonoid content in dry leaves reflect a greater ability to neutralize free radicals. However, when subjected to analyze the antioxidant potential of all methanolic extracts of T. *articulata,* all the four extracts exhibit significant antioxidant activity, nonetheless, methanolic extract of dry leaves displays the highest antioxidant activity and exhibit IC_{50} value of 49.08 ± 1.98 followed by methanolic extract of root 49.13 ± 1.46.

Recent reports suggest that the development of bacterial drug resistance against various approved drugs is a big challenge (Högberg et al., 2010). Therefore, searching for more potent antimicrobial agents using plant-based products/extracts plays a crucial role in preventing the cellular kinetics of pathogens (Bag et al., 2012). Plant-based extracts have been reported to be effective against multidrug-resistant microorganisms. Among them, S. *aureus* is one of the major challenging bacteria found in hospital-related infections with an approximate mortality rate of around 7–10% (Tatsimo et al., 2012). Previous reports revealed that owing to a high content of bioflavonoids and phenolic compounds, methanolic extracts of Hippophae *rhamnoides* exhibited promising activity against Gram-positive S. *aureus* and B. *subtilis* (Jeong et al., 2010; Kumar et al., 2013). Consistent with previous reports, all the four methanolic extracts of T. *articulata* shows the significant antibacterial activity as revealed by the zone of inhibition against both Gram-positive and Gram-negative bacteria when compared to positive control ampicillin and gentamycin respectively. However, methanolic extract of dry leaves of T. *articulata* exhibits maximum antibacterial activity against both Gram-positive and Gram-negative bacteria with zone of inhibition (20.1 ± 0.30 mm, 19.9 ± 0.18 mm, 18.1 ± 0.18 mm against P. *aeruginosa*, K. *pneumonia*, E. *coli*) and Gram-positive bacteria (22.7 ± 0.23 mm, 25. 3 ± 0.34 mm, 19.4 ± 0.12 mm against S. *aureus*, S. *epidermidis*, S. *pneumonia*) respectively. These results demonstrate that T. *articulata* could be used as promising antibacterial agents in the future.

Naturally occurring plant extracts and compounds are an important source of drugs against many diseases including cancer. Almost half of the FDA approved pharmaceutical drugs are either derived from plant source directly or from plant derivatives (Patridge et al., 2016). Still, there is a scope for more drugs with high efficacy on cancer cells and minimal toxicity on normal cells. In the recent past, a methanolic extract of Euphoria *terracina*

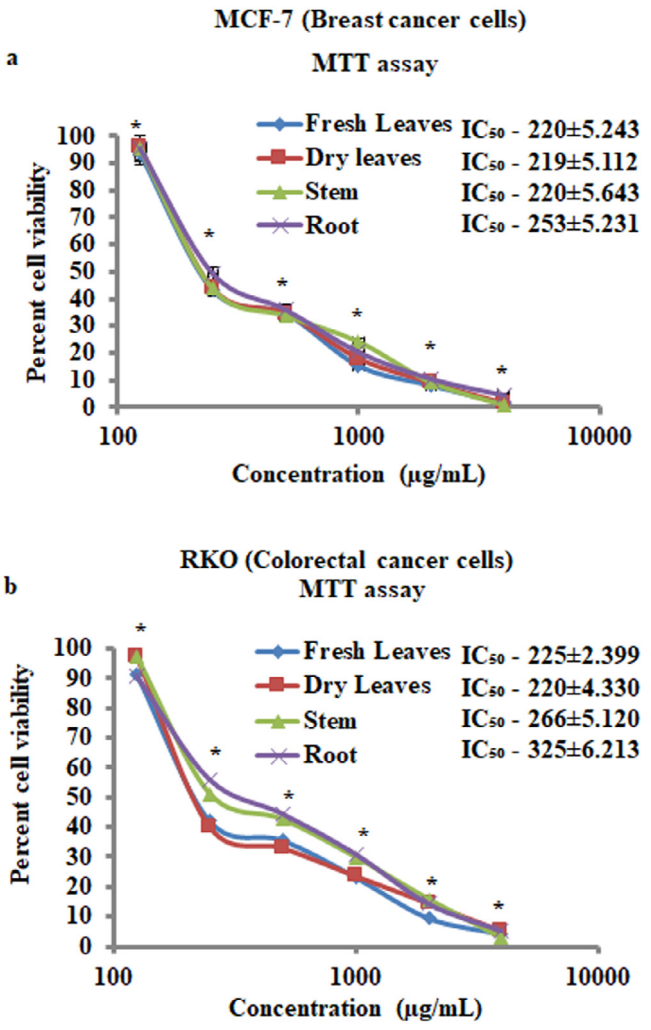

Fig. 3. Antiproliferative activity by MTT assay of methanolic extracts of T. *articulata*. (a) methanolic extracts of different parts of T. *articulata* inhibits cell viability of breast cancer (MCF-7) cells. (b) methanolic extracts of different parts of T. *articulata* inhibits cell viability of colorectal cancer (RKO) cells. The data represent the mean value ± SE of three independent experiments $^{*}p < 0.05$.

exhibits a significant antiproliferative effect on hepatocellular carcinoma cell line (HepG2) (El Manawaty et al., 2013). Additionally, natural compounds and their derivatives isolated from medicinal plant extracts have shown promising antitumor activities in vitro and preclinical studies (Chanda et al., 2012; Rah et al., 2015a; Zilla et al., 2014). Consistent with previous results, our findings revealed that T. *articulata* methanolic extracts display strong antiproliferative effect by reducing the cell viability of MCF-7 (breast cancer) and RKO (colorectal cancer) cells significantly; however the most promising effect was exerted by methanolic extract of dry leaves of T. *articulata* with IC_{50} values of 219 ± 5.112 µg/ml, and 220 ± 4.330 µg/ml against MCF-7, and RKO cancer cells, respectively. These results indicate that T. *articulata* extracts exhibit a promising antiproliferative effects on cancer cells.

5. Conclusion

T. *articulata* is one of the most abundant wild plants growing in the deserts of Saudi Arabia. Our results demonstrated for the first time the biological activities of T. *articulata* and showed promising antioxidant activity, which was strongly supported by total phenolic and flavonoid content. The antimicrobial activity was also exhibited by all the methanolic extracts against both Gram-positive and Gram-negative bacteria significantly. Furthermore, all the methanolic extracts exhibit antiproliferative activity in MCF-7 (breast cancer) and RKO (colorectal cancer). In summary, these findings provide evidence that T. *articulata* has promising biological activities and can be used for many pharmaceutical activities in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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