Exploring the Proximate, Phytochemical, and Antioxidant Potential of Hemp and Parthenium Residues

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Improper disposal of agricultural residues is becoming a looming environmental issue as a major contributor to pollution and depletion of natural resources. The current study aimed to evaluate the proximate compositions, phytochemical profile along with antioxidant properties of the residues of hemp (*Cannabis sativa*) and parthenium (*Parthenium hysterophorus*) as sustainable resources. The standard protocol of AOAC was followed for proximate analysis. Phytochemical profiling was done to identify key bioactive compounds through qualitative assays. Their antioxidant activity was assayed by DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging. Hemp recorded 50.2% more fibers than parthenium at 27.5% making it a better candidate for bio-material development. Future *in vivo* studies are recommended to elucidate the metabolic effects of these plants and their potential health benefits. Phytochemical analysis revealed the presence alkaloids, flavonoids, tannins, steroids, coumarins, and sterols, thus showing their bioactivity and possible health benefits. The antioxidant activity was significantly increased in hemp residues (0.1 ± 0.13 mg Trolox/g) compared to parthenium (0.057 ± 0.21 mg Trolox/g), whereas the activity from aerial parts was found lower. This demonstrates the wider application potentials of these residues in the industrial and pharmaceutical sectors as eco-friendly substitutes for conventional materials.

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INTRODUCTION

Human activities inevitably generate waste products. The growing complexity of these activities has led to a significant increase in byproducts and unutilized resources. In many cases, waste generation exceeds the biosphere's capacity to absorb it, resulting in air, water, and land pollution. This poses a serious threat to living systems and necessitates effective mitigation strategies. Developing countries, including Pakistan, often lack expertise in proper waste management, exacerbating the environmental consequences. Agricultural waste significantly contributes to environmental degradation. Processing agricultural products generates roughly 0.3 tons (30%) of residues per ton of product (Ajila *et al*. 2012). This translates to 15% of total residues, amounting to a global estimate of 998 million tons annually (Agamuthu 2009; Obi *et al*. 2016). These agricultural residues

encompass spoiled fruits and vegetables, cocoa husks, seeds, industry byproducts, animal dung, fisheries refuse, and plant peels. In Pakistan, inadequate knowledge about waste treatment, coupled with disposal costs, hinders proper management. Consequently, farmers resort to environmentally harmful practices such as open burning, discarding waste in heaps, or dumping it in waterways (Kwaghe *et al*. 2011; Kozak 2017). Improper agricultural waste management poses a severe threat to human health and environmental well-being. It promotes the proliferation of disease-causing organisms and releases greenhouse gases during decomposition (Mansur *et al*. 2014; Ndou and Rampedi 2022). Communities residing near polluted areas face heightened health risks.

The abundance of agricultural residues, along with its detrimental environmental effects, necessitates exploring alternative, sustainable uses. Maximizing nutrient benefits and recycling waste offer superior solutions compared to discarding or burning. Agricultural residues possess valuable properties, including nutrients, energy potential, and fertilizing capabilities, which can be harnessed through proper treatment and management (Liang *et al*. 2009). These properties are often lost due to current mismanagement practices in Pakistan. *Cannabis sativa* L., a member of the Cannabaceae family, is known for its adaptability and historical uses (Brenneisen (2007). Despite taxonomic debate regarding subspecies, *C. sativa* is recognized for its fiber, food, and medicinal applications (McPartland 2018). Cultivated for millennia, it has served various purposes, documented by historical records (Clarke and Merlin 2016). Cannabis possesses a rich chemical profile, containing over 550 bioactive compounds including cannabinoids, terpenoids, and flavonoids (Anderson 1980; Andre *et al.* 2016; Lowe *et al*. 2021). These diverse constituents have recently garnered renewed research interest in microbiology, oncology, and other fields (Whiting *et al*. 2015).

Similarly, *Parthenium hysterophorus* L., an annual herb, has traditionally been used to treat various ailments including fever, diarrhea, and skin conditions (Patel 2011). Ethnobotanical studies suggest its use for inflammation, rheumatism, and gynecological issues (Anonymous 2014). Parthenium exhibits promising pharmacological activity, including analgesic and anti-amoebic properties (Giupponi *et al.* 2020). The major constituent, parthenin, even shows potential anti-cancer properties (Oudhia 2001; Patel 2011).

Despite existing waste management methods, research on the nutritional potential of selected agricultural waste remains largely unexplored. This information is crucial for categorizing agricultural waste based on nutrient content and developing livestock feeding guidelines. It would also enable the creation of balanced and safe feed formulations for various livestock species.

This knowledge gap necessitates further research to determine the proximate properties of selected agricultural residues for their nutritional potential. The urgency to address this issue is heightened by the growing human population, leading to food scarcity, and increased pressure on livestock feed availability. An estimated 11.70% of the global population currently faces hunger, and this number is projected to rise with the expected population increase to over nine billion by 2050. This trend is likely to exacerbate malnutrition in both humans and livestock. Converting agricultural residues into livestock feed offers a cost-effective solution to improve protein and calorie intake in animals. Livestock plays a critical role in human food security. Therefore, exploring alternative feed sources is essential, particularly as supplementing silage and pasture with grains and protein concentrates for livestock production is becoming unsustainable due to competition for these resources as human food. Agricultural residues have the potential to provide a

cost-effective source of livestock nutrition, thereby contributing to improved protein/calorie supplies. This study aims to determine the proximate analysis of selected agricultural residues for their nutritional potential, with a focus on comparing the energy content and nutritional properties of these residues (Brenneisen 2007; Maliki *et al*. 2023). This study aimed to determine the proximate, phytochemical, and biochemical screening of hemp and parthenium residues. Furthermore, in line with the principles of a circular economy, the potential for subsequent utilization of these residues after extraction to maximize resource use and minimize waste is also considered.

EXPERIMENTAL

Proximate Analysis of Samples

In order to carry out the proximate analysis, the cleaned aerial parts of the samples were sun-dried for 3 days and then blended into powdered form using an electric blender. Analysis of collected samples for moisture, ash, protein, fat, and crude fiber contents were determined as per the methods described by AOAC, 2005. Total carbohydrate contents were determined by an indirect method, *i.e.*, nitrogen-free extract (NFE), by subtracting the sum of all other components from 100 g of the sample. All the analysis was carried out in triplicate and hence the mean value is noted.

Determination of Moisture Content

The moisture content of the selected residues samples of hemp and parthenium was determined gravimetrically, following the Association of Official Analytical Chemists (AOAC) method 950.46 (AOAC, 2005). An empty crucible with a cover, previously dried at 100 °C, was weighed accurately. Subsequently, about 3 g of the samples were precisely weighed and taken in separate crucibles. The crucible with the sample was placed in a thermostatically controlled air oven and dried at 105 °C for 24 hours. After drying, the crucibles were removed from the oven and cooled in a desiccator to room temperature. The crucible and its contents were then weighed again. The drying, cooling, and weighing steps were repeated at 30-min intervals until constant weight (± 0.0001 g) was achieved, indicating complete moisture removal.

$$\text{Moisture content}\,(\%) = \frac{A-B}{W} \times 100 \quad (1)$$

In Eq. 1, A denotes initial weight of crucible and sample, B is final weight of crucible and sample, and W is weight of sample. All were measured in grams.

Ash Determination

In order to determine the ash content of the selected samples, the gravimetrical protocol of AOAC method 942.05 (AOAC 2005) was followed. Clean, dry, and empty crucibles were weighed accurately, followed by taking 3 g of each sample. The crucible with the sample were then placed in a thermostatically controlled oven and dried at 105 °C for 24 h. After drying, the crucible was transferred to a muffle furnace and ignited at 600 °C for 5 h to ensure complete combustion of organic matter. The crucible was then removed from the furnace using appropriate tongs and cooled in a desiccator to room temperature. Finally, the crucible and its contents (ash) were weighed again. Ash content was calculated by the given formula,

$$\text{Ash (\%)} = \frac{A-B}{W} \times 100 \quad (2)$$

where A is the final weight of crucible and sample, B is the weight of the empty crucible, and W is the weight of the sample. All were measured in grams.

Determination of Nitrogen Content

The nitrogen content of the selected samples was determined by Kjeldahl digestion and distillation, following the AOAC method 992.15 (AOAC 2005). Two grams of each sample were accurately weighed into a Kjeldahl digestion flask. Additionally, 3 g of digestion mixture and 25 mL of concentrated sulfuric acid (H_2SO_4) were added to the flask. The digestion flasks were then placed in a Kjeldahl digestion and distillation apparatus. The digestion mixture was heated for 4 h to ensure complete conversion of organic nitrogen into ammonium sulfate ($(NH_4)_2SO_4$). The completion of digestion was typically indicated by a pale-yellow color of the digest. Following digestion, the ammonia (NH_3) was liberated from the digest by distillation and collected in a suitable receiving flask containing a known volume of standardized 0.1 N HCl solution. The excess HCl solution was then titrated with a standardized 0.1 N NaOH solution until the endpoint was reached. The volume (V_2) of NaOH solution used in the titration was recorded. Nitrogen content was then calculated using Eq. 3,

$$N\ (\%) = \frac{(S-B)*0.1*0.014*D*100}{Weight\ of\ Sample*V} \quad (3)$$

where S is the volume (mL) of titrant used for the sample, B is the volume (mL) of titrant used for the blank, 0.1 is the normality of H_2SO_4 solution used in the Kjeldahl method, 0.014 is the milliequivalent weight of nitrogen, D is the dilution factor, 100 is the conversion factor to express the result as a percentage, while V is the volume (mL) of the aliquot taken for titrant.

Determination of Protein Content

Protein content can easily be determined by multiplying the % nitrogen with the conversion factor. In order to determine the protein, the conversion factor of 6.25 was used.

Determination of Fiber

Fiber contents in the samples were determined by sequential acid and alkali digestions. About 2 g samples from each residues source, *i.e.*, from hemp and parthenium, was added to a flask containing 200 mL of 0.128 M H_2SO_4. The mixture was stirred periodically on a water bath for 30 min. The residue was then filtered, washed with hot water, and discarded. The filtrate was collected and added to a fresh flask containing 200 mL of 0.313 M NaOH solution. The mixture was mixed for 30 min in a water bath. The residue was filtered, washed with hot water, and discarded. The final filtrates for each sample were collected in a pre-weighed, dried crucible. The crucibles were dried in oven at 130 °C for 2 h, cooled in a desiccator, and then weighed. The crucible with the remaining fiber was then placed in a muffle furnace at 550 °C for 2 h. After aching, the crucible was cooled in a desiccator and weighed again. Equation 4 was used for obtaining the fiber content,

$$Fiber\ (\%) = \frac{W_1-W_2}{W_3} \times 100 \quad (4)$$

where W_1 denotes weight of sample, W_2 is weight of crucible with fiber, and W_3 is the weight of crucible with ash. All were measured in grams.

Determination of Crude Fat

Samples were first pre-dried in an oven to remove moisture. Meanwhile. Soxhlet thimbles were preheated in an oven for 30 min, cooled in a desiccator, and weighed. One gram of crushed sample from each plant was wrapped in a pre-weighed filter paper and placed inside a thimble. The thimble was then loaded into the Soxhlet extractor. Then, n-hexane was added to the extraction chamber. The extraction process was run until the solvent in the siphon tube became clear. After complete extraction, the solvent was evaporated from the collection flask containing the extracted fat. The dried flask was weighed again. Crude fat was calculated using Eq. 5,

$$Fat\ Content\ (\%) = \frac{W_2 - W_1}{W_s} \times 100 \quad (5)$$

where W_1 denotes the weight of extraction beaker, W_2 is the weight of extractant with oil, and W_3 is the weight of sample. All were measured in grams.

Determination of Cellulose

Cellulose in the samples were determined directly *via* Nitrogen Free Extract

$$NFE = 100 - (Moisture + Ash + Crude\ Protein + Crude\ Fiber) \quad (6)$$

Determination of Energy

The energy value of the selected samples was estimated using Atwater factors (4 kcal/g for carbohydrates and protein while 9 kcal/g for fat) which represent the average energy released. Following component analysis (*e. g.*, Kjeldahl method for protein, Soxhlet extraction for fat), the percentage of each macronutrient (dry weight basis) is multiplied by its respective Atwater factor. Summing these energy contributions provides the total energy value in kcal/g. Conversion to kJ/g was done by multiplying kcal/g by 4.2 (Effiong and Udo 2010).

Phytochemical Analysis

Qualitative screening of the selected residue samples *i.e.*, hemp and parthenium, was carried out by following the reported methods (Ayoola *et al*. 2008). The samples were prepared using cold extraction in methanolic mediums. All extracts were prepared by taking 200 g of powdered samples in 500 mL of methanol.

Total Alkaloids Content

Each extract (2 mL) was taken in a test tube and mixed with 3 to 5 drops of Wagner's reagent (2 g of iodine and 6 g of KI in 100 mL of water). The control was treated similarly after adding water instead of plant extract. Formation of reddish-brown precipitate or coloration as compared to control was considered positive for the presence of alkaloids.

Flavonoids Content with Alkaline Reagent Test

Each extract (2 mL) was mixed with 2 to 3 drops of 20% NaOH solution. Two milliliters of water served as control sample. Formation of dense yellow color which

became colorless by mixing with few drops of dilute HCl indicated the presence of flavonoid in the extract.

Foam Test for Saponins

Two milliliters of the extract were diluted with 6 mL of water. Formation of relentless foam confirmed the presence of saponins in the extract.

Braymer's Test for Tannins

Two milliliters of each extract was mixed with the 1 to 2 drops of 10% ethanolic ferric chloride solution. Creation of blue to greenish color showed the presence of tannins in the extract.

Determination of Steroids *via* Salkowski Test

One milliliter of sample solution and an equal volume of control water were prepared in separate test tubes. Two to three drops of a saturated alcoholic KOH solution were added to each tube, followed by gentle mixing. A color change to reddish-brown in the sample tube compared to the control suggests the presence of steroids.

Test for Coumarin

Two milliliters of extract were mixed with 3 mL of 10% NaOH solution. Appearance of yellow color when exposed to UV light indicates the presence of coumarin.

Liebermann-Burchard Test for Sterol

A sample solution (1.0 mL) and a water control were prepared initially. After adding acetic acid and acetic anhydride to both tubes, concentrated sulfuric acid is carefully layered to form a separate phase. The presence of sterols was indicated by a green, blue, or violet ring at the interface in the sample tube compared to the control.

Biochemical Composition

DPPH free radical scavenging assay

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity of the samples was assessed using a 96-well plate microplate reader method adapting from Stasiłowicz *et al*. (2020). A 0.2 mM solution of DPPH in methanol was prepared as the primary reagent. To initiate the reaction, 25 µL of each sample or Trolox solution was pipetted into individual wells containing 175.0 µL of the DPPH solution. The plate was then incubated in the dark at room temperature for 30 min with shaking. The absorbance of the reaction mixture was measured at 517 nm using a plate reader (Multiskan GO, Thermo Fisher Scientific, Waltham, MA, USA). A blank control containing only the DPPH solution and solvent was also measured at 517 nm for background correction. The percentage inhibition of DPPH radicals by the samples or Trolox was calculated using the following formula,

$$DPPH\ Scavenging\ Activity(\%) = \frac{A_0 - A_i}{A_0} \quad (7)$$

where A_o is the control sample absorbance, whilst A_i is the absorbance of the test sample.

RESULTS AND DISCUSSION

Proximate Analysis

The proximate analysis identified the total fiber content in hemp aerial part as 50.23±0.95% while 27.50% in parthenium suggesting the presence of cellulose alongside hemicellulose, lignin, and other components. Additionally, the proximate analysis for hemp and parthenium revealed the presence of moisture (4.75% and 8.33%, respectively), ash (4.11% and 4.97%, respectively), fat (5.98% and 3.77%, respectively), and protein (3.58% and 9.80%, respectively).

The moisture content was within an acceptable range for storage and handling, as reported (Waris *et al*. 2018; Golam *et al*. 2022). Similarly, the ash content aligns with the 2% to 7% range as reported by Waris *et al*. (2018). Similarly, Golam *et al*. (2022) has also reported a high ash, *i.e.*, 15%. Similar values also have been reported in flax fiber as 2.23% (Waris *et al*. 2018; Golam *et al*. 2022). The observed fat content (5.98%) deviated from the reported range of Waris *et al*. 2018 (11.17%), while 27.99% by Golam *et al*. (2022) but was found in line with the flax fiber of hemp *i.e.*, 5.74%. This could be attributed to sample variation, processing methods leading to higher fat content, or residual solvents used during processing. The protein content (3.58%) was also found lower than the typical range of 5% to 10%, as reported by Golam *et al*. (2022). This variation could also be due to the specific hemp species, harvesting time, or processing methods employed. The findings of protein content in this study are in line with the protein determined for flax fiber (3.84%) by Golam *et al.* (2022). The reported protein is high compared to Waris *et al*. (2018), who reported 0.76%. NFE and total energy was calculated by the standard protocol of AOAC (2005). All the findings are listed in Table.1. The findings of partheniums were compared with Owusu *et al*. (2008).

Ash content in parthenium was found in line with Holechek *et al*. (1998). The cited study investigated the influence of seasonal variations on crude fiber (CF) content. Due to its slow digestibility, CF offers less nutritional value compared to cell contents. The observed range of CF in this study exceeded that reported value for other forage species (Ashraf *et al*. 1995). As plant maturity progressed, the CF content generally increased across all species, albeit at varying rates. The measured CF content ranged from 15% to 42.4%, falling within the recommended range of 31.6%. Consequently, the studied land provided an adequate amount of CF to support the proper growth of grazing livestock.

Higher ether extract (EE) content in certain samples suggests a greater energy level for animals (Babayemi and Bamikole 2006; Odedire and Babayemi 2008). The EE constitutes the primary form of energy storage in plants, serving as a crucial substrate for animal maintenance and production. All plant components possess inherent nutritional value, and their consumption in appropriate ratios can significantly enhance physiological well-being. Future research should prioritize *in vivo* investigations, utilizing laboratory animals to elucidate the metabolic effects of these plant extracts. Nutritional composition exhibited significant variability, which is attributable to a multitude of factors, including cultivation region, prevailing growth conditions, soil characteristics, seasonal fluctuations, inherent genetic diversity among cultivars, storage practices, and even the timing of analysis (Imeh and Khokhar 2002). The role of ash content in promoting balanced animal growth is well-documented. While Kilcher (1981) observed a decrease in ash content with plant maturity, Liu (1993) reported the opposite trend. Interestingly, this study found an increase in ash content across all plant species. These contrasting observations regarding

the influence of maturity on ash content likely stem from variations in soil composition and other habitat characteristics, warranting further investigation.

Table 1. Proximate Analysis of Hemp and Parthenium Residues

	Hemp			Mean	Parthenium			Mean
	R1	R2	R3		R1	R2	R3	
Moisture (%)	5.5	3.58	5.16	4.75 ± 1.02	8.8	7.9	8.3	8.33 ± 0.45
Ash (%)	4.33	4	4	4.11 ± 1.09	5.5	4.4	5	4.97 ± 0.55
Fat (%)	6	5.74	6.2	5.98 ± 0.23	3.9	3.4	4	3.77 ± 0.32
Protein (%)	3.4	3.84	3.5	3.58 ± 0.23	10.4	9.1	9.9	9.80 ± 0.66
Fiber (%)	50.12	51.23	49.33	50.23 ± 0.95	26.5	28.8	27.2	27.50 ± 1.18
NFE (%)	30.65	31.61	31.81	31.36 ± 0.62	44.9	46.4	45.6	45.63 ± 0.75
Energy (kcal/g)	**190.2**	**193.46**	**197.04**	**193.57**	**256.3**	**252.6**	**258**	**255.63**

Phytochemical Analysis

The extracted cellulose specimens were subjected to phytochemical screening. The preliminary tests for phytochemicals in both hemp and parthenium residues revealed the presence of alkaloids, flavonoids, tannins, steroids, coumarins, and sterols. All the findings are listed in Table 2. It was also evident from the findings that saponins were absent in both the samples. Similar study has also been conducted on hemp and partheniums' residues by other researchers (Audu *et al*. 2014; Waris *et al*. 2018; Xu *et al*. 2022), who also determined the presence of the selected phytochemicals.

Table 2. Phytochemical Analysis of Hemp and Parthenium Residues

Phytochemical Tests	Hemp	Parthenium
Alkaloids	+	+
Flavonoid	+	+
Saponins	-	-
Tannins	-	+
Steroids	+	+
Coumarin	+	+
Sterols	+	+

where "+" shows the presence while "-" shows the absence.

Previous research (Davidson-Hunt 2000; Jin *et al*. 2020) has demonstrated that various plants possess a profile of active chemical constituents, including phytochemicals, minerals, and vitamins. These phytochemicals are plant-produced compounds arising from primary or secondary metabolic pathways (refer to biochemistry textbook for details on these pathways). Medicinal plants that are rich in these bioactive chemicals, particularly those with a high antioxidant content, are considered to be of fundamental importance in preventing various degenerative diseases and offer potential health benefits (Maciel *et al*. 2002). Antioxidants are chemical compounds that inhibit oxidation, thereby protecting

living cells from the damaging effects of oxidizing agents. Free radicals, such as reactive oxygen species (ROS) and reactive nitrogen species (RNS), are molecules or molecular fragments characterized by the presence of an unpaired electron, rendering them highly unstable and extremely reactive. These RONS are naturally produced within the mitochondria during cellular respiration, a series of chemical reactions essential for energy production (Funari and Ferro 2005). Antioxidants play a crucial role in safeguarding the body against the detrimental effects of uncontrolled ROS and RNS, counteracting their harmful side effects (Taura *et al* 2009).

DPPH Free Radical Scavenging Assay

During the current study, the DPPH assay exhibited the maximum antioxidant activity for hemp residues (0.100±0.13 mg TE) while the lowest for parthenium residues (0.057±0.21 mg TE) (Table 3). The study was compared with Aazza (2021), which focused on the optimization of phenolic antioxidants from *Cannabis sativa* residue. Their study differed from this study, as they focused on the mixture for optimization. The aerial part of the hemp and parthenium exhibited a very low antioxidant activity, as antioxidants are typically concentrated in the flowers, leaves, and seeds of plants. These parts are more exposed to sunlight and environmental damage, and antioxidants help protect them. The aerial part is the structural core of the plant and have less need for such protection. Cellulose on other hand itself is a carbohydrate, a polymer of glucose (Tutt *et al* 2013). It doesn't possess the chemical properties typically associated with antioxidants, which can neutralize free radicals or chelate metals (Sen and Reddy 2011).

Table 3. DPPH Assay of Hemp and Parthenium Residues

Sample	Extract	DPPH (mg Trolox/g)
Hemp	Methanolic	0.1 ± 0.13
Parthenium		0.057 ± 0.21

This current finding provided valuable insights into the composition of hemp and parthenium residues. However, this study also highlighted the necessity of considering the fate of these materials within a circular economy framework. Therefore, it is essential to explore the potential applications of both hemp and parthenium residues following the target bioactive compounds. For hemp, the higher fiber content suggests opportunities for biomaterial development, including composite materials and paper-based products as reported by Mwaikambo (2006), Sen and Reddy (2011), Ramamoorthy *et al.* (2015), Shekar and Ramachandra (2018), Gomez *et al* (2021) and Elfaleh *et al.* (2023), while parthenium residues may play a vital role in soil amendment practices or bio-energy production as reported by Kumar *et al.* (2013), Shafiq (2016), Deb *et al.* (2019), Sharma and Pant (2019), Abbas *et al.* (2024), and Kumar and Aggarwal (2024). Future research is essential to fully characterize these post-extraction residues, optimize processing methods, and evaluate the environmental and economic benefits of these secondary applications, contributing to a more sustainable and integrated approach to agricultural residue management

CONCLUSIONS

This study investigated the potential of hemp and parthenium residues as a valuable resource, focusing on their nutritional composition, presence of beneficial phytochemicals, and antioxidant properties. The findings revealed significant differences between the two plants.

1. Hemp residues exhibited a substantially higher fiber content compared to parthenium. This characteristic makes hemp a promising candidate for the development of bio-based materials, offering a sustainable alternative to conventional materials.
2. Both plants displayed moisture, ash, and fat content within acceptable ranges for efficient storage and industrial processing.
3. The protein content in hemp was lower than expected, potentially due to specific species or harvesting time. In contrast, parthenium's high crude fiber content suggests limited nutritional value for animal feed.
4. The study also investigated the presence of beneficial phytochemicals in both hemp and parthenium residues. The phytochemical screening identified a range of interesting compounds, including alkaloids, flavonoids, tannins, steroids, coumarins, and sterols. The presence of these compounds suggests potential bioactivity in the residues, warranting further exploration of their potential health benefits.
5. The antioxidant properties of the residues were explored. Hemp residues exhibited a higher overall antioxidant activity compared to parthenium. Interestingly, both materials displayed lower activity in the aerial parts (stems) compared to other plant structures like flowers, leaves, and seeds. This observation aligns with the known concentration of antioxidants in these exposed structures, where they play a vital role in protecting plants from environmental damage. Furthermore, cellulose, a major component of the aerial parts, lacks the chemical properties typically associated with antioxidant activity, such as free radical scavenging or metal chelation. This finding helps explain the observed antioxidant behavior.

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Conflict of Interest

The authors declare no conflict of interest.

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