Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

PHYTOCHEMICAL SIGNATURES, ALLELOPATHIC INTERACTIONS, AND METAL STRESS ADAPTATION IN *CYMBOPOGON JWARANCUSA* AND *ARUNDO DONAX*: A CROSS-DISCIPLINARY PERSPECTIVE ON PLANT–ANIMAL ECOLOGICAL

Muhammad Bilal Malik[1], Dr. Abid Ejaz[2], Mahrukh Mumtaz[3], Dr. Shahzad Hussain[4], Dr. Zill-E-Huma[5], Muhammad Azhar Khan[6], Dr. Sajid Mahmood[*7], Dr. Mian Jahan Zaib Rasheed[8]

[1]*Department of Biological Sciences, University of Lahore, Sargodha Campus, Pakistan.*
[2,3,8]*Department of Botany, University of Sargodha, Sargodha, Pakistan*
[4]*Department of Botany, University of Science and Technology Bannu, KP, Pakistan*
[5]*Department of Botany, University of Sargodha, Sargodha, Pakistan*
[6]*Department of Botany, Hazara University Mansehra, Pakistan*
[*7]*Department of Zoology, Hazara University Mansehra, Pakistan*

[1]muhammadbilalmalik8485@gmail.com,[2]abid155yahoo.com,[3]mahrukhy128@gmail.com, [4]biologist237@gmail.com,[5]humashah690@gmail.com,[6]azharfinal@gmail.com,[*7]sajid_sbs12@hu.edu.pk, [8]jahanzaibrasheedgc@gmail.com

DOI:

Keywords
Allelopathy, phytoremediation, heavy metals, bioaccumulation factor, translocation factor, root growth inhibition, environmental stress, hematological parameters

Article History
Received: 31 January 2026
Accepted: 15 March 2026
Published: 31 March 2026

Copyright @Author
Corresponding Author: *
Dr. Sajid Mahmood

Abstract

This study investigated the allelopathic potential, phytochemical composition, heavy metal accumulation, and associated hematological responses of Cymbopogon jwarancusa and Arundo donax. Methanolic extracts of both species were evaluated for their inhibitory effects on radish (Raphanus sativus) seed germination and root growth under varying concentrations (10-10,000 ppm). A strong dose-dependent allelopathic effect was observed, with maximum root inhibition reaching 65.61% in C. jwarancusa and 68.25% in A. donax at the highest concentration. Germination index decreased significantly ($p < 0.001$), indicating pronounced phytotoxicity. Phytochemical analysis revealed significantly higher concentrations of phenols (4.69 ± 0.02), flavonoids (4.12 ± 0.04), and saponins (3.21 ± 0.02) in C. jwarancusa compared to A. donax, suggesting enhanced bioactivity and stress tolerance. Heavy metal analysis demonstrated that C. jwarancusa exhibited higher uptake and bioaccumulation factors (BAF > 1) for several metals, particularly Cu, Cr, and Ni, along with translocation factors (TF ≈ 1), indicating efficient metal transfer to aerial parts. In contrast, A. donax showed lower BAF and TF (<1), reflecting restricted translocation and root-level metal retention. Hematological parameters in buffaloes varied significantly ($p < 0.001$) across seasons, with RBC counts ranging from 5.15 × 10^{12}/L to 7.21 × 10^{12}/L, indicating adaptive physiological responses to environmental and biochemical stressors. The results demonstrate that C. jwarancusa demonstrated strong potential as a phytoextractor, whereas A. donax functioned effectively as a phytostabilizer. The study highlights the dual role of these species in phytoremediation and allelopathic weed control, supporting their application in

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

sustainable environmental management.

INTRODUCTION

In the progressing countries for the maintanance of health 80% herbs are used by people. They are utilizing it for their protection, worth, cultural suitability and some minor harmful effects (Enioutina et al., 2017). *Cymbopogon jwarancusa* from family poaceae. Two words from Sanskrit language one is "Jwar" and the other is "Ankusha" meaning "fever and breaker" from which species name is taken correspondingly that evokes the admired medicinal property associated with the *Cymbopogon jwarancusa (Verma & Tewari, 2016)*. The plant *Cymbopogon jwarancus* can be found in these areas of the planet in these countries Africa, Arabia, Western Asia, Pakistan and vicinity, Asia tropical, India and its vicinity and all the Province of Pakistan. It has140 species,45 in Asia and more than 52 species in Africa**.** Plant can be found on roadsides, field boundaries and humified places as a weed throughout India (Digvijay *et al.,* 2014).

The plant has rising clumps, its length is 150 cm. Leaf-cutting edges have 30 cm long and 5 mm wide, color is white, limited from the base of plant, lessen to tip, the glabrous sheath is present at base, level or curled, the plant ligule has the length of 280.5mm (Tibenda et al., 2022). The concentrates of *C. jwarancusa* demonstrated questionable results. 250mg/kg exhibited most excessive lessening in rectal temperature of animals, which endured for only two hours. In concentration of 500mg/kg and 750mg/kg there was a decrease in rectal temperature of animals yet was not suffered for more than an hour (Alam *et al.*, 2016). The promising flukicidal development of *Cymbopogon jwarancusa* may be a result of the proximity of compound constituents like sweet-smelling isoprenoid containing terpenes and alkaloids (Sumaiya et al., 2024) and (Ahmed *et al.*, 2010). *Cymbopogon jwarancusa* is "Diuretic" in nature also. A1 receptor is basically affected by terpenoids present in plant it reduces the function of aldosterone hormone (Khan *et al.*, 2018).

Arundo donax is a hydrophyte however can develop in a wide scope of conditions, from wet well-depleted soils to those with a water table at or close to the surface. Soil inclinations are likewise expansive, happening on coarse sands, gravelly soils, substantial dirt's and waterway drags from freshwater to semi-saline soils on bitter estuaries or in trench, and along the banks of streams, streams and lakes (Bruno et al., 2019). In Hawaii, it has naturalized in beach front territories, frequently in bushes (Imada & Kennedy, 2020). In Brazil, Cuba, India, America, France, Germany, Kannada, Malaysia South Africa, Spain, Uruguay (Pilu et al., 2012).

Allelopathy is a process usually found in plants that are more often famous and have some importance in daily life in not only the respect of food production but they are able to control their growth and development as well. They can get more nutrients and chemicals for the defense of the plant life itself (Kalisz et al., 2021). Allelopathic effect was going to test that how *Arundo donax* blocks the growth and germination of the lentil seeds because these seeds were in the soil and their enzymes can be blocked by chemicals which have been present in the extract of the plant *Arundo donax* (Othman, Lazim, & Al-Wakaa, 2023).

The effect of *Arundo donax* was especially important because it may affect the species growth of seeds the main focus in this study was physiological growth and those part are no.1 plant root length and shoot length these two values are most important in determining whether plant is being supported by the water it is obtaining from the source. Initially the results show that 2% and 4% of the plant ware not much effective to inhibit the germination of the root length (Bais *et al.*, 2003) also mentioned by (Nishida *et al.*, 2005). Some special plants have ability to utilize and tolerate the effects of heavy metals (Monni *et al.,* 2001). The plants have some vigorous activity to empower their mechanism and support on the land the most pronounced of them are Pb, Cd, Zn, Cu and As. These species have two types of classifications no. 1 is pseudo metallophytes that can live on both metals filled aur metal less soils, the No.2 category of the plant is Metallophytes these plants have amazing amount of storage of the metals in their stem and parts and live more well on the soil filled with metals (Feki et al., 2021).

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

The hematological profile, which includes metrics like RBC, MCV, RDW, and HCT that show blood function and oxygen transport, is a crucial predictor of animal health. Environmental variables, exposure to heavy metals, and diet all have an impact on these parameters, which can interfere with normal blood formation and result in oxidative stress (Singh et al., 2011; Rafique & Tariq, 2016). However, antioxidants originating from plants, such as flavonoids and phenolics, may aid in blood cell protection (Ahmed et al., 2010; Khan et al., 2018). Hematological analysis is a trustworthy method for determining physiological health because seasonal variations can affect these indices (Radostits et al., 2007; Mahima et al., 2013).

The current study support the evidence that *Arundo donax* is the plant which is very much famous in the world than any other plant this plant is famous for the hyperaccumulator activity and this is very important for the growth of the plant the *Arundo donax* is more suitable even it allows to accumulate more salt for bio fuels and this plant is very much supportive for such targets and the problem is resolved when it became clear that *A. donax* have ben declared to have more Cd and Ni in their shoots specially stems (Bhat et al., 2025).

Material and Methods

Collection and extraction of Plant material

The plant material was collected from Jauharabad, Pakistan. Samples were dried and ground to fine powder. The dried samples were macerated in methanol and chloroform for seven days pursued by filtration and concentrated at reduced pressure. Extracts were labelled and stored at 4 °C.

Treatments and Exposure to Metal

Metal uptake was determined using two levels of exposure:

L1 (Low exposure level) -soil to which lower concentration of each metal was added.

L2 (High exposure level) -soil spiked with increased concentration of each metal.

The metals were well integrated into the soil to get homogenous contamination. Plants were kept within environmental conditions (temperature, light and irrigation) during the experiment and the length of exposure was [specify, e.g., 30 days].

Metal Analysis

Following the exposure period, plants were then harvested with caution so as to avoid contamination. Roots and shoots were divided, rinsed by means of distilled water, and dried in an oven at 70^0C until it did not change in weight. Metal analysis of samples was then done by grinding the samples to fine powder. The metal levels in the plant tissues were established [specify technique, e.g., Atomic Absorption Spectrophotometry (AAS)], after the standard digestion protocols with nitric acid and perchloric acid.

Phytoremediation Parameters

The parameters were calculated using the following parameters to determine the capacity of Arundo donax to remediate phytoremediation:

Uptake (%)

The proportion of metal that is taken by the plant tissues and compared to the total metal presented in the soil, as measured in L1 and L2 exposures respectively.

Bioaccumulation Factor (BAF)

BAF computed as the quotient of the concentration of metals in the plant tissues to that of the soil which shows that the plant can accumulate metals:

BAF=Metal concentration in soil (mg/kg)/Metal con centration in plant (mg/kg)

The values of BAF were obtained individually in L1 and L2.

Translocation factor

Translocation Factor (TF) refers to c0oncentration of a metal in the shoots over the roots, i.e. translocation ability of a plant between the root and the aerial part of the plant:

TF

TF=Metal concentration in root (mg/kg)/Metal conc entration in shoot (mg/kg)

L1 and L2 treatments were also measured in terms of TF values.

Allelopathic Bioassays

Root Growth Inhibition

Surface-sterilization of radish seeds was done using 1 per cent mercuric chloride and then seeded in the Petri dishes containing 5 mL each of the plant

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

extract with 10, 100, 500, 1000 and 10000 ppm. Ten seeds in each dish were incubated in 23 2 o C after solvent evaporation. The root length was obtained at 1-, 3- and 5-days time and calculated as a growth inhibition (%) by using:

Seed Germination Assay

To determine germination, 100 radish seeds were treated with three levels of extracts (100, 1000, 10000 ppm). The seed germination was counted after every day over a period of five days. The percentage of germination was determined as a percentage of sprouted seeds per day. Every experiment was conducted thrice and the results are in terms of mean standard deviation.

Qualitative phytochemical investigation of plant extricates

Test for Alkaloids

Reagent of (Mayer); Hgcl (0.356g) and we used of 60 ml of H2O and we also used KI2 (5g) plus 20 ml H2O.The total volume 1000 ml Reagent of Sol.A- Bismuth Nitrate 1.7g and mixed with Tartaric 20g and Then mixed in 80ml water Sol.B- KI2 16g plus 40ml of H2O and then we add Sol.A Sol.B with Ratio 1:1 plus plant extract (0.5g) plus 8 ml with 1% HCL. Firstly, warmed and the filtrate in then separately treated solution A and solution B. The results if ppt from the alkaloids present

Test for Flavonoids

For the test of flavonoids, we can use the extract of plant and also use test tube Petroleum ether and plant concentrate (0.5g). Then add 20ml of 80%Ethanol added then filter it 4ml added 1%KOH.

Test for Coumarins and Phenols

Filter paper covered test tube plus 1 N NaOH. Set in water bath boiling water and use UV lights to check it turn into yellow color its presents prove coumarin. For the test of phenols, we need FeCL3 three four drops and we also need the plant extract and mix them well by shaking or using stirrer) and its equals to bluish black color it shows that phenol is present.

Test for Saponins and Tannins

We use plant extracts in a test tube with boiling water. Cool and mixed well. Foam like appearance proved saponins. Concentrate of plant first boiled in water (20ml) then filtered. Then FeCl o.1% mixed in it. Tannins proved by appearance of brownish green or blue-black color.

Test for Glycoside

Concentrate 0.5g plus 2ml of glacial acetic acid one drop FeCL3 of 0.1% plus H2SO4ml.Brown ring proved glycosides present.

GC-MS Analysis

The analysis of plant extracts was performed by a QP 2010 GC-MS, which has a VF-5ms fused silica column (30 m by 0.25 mm by 0.25 8). The carrier gas was Helium (99.99), with 1.51 mL/min. The sample was injected in split less mode (1:40), and the oven temperature was set to go between 70 o C and 300 o C. The ionization was done with 70 eV and the mass spectra were measured between 50-600 amu. The identification of compounds was done by matching the spectra with a library of more than 62,000 patterns, and relative percentages were calculated based on the area of the peaks. Each run lasted 35 minutes.

Haematological Test

The UniCelDxH 800 analyser was used to analyse the blood samples. The UniCelDxH 800 Analyzer provides the following: CBC, Leukocyte 5-Part Differential (Diff), Reticulocyte (Retic), and Nucleated Red Blood Cell (NRBC) on whole blood.

Statistical analysis

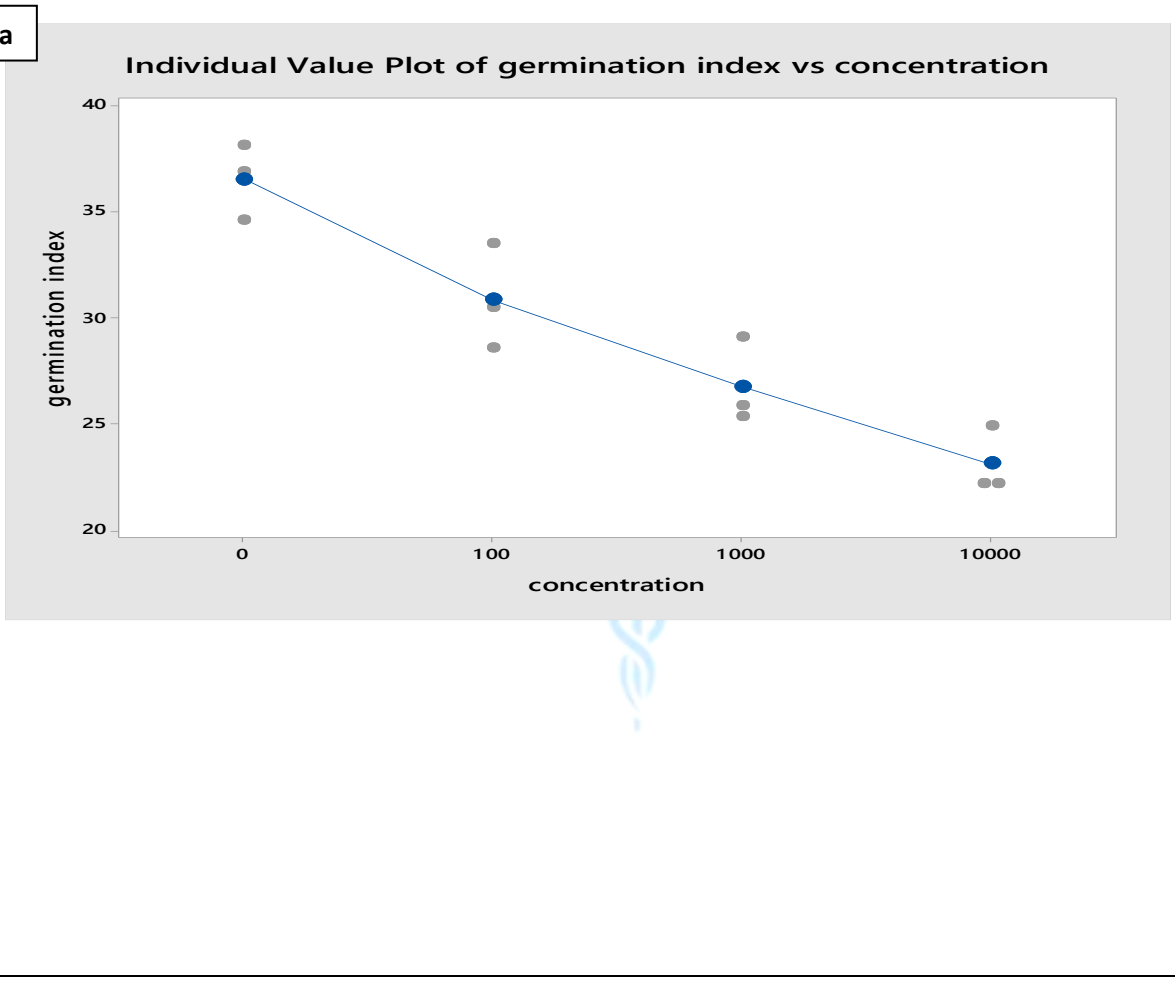
Descriptive analysis and statistical significance between the means was tested at 0.05, 0.01 and 0.001 levels of probability as suggested by Steel *et al.* (2006).

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Results

a



b

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

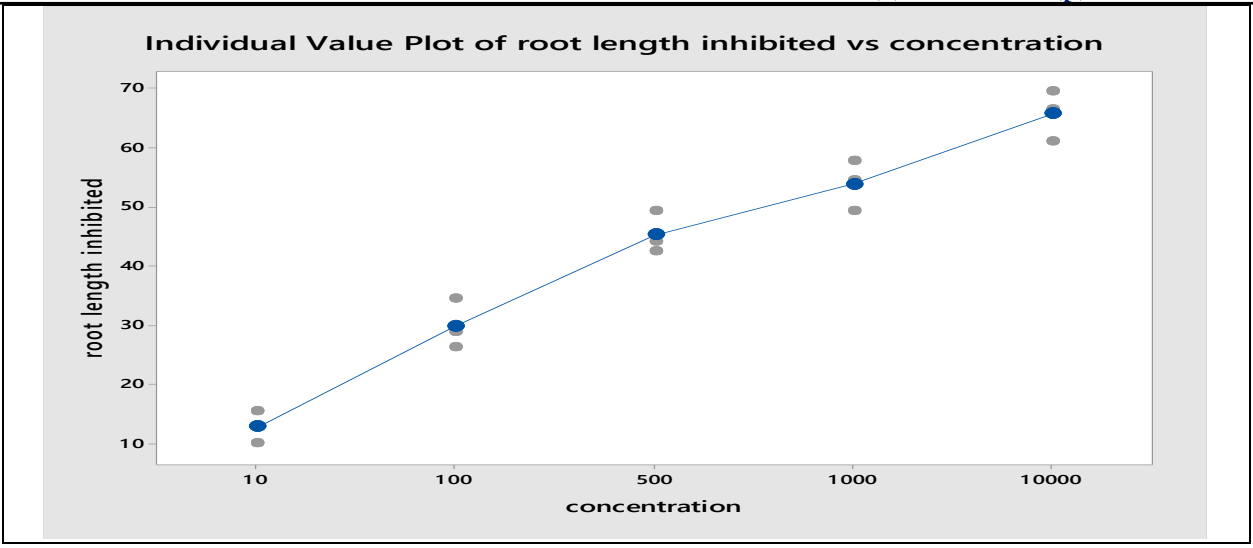


Figure 1: (1a-1b) a) Radish seed root length inhibition *b) Germination index of Radish seeds by Cymbopogon jwarancusa*

As concentration rose, root length inhibition increased steadily. There was very little inhibition (about 10-15%) at the lowest concentration (10). Inhibition increased to about 28-35% with a rise to 100. Inhibition rose to roughly 43-49% at 500 concentration and to roughly 49-57% at 1000. Strong suppression of root growth at high concentrations was demonstrated by the highest concentration (10000), which showed maximum inhibition ranging from 61 to 69% figure 1a.

The germination index, on the other hand, trended downward as concentration increased. With values between 35 and 38%, the control (0 concentration) had the highest germination index. At 100 concentration, this dropped to about 29–33%, and at 1000 concentration, it dropped even lower to 25–29%. Significant inhibition of seed germination at higher concentrations was shown by the lowest results, which were reported at 10000 concentration (about 22–25%) as in figure 1b.

Table 1: root inhibition of Radish seeds by *Cymbopogon jawarancusa*

Concentration	Mean	St dev	Grades
10,000	65.61	4.23	A
1000	53.79	4.18	B
500	45.21	3.69	B
100	29.76	4.19	C
10	12.72	2.64	D

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table 2: ANOVA Table for *Cymbopogon jawarancusa*

Source	DF	AdjSs	AdjMs	F-value	P-value
Concentration	04	5136.4	1284.10	87.77	0.000
Error	10	146.3	14.63		
Total	14	5282.7			

Table 3: ANOVA table for *Cymbopogon jwarancusa*

Source	DF	Adjss	AdjMs	F-value	P-value
Concentration	3	298.95	99.649	24.81	0.000
Error	8	32.13	4.016		
Total	11	331.08			

Table 4: Germination index for Cymbopogon jawarancusa

Concentration	N	Mean	St dev	Grades
0	3	36.53	1.78	A
100	3	30.83	2.50	B
1000	3	26.74	2.06	BC
10000	3	23.100	1.559	C

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

The impact of varying concentrations (10, 100, 500, 1000 and 10,000 ppm) of the methanolic extract of Cymbopogon jwarancusa on the growth inhibition of radish seedling roots was demonstrated in Figure 4.4. The more gradual gaining of root inhibition was also observed as the concentration of the extract increased. Minor inhibition of root growth was observed at 10 ppm which means that its phytotoxic impact at lower concentration was minimal.

The root inhibition was enhanced at 100 ppm with moderate inhibition of root elongation. Another rise in inhibitory effect was noted at level of 500 ppm with this time root growth being more evidently minimized. Inhibition was observed to be more pronounced at 1000 ppm which means that phytotoxic influence of the extract was stronger. Optimal root growth was inhibited at 10,000 ppm at which the root growth was repressed seriously (Table 1).

(Table 2), demonstrates the influences of various concentrations of different levels of extracts of the plant on the percentage of germination of radish seeds including 0, 100, 1000 and 10,000 ppm of extracts of the plant in methanol. The greatest percentage germination was registered in the control treatment (0 ppm) which showed normal germination of seed in the absence of the extract.

The decrease in the percentage of germination was realized at 100 ppm indicating that even lower concentration of the extract slightly inhibited seed germination. The inhibitory power of the extract on seed viability increased further as 1000 ppm reduced germination. The greatest percent of germination was at the concentration of 10,000 ppm, where the germination of the seed was the most inhibited.

The concentration effect was very high with a F - value of 24.81 and P-value of 0.000. The average square of the concentration was 99.649 with the error square being 4.016. These results prove that various concentrations made a significant difference in determining the germination index of radish seeds. The high difference between treatments proves the fact that the methanolic extract was highly phytotoxic to seed germination (Table 3). Table 4 shows the impact of varying concentrations of the extract of the plant, *Cymbopogon jwarancusa* on germination index of radish seeds. The same control (0 ppm) recorded the highest germination index of 36.53 ± 1.78 which is classified as grade A. When the percentage of germination index was at 100 ppm, it dropped to 30.83 ± 2.50 (grade B).

Further cutting was observed at 1000 ppm with average of 26.74 +.206 and fell within the B and C grades. At 10,000 ppm, the germination index was the lowest with a value of 23.10 +1.559 and this was classified as grade C. These findings reveal that the higher the levels of the plant extract, the lesser the seed germination thus showing its inhibitory and phytotoxic properties.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

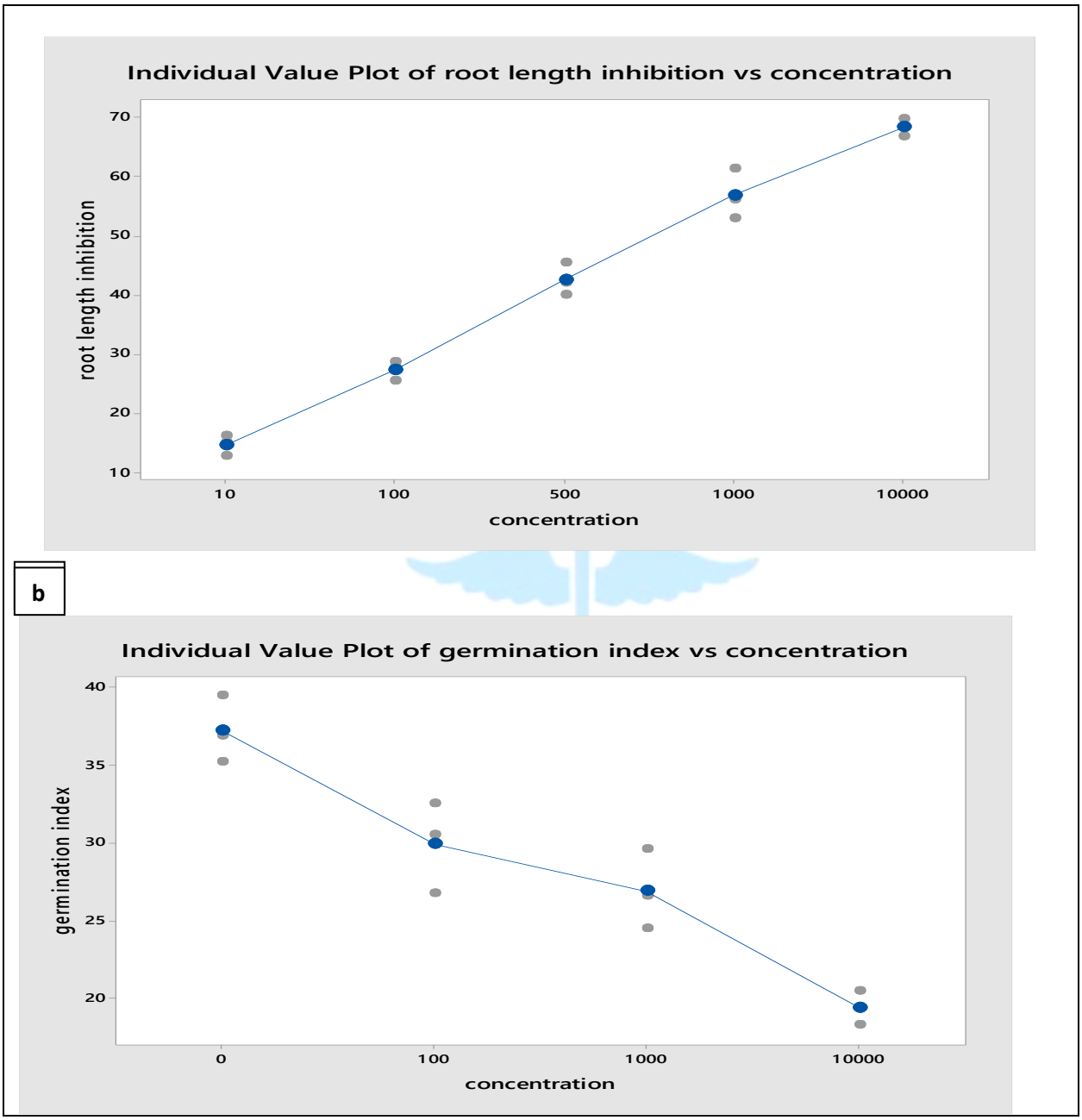


Figure 2: (2a-2b) a) Radish seed root length inhibition ***b) Germination index of Radish seeds by Arundo donax***

Root length inhibition increased progressively with increasing concentration, indicating a strong dose-dependent effect. At the lowest concentration (10), root inhibition was minimal, ranging around 13–16%. As the concentration increased to 100, inhibition rose to approximately 25–28%. A further increase to 500 resulted in moderate inhibition levels (about 40–45%). At 1000 concentration, root inhibition became more pronounced, reaching approximately 53–61%. The highest concentration (10000) exhibited maximum inhibition, with values ranging between 67–70% figure 2a.

As concentration increased, the germination index clearly exhibited a downward trend. The germination index was highest (about 36–38) at 0 concentration

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

(control), suggesting ideal germination circumstances. The germination index dropped somewhat to about 29–31 when the concentration was raised to 100. At 1000 concentration, a further decrease was noted, with values close to 26–27.

Strong inhibitory effects at greater concentrations were indicated by the lowest germination index, which was measured at 10000 concentration (about 18–20) as shown in figure 2b.

Table 5: Table of Root inhibition by *Arundo donax*

Concentrations	N	Mean	St dev	Grades
0	3	37.17	2.14	A
100	3	29.92	2.92	B
1000	3	26.88	2.57	B
10,000	3	19.383	1.075	C

Table 6: ANOVA table for *Arundo donax*

Concentrations	N	Mean	St dev	Grades
10,000	3	68.256	1.485	A
1000	3	56.79	4.28	B
500	3	42.50	2.69	C
100	3	27.289	1.646	D
10	3	14.633	1.713	

Table 7: Germination index of Radish seeds by Arundo donax

Source	DF	Adjss	AdjMs	F-value	P-value
Concentration	4	5620.83	1405.21	210.35	0.000
Error	10	66.80	6.68		
Total	14	5687.63			

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table 8:ANOVA table for *Arundo donax*

Source	DF	Adjss	AdjMs	F-value	P-value
Concentration	3	488.22	162.740	31.22	0.000
Error	8	41.71	5.213		
Total	11	529.93			

Inhibition of radish seed roots by the Arundo donax

The influence of various levels of the Arundo donax ethanol extract on the growth inhibition of the radish seedlings in terms of roots is depicted in table 5. Root inhibition was the highest at 10, 000 ppm and the mean was 68.256 with a standard deviation of 1.485, and was classified under grade A. Root inhibition reduced to 56.79 + 4.28 at 1000ppm and was graded as B.

An additional reduction in the inhibition was recorded at 500 ppm with the mean of 42.50 +/- 2.69 which falls in grade C. Inhibition at 100 ppm was 27.289 + 1.646, and was included in grade D. The minimum inhibition was recorded to be 10 ppm with an average of 14.633 + 1.713. These findings suggest that the root inhibitory effect of the extract of Arundo donax reduced with the declining concentration, indicating a concentration dependent effect of the phytotoxic effect.

ANOVA of root inhibition of Arundo donax

The analysis of variance of root inhibition of radish seed treated with Arundo donax is as shown in table 4.6. The findings revealed that concentration was a highly significant factor with F-value of 210.35 and P -value of 0.000. The average square concerning concentration was 1405.21 and the error average square was 6.68 (Table 6).

Index of germination of radish seeds by Arundo donax

Table 7 demonstrates how the germination index of the radish seeds is influenced by the various concentrations of the Arundo donax extract. The control (0 ppm) recorded the highest germination index with a mean of 37.17 and a standard deviation of 2.14 and belonged to grade A. The germination index at 100 ppm was 29.92 + 2.92 and it was graded in grade B. There was also a further decrease at 1000 ppm at a mean of 26.88 ± 2.57 which is also in grade B. At 10,000 ppm; the lowest germination index (19.383 ± 1.075) was achieved and this was classified under grade C.

ANOVA of germination index of Arundo donax

The analysis of variance of the germination index of the radish seed treated with arundo donax is shown in Table 4.8. The concentration effect was statistically significant with F-value of 31.22 and P-value of 0.000. The concentration mean square was 162.740 with the mean square error of 5.213. These findings indicate that the various concentrations had a great influence on the index of germination of radish seeds. The high difference between treatments proves the fact that a high phytotoxic activity of extract in relation to seed germination was observed in the case of extract of Arundo donax (Table 8).

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Hematological test

RBC (Red Blood Cells)

The mean RBC contents varied significantly ($p<0.001$) by influence of sampling seasons in lactating, young and dry buffaloes (Table: 9). The mean values of RBC in blood plasma of lactating buffaloes were 5.83×10^{12}/l(summer), 5.15×10^{12}/l(autumn), 6.15×10^{12}/l(winter) and 5.75×10^{12}/l(spring). The mean RBC concentrations in blood plasma of dry buffaloes were 5.18×10^{12}/l(summer), 5.42×10^{12}/l(autumn), 6.51×10^{12}/l(winter) and 6.56×10^{12}/l(spring). The average RBC contents in blood plasma of young buffaloes were 7.21×10^{12}/l(summer), 5.15×10^{12}/l(autumn), 6.26×10^{12}/l(winter) and 6.21×10^{12}/l(spring) as shown in (table 10). The detected orders of RBC contents were winter>spring>summer>autumn in lactating buffaloes, spring>winter>autumn>summer in dry buffaloes and summer>winter>spring>autumn in young buffaloes.

Table 9: Analysis of variance for RBC concentrations in blood plasma of buffaloes influenced by different seasons

Source of Variation (SOV)	Degrees of Freedom (df)	Mean Squares		
		Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Sampling Season	3	1.722***	5.184***	7.073***
Error	36	0.206	0.060	0.318

P <0.001= ***

Table 10: Descriptive analysis for RBC concentrations in blood plasma of buffaloes influenced by different seasons

Parameters	Blood plasma		
	Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Mean	5.720	5.917	6.210
Std. Error±	0.073	0.067	0.120
Median	5.830	6.010	6.325
Mode	5.500	6.980	4.950[a]

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Std. Deviation	0.801	0.730	1.311
Minimum	3.300	4.120	3.300
Maximum	7.700	7.650	8.980

a. Multiple modes exist. The smallest value is shown

MCV (Mean Cell Volume)

The MCV concentration in blood plasma non-significantly ($p>0.05$) influenced with respect to seasons in lactating and dry buffaloes but it was significantly ($p>0.001$) affected by the sampling seasons in young buffaloes (Table: 11). The mean MCV values in blood plasma of lactating buffaloes were 46.21 f1 (summer), 44.76 f1(autumn), 46.34 f1(winter) and 46.10 f1(spring). The mean concentrations of MCV in blood plasma of dry buffaloes were 49.9 f1 (summer), 49.02 f1(autumn), 46.72 f1(winter) and 46.54 f1(spring). The average MCVcontentin blood plasma of young buffaloes were 41.07 f1(summer), 44.76 f1(autumn), 41.49 f1(winter) and 41.44 f1(spring) as shown in (Table: 12). The detected orders of MCV contents were winter>summer>spring>autumn in lactating buffaloes, summer>autumn>winter>spring in dry buffaloes and autumn>winter>spring>summer in young buffaloes.

Table: 11 Analysis of variance for MCV concentrations in blood plasma of buffaloes influenced by different seasons

Source of Variation (SOV)	Degrees of Freedom (df)	Mean Squares		
		Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Sampling Season	3	5.223 ^{ns}	28.104*	29.693***
Error	36	6.909	9.076	2.735

P <0.001= ***, P <0.05=*, P >0.05=ns

Table: 12 Descriptive analysis for MCV concentrations in blood plasma of buffaloes influenced by different seasons

Parameters	Blood plasma		
	Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Mean	45.813	48.045	42.187

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Std. Error±	0.351	0.396	0.297
Median	45.950	47.475	42.030
Mode	41.000[a]	52.200	43.300
Std. Deviation	3.846	4.339	3.253
Minimum	38.300	40.980	21.000
Maximum	56.000	60.200	50.400

a. Multiple modes exist. The smallest value is shown

RDW% (Red Cell Distribution Width)

The RDW concentration in blood plasma significantly ($p<0.001$) influenced with respect to seasons in lactating and dry buffaloes but it was non-significantly ($p>0.05$) affected by the sampling seasons in young buffaloes (Table: 13). The mean RDW values in blood plasma of lactating buffaloes were 15.01%(summer), 14.10%(autumn),16.64%(winter) and 16.24%(spring). The mean concentrations of RDW in blood plasma of dry buffaloes were 15.57%(summer), 19.82%(autumn),17.11%(winter) and 17.27%(spring). The average contents of RDW in blood plasma of young buffaloes were 13.07%(summer), 14.09%(autumn), 13.49%(winter) and 13.44%(spring) as shown in (Table: 14).. The detected orders of RDW contents were winter>spring>summer>autumn in lactating buffaloes, autumn>spring>winter>summer in dry buffaloes and autumn>winter>spring>summer in young buffaloes.

Table: 13 Analysis of variance for RDW% concentrations in blood plasma of buffaloes influenced by different seasons

Source of Variation (SOV)	Degrees of Freedom (df)	Mean Squares		
		Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Sampling Season	3	13.537***	10.929***	1.762 [ns]
Error	36	0.458	0.220	9.100

P <0.001= ***, P >0.05=ns

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table: 14 Descriptive analyses for RDW% concentrations in blood plasma of buffaloes influenced by different seasons

Parameters	Blood plasma		
	Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Mean	15.493	17.444	13.526
Std. Error±	0.158	1.144	0.377
Median	15.900	16.400	12.980
Mode	14.400[a]	15.900	7.000[a]
Std. Deviation	1.731	12.531	4.129
Minimum	10.900	13.900	7.000
Maximum	18.100	153.000	25.050

a. Multiple modes exist. The smallest value is shown

HCT (Hematocrit)

The HCT concentration in blood plasma significantly ($p<0.001$) influenced with respect to seasons in lactating, young and dry buffaloes (Table: 15). The mean HCT values in blood plasma of lactating buffaloes were 27.62%(summer), 24.76%(autumn), 28.02%(winter) and 67.62%(spring). The mean HCT concentrations in blood plasma of dry buffaloes were 25.31%(summer), 25.27%(autumn),31.98%(winter) and 30.31%(spring). The average HCT contents in blood plasma of young buffaloes were 28.01%(summer), 24.76%(autumn),27.29%(winter) and 27.24%(spring) as in table 16. The detected orders of HCT contents were winter>summer>autumn>spring in lactating buffaloes, winter>spring>summer>autumn in dry buffaloes and summer>winter>spring>autumn in young buffaloes.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table: 15 Analysis of variance for HCT concentrations in blood plasma of buffaloes influenced by different seasons

Source of Variation (SOV)	Degrees of Freedom (df)	Mean Squares		
		Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Sampling Season	3	22.726**	136.240***	20.072***
Error	36	3.360	2.323	1.424

P <0.001= ***

Table: 16 Descriptive analysis for HCT concentrations in blood plasma of buffaloes influenced by different seasons

Parameters	Blood plasma		
	Lactating Buffaloes	Dry Buffaloes	Young Buffaloes
Mean	27.008	28.218	26.823
Std. Error±	0.285	0.456	0.247
Median	26.150	28.300	27.250
Mode	30.000	27.700	23.300
Std. Deviation	3.119	4.998	2.706
Minimum	20.300	0.001	19.600
Maximum	35.400	37.000	33.030

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

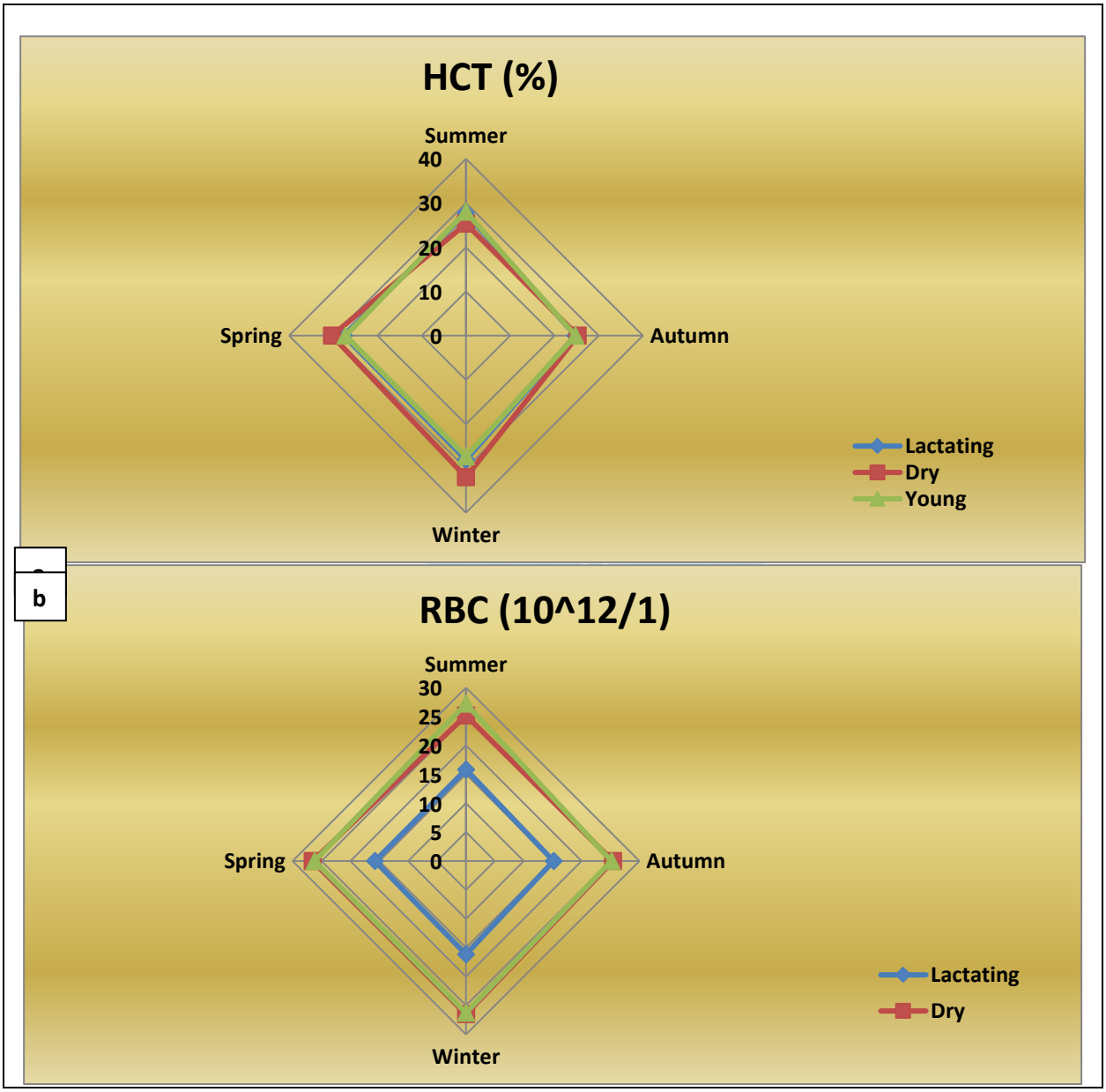


Figure 3: (3a-3b) a) Fluctuations in RBC b) Fluctuations in HCT values in blood plasma of buffaloes during different seasons

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

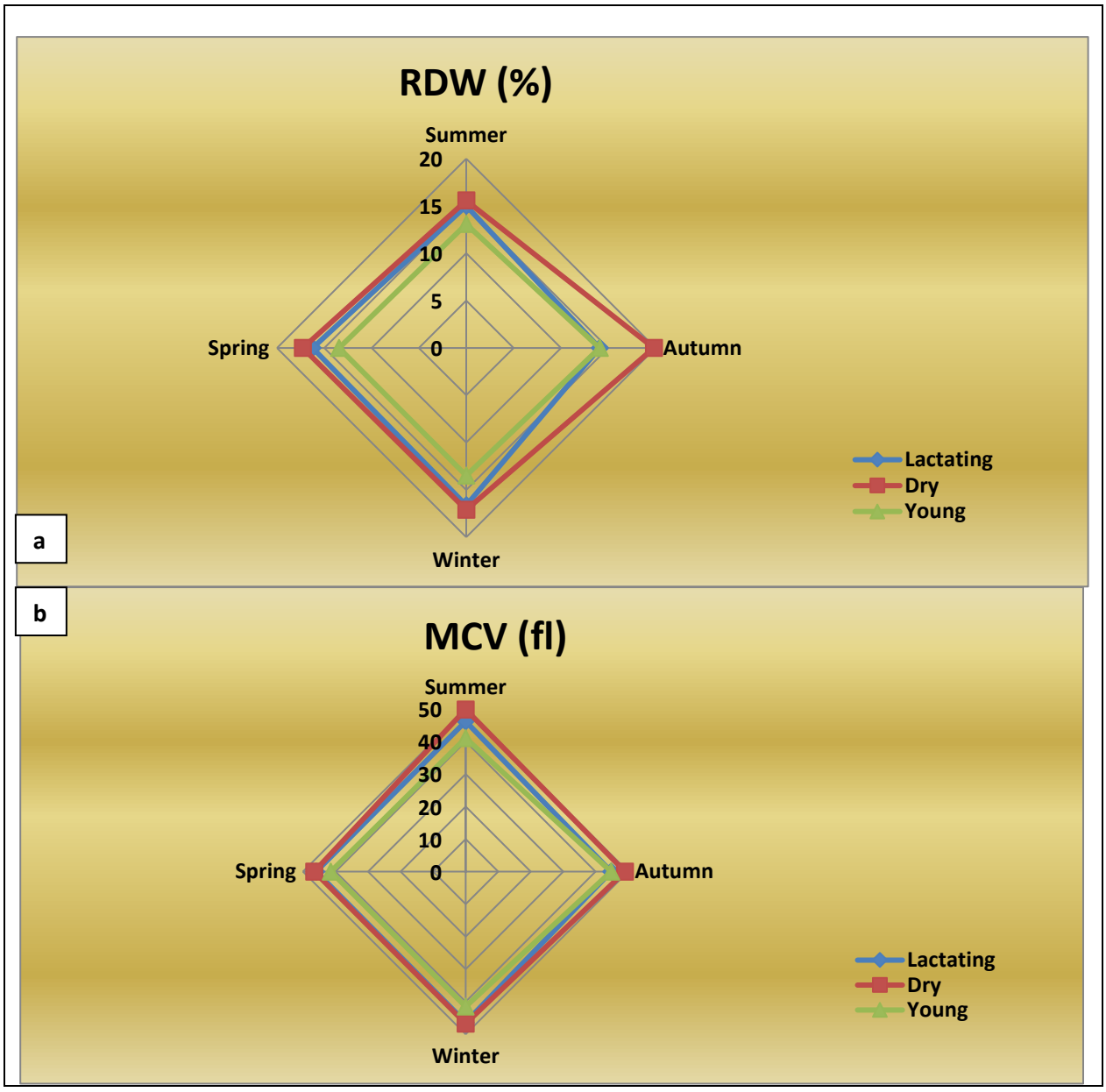


Figure 4: (4a-4b) a) Fluctuations in MCV b) Fluctuations in RDW% values in blood plasma of buffaloes during different seasons

Table 17: Phytochemical analysis of two fodder plants Arundo donax and Cymbopogan jwarancusa

Plant	Alkaloids	Flavonoids	Saponins	Tannins	Coumarins	Phenols
Arundo donax	2.32 ± 0.02	3.45 ± 0.03	2.92±0.02	0.20±0.01	2.01 ± 0.02	4.12±0.04
Cymbopogon jwarancusa	2.78 ± 0.02	4.12 ± 0.04	3.21±0.02	0.16±0.01	2.31 ± 0.01	4.69±0.02

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Table 18: Bioaccumulation, Transfer Factors, and Uptake of Heavy Metals in *Cymbopogon jwarancusa*"

Metal	Replicate	L1 Uptake	L2 Uptake	BAF L1	BAF L2	TF L1	TF L2
Cd	2.0 ± 0.58	17.0 ± 1.73	11.33± 1.2	0.8±0.0	0.9 ± 0.0	1.0 ± 0.0	1.1 ± 0.0
Cr	2.0 ± 0.58	50.0 ± 2.89	35.33±2.03	1.2±0.0	1.1 ± 0.0	1.1 ± 0.0	1.0 ± 0.0
Cu	2.0 ± 0.58	77.0 ± 7.09	48.0 ± 4.58	1.3±0.0	1.2 ± 0.0	1.1 ± 0.0	1.0 ± 0.0
Ni	2.0 ± 0.58	47.67 ± 1.45	37.67±1.45	1.2±0.0	1.1 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Pb	2.0 ± 0.58	37.67 ± 2.73	21.33 ± 2.4	1.1±0.0	1.2 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Zn	2.0 ± 0.58	25.0 ± 1.73	20.0 ± 1.15	1.0±0.0	1.1 ± 0.0	1.0 ± 0.0	1.0 ± 0.0

Table 19: Bioaccumulation, Transfer Factors, and Uptake of Heavy Metals in *Arundo donax*

Metal	L1 Uptake (%)	L2 Uptake (%)	BAF (L1)	BAF (L2)	TF (L1)	TF (L2)
Ni	33 ± 0.58	28 ± 0.58	0.33 ±0.006	0.40±0.006	0.21 ± 0.006	0.26 ± 0.006
Cd	37 ± 0.58	48 ± 0.58	0.44 ± 0.006	0.52±0.006	0.32 ± 0.006	0.68 ± 0.006
Cu	32 ± 0.58	36 ± 0.58	0.32 ± 0.006	0.36 ± 0.004	0.19 ± 0.006	0.23 ± 0.006
As	21 ± 0.58	25 ± 0.58	0.24 ± 0.006	0.29 ± 0.006	0.36 ± 0.006	0.54 ± 0.006
Pb	17 ± 0.58	15 ± 0.58	0.19 ± 0.006	0.50 ± 0.006	0.13 ± 0.006	0.17 ± 0.006
Zn	25 ± 0.58	11 ± 0.58	0.22 ± 0.006	0.32 ± 0.006	0.26 ± 0.006	0.31 ± 0.006

Table 20: Table Anova of phytochemical analysis of two fodder plants *Arundo donax* and *Cymbopogan jwarancusa*

Source of Variation	DF	Alkaloids	Flavonoids	Saponins	Tannins	Coumarins	Phenols
C(Plant)	1	0.3220 ***	0.6667 ***	0.1291 ***	0.00202 *	0.1350 ***	0.48735 ***
Error	4	0.00127 ns	0.00392 ns	0.00107 ns	0.00017 ns	0.00093 ns	0.00273 ns

ns = non-significant; *= 0.01 level of significant; *= 0.05 significant level; **= 0.001 level of significant;

Plant type exhibited a highly significant effect ($p < 0.001$) on alkaloids, flavonoids, saponins, coumarins, and phenols, according to one-way ANOVA, suggesting significant diversity in phytochemical composition. Tannins showed a significant effect ($p < 0.05$), indicating somewhat smaller but substantial

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

variance. On the other hand, the error values were non-significant ($p > 0.05$), indicating that the data was consistent and reliable. Plants differ in their metabolic activity, which is reflected in the notable variety among phytochemicals. In general, phytochemical profiles are greatly influenced by the type of plant.

Table 21: Bioaccumulation, Transfer Factors, and Uptake of Heavy Metals in *Cymbopogon jwarancusa*"

Source of Variation	DF	L1 Uptake (%)	L2 Uptake (%)	BAF (L1)	BAF (L2)	TF (L1)	TF (L2)
C(Metal)	5	1334.05 ***	842.67 ***	0.058 ***	0.023 ***	0.002 ns	0.003 ns
Error	12	38.39 ns	17.22 ns	0.000 ns	0.000 ns	0.001 ns	0.001 ns

ns = non-significant; *= 0.01 level of significant; *= 0.05 significant level; **= 0.001 level of significant;

Metal type had a substantial impact ($p < 0.05$) on both bioaccumulation factor (BAF) and L1 and L2 uptake, according to a one-way ANOVA. This suggests selective metal accumulation, where some metals are more effectively absorbed than others. The translocation factor (TF), on the other hand, revealed non-significant variations ($p > 0.05$), indicating consistent metal transfer within the plant. Metal-specific accumulation capacity is reflected in the variation in uptake and BAF. In general, the plant exhibits constant internal translocation and functions as a selective accumulator.

Table 22:Bioaccumulation, Transfer Factors, and Uptake of Heavy Metals in *Arundo donax*

Source of Variation	DF	L1 Uptake (%)	L2 Uptake (%)	BAF (L1)	BAF (L2)	TF (L1)	TF (L2)
C(Metal)	5	96.42 ***	312.58 ***	0.0185 ***	0.0241 ***	0.0213 ***	0.0897 ***
Error	12	2.33 ns	3.67 ns	0.0003 ns	0.0005 ns	0.0008 ns	0.0012 ns

Metal type showed a highly significant effect ($p < 0.05$) on all examined parameters, including uptake, BAF, and TF, according to ANOVA results. This indicates significant differences in the accumulation and translocation of certain metals. TF also displayed significant differences, suggesting metal-specific internal transport, in contrast to Cymbopogon jwarancusa. The plant's dynamic reaction was highlighted by the fact that no parameter displayed non-significant change.

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

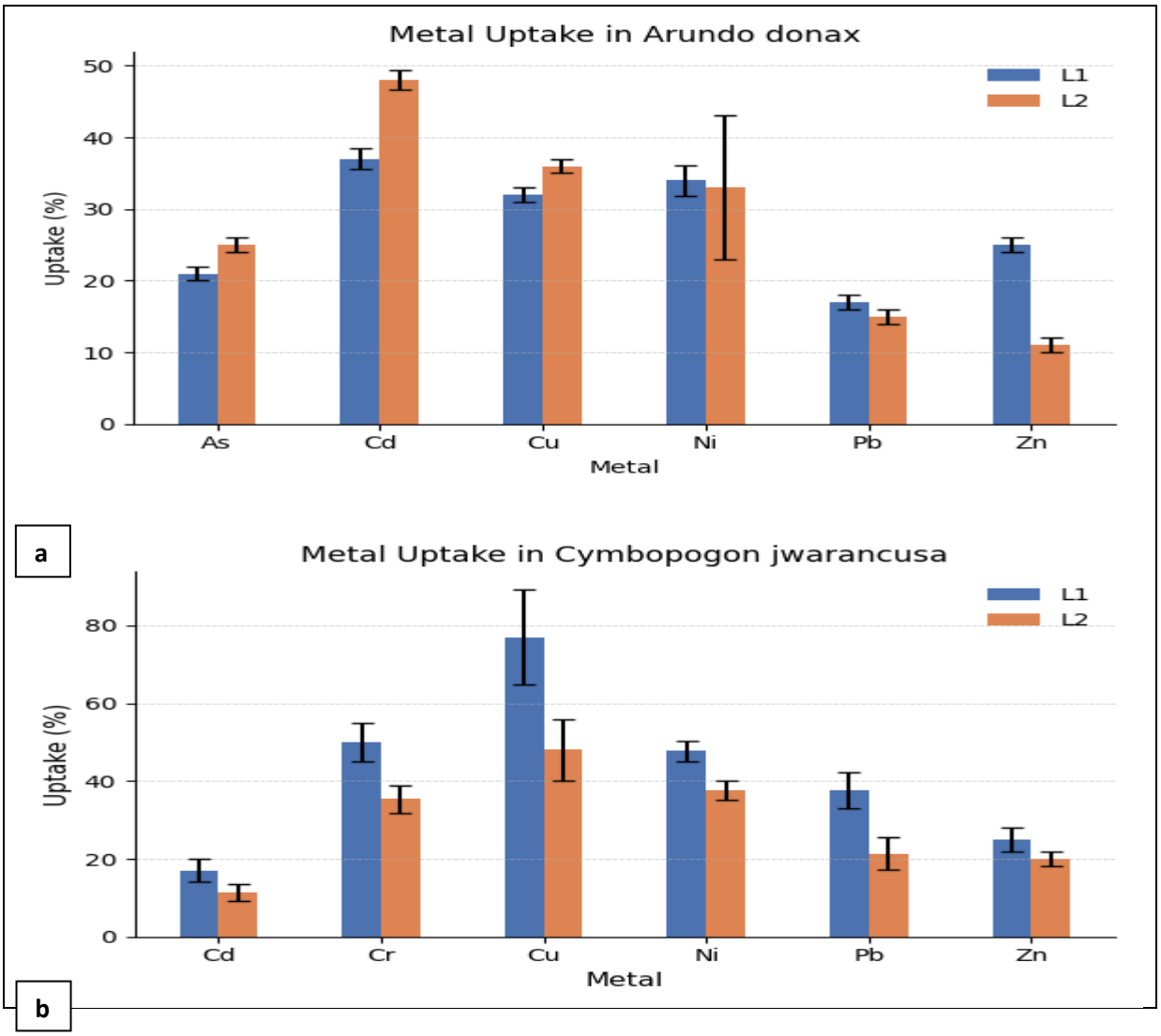


Figure 5: (5a-5b) a) Metal uptake in Arundo donax b) Metal uptake in Cambropogan jawarancusa

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

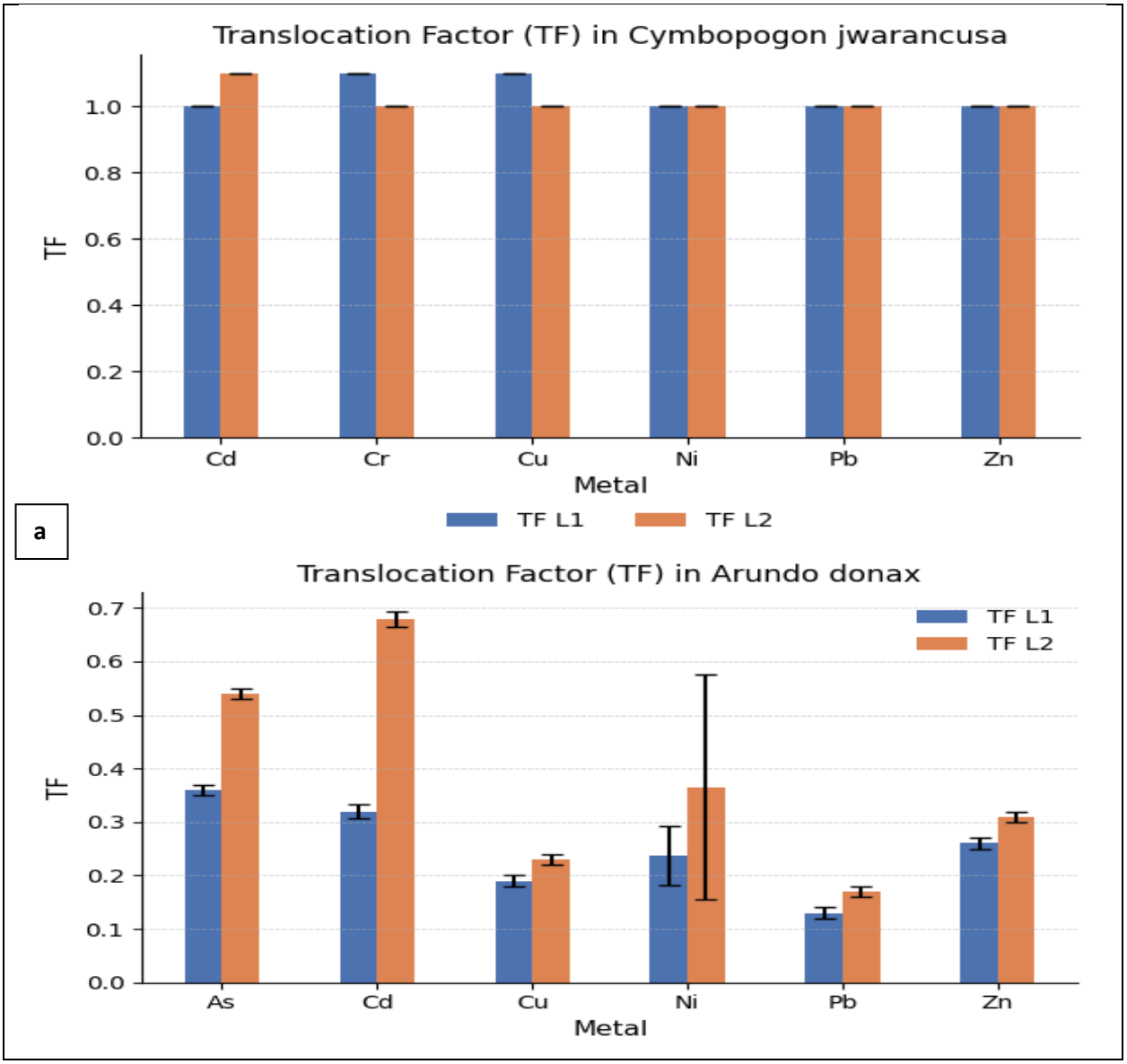


Figure 6:(6a-6b) a) Translocation factor in Arundo donax b) Translocation factor in Cambropogan jawarancusa

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

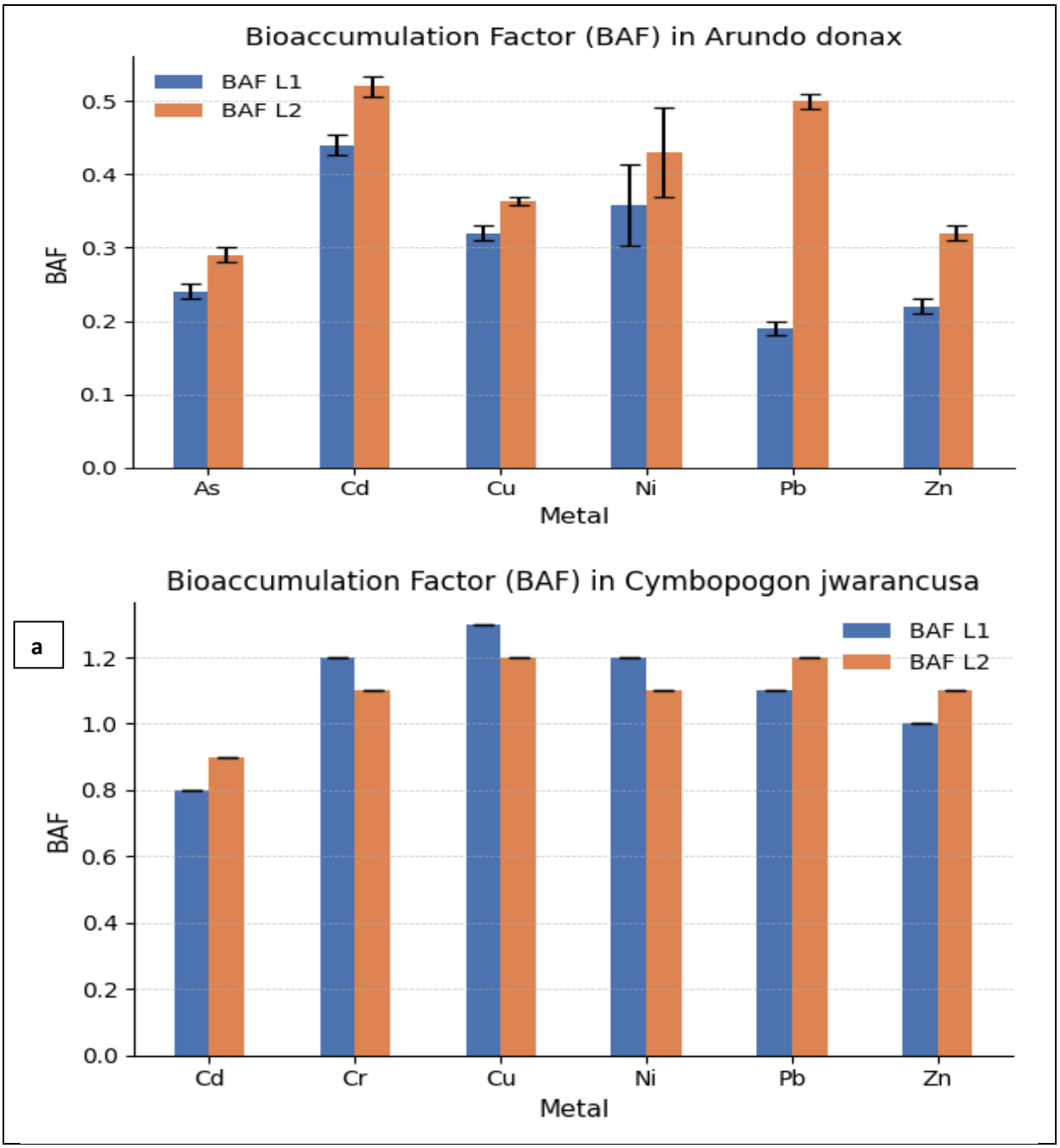


Figure 7:(7a-7b) a) Bioaccumulation factor in Arundo donax b) Bioaccumulation factor in Cambropogan jawarancusa

Metal Uptake

The two plant species and the sampling sites had very different metal uptake. For every metal under examination, consumption in Cymbopogon jwarancusa was consistently higher at location L1 than L2. Lead (Pb) and zinc (Zn) had intermediate uptake levels, while copper (Cu) had the highest uptake, followed by chromium (Cr) and nickel (Ni).

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

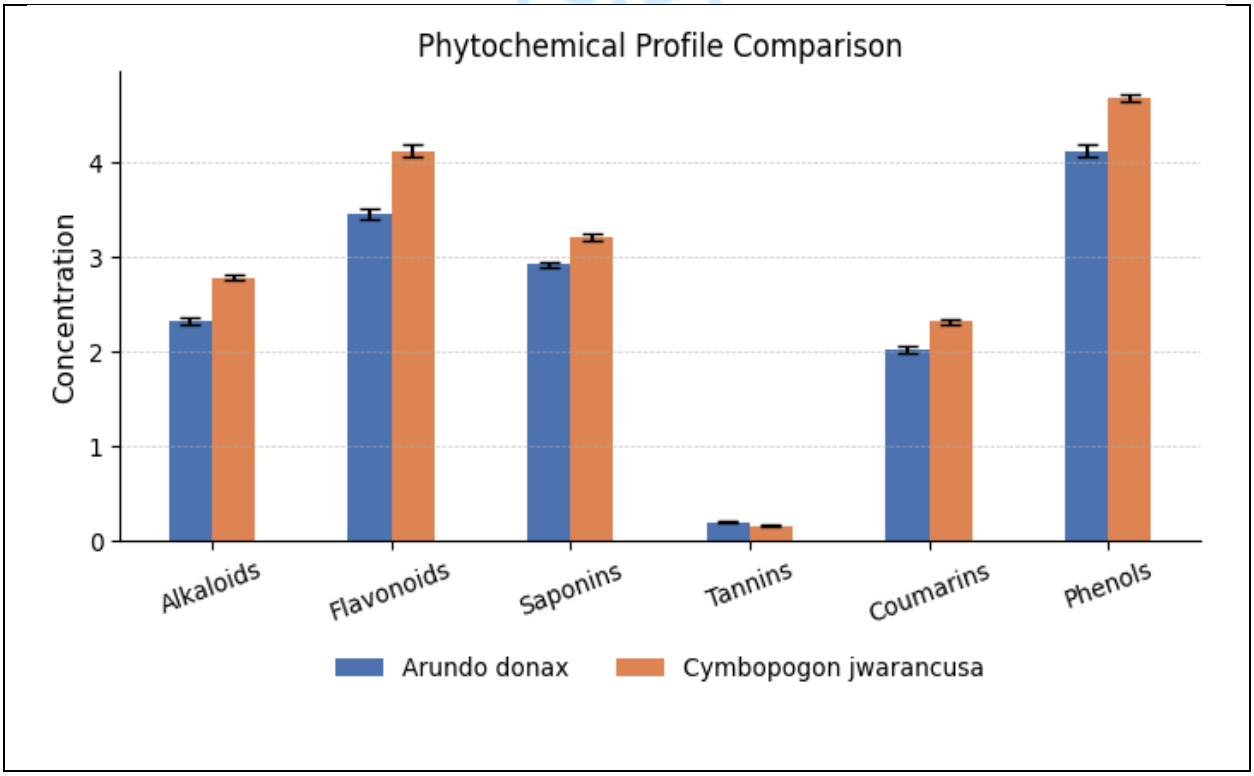
At both sites, cadmium (Cd) had the lowest uptake. Overall, the results obtained show that Cymbopogon jwarancusa has a great ability to accumulate metals, especially in L1 circumstances **(5a-5b)**.

Translocation factor

The translocation factor in Cymbopogon jwarancusa remained close to or slightly higher than one for all metals, demonstrating effective metal transfer from roots to shoots. For Cd, Cr, and Cu, somewhat larger TF values were found at L1, while values at L2 were often close to unity, indicating a balanced distribution among the plant tissues. In contrast, Arundo donax revealed significantly lower TF values, all below one, indicating restricted translocation. Cadmium and arsenic (As) had the greatest TF values in Arundo donax, especially at L2, whereas lead showed the lowest levels. Particularly at L2, nickel exhibited significant variability, suggesting uneven translocation behavior **(6a-6b)**.

Bioaccumulation factor

The differences between the two species were further emphasized by the bioaccumulation factor. BAF values in Cymbopogon jwarancusa above one for several metals, particularly Cu, Cr, and Ni, indicating a high accumulation potential. Cadmium had much lower BAF values, but lead and zinc displayed values near unity. BAF levels were often bigger at L1 than L2. Arundo donax, on the other hand, showed lower BAF values for every metal. Arsenic and zinc had comparatively lower values, whereas cadmium had the greatest accumulation, followed by nickel and copper. Overall, BAF readings were consistently higher at L2, and lead showed a noticeable rise in BAF at L2 compared to L1 **(7a-7b)**.



Phytochemical composition

Arundo donax and *Cymbopogon jwarancusa* had significantly different levels of beneficial substances, according to the phytochemical investigation. In comparison to *A. donax*, *C. jwarancusa* typically exhibited higher amounts of the majority of

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

phytochemicals. Phenols were found to be the most abundant in both species, with *C. jwarancusa* having significantly greater quantities. The second most prevalent substances were flavonoids, which once more accumulated more in *C. jwarancusa*. Both species had modest levels of saponins and alkaloids, with *C. jwarancusa* having somewhat higher levels. Similar trends were seen with coumarins, which showed greater quantities in *C. jwarancusa* than in *A. donax*. Tannins, on the other hand, were found in both species at extremely low amounts with just slight variations.

Discussion

Allelopathic Bioassays (Summary)

Effect on Seed Germination

The findings revealed that extracts of *C. jwarancusa* and *A. donax* greatly inhibited radish seed germination in a concentration-dependent manner. The control group had the highest value germination, and the phytotoxic character of the plant extracts was confirmed by a steady reduction with increasing extract concentrations. Allelochemicals like phenols, flavonoids, and coumarins, which are known to interfere with enzymatic activity, upset hormonal balance, and restrict water uptake during germination, are probably responsible for this inhibition (Lara-Núñez et al., 2009; Ahmed et al., 2010; Nishida et al., 2005). Allelopathic investigations have frequently documented similar inhibitory effects of plant extracts on seed germination (Bais et al., 2003; Ridenour & Callaway, 2001).

Effect on Root Length

Root growth was more sensitive to allelopathic stress than germination, and inhibition increased significantly with increasing extract concentration. The highest dose (10,000 ppm) caused the most root inhibition, while smaller amounts had negligible effects. Allelochemicals may directly impact root development by interacting with cell division and elongation processes, according to this strong dose-response relationship. While flavonoids and alkaloids can change membrane permeability and nutrient intake, phenolic chemicals and coumarins are known to decrease mitotic activity (Khan et al., 2018; Kayani et al., 2007; Lara-Núñez et al., 2009). Given that roots come into close touch with allelochemicals in the growth media, their increased sensitivity is in line with earlier research (Bais et al., 2003; Monni et al., 2001).

Arundo donax and *C. jwarancusa* both demonstrated significant allelopathic potential overall, with inhibitory effects growing in direct proportion to extract concentration. The coexistence of several phytochemicals points to a synergistic mechanism of action in which various substances work together to cause phytotoxicity. These results are in line with previous research showing the importance of allelopathy in plant competitiveness and ecological interactions (Ridenour & Callaway, 2001; Muller et al., 2000). The discovered phytotoxic effects underscore the significance of secondary metabolites in controlling plant growth and development, as well as the potential use of these plants in environmentally friendly weed management techniques (Baker et al., 2000; Ahmed et al., 2010).

Phytochemical profile and metal interaction

C. jwarancusa has a greater amount of alkaloids, flavonoids, phenols, and saponins than Arundo donax, according to the phytochemical analysis. It is widely accepted that these substances are necessary for detoxification and metal tolerance. Phenolic compounds decrease oxidative stress brought on by heavy metals by working as metal chelators and antioxidants (Ahmed et al., 2010). Flavanoids also help prevent plants from metal-induced oxidative damage by scavenging reactive oxygen species (Khan et al., 2018). *C. jwarancusa* increased stress tolerance is further supported by its greater flavonoid content.

According to Kayani et al. (2007), alkaloids and saponins can also collaborate with metal ions and change how they travel through plant tissues. Tannins may not have a significant effect on metal accumulation in this study because they are either either absent or present in very small amounts in both species. However, the overall detoxifying and accumulation processes are probably aided by the combined action of additional phytochemicals. At higher doses, *C. jwarancusa* and Arundo donax both showed significant phytotoxic effects, as indicated by a reduced germination index and increased root inhibition. These results are in line with previous studies showing that plant secondary metabolites can

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

impede seed germination by interfering with hormone balance, enzyme activity, and nutrient uptake (Ridenour & Callaway, 2001; Bais et al., 2003). Phenols, flavonoids, and coumarins probably played a role in the inhibitory effects that were seen. While coumarins can disrupt metabolic processes in developing seeds (Lara-Núñez et al., 2009).

When it came to metal absorption, translocation, and bioaccumulation, Cymbopogon jwarancusa outperformed Arundo donax overall. This species is well-suited for phytoextraction, as evidenced by TF values close to or above unity and BAF values greater than 1 for a number of metals. Its capacity to withstand and detoxify heavy metals is also improved by its rich phytochemical profile. Arundo donax, on the other hand, showed traits of a phytostabilizer, including a propensity to hold onto metals in its roots and lower TF and BAF values. Its modest absorption capability and resilience to a broad variety of climatic conditions make it appropriate for stabilizing polluted soils despite its reduced accumulation efficiency (Jackson et al., 1994).

Haematological parameters

Hematological indicators (RBC, MCV, RDW, and HCT) varied noticeably in the current investigation, indicating physiological reactions to exposure to the environment and bioactive compounds produced from plants. These indicators are well known for being sensitive indicators of stress and health, particularly if heavy metals and phytochemicals are present (Ahmed et al., 2015; Mahima et al., 2013).

The variations that have been observed in RBC counts indicate that erythropoiesis and red blood cell integrity may have been adversely affected by exposure to heavy metals as Cd, Pb, and Ni. It is widely recognized that heavy metals induce oxidative stress, which destroys membranes and reduces the life of red blood cells (Rafique & Tariq, 2016; Singh et al., 2011). However, because of their antioxidant activity, phytochemicals—especially flavonoids and phenolic compounds—may have lessened these harmful effects and prevented significant drops in RBC levels (Khan et al., 2018; Ahmed et al., 2010). Changes in MCV values correspond to changes in erythrocyte size, which can be caused by dietary imbalances and metal toxicity that interfere with hemoglobin formation (Jain & Lasmanis, 1978). Anisocytosis, a variation in red blood cell size that is frequently linked to stress and compromised erythropoiesis, is indicated by the elevated RDW values seen under specific circumstances. Such variability can result from heavy metals interfering with regular red blood cell formation (PetitClerc & Solberg, 1987). Antioxidant substances found in the investigated plants may also lessen oxidative damage and support the integrity of red blood cells (Khan et al., 2018).

Hematocrit (HCT) readings, which indicate variations in the percentage of red blood cells in blood, also fluctuated. According to Radostits et al. (2007) and Nordberg et al. (2015), exposure to heavy metals can reduce hematocrit by suppressing erythropoiesis and promoting cell death. These alterations may also be influenced by environmental stress.

The observed mild variation points to a balance between the preventive functions of phytochemicals and the harmful impacts of metals.

Overall, the hematological reactions seen in this investigation point to a complicated relationship between phytochemical defense and heavy metal toxicity. Metals often cause oxidative stress and interfere with normal blood physiology, however phytochemicals like flavonoids and phenols can mitigate these effects through antioxidant processes. The adaptive reactions of biological systems under combined environmental and biochemical effects are highlighted by this equilibrium.

Analysis of Metals

The results demonstrated a considerable difference in metal uptake between Arundo donax and Cymbopogon jwarancusa. Better absorption at moderate contamination levels was shown by Cymbopogon jwarancusa's greater uptake efficiency, especially under L1 circumstances. Pb and Zn had reduced uptake because of their restricted mobility, but metals like Cd, Cu, and Cr showed higher uptake. These results are consistent with previous research showing that plants exhibit varied metal uptake behavior (Alloway, 2013; Khan et al., 2018).

Bioaccumulation factor

Cymbopogon jwarancusa has a greater accumulation potential, according to BAF values, which are close

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

to or greater than unity for a number of metals. This implies that it is acceptable for phytoextraction. Arundo donax, on the other hand, displayed lower BAF values, suggesting minimal accumulation but some tolerance at greater exposure levels. For both hyperaccumulator and non-hyperaccumulator plants, similar findings have been documented (Baker et al., 2000).

Translocation factor

In Cymbopogon jwarancusa, the TF values showed effective metal transport from roots to shoots, with values around or above 1. Arundo donax, on the other hand, displayed TF values less than 1, indicating limited metal transport and retention in roots. Its function as a phytostabilizer is supported by this characteristic (Jackson et al., 1994).

Among the metals, Cu and Cr also showed strong uptake, and Cd exhibited great mobility and accumulation. Ni behaved moderately, while Pb's poor mobility kept it mostly confined to roots. Zn accumulation patterns were steady and modest. These patterns align with earlier research (Kabata-Pendias, 2011; Alloway, 2013). Because of its greater uptake, BAF, and TF values, Cymbopogon jwarancusa functions as an effective phytoextractor overall. Arundo donax, on the other hand, acts as a phytostabilizer by keeping metals in roots and restricting their mobility. These findings emphasize how crucial it is to choose plant species according to phytoremediation objectives (Baker et al., 2000). Cymbopogon jwarancusa may have a better metal tolerance due to its higher phytochemical content, particularly phenols and flavonoids. These substances improve detoxification and lessen oxidative stress by acting as metal chelators and antioxidants (Ahmed et al., 2010; Khan et al., 2018).

Conclusion

The present study confirms that *Cymbopogon jwarancusa* and *Arundo donax* exhibit significant allelopathic and phytoremediation potential. *C. jwarancusa* showed higher phytochemical content, strong metal accumulation (BAF > 1), and efficient translocation (TF ≈ 1), indicating its suitability for phytoextraction. In contrast, *A. donax* demonstrated lower accumulation but restricted metal mobility (TF < 1), supporting its role in phytostabilization. Both species significantly inhibited seed germination and root growth in a concentration-dependent manner. Hematological variations further indicated physiological responses to environmental stress. These findings suggest that both plants can be effectively utilized for sustainable management of heavy metal-contaminated soils and eco-friendly weed control strategies.

Declarations

Ethics approval

The Institutional Ethics and Guideline Committee of the University of Lahore, Lahore Pakistan has allowed all the protocols used in this experiment. All the experimental methods of this study followed all the appropriate guidance and regulations.

Consent for publication

All subjects gave their "informed consent" for the publication of details within the text ("informed consent") to be published in the above Journal and Article. Written "informed consent" was obtained from all authors for the publication of this manuscript.

Availability of data and materials

The data generated are provided within the manuscript and will be available from author at reasonable request

Competing Interest

All authors declare that there are no competing interests.

REFERENCES

Ahmed, M., Khan, M. P., & Hussain, A. (2010). Anthelmintic and antimicrobial properties of *Cymbopogon jwarancusa*. *African Journal of Biotechnology, 9*(45), 7725–7730.

Ahmed, N., Ahmad, I., & Khan, M. (2015). Hematological parameters in buffaloes under different environmental conditions. *Veterinary World, 8*(6), 748–753.

Ahmed, S., Khan, M. A., & Iqbal, Z. (2010). Phytochemical analysis and biological activities of medicinal plants. *Journal of Medicinal Plants Research, 4*(12), 1125–1132.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Ahmed, S., Rehman, A., & Khan, M. A. (2010). Phytochemical and antioxidant activity of plant extracts and their role in mitigating oxidative stress. *Journal of Medicinal Plants Research, 4*(12), 1234–1240.

Alam, M. T., Khan, M. A., & Rashid, U. (2016). Evaluation of antipyretic activity of *Cymbopogon jwarancusa* in experimental animals. *Journal of Ethnopharmacology, 189*, 163–168.

Al-Bulushi, S., Shawaf, T., & Al-Hasani, A. (2017). Hematological and biochemical parameters in animals. *Veterinary World, 10*(4), 461–466.

Bais, H. P., Vepachedu, R., Gilroy, S., Callaway, R. M., & Vivanco, J. M. (2003). Allelopathy and exotic plant invasion: From molecules to ecosystems. *Plant Physiology, 132*(1), 44–51.

Baker, A. J. M., McGrath, S. P., Reeves, R. D., & Smith, J. A. C. (2000). Metal hyperaccumulator plants and phytoremediation. In *Phytoremediation of contaminated soil and water* (pp. 85–107). CRC Press.

Bhat, B. A., Rather, M. A., Bilal, T., Nazir, R., Qadir, R. U., & Mir, R. A. (2025). Plant hyperaccumulators: A state-of-the-art review on mechanisms of heavy metal transport and sequestration. *Frontiers in Plant Science, 16*. https://doi.org/10.3389/fpls.2025.1631378

Bruno, D., Zapata, V., Guareschi, S., Picazo, F., Dettori, E., Carbonell, J. A., Millán, A., Velasco, J., & Robledano, F. (2019). Short-term responses of aquatic and terrestrial biodiversity to riparian restoration measures designed to control the invasive *Arundo donax* L. *Water, 11*(12), 2551. https://doi.org/10.3390/w11122551

Deshpande, S. D., et al. (1987). Hematological studies in buffaloes. *Indian Veterinary Journal, 64*, 123–126.

Digvijay, S., Sharma, P., & Kumar, A. (2014). Distribution and ecological significance of *Cymbopogon jwarancusa*. *Journal of Medicinal Plants Research, 8*(5), 233–240.

Douthit, T. (1994). Ecology of *Arundo donax*. *Environmental Management, 18*(2), 245–252.

Enioutina, E. Y., Salis, E. R., Job, K. M., Gubarev, M. I., Krepkova, L. V., & Sherwin, C. M. T. (2017). Herbal medicines: Challenges in the modern world. Part 5. Status and current directions of complementary and alternative herbal medicine worldwide. *Expert Review of Clinical Pharmacology, 10*(3), 327–338. https://doi.org/10.1080/17512433.2017.1268917

Fagiolo, A., Lai, O., & De Rosa, A. (2004). Blood parameters in buffaloes. *Buffalo Journal, 20*(1), 11–19.

Feki, K., Tounsi, S., Mrabet, M., Mhadhbi, H., & Brini, F. (2021). Recent advances in physiological and molecular mechanisms of heavy metal accumulation in plants. *Environmental Science and Pollution Research, 28*(46), 64967–64986. https://doi.org/10.1007/s11356-021-16805-y

Imada, C. T., & Kennedy, B. H. (2020). New Hawaiian plant records from Herbarium Pacificum for 2019. *Bishop Museum Occasional Papers, 138*, 1–11.

Inderjit, & Duke, S. O. (2003). Ecophysiological aspects of allelopathy. *Planta, 217*(4), 529–539.

Jackson, N. E., Anderson, B. W., & Rowlands, P. G. (1994). Ecology of *Arundo donax* in riparian habitats. *Ecological Applications, 4*(3), 567–575.

Jain, N. C., & Lasmanis, J. (1978). Hematological techniques in veterinary medicine. *Veterinary Clinics of North America, 8*(1), 33–45.

Kalisz, S., Kivlin, S. N., & Bialic Murphy, L. (2021). Allelopathy is pervasive in invasive plants. *Biological Invasions, 23*(2), 367–371. https://doi.org/10.1007/s10530-020-02383-6

Kamboj, V. P. (2000). Herbal medicine: Current status and future. *Current Science, 78*(1), 35–39.

Kapale, P. M., et al. (2008). Hematological variations in buffaloes. *Indian Journal of Animal Sciences, 78*(9), 945–948.

Kayani, W. K., Khan, M. A., & Ahmad, M. (2007). Chemical constituents of *Cymbopogon* species. *Pakistan Journal of Botany, 39*(6), 2005–2013.

Khan, M. A., Khan, S., & Shah, M. T. (2018). Role of phytochemicals in plant stress tolerance. *Environmental Science and Pollution Research, 25*(10), 10105–10118.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Khan, R. A., Khan, M. R., & Sahreen, S. (2018). Protective effects of flavonoids against heavy metal-induced toxicity: A review. *Environmental Science and Pollution Research, 25*(3), 2155–2168.

Khan, S. J., Afroz, S., & Khan, R. A. (2012). Diuretic effect of *Cymbopogon jwarancusa* after single and multiple doses in rats. *Journal of Ethnopharmacology, 140*(2), 321–325.

Kirtikar, K. R., & Basu, B. D. (1982). *Indian medicinal plants* (Vol. 4). International Book Distributors.

Lara-Núñez, A., Romero-Romero, T., Ventura, J. L., Blanco-Labra, A., & Anaya, A. L. (2009). Allelochemical stress and plant growth inhibition. *Plant Physiology and Biochemistry, 47*(8), 650–657.

Macías, F. A., Molinillo, J. M. G., Varela, R. M., & Galindo, J. C. G. (2007). Allelopathy as a weed control strategy. *Pest Management Science, 63*(4), 327–348.

Mahima, A. K., Verma, A. K., Kumar, V., Rahal, A., Kumar, V., & Roy, D. (2013). Hematological and biochemical changes in animals under environmental stress. *Veterinary World, 6*(8), 1–6.

Merck Veterinary Manual. (2009). Hematological reference ranges. Merck & Co.

Monni, S., Uhlig, C., Hansen, E., & Magel, E. (2001). Plant responses to heavy metal stress. *Environmental Pollution, 112*(3), 363–372.

Muller, I., & Römheld, V. (2000). Metal uptake and tolerance mechanisms. *Plant and Soil, 219*(1–2), 121–130.

Nishida, N., Tamotsu, S., Nagata, N., Saito, C., & Sakai, A. (2005). Allelopathic effects of volatile monoterpenes from plants. *Journal of Chemical Ecology, 31*(2), 255–267.

Othman, S. H., Lazim, Z. S., & Al-Wakaa, A. H. A. (2023). Allelopathic potential of aqueous plant extracts against seed germination and seedling growth of weeds. *IOP Conference Series: Earth and Environmental Science, 1262*, 032041. https://doi.org/10.1088/1755-1315/1262/3/032041

PetitClerc, C., & Solberg, H. E. (1987). Reference values in hematology. *Clinical Chemistry, 33*(4), 471–472.

Pilu, R., Bucci, A., Cerino Badone, F., & Landoni, M. (2012). Giant reed (*Arundo donax* L.): A weed plant or a promising energy crop? *African Journal of Biotechnology, 11*(38), 9163–9174. https://doi.org/10.5897/AJB11.2939

Radostits, O. M., Gay, C. C., Hinchcliff, K. W., & Constable, P. D. (2007). *Veterinary medicine: A textbook of the diseases of cattle, horses, sheep, pigs and goats* (10th ed.). Elsevier.

Rafique, N., & Tariq, S. (2016). Impact of heavy metals on blood parameters and oxidative stress in animals. *Pakistan Journal of Zoology, 48*(2), 1–8.

Ridenour, W. M., & Callaway, R. M. (2001). Allelopathy in plant invasion. *American Journal of Botany, 88*(5), 1–12.

Rice, E. L. (1984). *Allelopathy* (2nd ed.). Academic Press.

Roy, A., et al. (2010). Hematological studies in buffalo breeds. *Indian Journal of Animal Research, 44*(3), 198–201.

Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (2006). *Principles and procedures of statistics* (3rd ed.). McGraw-Hill.

Sumaiya, S., Siddiqui, A., Chaudhary, S. S., Aslam, M., Ahmad, S., & Ansari, M. A. (2024). Isolation and characterization of bioactive components from hydroalcoholic extract of *Cymbopogon jwarancusa*. *Journal of Ethnopharmacology, 319*, 117185. https://doi.org/10.1016/j.jep.2023.117185

Tibenda, J. J., Yi, Q., Wang, X., & Zhao, Q. (2022). Review of phytomedicine, phytochemistry, ethnopharmacology, toxicology, and pharmacological activities of *Cymbopogon* genus. *Frontiers in Pharmacology, 13*, 997918. https://doi.org/10.3389/fphar.2022.997918

Verma, R. K., & Tewari, V. P. (2016). Some important medicinal plants of cold desert regions of Himachal Pradesh, India. *Austin Journal of Pharmacology and Therapeutics, 4*(2), 1088.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Wagner, W. L., Herbst, D. R., & Sohmer, S. H. (1999). *Manual of flowering plants of Hawaii*. University of Hawaii Press.

Weston, L. A., Ryan, P. R., & Watt, M. (2012). Transport of allelochemicals in plants. *Journal of Experimental Botany, 63*(9), 3445–3454.