



OPEN Phytochemical and antimicrobial properties of *Morus nigra* and *Morus alba* grown in Fujairah, United Arab Emirates

Aishah Al Dhanhani¹, François Tsombou¹, Shaher Mirza¹, Suzan Shahin^{2✉} & Fouad Ridouane¹

Mulberry (*Morus* species) is a well-known economic crop that has served as an effective natural remedy in various traditional therapeutic practices, including the folk medicine of the United Arab Emirates (UAE). Despite this fact, no research has been done to explore the chemical composition and antimicrobial activity of *Morus* species grown in the UAE. Therefore, the main objective of this study is to evaluate the mineral content, phytochemical analyses, antifungal and antibacterial properties (for leaves, branches, and roots) of the only mulberry species present in the United Arab Emirates (UAE); *Morus nigra* (native) and *Morus alba* (exotic), both of which can be found within the wild flora of Fujairah. The study hypothesized that there are significant differences between the two tested species in terms of mineral content, nutrient levels, phytochemical profiles, and antimicrobial properties. Mineral content analyses for Sodium (Na), Potassium (K), Magnesium (Mg), Phosphorus (P), Calcium (Ca), Manganese (Mn), Zinc (Zn), Nickel (Ni), Copper (Cu), and Selenium (Se) were extracted via acid digestion, followed by flame photometry and atomic absorption spectrophotometry, referencing Association of Official Analytical Chemists (AOAC) methods. Heavy metals, specifically Cadmium (Cd) and Lead (Pb), were analyzed using inductively coupled plasma atomic emission spectroscopy (ICP–AES). Nutritional components such as dry matter, crude protein, crude fiber, crude fat, ash, total digestible nutrients (TDN), tannins, total phenols, and flavonoids were quantified using various standard methodologies, including oven drying, Soxhlet extraction, and Ultraviolet–Visible Spectrophotometry (UV–Vis spectrophotometry). Antimicrobial activities were assessed through the Disk Diffusion Method against selected bacterial strains (*Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, and *Clostridium botulinum*) and fungal strains (*Aspergillus flavus*, *Candida albicans*), with inhibition zones measured post-incubation. The experiment included statistical analyses using two-way Analysis of Variance (ANOVA), Tukey's test, and SYSTAT software. This study revealed a significant difference between *M. nigra* (native) and *M. alba* (exotic), in terms of the studies parameters. The investigation demonstrated that *M. nigra* exhibited substantial mineral content for key macronutrients, specifically Ca, K, Mg, and P, as well as elevated levels of the secondary macronutrient Na and significant concentrations of micronutrients Mn and Ni. The leaves of *M. nigra* were characterized by particularly high Ca content, measuring 1514.01 mg/100 g, which exceeds daily calcium requirements and significantly surpasses levels reported in previous studies. Meanwhile, the roots displayed rich concentrations of Mg, P, Na, and Ni, with levels of 454.18, 398.67, 183.54, and 1.36 mg/100 g, respectively. Similarly, *M. alba* also demonstrated considerable mineral content, particularly in Cu and Zn. Notably, the leaves contained high levels of Cu, at 1.08 mg/100 g, which exceeds daily dietary requirements, while the branches were rich in Zn, with a concentration of 1.58 mg/100 g. Notably, both species tested showed no detectable levels of Se and the heavy metals Cd and Pb, underscoring their potential safety for consumption. Phytochemical analyses revealed that the leaves of *M. nigra* exhibited elevated ash content (8.77%) and tannin levels (4.16%). In contrast, *M. alba* demonstrated superior nutritional qualities, including a higher dry matter content (74.45% from branches), protein levels (8.14 g/100 g from leaves), crude fiber content (25.97% from leaves), total digestible nutrients (TDN) (69.18% from branches), and flavonoid concentrations (3089.32 mg/kg from roots). While the analysis revealed low crude fat levels and undetectable phenolic content. Notably, *M. alba* demonstrated superior antimicrobial effects, attributed to its flavonoid content, with roots exhibiting the strongest activity. It was observed that antibacterial activities exceeded antifungal

activities, with a maximum inhibition zone of 32.66 mm recorded for *S. aureus*, compared to 24.66 mm for *C. albicans*. These findings highlight the rich chemical composition and significant antimicrobial potential of both species, underscoring their value in traditional uses and potential for sustainable applications in the pharmaceutical and nutritional industries.

Keywords Mulberry, *Morus nigra*, *Morus alba*, Mineral content, Phytochemical, Antibacterial, Antifungal properties, United Arab Emirates

¹Fujairah Research Centre, Fujairah, UAE. ²Umm Al Quwain University, Umm Al Quwain, UAE. ✉email: drsuzan.s@uaqu.ac.ae

Mulberry (*Morus* species) is a perennial deciduous woody tree belonging to *Moraceae* family. It is a fast-growing plant with unique adaptability to diverse climates, soil types (e.g., silt, sandy, and rocky), and altitudes from sea level up-to 4000 meters^{1,2}. The plant has gained recognition as versatile, contributing to environmental conservation, medicinal uses, and industrial applications (e.g., healthcare, pharmaceuticals, nutritional, food, apiculture, silk industry)^{3–5}.

Morus species originated from Himalayan foot hills of India and China, and widespread in many arid and semi-arid regions². There are more than 15 species of mulberry, out of which *M. nigra* (black mulberry) and *M. alba* (white mulberry) are the ones with significant importance due to several applications (e.g., nutritional, and biological activity).

For instance, the leaves, fruits, roots, and the stem of *M. nigra* and *M. alba* are rich source of nutritional components that include minerals, carbohydrate, proteins, fat, fibers, vitamins, tannin, and phytochemical composition^{6–9}. These natural bioactive components present great potential biological activities against various microbes. A Study showed that *M. nigra* genotypes grown in Turkey were found to be rich in nutrients; in which levels of sodium (Na), calcium (Ca), potassium (K), phosphorus (P), and magnesium (Mg) in leaves varied from 649 mg/100 g to 3402 mg/100 g. Leaves showed high levels of Na, Ca, and K. This has led to the recommendation that this species be widely utilized for human nutrition and as animal feed⁷. Another research conducted on *M. alba* recommended its leaves as a rich source of protein for sheep feeding. The analysis revealed that *M. alba* leaves contain 16.3% of ash, 20.1% of crude protein, and 12% of crude fiber⁶.

Furthermore, both *Morus* species have been reported to possess significant antimicrobial, antifungal, antioxidant, antiobesity, anticholesterol, antidiabetic, antimicrobial effects^{10–14}. Despite the higher antimicrobial, antifungal and the other pharmaceutical benefits behind *M. alba* and *M. nigra*, some microbes have been adapted to many antibiotics^{15,16}. Most of the earlier studies associated with anti-microbial activities and plant parts of *Morus* species showed an inhibition zone less than 20 mm^{17,18}, which is not significantly enough to impact on the microbial activities. Microorganisms and especially bacteria and fungi have significant genetic ability to adjust their behavior according to the changes occurring in their environment^{19,20}. Therefore, these groups of microbes are able to rapidly acquire resistance to drugs, which are used as therapeutic agents.

In this respect, the problem of microbial resistance is growing and the outlook for the use of antimicrobial drugs in the coming years is still uncertain^{2122–2425}. Among the different groups of microbes that significantly alter human health, some groups of bacteria and fungi are the major pathogens that greatly impact on human body integrity since they are responsible for various infectious diseases^{26–32}. For example, *Staphylococcus aureus* is considered a major pathogen that causes a wide range of clinical infections in human body, and its infectiousness covers about 30% of the human population³³. Recent studies demonstrated that *S. aureus* strain was resistant to some referential antibiotic, such as, erythromycin, clindamycin, ciprofloxacin, rifampicin, gentamicin, and trime-thoprim-sulfamethoxazole respectively³⁴. With regard to *Escherichia coli*, this microbe is considered the most dangerous pathogen that lives in human intestine, and can cause significant impact on human urinary tract, brain, lung, blood system, and has caused the emergence of antibiotic resistance³⁵. As for, *Bacillus cereus*, it's a gram-positive bacterium responsible for food alteration and human health due the production of enterotoxins³⁶. With focus on *Clostridium botulinum*, it's responsible for the botulism with neurotoxin considered the most known substance that can cause ill-ness and death in human population³⁷. Emphasizing *Aspergillus flavus*, this pathogen can cause significant negative effects on human health through the production of mycotoxin³⁸. *Candida albicans* is a major fungal pathogen of human body. Globally, the pathology associated with this microbe is responsible for about 200,000 deaths annually in human population³⁹.

Consequently, researchers around the world need to carry out many studies in this thematic which associated climatic conditions of the specific geographical zone in order to qualitatively and quantitatively assess the microbe adaptations to drugs from the natural bioactive products^{26–28}.

Globally, plants growing in the extreme environments face more stress than the other plants^{26–28}. Therefore, exploring their chemical composition can allow to identify novel metabolites which could be used against many microbes and that could literally break down their tolerance levels. As per this, chemical compounds resulting from those plants could play crucial role in improving medicines^{40–43}.

Located in one of the world's arid regions, the United Arab Emirates (UAE) is home to *Morus nigra* and *Morus alba*, which naturally thrive in various wild habitats, including Fujairah. *M. nigra* is considered the only native *Morus* species in the country, while *M. alba* is classified as an exotic species^{44,45}. In traditional folk practices, both species were utilized to treat ailments such as cough, fever, headache, toothache, and inflamed eyes. The edible fruits were consumed raw and used in jam preparation. Woody branches served as material for crafting cooking utensils, while the leaves were essential for feeding silkworms in silk production. Additionally, *Morus nigra* and *Morus alba* played a role in honey production, serving as nectar plants^{41,42}.

Studies reported the need to explore *M. nigra* and *M. alba* genotypes, highlighting that different climatic conditions significantly affect the physiocochemical and phytochemical composition^{6–9}. Despite this fact, reviewing the literature, there is no scientific research done on the phytochemicals and antimicrobial activities of these two species widely grown under the UAE climatic conditions.

Consequently, the main objectives of this study are twofold: First, to investigate the mineral content, nutrients and phytochemical profiles of various parts (leaves, branches, and roots) of both *M. nigra* (native) and *M. alba* (exotic) specimens thriving in the natural habitats of Fujairah, UAE. Tested minerals include macronutrients (Ca, K, Mg, P), secondary macronutrients (Na), and micronutrients including manganese (Mn), zinc (Zn), nickel (Ni), copper (Cu), as well as the metalloid selenium (Se). Tested heavy metals include cadmium (Cd) and lead (Pb). Second, to assess the antimicrobial activity of the same plant parts across both species. The evaluated antibacterial properties include *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, and *Clostridium botulinum*, while the tested antifungal activities encompass *Aspergillus flavus*, and *Candida albicans*. A diagram showing the overall conducted experiments in this study is represented in Fig. 1.

The study hypothesized that there are significant differences between *M. nigra* and *M. alba* in terms of mineral content, nutrient levels, phytochemical profiles, and antimicrobial properties. This will enable the identification of which species may serve as a more suitable candidate for specific applications. Furthermore, this investigation represents a pioneering effort to study *Morus* species grown under the environmental conditions of the United Arab Emirates. The outcomes of this research are anticipated to significantly contribute to the advancement of sustainable development goals (SDGs), particularly in the context of rapid increases in the global population and the urgent imperative to identify new, sustainable natural resources for nutritional and medicinal applications.

Materials and methods

Plant sample collection and identification

Plant collection had been done from public areas where the collection of plant material for research purposes does not necessitate formal authorization. Full mature plant parts including leaves, branches, and roots of *M. nigra* (native) and *M. alba* (exotic) were collected during May 2023 from the plants growing in the natural habitats around Fujairah, United Arab Emirates (UAE) (25.1288° N, 56.3265° E), as indicated by ArcGIS Online (Version 8.1, “2025.1”), a Cloud-based platform, in Fig. 2. The climatic conditions of Fujairah, retrieved from the National Center of Meteorology, are represented in Table 1. The collected herbarium samples were deposited and identified by Sharjah Seed Bank and Herbarium (SSBH), voucher specimen number for *M. nigra* (SSBH-4083) and for *M. alba* (SSBH-4082).

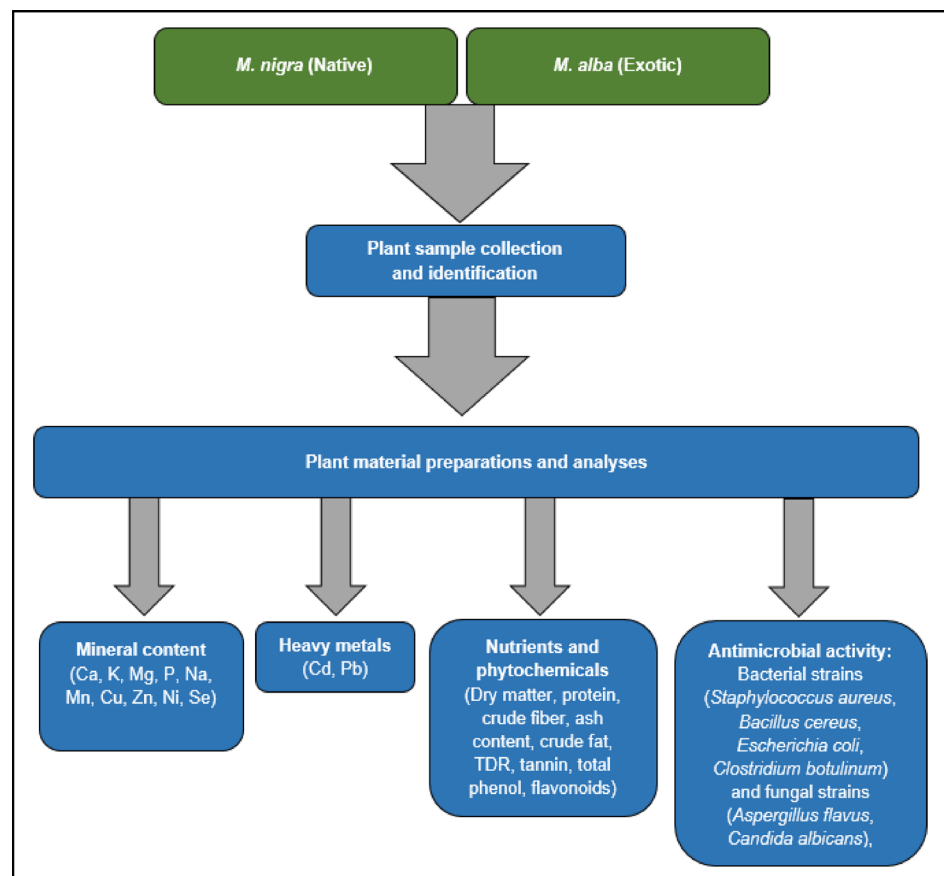


Fig. 1. The overall conducted experiments in this study.

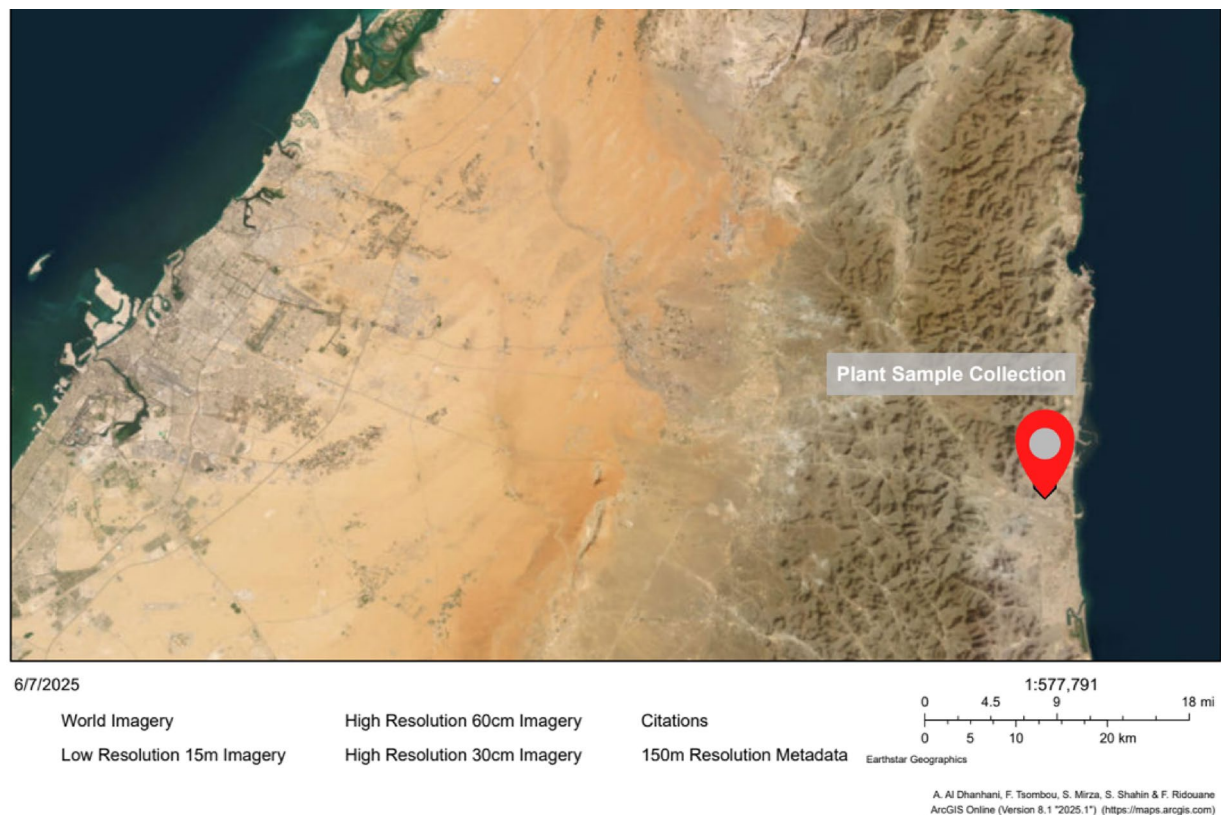


Fig. 2. Location of plant sample collection as indicated by ArcGIS Online (Version 8.1 “2025, 1”).

Maximum temperature	Minimum temperature	Mean temperature	Total precipitation
°C	°C	°C	mm
50.2	10.5	28.6	116.2

Table 1. Climatic conditions of Fujairah. Annual data retrieved from the National Center of Meteorology (Fujairah International Airport).

Plant material preparation

Plant samples were taken to the laboratory, washed delicately with running tap water, and then rinsed with distilled water. Thereafter, the cleaned plant parts were taken to the Middle East Laboratory for further analyses. Three samples from each of the tested plant parts (leaves, branches, roots) for both species were analyzed and considered in the study. The branches used in the experiment were lignified samples and the root samples were collected at the depth of 20 cm from the topsoil. All the chemicals were purchased from Chemstock Company.

Mineral content

Na and K extractions were performed by digesting 1 g of each plant sample with nitric acid (Code 39,335, S D Fine – Chem Limited, Mumbai, India) and hydrochloric acid (Code 56,331, S D Fine – Chem Limited, Mumbai, India), and then the calibrated sample was read through flame photometry according to the Association of Official Agricultural Chemists (AOAC 969.23)⁴⁶.

The amounts of Ca, Mn, Cu, Mg, P, Zn, Ni, and Se were determined by digesting 0.5 g of each sample with nitric acid and hydrochloric acid through a microwave digester for 30 min. Afterward, the mineral composition of the digested sample was determined using an atomic absorption spectrophotometer following the methods of the official agricultural chemists (AOAC 2013.06)⁴⁷.

Heavy metals content

The heavy metal content for Cd and Pb was determined by digesting 0.5 g of each sample with nitric acid and hydrochloric acid using a microwave digester. Following sample digestion, the solution was subjected to inductively coupled plasma atomic emission spectroscopy (ICP-AES) (AOAC 2015.01)⁴⁸.

Nutrients and phytochemical content

Dry matter 5 g of dry matter from each sample was oven-dried at 105 °C for 3 h until a constant weight was reached (AOAC, 922.06)⁴⁶.

Crude protein 1 g sample digested by using sodium sulfate (Code 28,214, S D Fine—Chem Limited, Mumbai, India) and copper sulphate (Code 37,849, S D Fine—Chem Limited, Mumbai, India) with sulphuric acid (Code 40,325, S D Fine—Chem Limited, Mumbai, India) and nitrogen is estimated by using distillation and applying factor 6.25 protein is calculated (AOAC 2001.11)⁴⁹ (Device: Buchi Multikjel, USA).

Crude fiber Fiber content was determined by digesting 2 g of each sample with 1.25% sodium hydroxide (Code 40,166, S D Fine—Chem Limited, Mumbai, India) and 1.25% sulfuric acid (28,204, S D Fine—Chem Limited, Mumbai, India) for 30 min. Afterward, the obtained residues were cooled and then collected in a crucible through filtration followed by hot water. Subsequently, the collected residues were oven-dried at 130 °C for 2 h, followed by ignition at 600 °C for 30 min. The weight of the remaining residues in the crude fiber was assessed after ignition (AOAC 962.09)⁵⁰.

Ash content Ash determination was performed by taking 2 g of each sample in a silica crucible at 600 °C in a muffle furnace for 2 h (AOAC 942.05)⁵¹ (Device: Nabertherm 30–3000, Germany).

Crude fat Fat was extracted through a Soxhlet apparatus by refluxing 2 g of each plant sample with petroleum ether for 16 h. Subsequently, the crude fat was obtained after evaporating the petroleum ether (Code 39,824, S D Fine—Chem Limited, Mumbai, India) and taking the weight (AOAC 920.39)⁵² (Device: Raypa, soxtest sx-6, Germany).

Total digestible nutrients (TDN) TDN was estimated from fat, protein, crude fiber, and nonvolatile ether extracts.

Tannin content Tannin extraction was performed by titrating the extract with standard potassium permanganate solution (Code 39,644, S D Fine—Chem Limited, Mumbai, India) through indigo carmine solution (Code 88,552, S D Fine—Chem Limited, Mumbai, India) and potassium permanganate solution (Code 39,644, S D Fine—Chem Limited, Mumbai, India) to obtain a light yellowish color (AOAC 955.35)⁴⁶ (Device: Hach, DR, 6000, USA).

Total phenol The phenol content was determined by using Folin-Ciocalteu (Code 29,058, S D Fine—Chem Limited, Mumbai, India) 1 N reagent followed by taking absorbance at UV Spectrophotometer (ISO 14,502–2)⁵³ (Device: Hach, DR, 6000, USA).

Flavonoid contents To assess the flavonoid contents, each plant part was minced into small pieces and macerated with methanol (1:20, w/v) for 72 h at room temperature (28 ± 2 °C) with occasional stirring. The extract was then filtered, and the obtained residue was remacerated with the same solvent until the extraction was exhausted. The filtrates obtained from the maceration were subsequently combined and then evaporated with a rotary evaporator. Twenty-five milligrams of the extract was weighed and dissolved in 10 mL of ethanol to obtain a concentration of 2500 ppm. A 1 mL aliquot was pipetted from the solution, after which 3 mL of methanol (Code 76,380, S D Fine—Chem Limited, Mumbai, India), 0.2 mL of 10% aluminium chloride (Code 37,073, S D Fine—Chem Limited, Mumbai, India), 0.2 mL of 1 M potassium acetate (Code 39,581, S D Fine—Chem Limited, Mumbai, India), and 10 mL of aquadestilata were added. Afterward, the samples were incubated for 30 min at room temperature, after which the absorbance was measured via Ultraviolet–Visible Spectrophotometry (UV–Vis spectrophotometry) at a wave-length of 431 nm. The readings were performed from three replications for each analysis. The levels of flavonoids were obtained through the following equation:

$$\text{Total Flavonoid} = \text{Sample Volume} \times \text{Initial Concentration} \times \text{Dilution Factor of Sample weight}$$

Preparation of Standard Solution: 10 mg of standard quercetin standard (Code 23,160, S D Fine—Chem Limited, Mumbai, India) was weighed and dissolved in 10 mL of methanol purissima analytica (p.a) (Code 76,380, S D Fine—Chem Limited, Mumbai, India) for 1000 ppm concentration. The stock solution of 1000 ppm quercetin (Code 23,160, S D Fine—Chem Limited, Mumbai, India), pipetted 1 mL and dissolved in 10 mL of methanol p.a to obtain 100 ppm. Then made several concentrations of 4 ppm, 5, 6 ppm, 7 ppm, and 8 ppm. From each concentration of the quercetin standard solution, add 3 mL of methanol, 0.2 mL of 10% AlCl₃, 0.2 mL of 1 M potassium acetate were added, and add aquadestilata up to 10 mL, incubated for 30 min at room temperature. The absorbance was measured on UV–Vis spectrophotometry with a wavelength of 431 nm.

Antimicrobial activities (Inhibition zone)

Antibacterial and antifungal tests were performed by the Disk Diffusion Method (ISO 16,782:2016). *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium botulinum*, and *Escherichia coli* were the bacterial strains, while *Aspergillus flavus* and *Candida albicans* were the fungal strains.

Antibacterial activities The antimicrobial activities of extracts of *M. nigra* and *M. alba* plant parts were determined on Mueller Hinton agar using the agar disc method⁵⁴. Bacterial inoculation was performed by suspending colonies from a 24-h culture in 9 ml of sterile distilled water saline. Subsequently, a spectrophotometer (DO = 0.08–0.1/ = 625 nm) was used to modify the cell density of each inoculum to achieve a final concentration of approximately 108 colony forming unit (CFU) (0.5 McFarland standard). In this approach, a 108 CFU inoculum is dispersed over the surface of 3–4 mm thick Mueller–Hinton agar. Wattman paper discs (N°3, 6 mm) containing 10 µl of crude extract of each plant organ were dissolved in 100% Dimethyl Sulfoxide (DMSO) and placed on plates after drying (for no more than 15 min). After 24 h of incubation at 37 °C, the diameter of the inhibitory zone (in mm) was determined to determine the antimicrobial activity of each tested microbe.

Antifungal activities The antifungal activities of the tested fungi were similar to those of the bacteria. The density was maintained between 0.12 and 0.15 at 530 nm by analyzing the microbes in liquid form using the Spectrometer (Hach, DR, 6000, USA) at 530 nm through dilution. However, the culture medium was adjusted to Mueller Hinton + 2% glucose + 0.5 g/ml methylene blue/pH 7.4. A spectrophotometer was used to regulate the cell density of the inoculum ($DO = 0.12\text{--}0.15/\lambda = 530\text{ nm}$), and then the readings were obtained. As reference antimicrobials, ciprofloxacin, gentamycin, and amphotericin B were utilized as positive controls, and pure solvent was used. Antimicrobial activity is assessed beginning with a diameter of 6 mm or greater according to the Agar disk-diffusion method.

Statistical analysis

The collected data were analyzed in triplicate, and two-way analysis of variance (ANOVA) was conducted to assess the effect of species and plant parts on the nutritive value of the tested plants. Two-way ANOVA was also performed to assess the effect of species and plant part extracts on the microbial activities of the studied microbes. Tukey's test (honest significant difference, HSD) was used to identify significant differences between the means. Scatterplots and linear regressions were generated to assess the associations between the flavonoid extracts and antimicrobial activities, and ANOVA was subsequently performed to determine the significance of the relationships. All the data were statistically analyzed with SYSTAT (version 13).

Results

Mineral content variability in plant parts of both species

The two species, plant parts, and their interactions had significant ($p < 0.001$) effects on the mineral composition of *M. nigra* and *M. alba* (Fig. 3 and Table 2). The concentrations of the different elements varied strongly between the two plant species and within the plant parts. The levels of Ca, K and Mn recorded in the leaves of the two plant species were greater than those recorded in the branches and roots. The leaves of *M. nigra* had significantly greater amounts of Ca (1514.01 mg/100 g), K (1182.44 mg/100 g) and Mn (2.07 mg/100 g) than those of the branches and roots, and these values were greater than that of *M. alba*. Cu (1.08 mg/100 g) levels were significantly greater in the leaves of *M. alba* than in the branches and roots, and these concentrations were greater than those observed in the plant parts of *M. nigra*. The roots of *M. nigra* contained more Mg (454.18 mg/100 g), Na (183.54 mg/100 g), P (398.67 mg/100 g), and Ni (1.36 mg/100 g) than did the leaves and branches, and these levels were greater than those of *M. alba*. With regard to Zn concentrations, the branches of the two plant species showed significant differences compared to the leaves and roots, and greater amounts of Zn were detected in the branches of *M. alba* (1.58 mg/100 g). Se contents of the plant leaves, branches, and roots of the two species were also analyzed, but the analyzed samples had no Se content.

Heavy metal analysis

Plant parts of *M. nigra* and *M. alba* were subjected to the toxicity analyses associated with Pb and Cd. The analysed plants samples had no toxicity related to Pb and Cd.

Nutrient and phytochemical contents in plant parts of both species

Statistically, plant parts and the two species had significant ($p < 0.001$) effects on the nutritional components of the tested plants (Fig. 4 and Table 3). *Dry matter* contents were greater in the plant branches of *M. alba* (74.45%) than the root and the leaves, and these amounts were significantly higher compared to those of *M. nigra*. Plant leaves of *M. alba* showed more important contents in *proteins* (8.14 g/100 g) than the branches and the roots, and these values were greater than those of the *M. nigra*. Plant branches of *M. alba* revealed more important *crude fiber* (25.97%) than the root and the leaves, and that observed in *M. nigra*. Significantly higher concentrations of ash (8.77%) were obtained in the plants leaves of *M. nigra* compared to the roots and the branches, and these levels were more important than those of *M. alba*. No significant difference was obtained between the two plants species and their different parts on the *ash contents*. TDN percentages were greater in the branches of *M. alba* (69.18%) than the roots and the leaves, and these amounts were significantly higher compared with that of *M. nigra*. No significant difference was obtained in *tannin* levels of the two plants species, but great effect ($p < 0.001$) was observed between different plant parts of the two species, and their interactions. The leaves of *M. nigra* showed significant amounts of tannin (4.16%) compared with the branches and the roots, and these levels were more important than those of *M. alba*. Plant roots of *M. alba* revealed greater levels of *flavonoids* (3089.32 mg/kg) than the leaves and branches, and these values were more important than of the *M. nigra*. Recorded *crude fat* levels were seen to be less than 0.1% for the two plants species. Plant parts of the two species were also investigated for *phenol* contents, and no levels of detectability was revealed.

Antimicrobial activities in plant parts of both species

Plants species and plant organs had significant ($p < 0.001$) effects on the microbial activities (Fig. 5 and Table 4). The interactions between plant species and parts had significant ($p < 0.01$) effects on the microbial activities compared with the other microbes. In sum, plant roots of the two species had greater antimicrobial effects than the branches and the leaves. The effects of antimicrobial activities were roots > branches > leaves. Roots extracts of *M. alba* showed significant ($p < 0.001$) higher antimicrobial activities than that of *M. nigra*. The values of inhibition zones were 32.66 mm, 32.66 mm, 31.66 mm, 24.66 mm, 21.66 mm and 20.66 mm respectively for the root extracts of *M. alba* on *S. aureus*, *E. coli*, *B. cereus*, *C. albicans*, *A. flavus*, and *C. botulinum*. Those for *M. nigra* were 30.33 mm, 29.33 mm, 29.33 mm, 21.66 mm, 20.66 mm, and 19.66 mm respectively on the antimicrobial of *E. coli*, *S. aureus*, *B. cereus*, *C. albicans*, *C. botulinum*, and *A. flavus*. It was found that antibacterial activities were higher than antifungal activities with a maximum of 32.66 mm in *S. aureus* against 24.66 mm in *C. albicans*.

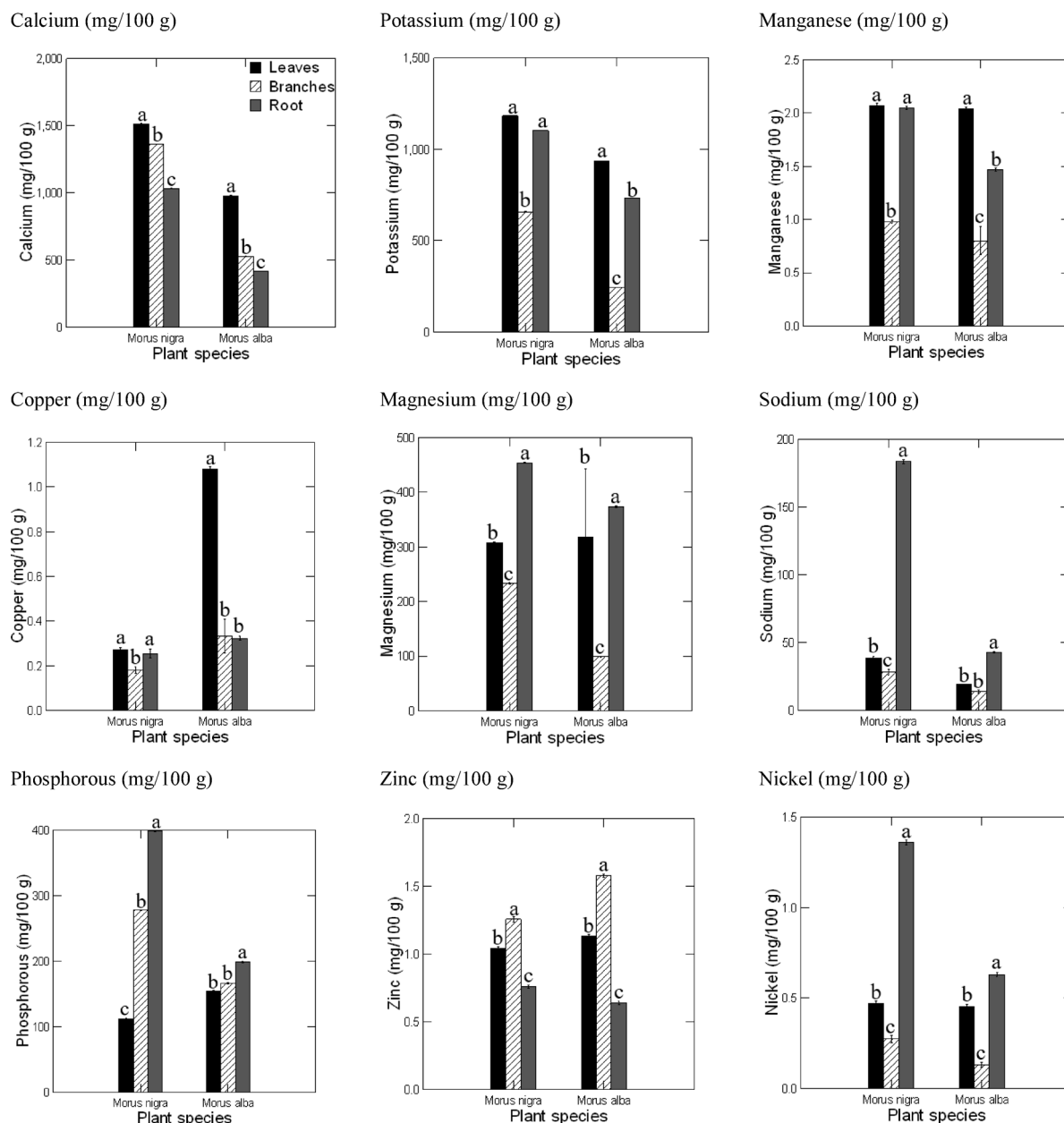


Fig. 3. Effects of species and plant parts on the mineral composition of *M. nigra* and *M. alba*.

Source of variation	df	Ca	K	Mn	Cu	Mg	Na	P	Zn	Ni
Species (S)	1	1,379,598.047***	598,000.052***	177.567***	821.368***	13,168.633***	18,579.813***	46,929.541***	352.000***	3,264.727***
Plant Parts (PP)	2	286,830.797***	685,466.299***	1,244.777***	500.795***	114,475.052***	19,097.264***	53,001.110***	6,343.682***	8,037.318***
S*PP	2	25,286.908***	12,299.740***	67.762***	379.137***	18,873.605***	9,393.007***	29,105.619***	603.591***	1,766.227***
Error	12									

Table 2. Results of two-way ANOVA (F-values) testing the effects of species (*M. nigra* and *M. alba*) and plant organs on magnesium (Mg), phosphorous (P), calcium (Ca), potassium (K), sodium (Na), manganese (Mn), and zinc (Zn) amounts (mg/100 g). *** $p < 0.001$.

Correlation between flavonoids extracts and the antimicrobial activities

Morus nigra

Flavonoids extracts showed positive and moderate correlation with the antimicrobial activities of *S. aureus*, *E. coli*, *B. cereus*, *C. albicans*, and *C. botulinum*. The relationship observed between flavonoids extracts and

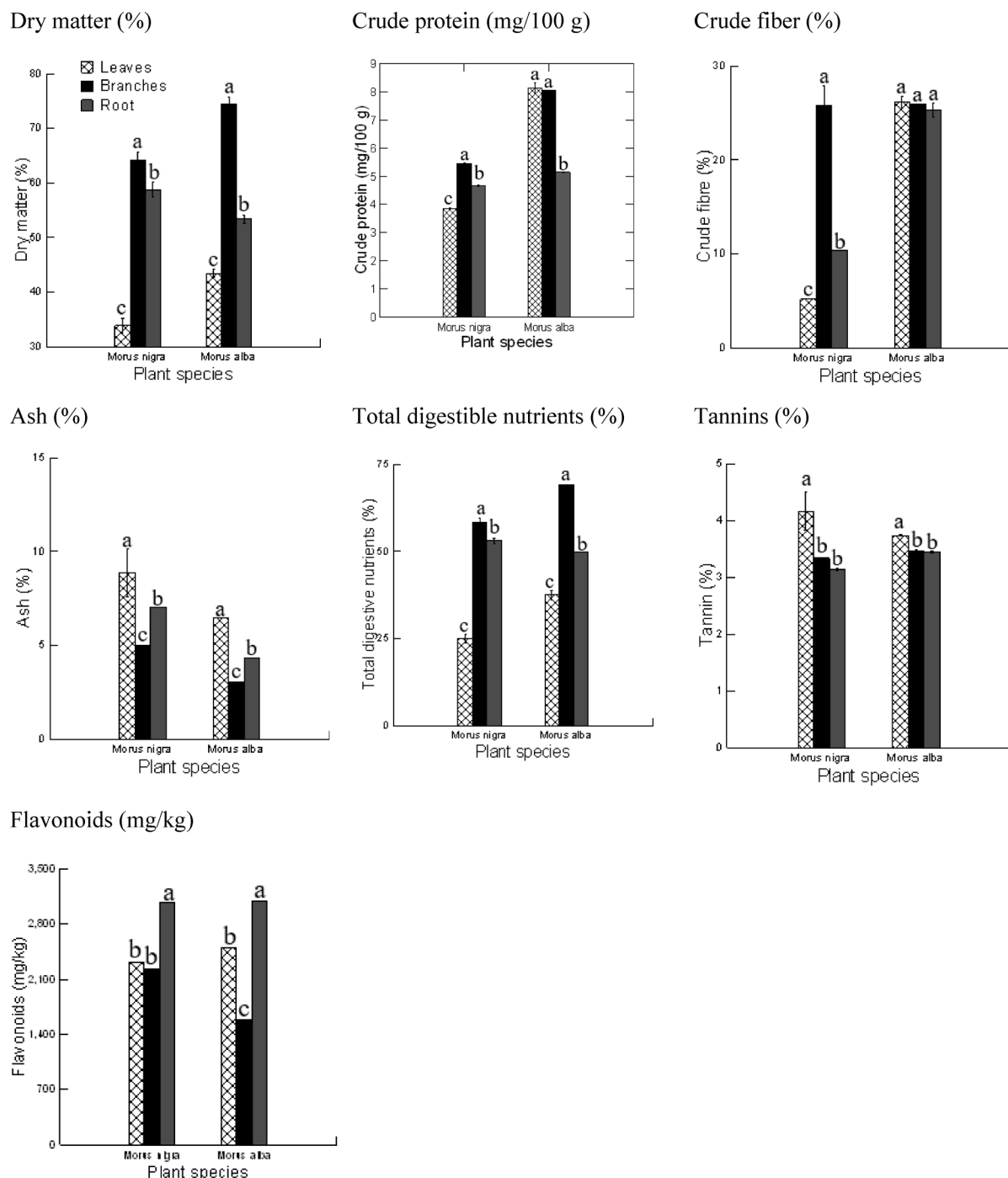


Fig. 4. Proximate and phytochemical analyses of the leaves, branches, and roots of *M. nigra* and *M. alba*.

Source of variation	df	DM	CP	Fibre	Ash	TDN	Tannin	Flavonoid
Species (S)	1	132.431***	105,705.800***	1,347.157***	155.431***	363.826***	0.005 ns	122,431.282***
Plant Parts (PP)	2	1,814.168***	20,634.956***	360.408***	125.880***	2,948.397***	70.474***	2,671,132.115***
S*PP	2	148.307***	20,776.200***	359.749***	1.385 ns	207.055***	20.631***	370,165.967***
Error	12							

Table 3. Results of two-way ANOVA (F-values) assessing the effects of species (*M. nigra* and *M. alba*) and plant parts on the proximate and phytochemical analyses of *M. nigra* and *M. alba*. *** $p < 0.001$, ns: non-significant, DM: dry matter, CP: crude protein, TDN: total digestive nutrients.

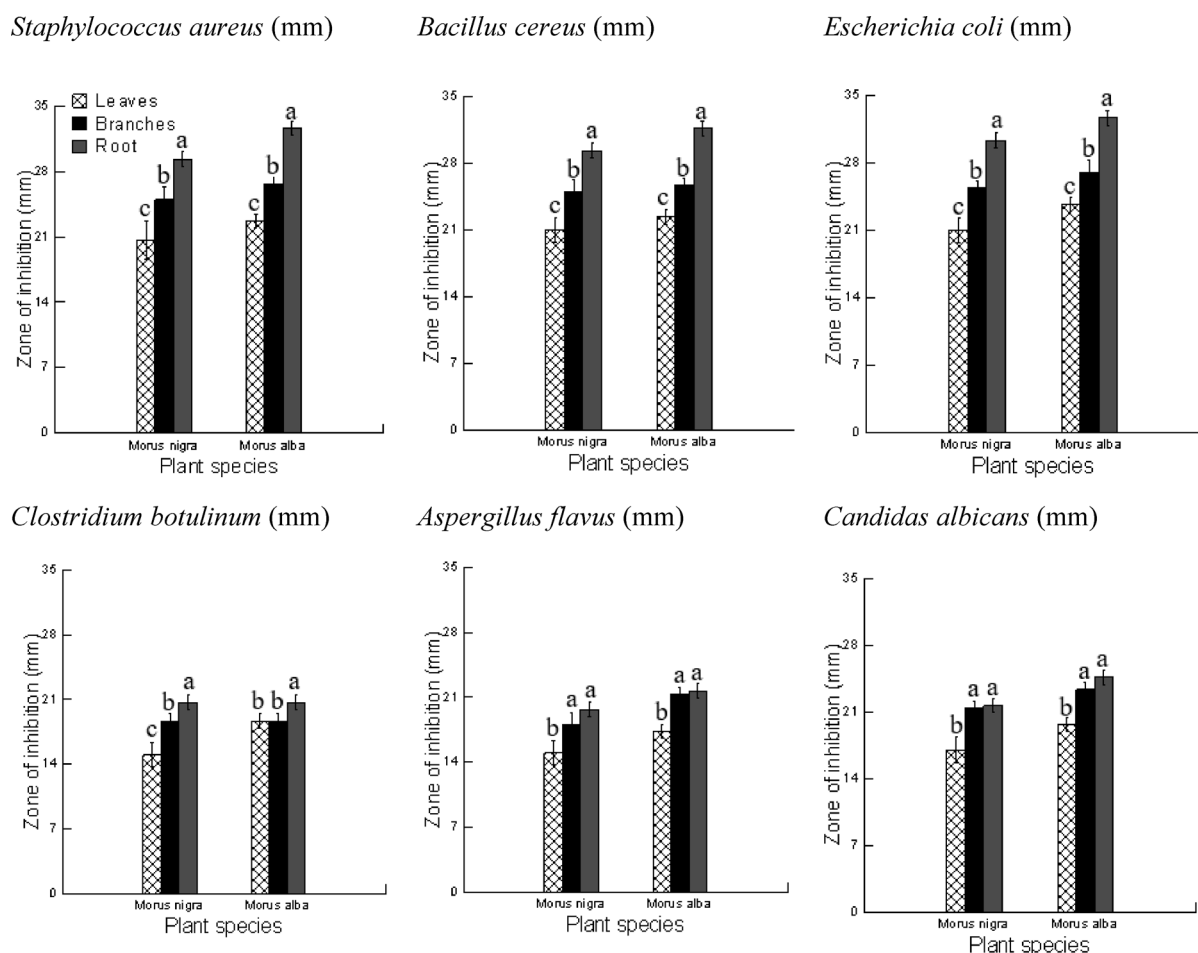


Fig. 5. Zone of inhibitions from the plant parts of *M. nigra* and *M. alba* against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, *Candida albicans*.

Source of variation	Df	SA	BC	EC	CB	AF	CA
Species (S)	1	31.500***	16.900**	40.000***	15.125**	52.900***	66.125***
Plant Parts (PP)	2	168.643***	212.700***	228.900***	49.625***	60.300***	90.125***
S*PP	2	1.500 ns	1.900 ns	0.700 ns	15.125**	1.300 ns	0.875 ns
Error	12						

Table 4. Results ANOVA (F-values) assessing the effects of species (*M. nigra* and *M. alba*) and plant parts extracts against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, *Candida albicans*. ** $p < 0.01$, *** $p < 0.001$, ns: non-significant, SA: *Staphylococcus aureus*, BC: *Bacillus cereus*, EC: *Escherichia coli*, CB: *Clostridium botulinum*, AF: *Aspergillus flavus*, CA: *Candida albicans*.

antimicrobial activities were significant ($p < 0.05$, $p < 0.01$) for *S. aureus*, *E. coli*, *B. cereus*, and *C. botulinum*, and non-significant for *C. albicans* (Fig. 6, and Table 5).

Morus alba

Flavonoids extracts from the different plant parts revealed positive and moderate, and non-significant ($p < 0.01$) correlation with *S. aureus* (0.49), *B. cereus* (0.53), and *E. coli* (0.515) (Fig. 7, and Table 6). The associations between flavonoids extracts and *C. botulinum* were positive and strong (0.713), and significant ($p < 0.05$). Correlation between flavonoids extract and *C. albicans* was weaker and non-significant. Negative (−0.053) and non-significant correlation was observed with the effects of *A. flavus*.

Discussion

This research investigated the chemical composition of different parts (leaves, branches, and roots) of two *Morus* species (the native *M. nigra* and the exotic *M. alba*), naturally grown in the UAE's wild flora.

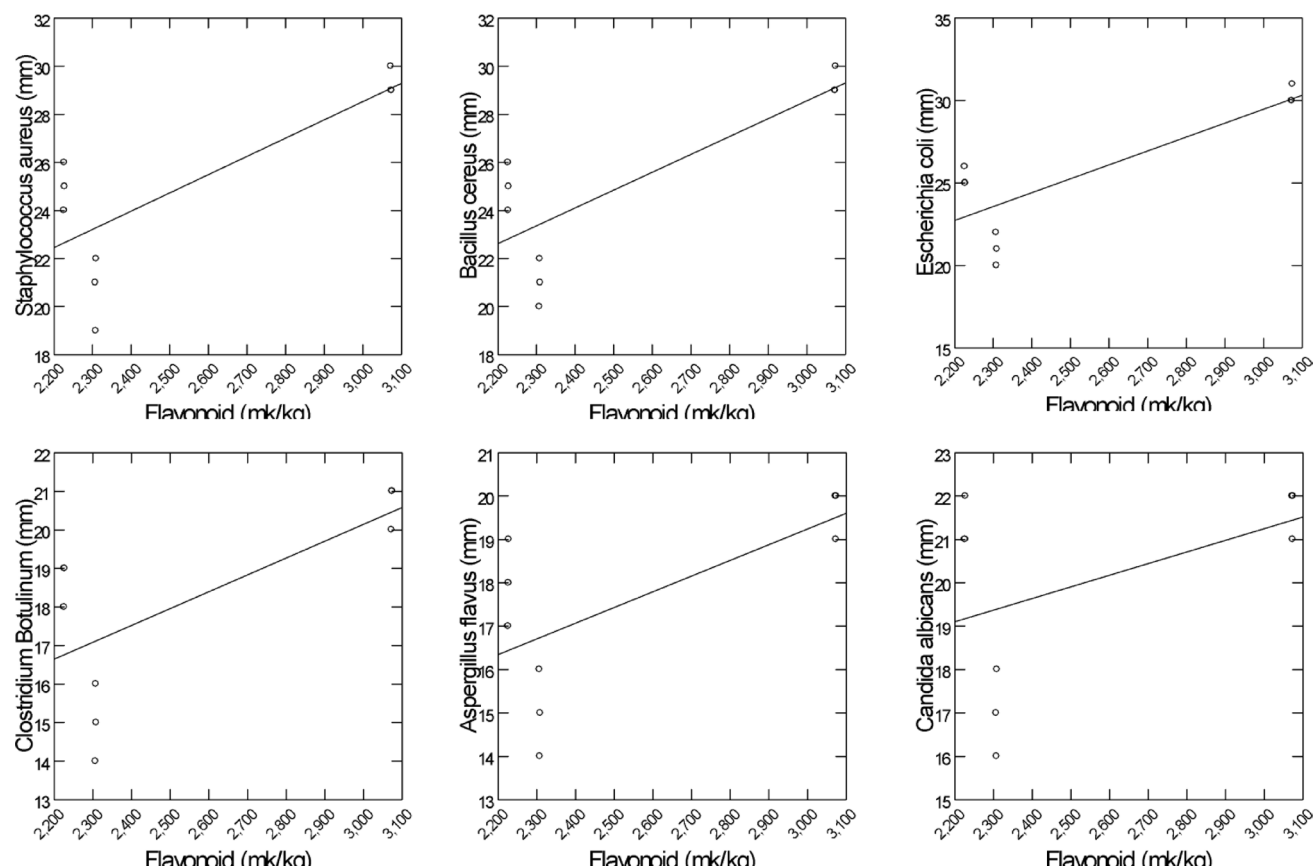


Fig. 6. *M. nigra* was studied for its flavonoids extracts and their correlation with antimicrobial activities against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, and *Candida albicans*.

Tested microbes	Coefficient of correlation	F-Values
<i>Staphylococcus aureus</i>	0.794	11.92*
<i>Bacillus cereus</i>	0.814	13.76**
<i>Escherichia coli</i>	0.831	15.68**
<i>Clostridium botulinum</i>	0.689	6.33*
<i>Aspergillus flavus</i>	0.670	5.70*
<i>Candida albicans</i>	0.461	1.89 ns

Table 5. ANOVA (F-Values) and coefficient of correlation between flavonoids extracts from *M. nigra* plant parts and antimicrobial activities against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, and *Candida albicans*. * $p < 0.05$, ** $p < 0.01$, ns: non-significant.

In *M. nigra*, our proximate analyses showed rich mineral contents for the macronutrients (Ca, K, Mg, P) and higher secondary macronutrients (Na), as well as, high micronutrients (Mn, Ni). Leaves were rich in Ca, K, and Mn, with content levels of 1514.01, 1182.44, and 2.07 mg/100 g, respectively. While roots were rich in Mg, P, Na, and Ni, with content levels 454.18, 398.67, 183.54, and 1.36 mg/100 g, respectively.

The leaves of the native *M. nigra* exhibit notably high Ca content, with levels (1514.01 mg/100 g) significantly surpassing those documented in other studies⁵⁵ and exceeding daily Ca requirements. This makes *M. nigra* leaves a potential valuable Ca source for food production, important for bone health and quality⁵⁶. The elevated levels of Mg, P, Na, and Ni in the roots of *M. nigra* underscore their essential role in promoting root growth under stressful conditions^{58,59}. In addition, play vital roles in human metabolism, including muscle and nerve health, sugar regulation⁶⁰, and metabolic and hormonal activities^{61,62}. In order to preserve the roots' high detected Mg levels, it is recommended to ash the samples and then use it to determine the amounts of Mg through atomic absorption. Ni is crucial for metabolic reactions in plants and for hormonal activities and lipid metabolism in animals. Our study reveals a Na/K ratio (0.166) considered acceptable for food quality, potentially reducing the risk of cardiovascular disorders⁶³. Although the K levels identified are below daily requirements, they are higher

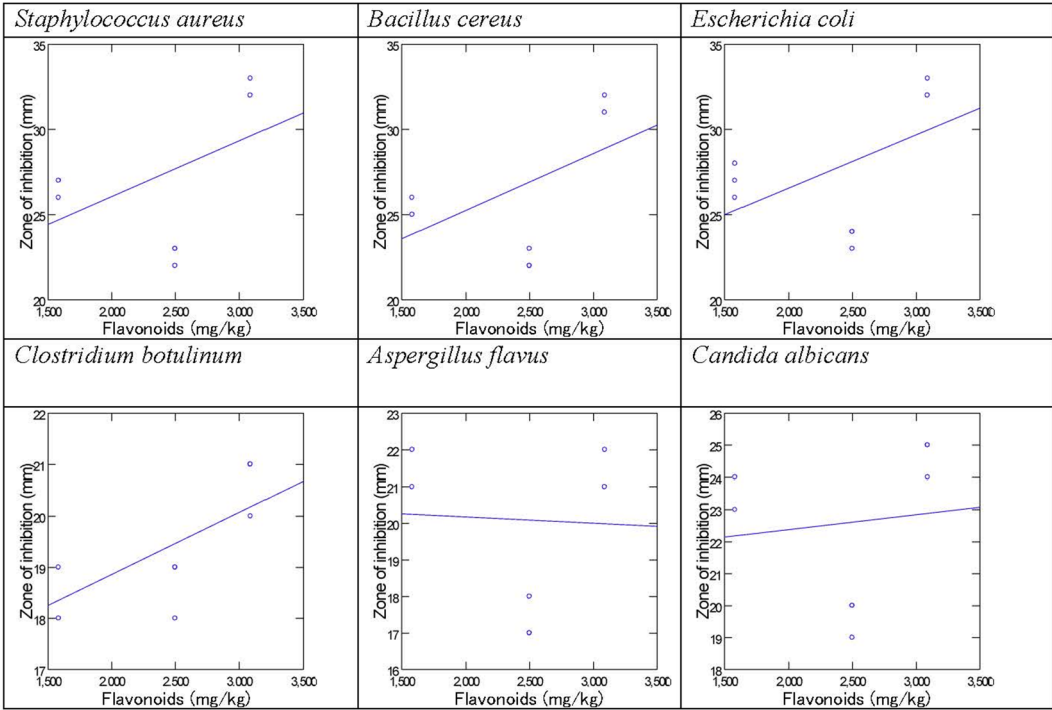


Fig. 7. *M. alba* was studied for its flavonoids extracts and their correlation with antimicrobial activities against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, and *Candida albicans*.

Tested microbes	Coefficient of correlation	F-Values
<i>Staphylococcus aureus</i>	0.49	2.206 ns
<i>Bacillus cereus</i>	0.53	2.74 ns
<i>Escherichia coli</i>	0.515	2.525 ns
<i>Clostridium botulinum</i>	0.713	7.259*
<i>Aspergillus flavus</i>	-0.053	0.019 ns
<i>Candida albican</i>	0.133	0.127 ns

Table 6. ANOVA (F-Values) and coefficient of correlation between flavonoids extracts from *M. alba* plant parts and antimicrobial activities against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Clostridium botulinum*, *Aspergillus flavus*, and *Candida albicans*. * $p < 0.05$, ns: non-significant.

than those reported in prior research⁵⁷. This macronutrient is crucial for maintaining the body’s water balance and mineral regulation.

In *M. alba*, our proximate analyses reported rich mineral contents for the micronutrients Cu and Zn. Leaves showed the highest Cu content (around 1.05 mg/100 g), while branches showed the highest Zn content (around 1.55 mg/100 g). Both minerals play significant roles in plant and human physiology, with Cu being essential for photosynthesis and immune function, and Zn for enzymatic reactions, ion transport, and cell growth^{64–67}. The levels of Cu identified suggest that *M. alba* could be an excellent source of this mineral, meeting and possibly exceeding daily requirements. Our observation aligns with other findings reported by Hudzicki, J. (2009)⁴³, and it underscores the intricate relationship between plant species’ adaptability to environmental conditions and their nutritional and mineral content.

Notably, the both species tested showed no content of Se, as well as the heavy metals Cd, and Pb, highlighting their potential safety for consumption^{68,69}.

This detailed mineral analysis contributes to understanding the adaptive strategies of *Morus* species in the UAE’s challenging environmental conditions and their potential health benefits, aligning with the broader goal of exploring sustainable natural resources.

This study revealed that *M. nigra* showed higher levels of ash content (around 8%) and higher levels of tannins, in leaves (around 4.2%). While the exotic *M. alba* demonstrated significantly higher levels of dry matter, protein, crude fibers, TDN, and flavonoids compared to the native *M. nigra*. The nutritional superiority of *M. alba* may contribute to its aggressive invasiveness in non-native environments, a characteristic observed in various

countries. This aligns with⁷⁰ observations in Australia, where exotic plants were found to have higher nutritive value than natives, potentially due to their more efficient exploitation of soil nutrients, as suggested by⁷¹.

Proteins and fibers play crucial roles in both plant and animal physiology. In humans, proteins are essential for growth, development, and various regulatory functions, while dietary fibers can reduce cardiovascular disease risk by lowering cholesterol levels. Remarkably, our findings indicate that *M. alba* contains more protein than common vegetables like lettuce, highlighting its potential as a superior dietary source⁷².

Furthermore, *M. alba* exhibits a significant flavonoid content, surpassing that of *M. nigra*. Flavonoids are known for their various functions in plants, including cell growth, pollination, and stress response, and have been observed in higher concentrations in exotic species like *Acacia dealbata* compared to native plants^{73,74}. This suggests that regular consumption of flavonoid-rich *M. alba* could offer health benefits, underscoring its potential medicinal value. *M. alba* was found to contain higher levels of tannins extracted from their branches and roots comparing to *M. nigra*. Tannin compounds recognized for their anticancer, antimicrobial, and anti-inflammatory properties^{75,76}. This difference highlights the unique phytochemical profiles and potential health benefits of each species.

The study noted that crude fat levels were below 0.1%, lower than daily requirements, indicating that fat content varies with plant parts, age, and environmental conditions⁷⁷. Despite the low fat content observed, fats remain an essential nutrient, underscoring the importance of balanced dietary intake to meet nutritional needs. Besides, the analysis of total phenols indicated that no detectable levels were observed. Further investigation may be necessary to pinpoint the exact reasons for the undetectable levels of both crude fat and total phenol content. This could include optimizing extraction techniques, expanding the analysis to include a larger sample size, and considering different environmental or biological factors that may influence phenolic content.

The antimicrobial effects of extracts from different parts (leaves, branches, and roots) of *M. nigra* and *M. alba* were studied on a range of microbial species including *S. aureus*, *E. coli*, *B. cereus*, *C. albicans*, *A. flavus*, and *C. botulinum*. The results indicate significant variability in antimicrobial activity between the *Morus* species, with extracts from the roots of *M. alba* (exotic) showing notably higher efficacy against these microbes, particularly bacteria over fungi. This finding aligns with the understanding that fungi possess greater efficiency in nutrient assimilation and storage, rendering them more specialized than bacteria⁷⁸.

In contrast to previous research, our study emphasizes the importance of examining the effects of specific plant parts in a congeneric approach. The antimicrobial activities we observed were significantly stronger than those reported in other studies involving the same plant species and other botanicals, including some reference antibiotics. For instance, research on *Arnica montana* and *Chamaemelum nobile* indicated in-hibition zones against *E. coli* and *B. cereus* that were considerably smaller than those we measured⁷⁹. Similarly, studies on *Moringa oleifera* and *Psidium guajava* against *S. aureus* and *C. albicans*, respectively, showed lesser antimicrobial effects compared to our findings⁸⁰.

Our results also exceed the antimicrobial activity reported against *A. flavus* in prior research, highlighting the exceptional antimicrobial potential of the exotic *Morus* species. This enhanced activity may be attributed to its distinct chemical composition, especially the correlation between flavonoid content in *M. alba* and antimicrobial effects against *S. aureus*, *B. cereus*, *E. coli*, and *C. botulinum*, echoing the findings of other studies⁷⁸. Flavonoids, recognized for their broad-spectrum antimicrobial properties, impact different pathogens variably, as demonstrated by other scientists in their study on the varied effects of flavonoids on *S. aureus* strains⁸¹.

Additionally, tannins have been identified as possessing potent antimicrobial properties. Research characterizing the tannin profile of *Cytinus hypocistis* and *Chromobacterium rubrum* revealed strong activity against *Staphylococcus* species and *Enterococcus faecium*^{74,82}, further supporting our observations. This comprehensive analysis underscores the potential of the exotic *M. alba*, facilitated by its unique phytochemical profile, to serve as a powerful source of antimicrobial agents.

Our findings advocate for the continued research and development of *Morus* species as a significant natural resource. The distinctive nutritional, phytochemical, and antimicrobial profiles of *M. M. nigra* and *alba* highlight their potential as sustainable sources for food, health, and medicinal applications, paving the way for their integrated use in addressing global health and environmental sustainability objectives. This research not only advances our understanding of the adaptive strategies and potential health benefits of the *Morus* species in the UAE, but also contributes to the global efforts towards achieving Sustainable Development Goals (SDGs). By exploring sustainable natural resources for medicinal and nutritional applications, this study underscores the importance of conserving and utilizing biodiversity in a manner that supports the health and well-being of the global population amid rapid environmental changes and challenges.

Further research should aim to optimize extraction methods and expand sample sizes to better assess the phytochemical composition of both species. Ultimately, this research not only contributes to our understanding of the nutritional and medicinal potential of *Morus* species but also informs future conservation efforts and utilization strategies for these valuable plants.

Future studies are required to examine the influence of seasonal variations on the two species' mineral content, phytochemical profiles, and antimicrobial activities. Furthermore, it is needed to investigate the same for fruits of *M. nigra* and *M. alba*. In addition, *in vivo* and clinical studies are essential for nutritional, healthcare and medicinal applications. In addition, exploring the mechanisms of action and the active compounds responsible for these effects, which could inform practical applications in medicine and agriculture.

Conclusion

This study revealed a significant difference between *M. nigra* (native) and *M. alba* (exotic) grown naturally in Fujairah, in terms of mineral content, phytochemical composition, and antimicrobial profile. In which the plant parts of each species demonstrated unique superior performance across different analyses.

The investigation revealed that *M. nigra* showed rich mineral contents for the macronutrients (Ca, K, Mg, P) and higher levels from the secondary macronutrients (Na), as well as, high micronutrients (Mn, Ni). *M. nigra* Leaves showed high levels of Ca, K, and Mn, with notably high Ca content (1514.01 mg/100 g) exceeding daily Ca requirements and significantly surpassing those documented in other studies. While roots were rich in Mg, P, Na, and Ni, with content levels of 454.18, 398.67, 183.54, and 1.36 mg/100 g, respectively. While *M. alba* showed also rich mineral content, especially in Cu and Zn, in which high levels of Cu extracted from the leaves (1.08 mg/100 g) with levels exceeding the daily requirements, and rich levels of Zn extracted from the branches (1.58 mg/100 g). Both *M. nigra* and *M. alba* did not show detectable levels of Se in the analysis. Furthermore, there were no signs of toxicity related to Pb and Cd, supporting their safe consumption.

The nutritional profiles revealed that *M. nigra* leaves exhibited higher ash content (8.77%) and tannin levels (4.16%), while *M. alba* demonstrated superior nutritional qualities, including increased dry matter (Extracted from branches: 74.45%), protein (Extracted from leaves: 8.14 g/100 g), crude fibers (Extracted from leaves: 25.97%), TDN (Extracted from branches: 69.18%), and flavonoids (Extracted from roots: 3089.32 mg/kg). The notable nutritional superiority of *M. alba* may explain its aggressive invasiveness in non-native environments, consistent with patterns observed in other regions. Proteins and fibers are critical for promoting healthy physiological functions in both humans and animals, with *M. alba* standing out as a promising dietary source compared to common vegetables. Furthermore, its high flavonoid content suggests potential health benefits, emphasizing its medicinal value. The enhanced levels of tannins in *M. alba* indicate additional therapeutic possibilities due to their known anticancer, antimicrobial, and anti-inflammatory properties.

While the analysis indicated low crude fat levels and undetectable phenolic content, these findings underscore the complexity of plant nutrient profiles influenced by various factors, including plant parts, age, and environmental conditions.

The antimicrobial analysis demonstrated that extracts from *M. alba*, especially from its roots, possess significantly higher antimicrobial activity against a range of bacteria and fungi. Notably, root extracts of *M. alba* showed significantly higher antimicrobial activities ($p < 0.001$) than those of *M. nigra*. The inhibition zones for *M. alba* were recorded at 32.66 mm against the bacteria *S. aureus*, and same inhibition zone against the bacteria *E. coli*, 31.66 mm against the bacteria *B. cereus*, 24.66 mm against the fungus *C. albicans*, 21.66 mm against the fungus *A. flavus* and 20.66 mm against the bacteria *C. botulinum*. In contrast, *M. nigra* demonstrated inhibition zones of 30.33 mm against the bacteria *E. coli*, 29.33 mm against the bacteria *S. aureus*, and same inhibition zone against the bacteria *B. cereus*, 21.66 mm against the fungus *C. albicans*, 20.66 mm against the bacteria *C. botulinum*, and 19.66 mm against the fungus *A. flavus*.

The results indicate that antibacterial activities were consistently higher than antifungal activities, with the maximum antibacterial effect observed at 32.66 mm for *S. aureus*, compared to 24.66 mm for *C. albicans*. This enhanced antimicrobial potential may be closely linked to its phytochemical composition, including flavonoids and tannins, which have been identified as key contributors to the observed antimicrobial efficacy.

These findings underscore the medicinal and therapeutic potential of both species, particularly *M. alba*, in developing natural antimicrobial alternatives, as well as new antibiotics and antifungal drugs. Both serve as sources of bioactive compounds and offer innovative natural solutions to combat antimicrobial resistance. In addition to their medicinal and pharmaceutical applications, their rich mineral and nutrient profiles highlight their significant potential for industrial use in food supplements and healthcare sectors. Furthermore, their antimicrobial properties make them valuable in food preservation and cosmetic industries by inhibiting microbial growth. Notably, both species also show promise for environmental applications in agriculture, such as soil enrichment and biopesticide development, and their potential application as nutritious animal feed.

Overall, *M. nigra* and *M. alba* provide notable nutritional and antimicrobial benefits, making both species valuable resources for various promising industrial applications. Further studies should explore the impact of seasonal variations on their phytochemical profile and microbial activity. This crucial step aims to identify and optimize the agricultural parameters to maximize yield and efficacy. Additionally, clinical studies are necessary to develop integrated approaches for safe and effective therapeutic applications.

Data availability

All data supporting the findings of this study are available within the paper and its Supplementary data file.

Appendix 1

Table 6. Design table

You must include this mandatory *Design table*. The columns are prescribed; the number of rows will depend on the number of research questions you will address in your Registered Report.

- Ensure that there is an *exact* correspondence between each scientific hypothesis and each statistical test. For example, it is not appropriate to write: Condition A will affect performance differently from Condition B. Instead, you must define the performance measure (e.g. Reaction Time) and the predicted direction of the difference. This would translate to, e.g.: Reaction times will be significantly higher in Condition A than Condition B.
- If your analysis strategy will depend on the results (e.g. normal vs. non-normal distribution) then specify the contingencies for making different choices, i.e. IF–THEN statements.

You cannot interpret lack of evidence for the existence of an effect in NHST (e.g. a $p > 0.05$ in a t-test) as evidence for the absence of an effect. To be able to interpret null results, you must commit to using Bayes Factors or equivalence testing.

Question	Hypothesis (if applicable)	Sampling plan (e.g. power analysis)	Analysis Plan	Interpretation given to different outcomes
In the UAE, which species of the two Mulberry species, <i>M. nigra</i> (native) and <i>M. alba</i> (exotic), has rich mineral content, nutrients, and phytochemical profile, as well as, a better antimicrobial activity?	The study hypothesized that there are significant differences between <i>M. nigra</i> and <i>M. alba</i> in terms of mineral content, nutrient levels, phytochemical profiles, and antimicrobial properties	Mineral content, nutrients and phytochemical profiles of the native and the exotic <i>Morus</i> species parts (leaves, branches, and roots) Antimicrobial activity of the native (<i>M. nigra</i>) and the exotic (<i>M. alba</i>) Mulberry species parts (leaves, branches, and roots)	Significance level: $p < 0.01$ Two-way ANOVA (analysis of variance) Tukey's test (honest significant difference, HSD) Scatterplots and linear regressions	Kindly refer to the detailed discussion section

Received: 25 August 2024; Accepted: 4 September 2025
Published online: 07 October 2025

References

1. Ozgen, M., Serce, S. & Kaya, K. Phytochemical and antioxidant properties of anthocyanin rich *Morus nigra* and *Morus rubra* fruits. *Sci. Hortic.* **119**, 275–279. <https://doi.org/10.1016/j.scienta.2008.08.007> (2009).

2. Rohela, G. K., Shukla, P., Kumar, R. & Chowdhury, S. R. Mulberry (*Morus* spp.): An ideal plant for sustainable development. *Trees For People* **2**, 100011. <https://doi.org/10.1016/j.tfp.2020.100011> (2020).

3. Lin, Z. et al. Anti-Inflammatory activity of mulberry leaf flavonoids in vitro and in vivo. *Int. J. Mol. Sci.* **23**, 7694. <https://doi.org/10.3390/ijms23147694> (2022).

4. Huang, J. et al. Metabolome and transcriptome integrated analysis of mulberry leaves for insight into the formation of bitter taste. *Genes* **14**, 1282. <https://doi.org/10.3390/genes14061282> (2023).

5. Baci, E. D., Baci, G. M., Moise, A. R. & Dezmirean, D. S. A status review on the importance of Mulberry (*Morus* spp.) and prospects towards its cultivation in a controlled environment. *J. Hortic.* **9**, 444. <https://doi.org/10.3390/horticulturae9040444> (2023).

6. Kandyli, K., Hadjigeorgiou, I. & Harizanis, P. The nutritive value of mulberry leaves (*Morus alba*) as a feed supplement for sheep. *Trop. Anim. Health Prod.* **41**, 17–24. <https://doi.org/10.1007/s11250-008-9149-y> (2009).

7. Koyuncu, F., Çetinba, M. & Ibrahim, E. Nutritional constituents of wild-grown black mulberry (*Morus nigra*). *J. Appl. Bot. Food Qual.* **87**(1), 93–96. <https://doi.org/10.5073/JABFQ.2014.087.014> (2014).

8. Chen, C., Mohamad, R. U. H., Saikim, F. H., Mahyudin, A. & Mohd, N. *Morus alba* plant: Bioactive compounds and potential as a functional food ingredient. *Foods* **10**, 689. <https://doi.org/10.3390/foods10030689> (2021).

9. Mehta, M. & Kumar, A. Nutrient composition, phytochemical profile and antioxidant properties of *Morus nigra*: A review. *IJISR* **6**(2), 1–9 (2021).

10. Wang, W., Zu, Y., Fu, Y. & Efferth, T. In vitro antioxidant and antimicrobial activity of extracts from *Morus alba* L. leaves, stems and fruits. *Am. J. Chin. Med.* **40**(2), 1–7. <https://doi.org/10.1142/S0192415X12500279> (2012).

11. Solares, M. D. et al. Evaluation of the antimicrobial activity of fresh extracts of *Morus alba* L. leaves. *Pastor. y Forrajes* **40**, 40–45 (2017).

12. Laohasilpsomjit, S., Bronlund, J. E. & Utto, W. Antimicrobial activity of Mulberry leaf extract on postharvest soft rot caused by *Erwinia carotovora*. *Rajabhat Agric.* **16**(1), 1–8 (2017).

13. Aulifa, D. L., Haque, S., Riasari, H. & Budiman, A. Antibacterial effects of black mulberry (*Morus nigra*) stem bark extract on *Streptococcus mutans*. *Res. J. Pharm. and Tech.* **14**(8), 1–4. <https://doi.org/10.52711/0974-360X.2021.00763> (2021).

14. Masood, S. H. & Aslam, N. In vitro susceptibility test of different clinical isolates against ceftriaxone. *Oman Med. J.* **25**(3), 1–4. <https://doi.org/10.5001/omj.2010.56> (2010).

15. Ahmad, R. & Ahmed, A. Evaluation of antibacterial activity of *Morus nigra* and *Citrus limon*. *Int. j. Ayurvedic herb. med.* **2**(6), 213–217 (2016).

16. Putri, D. H., Hafids, V. H., Sofani, A. & Susanti, T. Potential of andalas (*Morus macroura*) ethanol extract in inhibiting the microbial growth. *Adv. Biol. Sci. Res.* **10**, 1–4. <https://doi.org/10.2991/absr.k.200807.001> (2019).

17. Selbmann, L. E. E. et al. Biodiversity, evolution, and adaptation of fungi in extreme environments. *Plant Biosyst.* **147**(1), 1–8. <https://doi.org/10.1080/11263504.2012.753134> (2013).

18. Deveau, A. et al. Bacterial-fungal interactions: Ecology, mechanisms, and challenges. *FEMS Microbiol. Rev.* **42**, 335–352. <https://doi.org/10.1093/femsre/fuy008> (2018).

19. Nascimento, G. G. F., Locatelli, J., Freitas, P. C. & Silva, G. L. Antibacterial activity of plant extracts and phytochemicals on antibiotic resistant bacteria. *Braz. J. Microbiol.* **31**, 247–256. <https://doi.org/10.1590/S1517-8382200000400003> (2000).

20. Mathur, P., Singh, A., Srivastava, V., Singh, D. & Mishra, Y. Antimicrobial activity of indigenous wildy growing plants: Potential source of green antibiotics. *Afr. J. Microbiol. Res.* **7**, 3807–3815 (2013).

21. Andersen, B.M., Lereim, I. & Hochlin, K. *Handbook in Hygiene and Infection Control for Hospitals*. (Ullevål University Hospital, 2008).

22. Andersen, B.M. *Handbook in hygiene and infection control for hospitals. Part 1. Microbiology and infection control*. (Fagbokforlaget, 2014).

23. Andersen, B.M. *Dangerous microbes. prevention and control of infections in hospital*. https://doi.org/10.1007/978-3-319-99921-0_8 (2018).

24. Shahin, S. M., Kurup, S., Cheruth, J., Lennartz, F. & Salem, M. Growth, yield, and physiological responses of *Cleome amblyocarpa* Barr. & Murb. under varied irrigation levels in sandy soils. *J. Food Agric. Environ.* **16**, 124–134 (2018).

25. Shahin, S. M., Jaleel, A. & Alyafei, M. A. M. Yield and in vitro antioxidant potential of essential oil from *Aerva javanica* (burm. F.) juss. Ex. schul flower with special emphasis on seasonal changes. *Plants* **10**, 2618. <https://doi.org/10.3390/plants10122618> (2021).

26. Shahin, S., Kurup, S., Cheruth, A. J. & Salem, M. Chemical composition of *Cleome amblyocarpa* Barr. & Murb. essential oils under different irrigation levels in sandy soils with antioxidant activity. *J. Essent. Oil-Bear. Plants* **21**, 1235–1256. <https://doi.org/10.1080/0972060X.2018.1512422> (2018).

27. Kivanc, M. & Yapici, E. Survival of *Escherichia coli* O157: H7 and *Staphylococcus aureus* during the fermentation and storage of kefir. *Food Sci. Technol. Campinas* **39**, 225–230. <https://doi.org/10.1590/fst.39517> (2019).

28. Carolus, H., Van, D. K. & Van, D. P. *Candida albicans* and *Staphylococcus* species: A threatening twosome. *Front. Microbiol.* **10**, 1–9. <https://doi.org/10.3389/fmicb.2019.02162> (2019).

29. Bose, S., Singh, D. V., Adhya, T. K. & Acharya, N. *Escherichia coli*, but not *Staphylococcus aureus*, functions as a chelating agent that exhibits antifungal activity against the pathogenic yeast *Candida albicans*. *J. Fungi* **9**, 1–8. <https://doi.org/10.3390/jof9030286> (2023).

30. Nrior, R., Ugboma, C., Lugbe, Q. & Ogbonna, D. Susceptibility of *Candida albicans*, *Staphylococcus aureus* and *Escherichia coli* to extracts of mango (*Mangifera indica*). *J. Adv. Microbiol.* **23**(5), 46–57. <https://doi.org/10.9734/JAMB/2023/v23i5725> (2023).
31. Tong, S. Y. C., Davis, J. S., Eichenberger, E., Holland, T. L. & Fowler, V. G. *Staphylococcus aureus* infections: epidemiology, pathophysiology, clinical manifestations, and management. *Clin. Microbiol. Rev.* **28**(1), 1–14. <https://doi.org/10.1128/cmr.00134-14> (2015).
32. Talapan, D., Sandu, A. M. & Rafila, A. Antimicrobial resistance of *Staphylococcus aureus* isolated between 2017 and 2022 from infections at a tertiary care hospital in Romania. *Antibiotics* **12**, 974. <https://doi.org/10.3390/antibiotics12060974> (2023).
33. Wang, S. et al. Antibiotic resistance spectrum of *E. coli* strains from different samples and age grouped patients: a 10-year retrospective study. *BMJ Open* **13**, 1–8. <https://doi.org/10.1136/bmjopen-2022-067490> (2023).
34. Fiedler, G. et al. Antibiotics resistance and toxin profiles of *Bacillus cereus*-group isolates from fresh vegetables from German retail markets. *BMC Microbiol.* **19**, 250. <https://doi.org/10.1186/s12866-019-1632-2> (2019).
35. Barash, J. R., Castles, J. B. & Arnon, S. S. Antimicrobial susceptibility of 260 *Clostridium botulinum* type A, B, Ba, and Bf strains and a neurotoxicogenic *Clostridium botulinum* type F strain isolated from California infant botulism patients. *Antimicrob. Agents Chemother.* **62**, 1–12. <https://doi.org/10.1128/aac.01594-18> (2018).
36. Yu, J., Cleveland, T. E., Nierman, W. C. & Bennett, J. W. *Aspergillus flavus* genomics: Gateway to human and animal health, food safety, and crop resistance to diseases. *Rev. Iberoam. Micol.* **22**(4), 194–202. [https://doi.org/10.1016/S1130-1406\(05\)70043-7](https://doi.org/10.1016/S1130-1406(05)70043-7) (2005).
37. Richardson, J. P. *Candida albicans*: A Major fungal pathogen of humans. *Pathogens* **11**, 459 (2022).
38. Vilà, M. & Weiner, J. Are invasive plant species better competitors than native plant species?—Evidence from pair-wise experiments. *Oikos* **105**(20), 229–238. <https://doi.org/10.3390/pathogens11040459> (2004).
39. Slate, M., François, M. T., Callaway, R. & El-Keblawy, A. Exotic *Prosopis juliflora* suppresses understory diversity and promotes agricultural weeds more than a native congener. *Plant Ecol.* **221**, 1–8. <https://doi.org/10.1007/s11258-020-01040-1> (2020).
40. Tsombou, F. M., El-Keblawy, A., Elsheikh, E. A. E., Abuqamar, S. F. & El-Tarabily, K. A. Allelopathic effects of native and exotic *Prosopis* congeners in Petri dishes and potting soils: Assessment of the congeneric approach. *Botany* **100**(3), 329–339. <https://doi.org/10.1139/cjb-2021-0064> (2022).
41. Macel, M., Vos, R. C. H. D., Jansen, J. J., Putten, W. H. D. V. & Dam, N. M. V. Novel chemistry of invasive plants: exotic species have more unique metabolomic profiles than native congeners. *Ecol. Evol.* <https://doi.org/10.1002/ecs3.1132> (2014).
42. Ramadan, S. *The United Arab Emirates Indigenous Essential Oil-Bearing Plants: Essential Oils of Aerva javanica and Cleome amblyocarpa Grown in Sandy Soils under Arid Conditions. Dissertations. United Arab Emirates University (United Arab Emirates, 2018).* https://scholarworks.uaeu.ac.ae/all_dissertations/114
43. Byalt, V. V., Korshunov, M. V. & Korshunov, V. M. The Fujairah Scientific Herbarium—a new herbarium in the United Arab Emirates. *Skvortsovia* **6**, 7 (2020).
44. Hudzicki, J. Kirby-Bauer disk diffusion susceptibility test protocol. *Am. Soc. Microbiol.* **1**, 23 (2009).
45. Sayeed, A. et al. Nutritional status of exotic and indigenous vegetables. *Int. J. Veg. Sci.* <https://doi.org/10.1080/19315260.2020.1713957> (2020).
46. Piste, P., Sayaji, D. & Avinash, M. Calcium and its role in human body. *Int. J. Res. Pharm. Biomed. Sci.* **4**, 2229–3701 (2013).
47. Report of the AOAC INTERNATIONAL Task Force on Methods for Nutrient Labeling Analyses, *Journal of AOAC INTERNATIONAL* **76**, 6, 1 (1993), 180A–201A, <https://doi.org/10.1093/jaoac/76.6.180A>
48. Julshamn, K. et al. Determination of arsenic, cadmium, mercury, and lead in foods by pressure digestion and inductively coupled plasma/mass spectrometry: First action 2013.06. *J. AOAC Int.* **96**, 1101–1102. <https://doi.org/10.5740/jaoacint.13-143> (2013).
49. Briscoe, M. Determination of heavy metals in food by inductively coupled plasma-mass spectrometry: First Action 2015.01. *J. AOAC Int.* **98**, 1113–1120. <https://doi.org/10.5740/jaoacint.2015.01> (2015).
50. Thiex, N. Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. *J. AOAC Int.* **92**(1), 61–73. <https://doi.org/10.1093/jaoac/92.1.61> (2009).
51. Changes in AOAC Official Methods of Analysis, *Journal of AOAC INTERNATIONAL* **79** (1996), 363–367, <https://doi.org/10.1093/jaoac/79.1.363>
52. Thiex, N., Novotny, L. & Crawford, A. Determination of ash in animal feed: AOAC official method 942.05 revisited. *J. AOAC Int.* **95**, 1392–1397. <https://doi.org/10.5740/jaoacint.12-129> (2012).
53. Thiex, N., Anderson, S. & Gildemeister, B. Collaborators: Crude Fat, diethyl ether extraction, in feed, cereal grain, and forage (Randall/Soxtec/submersion method): collaborative study. *J. AOAC Int.* **86**, 888–898. <https://doi.org/10.1093/jaoac/86.5.888> (2003).
54. Nurlinda, N., Handayani, V. & Rasyid, F. Spectrophotometric determination of total flavonoid content in *Biancaea sappan* (*Caesalpinia sappan* L.) leaves. *J. Fitofarmaka Indonesia* **3**, 8. <https://doi.org/10.33096/jffi.v8i3712> (2021).
55. Hanifa, M. A. et al. Analytical evaluation of three wild growing Omani medicinal plants. *Nat. Prod. Commun.* **6**(10), 1–7. <https://doi.org/10.1177/1934578X110060> (2011).
56. Newman, E. I. & Andrews, R. E. Uptake of phosphorus and potassium in relation to root growth and root density. *Plant Soil* **38**, 49–69. <https://doi.org/10.1007/BF00011217> (1973).
57. Ishfaq, M. et al. Physiological essence of magnesium in plants and its widespread deficiency in the farming system of China. *Front. Plant Sci.* **13**, 1–18. <https://doi.org/10.3389/fpls.2022.802274> (2022).
58. Al Alawi, A. M., Majoni, S. & Falhammar, H. Magnesium and human health: Perspectives and research directions. *Int. J. Endocrinol.* **8**, 1–17. <https://doi.org/10.1155/2018/9041694> (2018).
59. Patra, A., Dutta, A., Mohapatra, K. K. & Pradhan, S. Nickel the ultra-micronutrient: Significant for plant growth and metabolism. *Food Chem. Toxicol.* **1**, 35–37 (2020).
60. Zdrojewicz, Z., Popowicz, E. & Winiarski, J. Nikiel—rola w organizmie człowieka i dziaanie toksyczne [Nickel—role in human organism and toxic effects]. *Pol. Merk. Lekarski* **41**(242), 115–118 (2016).
61. Levings, J. L. & Gunn, J. P. The imbalance of sodium and potassium intake: implications for dietetic practice. *J. Acad. Nutr. Diet.* **114**(6), 838–841. <https://doi.org/10.1016/j.jand.2014.02.015> (2014).
62. Yruela, I. Copper in plants: Acquisition, transport, and interactions. *Funct. Plant Biol.* **36**(5), 1–23 (2009).
63. Hamzah, S. M., Usman, K., Rizwan, M., Al Jabri, H. & Alsafran, M. Functions and strategies for enhancing zinc availability in plants for sustainable agriculture. *Front. Plant Sci.* **7**, 13. <https://doi.org/10.3389/fpls.2022.1033092> (2022).
64. Araya, M., Olivares, M. & Pizarro, F. Copper in human health. *Int. J. Environ. Health* **1**(4), 1–14. <https://doi.org/10.1504/IJENVH.2007.018578> (2007).
65. Bhowmik, D., Bhattacharjee, C. & Kumar, S. A potential medicinal importance of zinc in human health and chronic disease. *Int. J. Pharm. Biomed. Sci.* **1**, 5–11 (2010).
66. Pannico, A. et al. Selenium biofortification impacts the nutritive value, polyphenolic content, and bioactive constitution of variable microgreens genotypes. *Antioxidants* **9**, 1–21. <https://doi.org/10.3390/antiox9040272> (2020).
67. Sakizadeh, M., Sharafabadi, F. M., Shayegan, E. & Ghorbani, H. Concentrations and soil-to-plant transfer factor of selenium in soil and plant species from an arid area. In: *World Multidisciplinary Earth Sciences Symposium, Earth Environ. Sci.* **44**, 1–8 (2016). <https://doi.org/10.1088/1755-1315/44/5/052027>
68. McGregor, B. Nutritional value of some exotic and indigenous plants browsed by goats in southern Australia. In: *Proceedings of the Australian Society of Animal Production* **19**, 1–5 (1992). 10536/DRO/DU:30065988
69. Meisner, A., Boer, W. D., Verhoeven, K. J. F., Boschker, H. T. S. & Putten, W. H. Comparison of nutrient acquisition in exotic plant species and congeneric natives. *J. Ecol.* **99**, 1308–1315. <https://doi.org/10.1111/j.1365-2745.2011.01858.x> (2011).

70. Song, J. et al. Nutritional quality, mineral and antioxidant content in lettuce affected by interaction of light intensity and nutrient solution concentration. *Sci. Rep.* **10**, 1–9. <https://doi.org/10.1038/s41598-020-59574-3> (2020).
71. Chaves, L. N., González, F. M. & Aliás, G. J. C. Comparison of the allelopathic potential of non-native and native species of Mediterranean ecosystems. *Plants* **12**, 972. <https://doi.org/10.3390/plants12040972> (2023).
72. Dias, M. C., Pinto, D. C. G. A. & Silva, A. M. S. Plant flavonoids: Chemical characteristics and biological activity. *Molecules* **26**, 5377. <https://doi.org/10.3390/molecules26175377> (2021).
73. Sharma, K. et al. Health effects, sources, utilization, and safety of tannins: a critical review. *Toxin Rev.* **40**, 1–13. <https://doi.org/10.1080/15569543.2019.1662813> (2019).
74. Ojo, M. A. Tannins in foods: Nutritional implications and processing effects of hydrothermal techniques on underutilized hard-to-cook legume seeds—a review. *Prev. Nutr. Food Sci.* **27**(1), 14–19. <https://doi.org/10.3746/pnf.2022.27.1.14> (2022).
75. Koutsoukis, C., Akrida-Demertzi, K., Demertzis, P. G., Voidarou, C. R. C. & Kandrelis, S. The variation of crude protein and total fat of the main grassland plants, in various stages of growth, in “Kostilata” subalpine grassland in Theodoriana, Arta. *Greece. Ekin J. Crop Breed. Genet.* **2**(2), 69–75 (2016).
76. Dell’Anno, F. et al. Fungi can be more effective than bacteria for the bioremediation of marine sediments highly contaminated with heavy metals. *Microorganisms* **10**, 993. <https://doi.org/10.3390/microorganisms10050993> (2022).
77. Suriyaprom, S., Kaewkod, T., Promputtha, I., Desvaux, M. & Tragoolpua, Y. Evaluation of antioxidant and antibacterial activities of white Mulberry (*Morus alba* L.) fruit extracts. *Plants* **10**, 2736. <https://doi.org/10.3390/plants10122736> (2021).
78. Misbah, S. Evaluation of phytochemical and antibacterial properties of white mulberry (*Morus alba*). *Malays. Appl. Biol.* **49**, 107–112. <https://doi.org/10.55230/mabjournal.v49i4.1599> (2021).
79. Barral-Martinez, M. et al. Evaluation of the antimicrobial potential of extracts from plants of the family Asteraceae. *Med. Sci. Forum* **12**, 17. <https://doi.org/10.3390/eca2022-12726> (2022).
80. Lahlou, Y., El Amraoui, B., El-Wahidi, M. & Bamhaoud, T. Chemical composition, antioxidants and antimicrobial activities of Moroccan species of *Psidium guajava* extracts. *Rocz. Panstw. Zakl. Hig.* **73**, 65–77. <https://doi.org/10.32394/rpzh.2022.0199> (2022).
81. Thebti, A. et al. Antimicrobial activities and mode of flavonoid actions. *Antibiotics* **12**, 225. <https://doi.org/10.3390/antibiotics1202225> (2023).
82. Maisetta, G. et al. Tannin profile, antioxidant properties, and antimicrobial activity of extracts from two Mediterranean species of parasitic plant *Cytinus*. *BMC Complement. Altern. Med.* **19**(82), 1–11. <https://doi.org/10.1186/s12906-019-2487-7> (2019).

Acknowledgements

We express our appreciation to Sharjah Seed Bank and Herbarium and Sharjah’s Environment and Protected Areas Authority for the great support in plants’ identification. Special thanks goes to Mr. Tamer Mahmoud (Sharjah Seed Bank and Herbarium), Ms. Khafiya Al Ketbi (Director of Sharjah Seed Bank and Herbarium) and Prof. Ali El-Keblawy (University of Sharjah) for their great assistance in the plants’ identification mission. The authors received no specific funding for this work.

Author contributions

Conceptualization, F.T., S.M., S.S. and F.R.; methodology, F.T. and A.A.; software, F.T.; validation, F.T., S.M., S.S.; formal analysis, F.T., S.M. and A.A.; investigation, F.T., S.M., S.S.; resources, F.R. and A.A.; data curation, F.T.; writing—original draft preparation, F.T.; writing—review and editing, S.M. and S.S.; visualization, F.T., S.M., S.S. and A.A.; supervision, S.M., S.S. and F.R.; project administration, S.M. and F.R.; open access funding acquisition, F.R. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1038/s41598-025-18872-4>.

Correspondence and requests for materials should be addressed to S.S.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

© The Author(s) 2025