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Habitat-elevation and plant organ-type affect the phytochemical contents and the medicinal properties of *Senna italica* in the arid climate of Fujairah

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Extreme milieus are environments characterized by harsh weather conditions which strongly affect plant physiology. Previous works have attempted to examine the impacts of environmental conditions on the plants metabolism. However, there is lack of scientific data addressing these biological phenomena in the arid regions. The present work was designed to understand how arid conditions affect the phytochemical and antimicrobial analyses of *Senna italica* plant considering plant organ, organ-age, and elevational effects. In the first study, young and mature organs of *Senna italica* were subjected to pigments analyses to see how pigments contents vary according to the elevation, while the second study evaluated the effects of plant organs on the phytochemical and antimicrobial analyses of *S. italica*. Based on our results, plant growing from highest elevations exhibited greater values of pigments contents than the other. Higher pigments contents were recorded in the leaves than the branches. Greater values of pigment were observed in the mature than the young leaves, and young branches had more pigments levels than the matures. Calcium, manganese, ash, total flavonoids, vitamin E and B1 contents were greater in the leaves while; phosphorous, zinc, magnesium, copper, crude protein, total digestible nutrients were higher in the seeds. Branches exhibited elevated levels of sodium, dry matter, tannins and potassium, while fibers contents were greater in the fruits. Fruits extract showed higher antimicrobial effects than the other organs with the inhibition zones ranging from 14.33 to 16.33 mm. The findings of this work indicates that pigments adjustments could be one of the mechanisms of adaptations of *S. italica* and this adaptation could help identifying novel metabolites that could be used against drug-resistant microbes in the arid regions.

Keywords Habitat-elevation, Plant organ-type, Phytochemical profile, Antimicrobial activities, *Senna italica*, Arid environment

Photosynthesis process by which sunlight is converted into chemical energy is the main foundation for any kind of life. Photosynthetic and metabolic reactions in plants are strongly affected by intrinsic and extrinsic variables, which determine the types and the levels of metabolites[1–4]. Chlorophylls and the accessory pigments as well as their regulation play critical role in the mechanism of survival of many plant species[5,6]. Chlorophylls are the main components of the photosynthesis machinery, and these phytochemical elements could be damaged when exposed to extreme conditions.

With this regard, carotenoids which are the accessory pigments play critical function in protecting the chlorophylls against photo-oxidative stress and photoinhibition. Since the weather conditions can importantly vary under different ecological situations, then, the concentrations of chlorophylls and accessory pigments could be dramatically adjusted according to the local conditions[7,8]. The roles of photosynthetic pigments in helping plants species coping with various weather conditions have been intensively addressed in many earlier works[9,10]. However, the literature review is less documented regarding the arid regions.

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Furthermore, altitudinal effects can significantly induce change in plants pigments quality and quantity, and the impacts could be much higher in the extreme environments than the other[11,12]. Significant adjustments in pigments contents could be observed in the plants exposed to higher elevation compared to those of lower altitudes. Strategically, regulating the biosynthesis of the pigments could help plant withstand with excessive light and temperature, and water scarcity recorded at higher elevation. Plants growing at higher elevation might increase pigments contents to maximize light absorption which is critical for the photosynthesis processes. To illustrate this, the levels of carotenoids were reported to increase with the increase of the altitudes in *Prunus mira* plant[13]. In the other works[14], found that young leaves of *Moringa peregrina* plant growing from the upper habitats contained more chlorophyll than the mature, while the opposite trends were recorded at lower altitudes. Moreover[15], recorded higher chlorophyll contents at the altitude of 3200 m compared to 2905, and these amounts were found to decrease with the increase of the elevation. Although, variability in pigments contents could be one of the keys of survival of plant species, only few previous works have attempted to explain how these environmental constraints affect plants physiology under arid regions.

Adjustments in plants minerals, nutrients, vitamins and the other chemical compounds, and their distribution within plant organism can help this latter coping with extreme changes that could damage their apparatus[16]. recorded greater levels of Ca, Mg, Mn, Zn in the plant leaves of *Sambucus* species, while the amounts of K and P were higher in the stalks. Corroborating findings were reported by[17] in *Pterocarpus erinaceus* plant. The work of[18] on the comparative studies between the leaves and the seeds of one of the most drought tolerant plant *Calotropis porcera* revealed important levels of minerals, crude fat, ash, crude protein in the leaves than the seeds. Similar statements were reported by[19] in five wild plants of the arid region of Fujairah in the United Arab Emirate (UAE). Predictions on human population growth revealed that the growing rates will increase importantly in the coming years[20]. Greater increment in human population growth could be laid to environmental degradation and natural resources depletion[21]. In general, arid regions are those geographical zones experiencing more stressful environmental conditions than the other. Therefore, the impacts associated to human population growth could be much higher in these regions than the other. Socioeconomically, metabolites resulting from the plants of the extreme milieus could be pharmacologically and clinically analysed and then integrated in the food and medicine production in the arid regions to prevent food shortage However, there is a lack of scientific information addressing these environmental effects on plant phytochemical, antimicrobials, and nutritional value with focus on wild plants of most of the extreme environments.

Antimicrobials including antibiotics, antivirals, antifungals, antiparasitic are pharmaceutical products used to treat and to prevent many health issues related to human populations[22]. Over the past decades, many of those antimicrobial products have become ineffective against some specific microbes and parasites[23]. To date, microbes resistant to antimicrobials is the major concern globally and this could constitute a significant threat for the future generation. Overall, *Mycobacterium tuberculosis*, *Salmonella*, *Shigella*, *Neisseria*, *Gonorrhoeae*, *Pseudomonas aeruginosa*, *Staphylococcus aures*, *Streptococcus* species, *Escherichia coli*, *Bacillus* species, and *Enterococcus Klebsiella pneumoniae* were recently reported as the most critical pathogens[24,25] while *Candida albicans*, and *Aspergillus* species were ranked as the most virulent fungi that significantly alter human health[26]. Furthermore, *Saccharomyces cerevisiae* commonly known as baker, yeast present multiples uses and benefits for human well-being[27] but however, under certain environmental conditions, this fungus can cause important damages to human health and disrupt many physiological functions[28]. With this respect, many studies have been carried out with the main goal to elucidate the mechanisms of adaptabilities of those pathogens and the efficient method to mitigate their proliferation and nuisances within human population. However, the problem of microbes resistant to antibiotics is still growing faster. Therefore, it seems very important to explore and to experiment plants species growing under different geographical regions and environmental conditions which could help identifying novel metabolites with strongest antimicrobial effects. Unfortunately, most of the previous works on this thematic were not addressed in the arid regions.

Senna italica is a perennial small shrub ranked under *Fabaceae* family growing in many habitats in the Emirate of Fujairah with higher adaptations to the harsh conditions (Fig. 1).

In UAE, as well as in the other countries, *Senna italica* plant is considered very valuable medicinal plants[29,30]. Local people reported that plant parts of *S. italica* positively affect the health of animals exposed to it. Field observations showed that this plant grows at different elevations in the Emirate of Fujairah. Plants experiencing changing associated with elevation might significantly adjust their pigment contents according to the plant organ-type to increase their survival capacity. Chlorophylls contents are vital for plant survival. Under harsh conditions, plants might maximize the storage of these metabolites in the branches to optimize their adaptability, and this might also vary according to the organ-age. Plant pigment content is directly associated with plant species, plant organ-type and organ-age, and environmental conditions. Therefore, the concentrations of plants pigments could determine its performance according to the environmental constraints. Nitrogen and other minerals are critical for pigments biosynthesis. Environments with deficiencies in nitrogen can therefore decrease chlorophyll production in plant and impair photosynthesis process[31]. The levels of nitrogen of the plants growing at higher altitudes could be regulated to increase the production of chlorophyll. Higher chlorophyll contents could be correlated to higher photosynthetic efficiency which allow plant to maximize light absorption. As per this, any noticeable changes in pigments contents could be considered as one of the survival strategy of the plant experiencing this environmental constraint. Therefore, exploring the pigment contents of *S. italica* might help understanding how this plant challenges with elevational effects through pigments adjustments. Although intensive works have been carried out and addressed on this subject, the current literature review is still poorly documented regarding the arid regions globally. Besides this, most of the earlier works had no much interest considering plant organ-age as one of the factors that could help optimizing plant adaptabilities when exposed to altitudinal effects. Furthermore, minerals, vitamins, and nutrients of the plant facing extreme conditions might strongly vary from plant organ-to-organ to help this latter withstand the changing occurring around its

Fig. 1. Full mature plant of *Senna italica* (**a**), and fresh fruits (**b**) growing in the Emirate of Fujairah.

surrounding environment. Therefore, nutrients and other chemical elements could be disproportionately stored from organ-to-organ according to the plant demand. Some previous studies have attempted to address these observations. However, there is a lack of published papers examining these biological phenomena under arid regions which could be beneficial for pharmaceutical and food industries, and environmental protection.

Therefore, in the first part of this work, we examined the pigments contents of *S. italica* considering plant organ-age and elevational effects which might help explaining its higher capacity to challenge the harsh environments. The second study evaluated the effects of plant organs on the phytochemical composition and antimicrobial activities of *S. italica* which could help optimizing pharmacological tests and food production in the arid regions.

Materials and methods

Site study and samples preparation for the analyses

The present investigations were conducted within the Emirate of Fujairah during October 2024. In UAE, October is considered a transitional month as it falls between the end of the summer and the beginning of the winter. The average temperature of October month is estimated at 34 ° C with no rainfall occurring. The tested plant was taxonomically identified by Dr. François, Botanist in the Plant Department of Fujairah Research Centre. *Senna italica* plant samples with the habitat and botanical information were deposited to Sharjah Seeds Bank and Herbarium, Sharjah, UAE under the voucher number 4088. The current study was designed in two separated experiments. The first study assessed the impacts of elevation on the pigments contents of *S. italica* collected under 08 habitat-elevation within the Emirate of Fujairah emphasizing plant organ-age (young and mature leaves, young and mature branches), while the second work investigated the phytochemical composition and the antimicrobial activities of the selected plant considering plant organs effects (flowers, fruits, seeds, leaves and branches) (Fig. 2).

For the first experiment, collected plants were separated into young and mature leaves, young and mature branches. Young and mature parts were identified through their phenotypes (Fig. 3).

In the second experiment, plant samples were segregated into flowers, fruits, seeds, leaves, and branches. Thereafter, the separated plant parts were washed using running tap water and then rinsed thrice with distilled water prior the analyses. The study adhered with the ethical standards and legal guidelines needed for plant samples collection in unrestricted areas in UAE. An authorization letter allowing plant sampling has been submitted as supporting document.

Biotic and abiotic factors can affect the mechanisms of plants growing at various altitudes. These factors can disrupt many physiological functions in plants depending on their magnitude. *Senna italica* is well-known as drought resistant plant, and it is found growing in many habitats in the Emirates of Fujairah. Leaves and branches greenness is one of the most phenotypic characters of *S. italica*. As per this, in the current work, we hypothesized that plant pigment contents of *S. italica* would strongly vary according to the elevation and plant organ-age. Moreover, in the Emirate of Fujairah, farmers argued that plant parts of *S. italica* significantly and positively affect the healthiness of camel, cattle, and sheep when exposed to this latter. We, therefore, also hypothesized that phytochemical and antimicrobial analyses of *S. italica* would greatly vary from organ-to-organ. The information on the utilities of *S. italica* was directly collected through interviewing the local people who have experienced this plant. In this first report, plant growing at highest altitude (408 m) was selected for phytochemical and antimicrobial analyses considering plant organs effects.

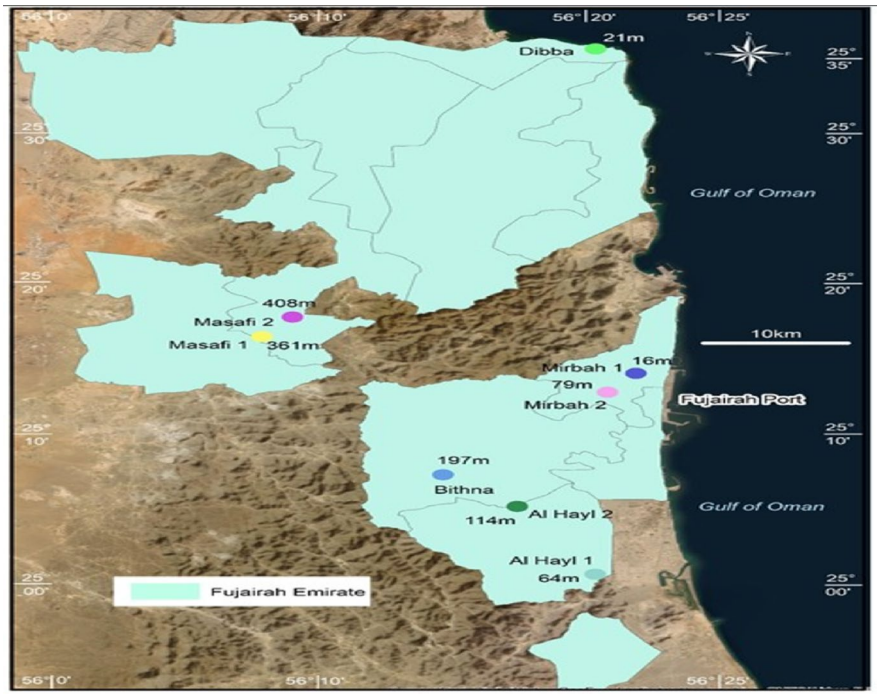

Fig. 2. Location-point of collection of *Senna italica* plant samples and the altitudes within the Emirate of Fujairah.

Fig. 3. Young (**a**) and mature (**b**) leaves, young (**c**) and mature (**d**) branches of *Senna italica*.

Pigments analysis

The collected young and mature organs of *Senna italica* were subjected to chlorophyll a, chlorophyll b, and total carotenoids analyses. The analyses were conducted according to the work of[32] with slight adjustments. To do this, 150 mg of fresh plant-organ were cut into small piece and then kept in the 50 ml falcon tube containing 15 ml of methanol. Thereafter, each tested tube was wrapped with aluminium foil and kept at 4° C for 48 h until the samples were colourless. Subsequently, the extracts were centrifuge at 4500 rpm for 10 min and then the supernatant was transferred to other tubes, and the absorbance of the extracts were measured at 666 for chlorophyll a, 653 for chlorophyll b, and 470 for total carotenoids. The following equations were performed to determine the photosynthetic pigment for each type with V being the extract volume (mL) and W the plant-organ fresh weight (g).

$$\text{Chlorophyll a (mg/g)} = [15.65 \times (\text{A666}) - 7.34 \times (\text{A653})] \times \text{V}/(1000 \times \text{w})$$

$$\text{Chlorophyll b (mg/g)} = [27.05 \times (\text{A653}) - 11.21 \times (\text{A666})] \times \text{V}/(1000 \times \text{W})$$

$$\text{Total carotenoids (mg/g)} = [1000 \times (\text{A470}) - 2.86 \times (\text{Chla}) - 129.2 \times (\text{Chlb})]/245 \times \text{V}/(1000 \times \text{W})$$

Nutrients and chemical analyses

Total ash: Total ash determination was performed by taking 2 g of the dry plant sample to the silica crucible at 600° C in the muffle furnace for 2 h (AOAC, 942.05). Dry matter: To estimate the dry matter content, then

5 g of each plant sample was taking to the oven-dried adjusted at 105° C for 3 h until unchanging dry weight values following (AOAC, 922.06). Crude fat: Total crude fat levels were obtained through the Soxhlet device by taking 2 g of plant sample refluxed with petroleum ether for 16 h. Thereafter, the crude fat was estimated after the evaporation of the petroleum ether and then the weight was measured (AOAC,920.39). Crude fibre: Crude fibre determination was conducted by digesting 2 g of plant samples with 1.25% of sodium hydroxide and 1.25% of sulphuric acid respectively for 30 min. Thereafter, the collected sample was allowed to cool down and the residues were subsequently oven-dried at 130° C for 2 h followed by the ignition at 600° C scheduled for 30 min. Finally, total crude fibre levels were evaluated by taking the weight of the left residues after ignition (AOAC, 962.09). TDN: The analyses of total digestible nutrients were carried out considering fat, protein, crude fibre, and non-volatile ether extract basis. Crude protein: Crude protein contents were determined following the Kjeldahl method and the official methods of analysis international, edition 2023. To do this, 0.5 g of each dried plant sample was taken to Kjeldahl tube containing 15 ml of sulphuric acid and then two Kjeldahl tablets were added to the tube. Afterward, the sample was digested at 350° C for 1 h. Finally, distillation and titration steps were completed automatically by the device. Tannin: Tannin analyses were conducted following the work of[33]. Vitamin E and B1: Vitamins analyses were performed as per the work of[34,35]. Total flavonoids: Total flavonoids contents were performed in accordance with the work of[36]. Mineral determination: Na and K were characterized by digesting 1 g of sampling plant with nitric and hydrochloric acid following the Association of Official Agriculture Chemists (AOAC 969.23) while, Ca, P, Mg, Mn, Zn, and Cu were performed as per the Official Agricultural Chemists (AOAC 2015.01). Heavy metal analyses: Food contaminated by heavy metals can adversely affect human health and disrupt many physiological functions. Although various heavy metals can alter food quality, the levels of cadmium and lead remain preponderant in many foods[37]. Therefore, plant samples of *Senna italica* were analysed for heavy metals including cadmium and lead to determine their toxicity levels. To do this, 0.5 g of each sample was digested with nitric and hydrochloric acids using microwave digestor (AOAC 2015.01).

Microbial activities investigations: inhibition zones

Antimicrobial activities of plant extracts parts of *Senna italica* (flowers, fruits, leaves and branches) collected at highest altitude (408 m) were tested against bacterial and fungal strains by disk diffusion method (ISO 16782:2016) following the works of[14,38]. Bacterial strains were *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Salmonella enterica*, *Streptococcus pyogenes*, Vancomycin-Resistant *Enterococcus*, Methicillin-Resistant *Staphylococcus aureus*, and *Escherichia coli* and *Klebsiella pneumoniae* whereas, the fungal strains were *Candida albicans*, *Saccharomyces cerevisiae*, *Aspergillus niger*, and *Aspergillus flavus.* Bacterial inoculum was carried out by suspending colonies for 24 h culturing in 9 ml of saline distilled water. Thereafter, a spectrophotometer (DO = 0.8–0.1/= 625 nm) was applied to adjusted the cell density of each inoculum in order to reach the final concentration of about 108 CFU (0.5 McFarland Standard). Doing so, a 108 CFU inoculum is dispersed over the surface of a 3–4 mm thick Muller-Hinton agar. Afterward, 10 µl of each crude extract was sprayed in each experimental plate. Subsequently, all the plates were incubated at 37° C for 24 h and then the inhibition diameters were determined in mm. antifungal activities assessments were similar to those of the bacteria with some modifications. For the antifungal tests, the culture medium was adjusted to have Muller Hinton + 2% glucose and 0.5 g/ml of methylene blue at pH of 7.4. Then, spectrophotometer was utilized to regulate the cell density of the inoculum (OD = 0.12–0.15/= 530 nm).

Data analysis

In the current work, two factors including plant organ-age and altitude were experimented on the pigment contents of *Senna italica*. The collected data were analysed in triplet and two-way ANOVAs (analyses of variance) were performed between the different tested variables. Furthermore, one-way ANOVA was used to assess the plant organ effects on the phytochemical composition and medicinal properties of *S. italica.* Tukey test (Honestly significant differences, HSD at $p < 0.05$) was carried out to identify difference between the means. All the data were statically analysed through SYSTAT version 13.0.

Results

Impacts of altitude and plant organ-age (young and mature leaves) on the photosynthetic pigment of *Senna italica*

Altitudinal and plant organ-age, and their interactions showed significant effects on the photosynthetic pigment of *Senna italica* with mature leaves exhibiting greater values of pigment contents than the young (Fig. 4; Table 1). Chlorophyll a (3.746 mg/g), carotenoids (1.482 mg/g), and chlorophyll b (1.314 mg/g) values were significantly higher at 361 and 408 m in the mature leaves respectively. Overall, pigment contents of *S. italica* were found to increase with the augmentation of the altitude with some noticeable variations in the chlorophyll b analyses.

Impacts of altitude and plant organ-age (young and mature branches) on the photosynthetic pigment of *Senna italica*

Statically, there were significant effects when considering altitude and plant organ-age on the photosynthetic pigment of *Senna italica* with young branches revealing more important contents than the mature (Fig. 5; Table 2). Greater variations were noticeable between the different tested altitudes with 361 m exhibiting slightly more chlorophyll a (0.537 mg/g) in the young branches than 64 m, and these values were higher than the mature and other plant locations. However, the amounts of chlorophyll b (0.322 mg/g) in the young branches collected at 361 m were higher than those of the lower elevations. Surpassingly, total carotenoids contents (0.357 mg/g) were importantly higher in the young branches sampling at highest altitude (361 m) than the mature and the other habitat-elevation.

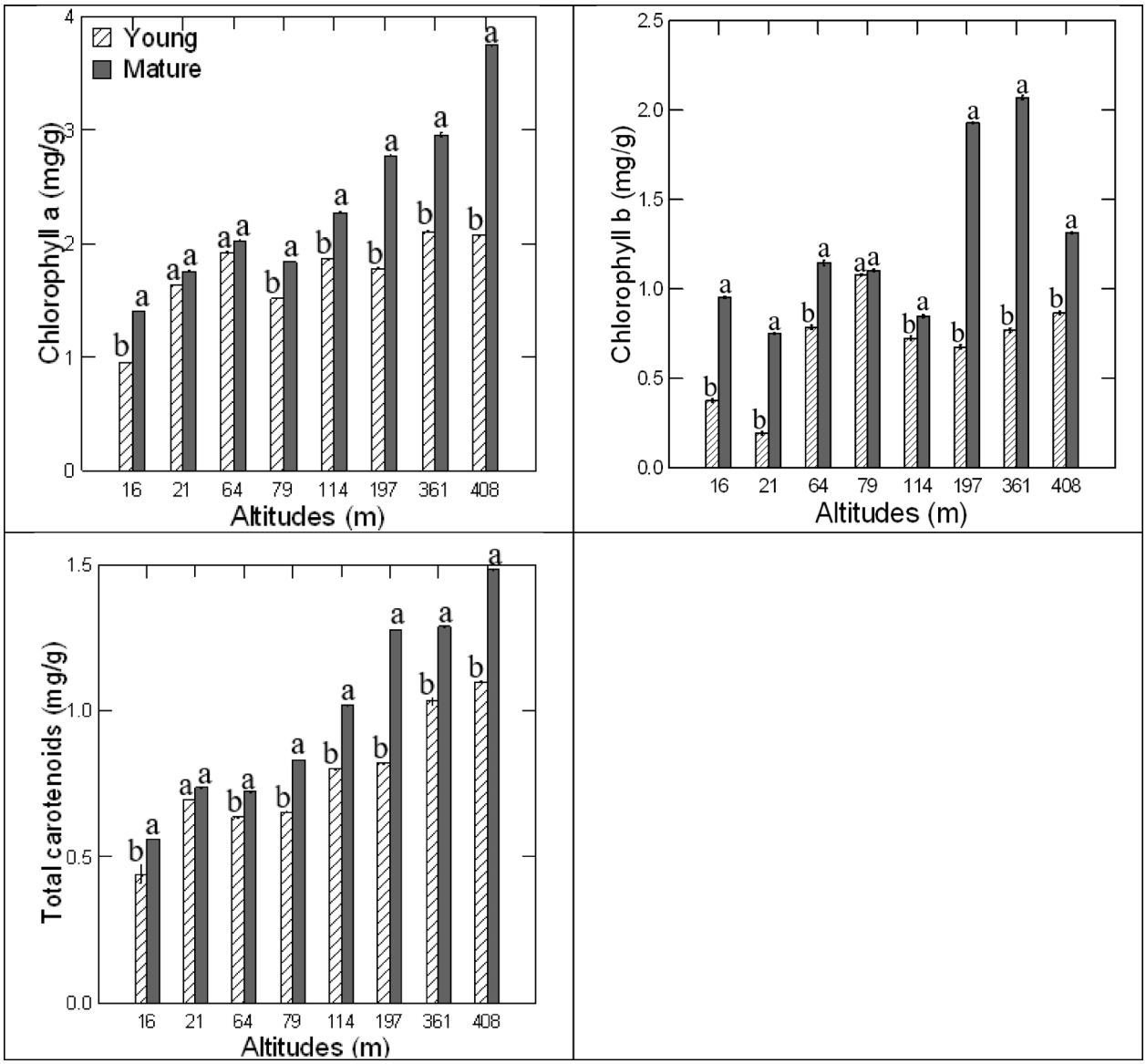

Fig. 4. Effects of altitude and plant organ-age (young and mature leaves) on the photosynthetic pigment of *Senna italica* plant.

Variables	Df	Chlorophyll a	Chlorophyll b	Total carotenoids
Organ-age (OA)	1	166,578.751***	80,722.327***	13,554.869***
Altitudes (A)	7	64,080.354***	12,228.659***	10,360.186***
OA*A	7	15,538.320***	6,629.904***	737.570***
Error	32			

Table 1. Results of two-way ANOVAs (F-Value) assessing the impacts of altitude and plant organ-age (young and mature leaves) on the photosynthetic pigment (mg/g) of *Senna Italica* plant. ***$P < 0.001$.

Impacts of plant organs (flowers, fruits, seeds, leaves and branches) on the mineral composition of *Senna italica*

Statically, plant organs had significant effects on the mineral composition of the tested plant (Fig. 6; Table 3). The levels of Ca (1966.83 mg/100 g) and Mn (3.06 mg/100 g) were found to be greater in the leaves than the other organs. Seeds exhibited more important P (329.67 mg/100 g), Zn (2.07 mg/100 g), Mg (347.10 mg/100 g) compared with the other tested plant organs. The amount of Na (38.43 mg/100 g) recorded in the branches were much higher than those of the other plant parts whereas, Cu (1.34 mg/100 g) and K (1959.41 mg/100 g) fruits

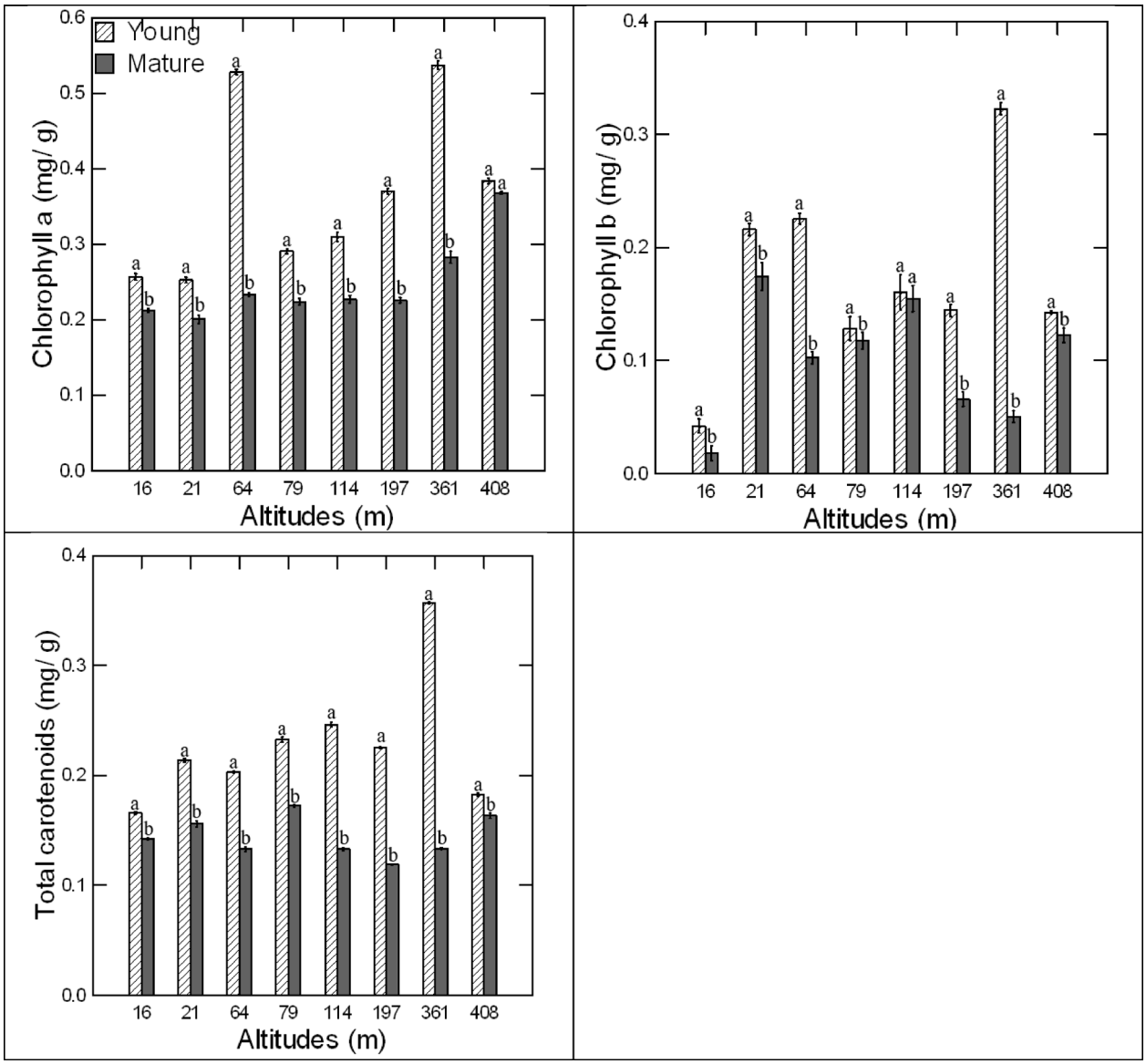

Fig. 5. Effects of altitude and plant organ-age (young and mature branches) on the pigment contents of *Senna italica* plant.

Variables	df	Chlorophyll a	Chlorophyll b	Total carotenoids
Organ age (OA)	1	15,179.810***	1,683.692***	57,170.004***
Altitudes (A)	7	2,775.282***	456.190***	3,158.952***
OA*OA	7	1,418.560***	329.791***	4,339.368***
Error	32		1,683.692***	57,170.004***

Table 2. Results of two-way ANOVAs (F-Value) evaluating the impacts of altitude and plant organ-age (young and mature branches) on the pigment contents (mg/g) of *Senna Italica* plant. ***P ˂ 0.001.

contents showed elevated values compared with the other organs. The selected plant parts of *Senna italica* were also investigated for selenium analyses but no levels of detectability of this chemical element were recorded.

Heavy metal analyses

Plant organs of *Senna italica* (flowers, fruits, seeds. Leaves and branches) were investigated for heavy metal analyses considering cadmium and lead but none of these plant samples exhibited contents in the selected chemical elements.

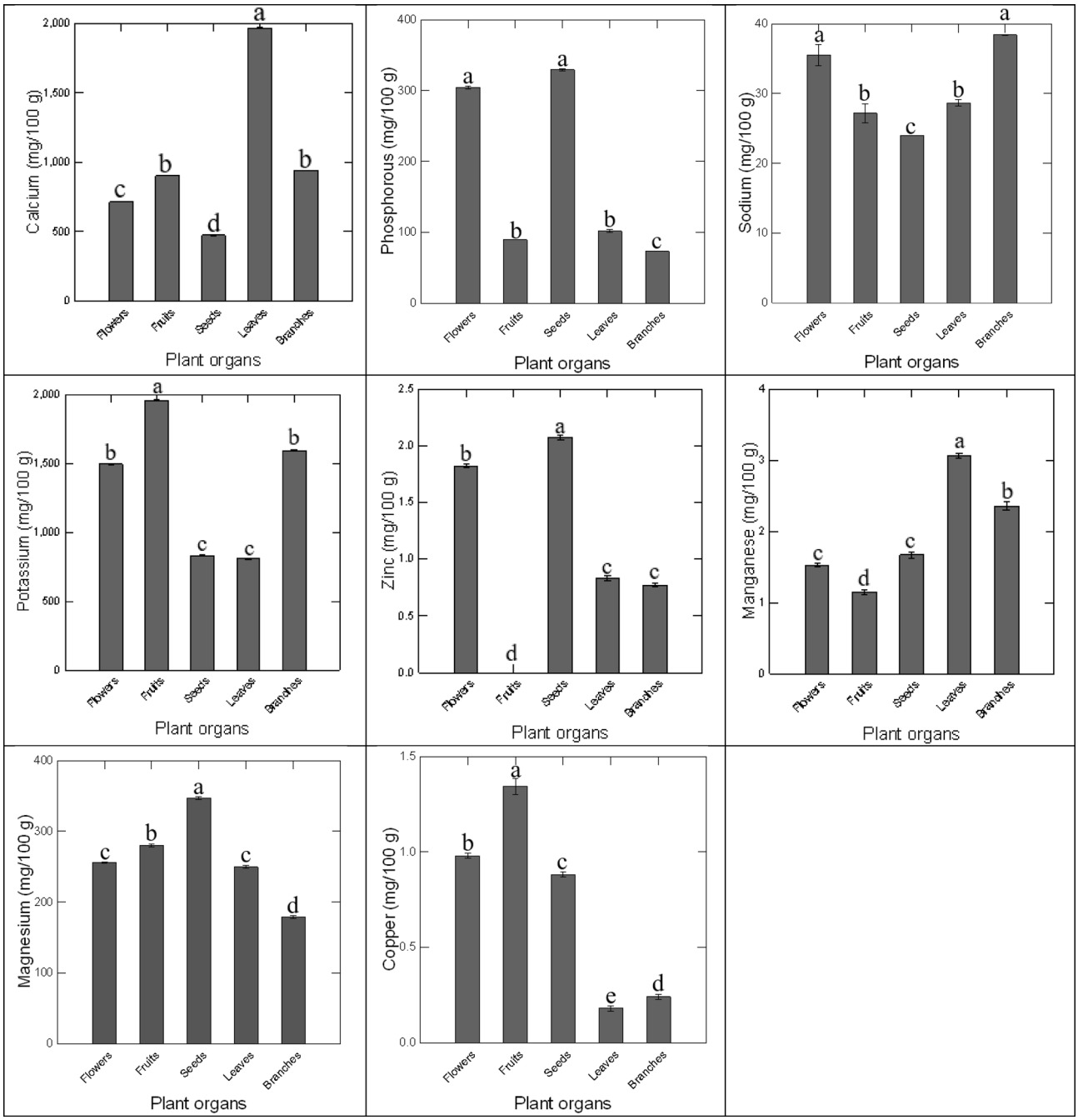

Fig. 6. Impacts of plant organs (flowers, fruits, seeds, leaves and branches) on the mineral contents of *Senna italica*.

Variables	df	Ca	*P*	Na	K	Zn	Mn	Mg	Cu
Plant organs	4	369,911.611***	41,705.573***	224.146***	129,491.999***	5,760.321***	1,771.881***	5,172.598***	2,822.725***
Error	10								

Table 3. One way ANOVA (F-value) testing the effects of plant organs (flowers, fruits, seeds, leaves, and branches) on the mineral concentrations (%) of *Senna italica*. ***P < 0.001.

Proximate and phytochemical analyses of plant organs of *Senna italica* (flowers, fruits, seeds, leaves and branches)

Plant organs had significant effects on the chemical components of *Senna italica* (Fig. 7; Table 4). Overall, dry matter (89.88%) and tannins (4.14%) levels were greater in the branches compared with the other tested plant parts, and the lower values were recorded in the flowers, and the values were 48.04% and 2.73% respectively for the dry matter and the tannins. The amounts of both crude protein (17.64%) and TDN (84.86%) were seen to be significantly higher in the seeds than the other plant parts. The levels of crude fibre (36.68%) were noticeably much higher in the fruits than the other plant parts, with lower concentrations found in the fruits (4.75%). Leaves of the tested plant exhibited elevated amounts of total ash (8.85%), total flavonoids (2756.97 mg/kg), vitamin E (189.52 mg/kg), and vitamin B1 (63.60 mg/kg) compared with the other plant parts. The selected plant organs were also subjected to vitamin A analyses but none of the tested parts had a content in vitamin A. Furthermore, sampling samples of *S. italica* were also investigated for the total fat analyses, and the recorded levels were less than 0.1% for all the tested samples.

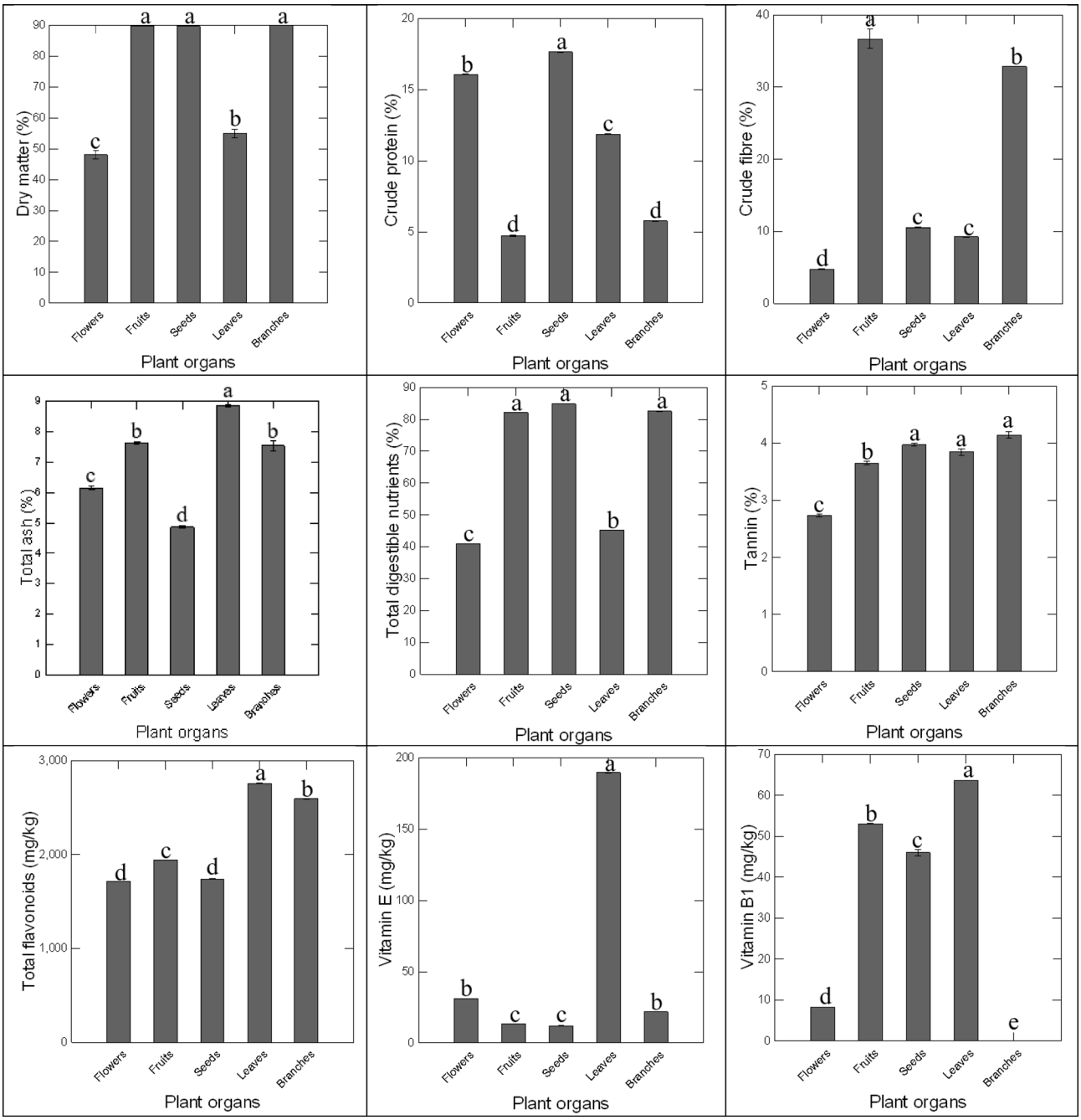

Fig. 7. Impacts of plant organs (flowers, fruits, seeds, leaves and branches) on the proximate and phytochemical analyses of *Senna italica*.

Variables	df	Dry matter	Crude protein	Crude fibre	Total ash	TDN	Tannins	TFla	Vit. E	Vit. B1
Plant organs	4	3,381.269***	140,095.718***	3,301.985***	2,004.837***	1,342,028.721***	879.994***	174,042.822***	3,654,406.479***	20,750.358***
Error	10									

Table 4. Results of one-way ANOVA assessing the effect of plant organs (flowers, fruits, seeds, leaves and branches) on the proximate and phytochemical components of *Senna italica.* TDN = total digestible nutrients, TFla = total flavonoids, Vit. E = vitamin E, Vit. B1 = vitamin B1, ***P < 0.001.

Effects of plant organs (flowers, fruits, leaves and branches) of *Senna italica* against the tested pathogens: Inhibition zone

The studied plant organs extracts of *Senna italica* revealed significant inhibitory effects on the growth of *Staphylococcus aureus*, *Candida albicans*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Salmonella enterica*, *Saccharomyces cerevisiae*, *Aspergillus niger*, *Aspergillus flavus*, and *Streptococcus pyogenes*, Vancomycin-Resistant *Enterococcus* (VRE), Methicillin-Resistant *Staphylococcus aureus* (MRSA), and Extended-Spectrum Beta-Lactamase producing *Escherichia coli* and *Klebsiella pneumoniae* (ESBL) (Fig. 8; Table 5). However, the antimicrobial effects were not significant against *Escherichia coli*, and VRE. Overall, fruits extract of *S. italica* showed much higher antimicrobial activities than the other tested parts with the inhibition zones of 14.33, 15, 15.33 and 16, 16.33 mm recorded from *S. aureus*, *E. coli*, *B. subtilis*, *S. enterica*, *S. cerevisiae*, *S. pyogenes*, VRE, MRSA, ESBL, *C. albicans*, *A. niger*, and *A. flavus* respectively. Fruits and leaves extract were seen to have similar values of antimicrobial effects against *S. enterica* (15.33 mm). Similarly, fruits and branches extract exhibited equal antimicrobial effects against *S. pyogenes* (15.33 mm). Contrary to the other plant organs, branches extract of *S. italica* showed elevated values of inhibition zone against *P. aeruginosa*, with lower values found in the flowers and fruits (13.33 mm).

Discussion

Arid regions are mainly characterized by extreme weather conditions that strongly influence the physiological behavior of the local flora. The impacts associated with extreme conditions could be more important on the plants growing from the high elevations than the other in those ecological zones.

Based on our results, *Senna italica* plant pigments contents varied significantly when considering plant organ-age and habitat-elevation. In sum, mature leaves and young branches collected at highest altitude showed greater values of pigments levels than the other plant organs and other altitudes. These findings are not aligned with those reported by[14]. In their work, they observed that chlorophyll contents were greater in the young leaves collected at highest elevation compared with mature, and less than those of the lower habitats during the hot summer of UAE. For the current work, pigments analyses were performed in October month, which is cooler than the summer in UAE. Plant chlorophyll content is an important key factor that affects the adaptabilities of many plants species, and this plant attribute is impacted by intrinsic and extrinsic variables. Increasing elevation may importantly affect edaphic factors, and nutrients availability which are essential for plant growth. In the subtropical zone of China, receiving 21° C annually, and with 1900 mm of precipitation[39], found that increasing altitude positively affected the amounts of soil organic carbon, and microbial biomass. However, in the geographical regions such as hottest regions which face extreme weather conditions, increasing elevation may importantly increase temperature rates. In this respect, increment in air temperature would ineluctably affect the soil microbial activities, soil nutrients, water availability, and air oxygen availability. Long-term application of high temperature was seen to alter the levels of oxygen and the physiological attributes of *Scenedesmus almeriensis*[40]. Furthermore, nitrogen is one of the most important chemical elements that significantly affects chlorophyll synthesis in plant. This chemical element is also involved in the amino acid synthesis. Therefore, plant growing at higher elevation might regulate the concentrations of nitrogen to maximize protein and chlorophyll production to enable plants absorbing optimal light and maintain the growth.

In the present work, we found greater amounts of carotenoids in the plant leaves and young branches growing at high elevation compared with those of the lower altitudes. Plant growing from upper habitats in the arid regions might experience more light and heat stress than that of the lower altitudes which can induce the accumulation of reactive oxygen species within the plant body. As per this, physiological modifications in the carotenoids metabolism could have helped *Senna italica* coping with this environmental embarrassing factor to protect the photosynthetic apparatus.

Carotenoids are essential for plants functioning, and they act as photo-protective agents to help plant surviving under harsh conditions. Therefore, metabolism of carotenoids could be activated and regulated to increase the survival capacity of *Senna italica* growing at higher elevations. The levels of carotenoids were found to increase in Spinach seedlings under high light compared with the lower[41]. Similar statements were addressed by[42] in *Lymus selcalinus* plants growing at high elevation compared to those of the lower.

In the present study, young branches contained more pigments than the mature with greater chlorophylls and carotenoids recorded at highest elevation. Compared to the other ecosystems, plants of the desert systems face more environmental stressful conditions than the other. Excessive light and heat can alter the biosynthesis of the pigments and cause significant damage to the plants. Strategically, some desert plants have adapted to this ecological situation by synthesizing and accumulating pigments at their branches levels to maximize their survival capacity. Phenotypically, young branches of *Senna italica* plant are greener and less hard than the mature, which might help this latter increasing the photosynthetic rate to maintain optimal growth when experiencing extreme conditions[14]. found higher nitrogen content in the young than the mature branches of

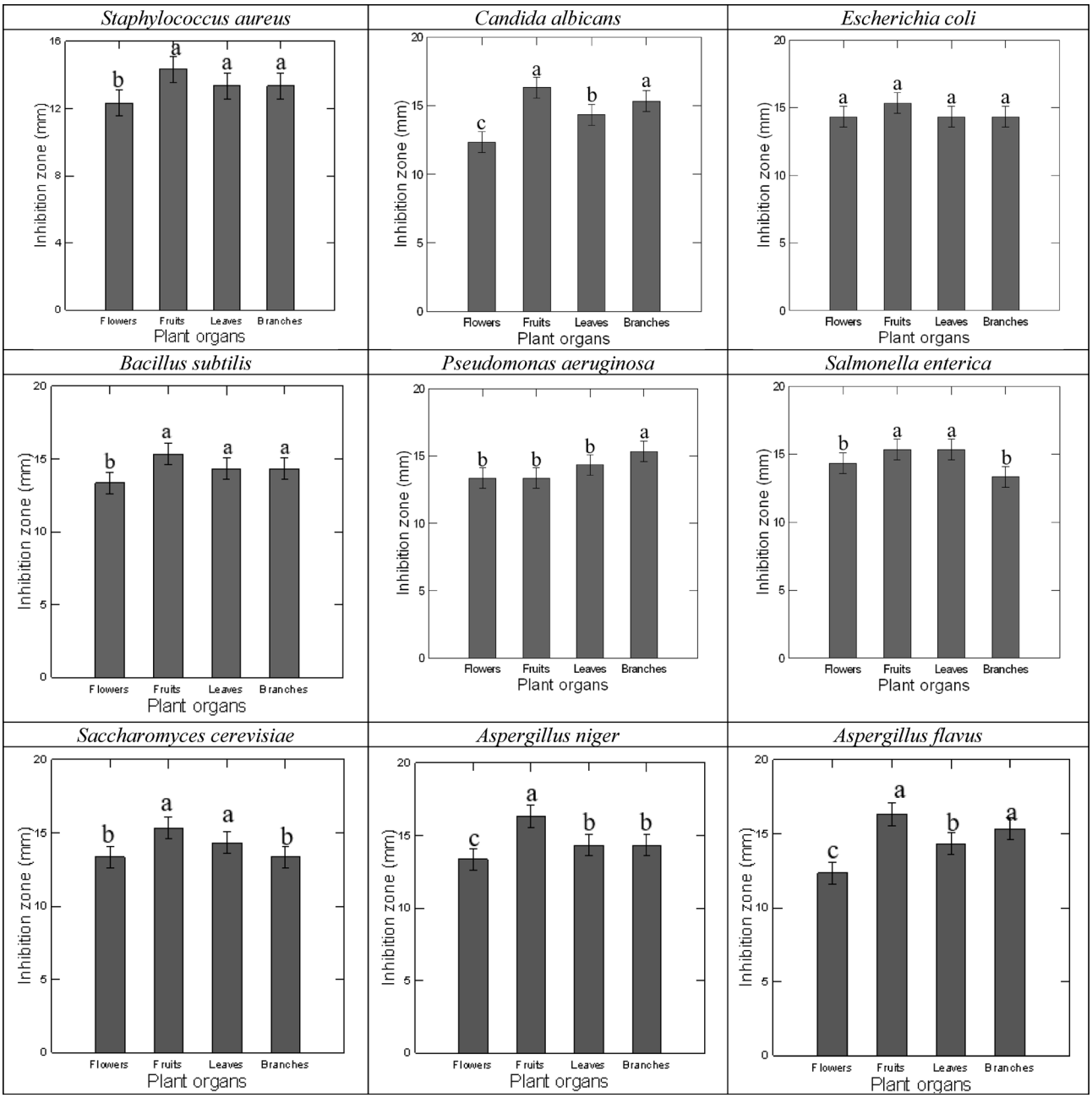

Fig. 8. Effects of plant organs (flowers, fruits, leaves and branches) of *Senna italica* on the microbial activities of *Staphylococcus aureus*, *Candida albicans*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Salmonella enterica*, *Saccharomyces cerevisiae*, *Aspergillus niger*, *Aspergillus flavus*, *Streptococcus pyogenes*, *Escherichia coli*, VRE, MRSA, ESBL and *Klebsiella pneumoniae*.

Moringa peregrina growing at high elevation compared to those of the lower. Naturally, branches are less exposed than the leaves and therefore, these plant organs might face less photooxidative stress than the leaves which are fully exposed. As per this, plants of extreme environments could strategically carry out and maintain the photosynthesis process when facing dramatical changes related to their habitats from the young branches.

Macro and micro elements are vital for plant functioning and their accumulation, and distribution within the plant body might change according to the environmental conditions. Globally, human population growth has reached greater levels, and this is expected to increase rapidly in the coming years. Therefore, it seems crucial to correlate this much growth with the available natural resources to avoid food shortage, and environmental degradation. Generally, wild native plants are more adapted to the local climate than most of the common vegetable found growing in the extreme environments. With this regard, investigating the nutritional value of those plants could allow to identify plants with greater nutritional components that could be used to improve food production in those geographical zones.

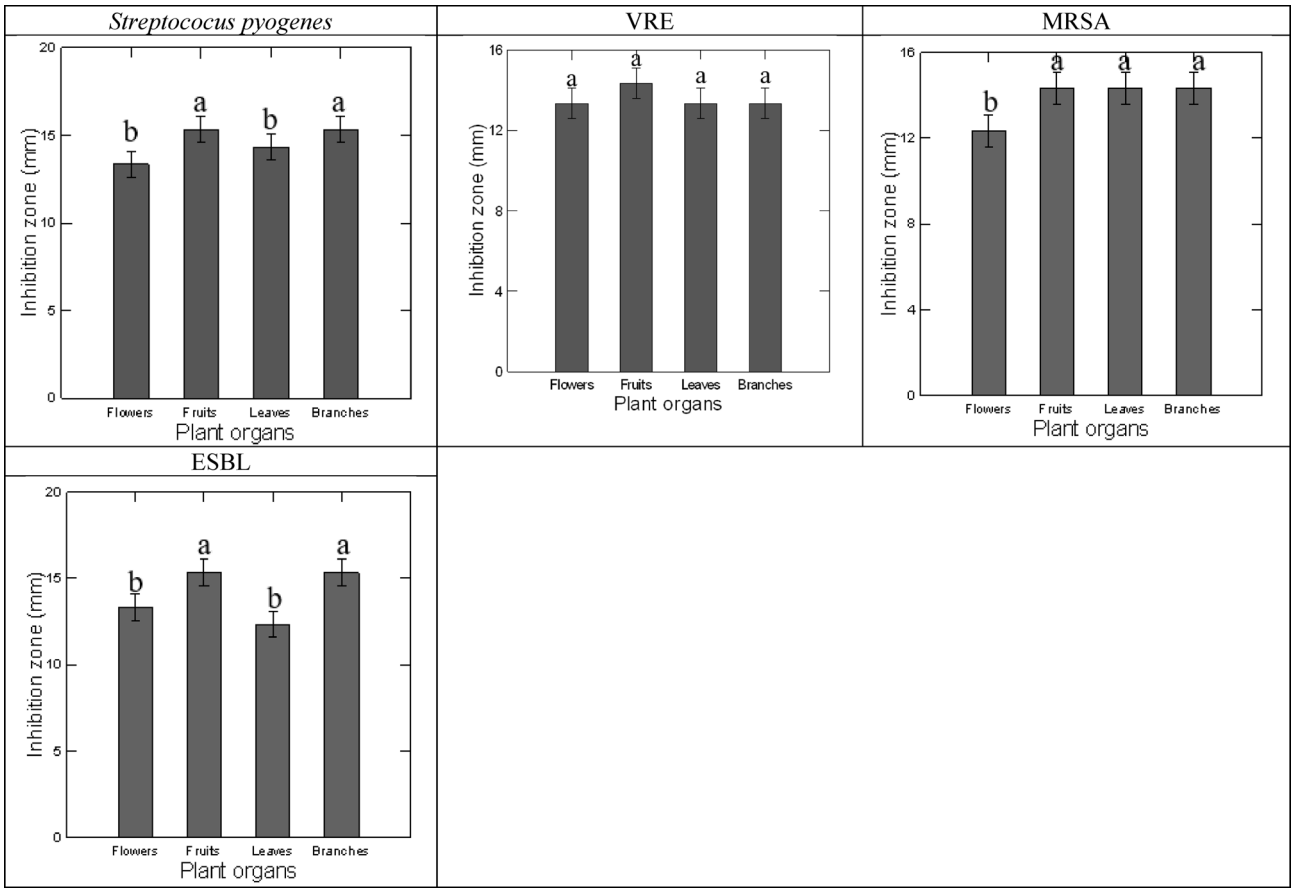

Fig. 8. (continued)

In the present work, higher amounts of **Ca** and **Mn** were recorded in the leaves of *Senna italica* compared with the other plant organs. The findings of this work are not in alignment with the work of[43]. **Ca** plays various functions in plants including structural, hormonal, defense against pathogens and stress. Besides this, **Ca** is one of the key component in the movements of stomata in plants. Therefore, increasing the amounts of **Ca** in the leaves of *S. italica* might help this latter improving gas exchange capacity and stomata conductance[44]. **Ca** deficiencies in animal body can alter muscle contraction, blood coagulation, and gastrointestinal system in the animal body[45,46]. With focus on **Mn**, in plants, this elements is involved in the catalyzed reactions including redox reactions, phosphorylation, decarboxylation, and hydrolysis[47].

Based on the current findings, the levels of **P**, **Zn**, and **Mn** were greater in the tested seeds than the other studied organs. These values were significantly higher than those recorded in *Cassia occidentalis* seeds[48]. In plant body, these chemical elements play diverse roles. **P** is involved in the physiological responses regulation to enhance abiotic stress tolerance in plants that might include heat, salinity, drought, and heavy metal toxicity[49], while in animal physiology, this latter is associated to the growth and maintenance of bones, muscles, and teeth. **Mg** is essential for chlorophylls synthesis in plants, and it helps this latter absorbing light and converting it into carbohydrate[50]. **Zn** is indispensable for plant growth and development through regulating many enzymatic and metabolic reactions.

The levels of **Na** observed in the present work were much higher in the branches than the other plant organs, and greater than those addressed by[51] in some wild plants of Egypt. This element might not be essential for most of the plants, but it plays beneficial function including osmotic pressure regulation, help in anions transport and aid in chlorophyll synthesis[52]. In the animal physiology **Na** is essential for nerves functioning, muscles contractions, and nutrients transport[53]. Although this chemical elements play crucial role in animal body, excessive amounts could be laid to heart dysfunctioning. Interestingly, in the present work, the ratio of **Na** to **K**, which is an important key factor for the food quality was less than 1 indicating that plant organs of *Senna italica* could be potentially used to improve food production in the arid regions.

The values of **Cu** and **K** recorded in the fruits of *Senna italica* were importantly higher than those of the other plant organs. **Cu** and **K** are essential elements for plant growth and development, and these chemical elements can increase plant resilience to the stress under extreme conditions[54,55]. The amounts of **K** recorded in this work were much higher than those reported by[56].

In the current study, proximate and phytochemical analyses revealed that the assessed chemical elements varied strongly according to *Senna italica* plant organ. Dry matter and tannins concentrations were greater in the branches than the other tested plant organs. Tannins concentrations in plant may be affected by many factors

Variables	F-Value
Staphylococcus aureus	6.000*
Candida albicans	26.250***
Escherichia coli	2.250 ns
Bacillus subtilis	6.000*
Pseudomonas aeruginosa,	8.250*
Salmonella enterica	8.250**
Saccharomyces cerevisiae	8.250**
Aspergillus niger	14.250**
Aspergillus flavus	26.250***
Streptococcus pyogenes	8.250**
VRE	2.250 ns
MRSA	9.000**
ESBL	20.250***

Table 5. ANOVA analyses (F-value) testing the effects of plant organs (flowers, fruits, leaves, and branches) of *Senna italica* plant extracts on the microbial growth (mm) of *Staphylococcus aureus*, *Candida albicans*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Salmonella enterica*, *Saccharomyces cerevisiae*, *Aspergillus niger*, *Aspergillus flavus*, *Streptococcus pyogenes*, *Escherichia coli*, VRE, MRSA, and ESBL and *Klebsiella pneumoniae*. VRE = vancomycin-resistant *Enterococcus*, MRSA = methicillin-resistant *Staphylococcus aureus*, ESBL = extended -spectrum beta-lactamase producing *Escherichia coli* and *Klebsiella pneumoniae*, *P ˂ 0.05, **P ˂ 0.01, ***P ˂ 0.001, ns = non-significant.

including plant-organ and organ-age, plant growing stage, predation, and the surrounding plant environment, with the main role to protect plant organism against abiotic stress[57]. Therefore, high temperatures and light could have induced tannins production to protect the tested plant against abiotic stress.

In most of the parts of the world, where population is expected to grow significantly, protein deficiencies could be laid to many disorders in human population. In the current work, protein and TDN values recorded in the seeds of *Senna italica* were much higher than that of the other tested plant organs, and significantly higher than that of some wild plant reported by[58]. Protein play crucial function in human boy including structural, hormonal, and enzymatic[59]. Furthermore, the amounts of fiber found in the fruits were more important than those of the other plant organs. Fiber play remarkable function in the human body by improving the digestive system and could prevent human system from many disorders including diabetes, heart diseases, and some of the cancers. Therefore, seeds and fruits of *S. italica* could be potentially integrated into food production in the arid regions to improve the food quality.

In this study, leaves showed higher contents in flavonoids, vitamin E, and vitamin B1. In plants, flavonoids play many physiological functions in regulating plant growth and development. Flavonoids can increase plant stress resilience by improving plant pigment contents, and UV protection. In general, in plants, photosynthesis reactions are carried out in the leaves or within the greener parts. These plant parts are much sensitive to abiotic factors than the other and could be therefore adversely altered. Regulating the levels of these antioxidants compounds might therefore optimize the adaptability of the plants experiencing extreme conditions.

To date, microbes resistance to antibiotic is the major concern globally, and this could increase the risk of disease spreading within human population. Many earlier works have attempted to solve this health issue but still, no efficient method or technique has been discovered to completely fight against those pathogens. Therefore, considering plant organs as one of the factors that can affect plant phytochemical composition can help identifying novel metabolites with strongest antimicrobial activities. Furthermore, plant growing under different climatic conditions could present variations in their metabolisms. In general, plants of the desert system experience more stress than the other. As per this, mechanisms of adaptations of those plants could importantly help improving medicines production. Unfortunately, the available literature is less documented in considering these factors in the arid regions and globally.

In our work, fruits parts of *Senna italica* exhibited much higher antimicrobial effects than the other tested organs. These findings were greater than those reported by[60–62]. The microbial activities obtained in this work could be attributed to the plant phytochemical analyses. The values recorded in this work on the phytochemical composition of *S. italica* were importantly higher than those of the previous work, which could be ecologically explainable by the local climate. To date, microbes resistance to antibiotic is the major concern globally as this might increase the risk of disease spread within human population. Plants growing under extreme environmental conditions have spectacularly sophisticated their machinery to cope with the embarrassing ecological factor. These adjustments in the plant metabolism may have significant implications in the pharmacological studies to improve medicines productions in the arid zones. The tested fruits were found to be loaded with greater amounts of vitamin B1 and tannins. Tannins have been found inhibiting the microbial growth through disrupting their cells membranes[63], while exposing minced beef meat to vitamin b1 was found enhancing the bio-preservative storage and antimicrobial effects[64].

In the current study, branches of the tested plant showed strongest antimicrobial effects against *Pseudomonas aeruginosa*. Based on our results, branches of *Senna italica* contain higher amounts of sodium, potassium, and

tannins, and these levels were importantly higher than some of the previous works. Macro elements are vital for plant and animal growth as these chemical elements strongly impact on many physiological functions. Sodium and potassium were reported to have strongest antimicrobial activities against many pathogens[65]. Increasing the amounts of sodium and potassium were found to increase the diameter of inhibition of some pathogens related to food spoilage. The role play by the tannin is crucial for the plant adaptations under different ecological situations. These chemical elements protect animal cells from damage by harmful pathogens through strengthening the cell membranes. Therefore, branches of *Senna italica* could constitute an important source of tannin that could be used to improve medicine production in the arid milieus.

Conclusion

The findings of the present work demonstrate that pigments contents of *Senna italica* vary strongly according to the habitat-elevation, and plant organ-age which could help the tested plant challenging the harsh conditions. Overall, increasing the elevation showed a net increase in the pigments contents, with highest altitude exhibiting greater values compared to the lower. Mature leaves collected at higher habitat-elevation had greater values of pigments than the young and other elevations, while the opposite trends were noticeable in the branches. Furthermore, plant organs of *S. italica* revealed significant variations in the minerals composition with highest values of Ca and K recorded in the leaves and fruits respectively compared to the other selected plant organs. The amounts of Cu were significantly lower than the other tested chemical elements. Moreover, none of the tested organs had detectable content in selenium. Interestingly, much higher nutrients levels were found in the fruits, seeds, and leaves of *S. italica*, with the leaves exhibiting higher flavonoids, vitamin E, and vitamin B1. In addition, antimicrobial effects were plant organs dependent, with strongest inhibitory effects associated with the fruits than the other selected organs. The data obtained on the nutritional and medicinal values of *S. italica* of this work showed higher values than those reported in the literature review. Therefore, plant organs of this plant could be deeply tested for the toxicity levels and then integrated into food and medicines production in the arid regions. Furthermore, not only pigments analyses can help explaining the adaptabilities of *S. italica* growing at various altitudes. Other research works should be conducted furtherly considering many plant attributes to fully understand the mechanisms of adaptations of this plant under its natural habitat. Moreover, in the current work, heavy metals were not analyzed from the soil which might not clearly explain the levels of their toxicity within plant organs. Therefore, other studies should also consider soil collected around the tested plant for heavy metal analyses.

Data availability

All the data supporting the findings of the present work are available within the paper and its Supplementary data file.

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Declarations

Competing interests

The authors declare no competing interests.

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