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Comparative assessment of vegetable yield with and without biochar derived from locally sourced apricot shells

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Extreme climatic conditions and isolation from the rest of the world make it extremely challenging and difficult to obtain green vegetables in Kargil during the winters. Application of biochar enhances the productivity of vegetables during the short agricultural season so that the dry vegetable available throughout the winter. This research evaluates the potential use of biochar made from local apricot (*Prunus armeniaca*) seed shells (ASSBC) as a viable soil enhancer in the agriculturally difficult terrains of Kargil. Four vegetables that are relevant to the area selected for the investigations: spinach, lettuce, root beet, and mustard. Local veggie food security depends on these vegetables, especially around the winter when fresh green vegetables are unavailable. The shells of apricots, which were once considered trash, were collected, rinsed with distilled water, dried, crushed into uniform fragments, and then subjected to pyrolysis in nitrogen-laden conditions to form biochar. The obtained biochar was added to the soil kept in color coded experimental jars at a rate of 8%. The findings indicated that the number and size of leaves for spinach, lettuce, and mustard had significantly increased, while the length of the leaves for root beet has shown changes only in terms of the length of the leaves. Spinach, responde the most increasing leaf number from 07 to 45 without and with biochar respectively .Further evidence of the positive effects of biochar as a soil enhancer came from increases in soil pH, conductivity, and specific surface area following biochar addition. This research demonstrates how waste-to-best management may enhance soil quality, increase the production of vegetables grown nearby, and guarantee dried vegetable supply throughout the winter. The results show that using apricot shell biochar reduce adverse environmental impacts and improve yields from agriculture even in harsh conditions.

Keywords Biochar, Soil enhancer, Dried vegetables, Kargil, Apricot (*Prunus armeniaca*), Seed shell, Waste-to-best

Research has indicated that adding biochar to soil may improve agricultural yields and soil nutrient availability; nevertheless, it is necessary to determine how much nitrogen, phosphorus (P), and potassium (K) the biochar contributes to plant growth. The impact of a maize straw-based biochar (BC) amendment on spinach fresh yield and dry biomass production was investigated in a pot experiment. The results were compared to non-biochar chemical fertilisation and non-biochar non-fertilization control. Fresh leaf yield after 50 days of growth was remarkably higher under maize straw-based biochar or non-biochar chemical fertilisation than under non-biochar non-fertilization control by 63.7% or 38.0%, and under straw-based biochar than under non-biochar chemical fertilisation by 18.7%. In the meanwhile, total plant biomass (leaves + roots) and leaf dry biomass were comparable under straw-based biochar and non-biochar chemical fertilisation, but much larger under maize straw-based biochar (47.5% in total) and NBF (56.2% in total) than under non-biochar non-fertilization control.

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Hence, application of biochar brings many fold increase in fresh leaf yield up to 63.7% as compared to untreated conditions[1].

The combined effect of biochar and arbuscular mycorrhizal fungi resulted significant effect on various parameters in plant growth, such as physiological properties, root morphological characters, physiological properties, and soil enzymatic activities as compared with rest of other treatments. The results suggested that the combined biochar and biochar and arbuscular mycorrhizal fungi led to the highest levels of spinach plant growth, microbial biomass, and soil enzymatic activity. Hence, use of biochar significantly impact morphology of roots and physiological properties, facilitating for growth parameters such as shoot length and leaf number[2].

A study conducted to determine the impacts shown by blended biochar made from greenhouse crop residues with perlite in water culture enhances output of leafy vegetables such as lettuce besides improvement in chemical parameters of soil. The yield enhanced by almost 100% as than the lettuce grown in perlite conditions alone[3].

The application of biochar growing media significantly brought improvements in nitrogen management, a crucial mechanism for production in leafy vegetables[4].

Soil modified with biochar remarkably accelerates better potassium and nitrogen usage by spinach (*Spinacia oleracea*). Hence, efficiency of nitrogen usage and productivity of spinach increases due to interaction between and nitrogen fertilizers and biochar.

Reliance on inorganic fertilizers can be remarkably decreased by applying biochar leading to encouraged yield in leafy vegetables. Amplification of bioactive compounds-very essential for health benefits, resulted due to conditions made by biochar[5,6]. Application of biochar on cauliflower made the vegetable marketable in terms of yield due to declining rate of nitrate leaching and increase in chemical properties of soil[7]. Maintaining soil moisture is challenge in arid conditions. This is significantly managed by utilizing biochar biochar[8].

Biochar application ensures availability of essential nutrients including nitrogen which encourages It increases the availability of essential nutrients, such as nitrogen, leading to better plant growth and higher yields[2,9] improved plant growth and higher productivity. Biochar can prepared and modified that may purposefully serve need of crop and soil such as production of crops, ensuring security of food, sustainable development and environmental remediation[7,10]. Application of biochar remarkably enhances fresh weight of various green leafy. The enhancement recorded up to 126.1% in crops like lettuce[11]. Applying biochar increased pH, organic carbon, available phosphorous, electrical conductivity, total nitrogen, cation exchange capacity, and exchangeable bases substantially[12,13]. The findings of the study reveals the addition of biochar to soils, compared to control conditions, boosted surface crop yield, soil microbial mass, rhizobia nodulation of rhizobia, soil Phosphorus (P), Potassium (K), plant Potassium K tissue concentration, Total Soil Nitrogen (N), and Total soil Carbon (C) on average. These outcomes recorded despite the variability that was caused by soil and climate. A decline in acidity was detected in the pH of the soil upon a dose of biochar[14]. The study shows that by altering the physiological and metabolic profiles under Cadmium (Cd) stress, BC could be able to minimize harmful effects of Cd in spinach[15]. According to results of the research, tea-waste can be efficiently converted to biochar at temperatures ranging 450 to 500 °C with residence time 45 to 60 min. This demonstrates the functional capabilities of chemicals response under Cd stress for boosting rate of volatilization at optimal conditions like temperature and residence time[16]. It was also recorded that rice husk biochar (RB) perlite (PL) PL + RB hydroponic substrate might be effective for controlling undesirable algal growth in nutrient solutions and assisting in producing large amount of leafy vegetables[17]. It was discovered that high-temperature rice husk biochar synthesis highly nutritive biochar with high, EC, pH, and readily available Phosphorus and Silicon[18]. The growth and crop development (such as delayed leaf senescence) made possible by the general improvement in soil quality, and this might lead to an enhancement in crop productivity (such as crop yield and aboveground biomass[19]. Research also indicates the supplement of biochar improved physical and hydrological characteristics of soil over time while also raising rice yield[19]. Over the course of the three-year field trial, findings indicated notable change in the physical and hydraulic properties of the soil plants treated with biochar and those left untreated. This suggests that mixing of biochar had a long-term impact on the properties of soil and boosted rice yield. When compared to the original biochar treatment, the effects of aged-biochar fertility of soil and cabbage growth were generally inhibited[20]. Application of biochar on soil as supplement appears to enhance soil nutrient density, water-retention potential, and requirements of fertilizer, improves microbiology soil, and boost crop yields. Furthermore, using biochar has a number of positive effects on the environment, the economy, and possible integration with carbon credit schemes[21].

As it is fairly established study that application of biochar increases productivity many folds, so dry produce can be stored for winter months. This long-term availability of sustainable long term activities ensure not only good quality produce but availability also. This results a huge respite for the local people during winters due to availability of produce in storage form[22].

As application of biochar improves, nutritional status among green leafy vegetables hence improves nutritional security. The approach promises eradication of nutritional deficiencies in indigenous people specifically during winters when there is no fresh produce available. Use of biochar is one of the sustainable method of advance, which can solve many agriculture, related issues in local areas when no fresh produce is available[23]. Spinach (*Spinacia oleracea*): various research studies show that use of biochar increases many a fold in *Spinacia oleracea* which not only results high yielding but also increases nutrient content in including vitamins A, C, and B[24].

Good soil health is crucial for root crops like Beta vulgaris that can be achieved by applying biochar on soil. Research studies showed that utilization of biochar can improve soil and brings positive changes in root crops like Beta vulgaris.

Similarly, Lettuce (*Lactuca sativa*) also shows good response to biochar reveling improved structure of soil and immobilization of nutrients[25].

Research studies showed that glucosinolate content –health promoting characters in Mustard (*Brassica rapa*) remarkably increased due to application of biochar[26].

Spinach (*Spinacia oleracea*), root beet (*Beta vulgaris*) mustard (*Brassica rapa*) lettuce (*Lactuca sativa*), are the vegetable species having wide range adaptability in many soil. This makes them most suitable for receiving biochar for obtaining maximum yield[27].

Due to positive allelopathic response shown by spinach, root beet, lettuce mustard, results further increment in their growth when grown in biochar-modified soils[28].

Sustainable agriculture, essential for maintaining food production, necessitates the restoration of soil nutrient concentrations, notably nitrogen (N) and phosphorus (P). However, this poses challenges in organically farmed areas devoid of inorganic fertilizers and small-scale agricultural settings where farmers lack access to fertilizers. The significance of both academic and industrial research in the application of biochar in agriculture and the environment is underscored. In remote regions like Kargil, and Ladakh, farmers are compelled to adopt synthetic fertilizers to meet the communities' food demands amid global population expansion. Hence locally available feed stock apricot seed shell for biochar may address the issue sustainably.

The present study conducted in the agriculturally challenging terrain of district Kargil, of newly formed union territory of Ladakh, erstwhile Jammu & Kashmir. The focus of the study is to determine the productivity of four locally grown vegetables-Spinach (*Spinacia oleracea*), Lettuce (*Lactuca sativa*), Root beet (Beta *vulgaris*), and Mustard (*Brassica rapa*),with and without application of biochar derived from locally grown apricot (*Prunus armeniaca*) seed shell waste (ASSBC). This purposeful application of biochar is to increase in productivity among leafy vegetables, combats issue of waste disposal, improvement in soil quality. Assurance of winter dry veggies buffer stock besides declares a future window in the field of biochar and ultimately sustainable agricultural practices in these arid clod climatic conditions serves economics, scientific social prospective.

Materials and methods

Site description

Study Research conducted in Kargil, situated at approximately 34.5732° N latitude and 76.1942° E Longitude, with an altitude of 3292 m above mean sea level (AMSL). Positioned on rain-free side of the Himalayas, Kargil experiences distinctive climate and soil conditions shaped by dry monsoon winds that arrive after shedding their moisture in the plains and Himalayan peaks. The resultant climate combines features of both desert and arctic environments, earning Ladakh the moniker "COLD DESERT". Annual precipitation is minimal, primarily manifesting as snowfall, with communities experiencing snow accumulation ranging from 2 to 5 meter.

Notably, the entire region exhibits minimal or no natural vegetation, contributing to the unique ecological challenges faced. The soils found on steep to extremely steep slopes have a texture ranging from loamy to sandy, with sand concentrations ranging from 84 to 91% and silt and clay contents from 2–7% and 6–7%, respectively[29].

Soil sampling

Daiki Rika Kogyo (DIK) equipped with 100 cm ring cutter soil sampler was used for soil sampling. The sampling process conducted thrice within each experimental site. Soil samples collected during (2022) from the nearby neighborhood in the Kargil district, specifically from the horizon ranging from 0 to 20 cm depth utilizing a soil auger (STEPS-42101, Germany). The collected soil sample was air-dried and then sieved through a 2.4 mm mesh to achieve uniform particle size. Soil sample was physico-chemically analyzed for various macro and microelements. Soil sample was also sieved to obtain homogenous particles for homogenized mixing of soil with subsequently synthesized biochar.

Collection of apricot shells

The apricot seed shells used in this study were sourced from nearby orchards in Kargil, a region famous for its high-quality apricots *Prunus armeniaca*. Apricot seed shells collected locally from various locations of District headquarter, Kargil. The selection criteria decided for choosing of orchards include accessibility, the previous health status of the apricot trees in the orchards, verbal confirmation from the orchard owners that only farm yard manures used.

It was also confirmed that no synthetic chemical fertilizers were used in the orchards that could compromise the purity of the shell. The sampling process include visit of nearby orchards to gather a representative sample of apricot seed shells.

Handling and transportation To avoid any microbial or fungal development during transit of shells from orchards to laboratory, the collected shells were carried in breathable, hygienic bags.

Cleaning of shells To make it sure that the shell are free from of dirt, dust, and any other impurities, these seed shells rinsed completely with distilled water. This process include placing the apricot seed shells in large plastic containers and washing these under a gentle normal stream of water while manually agitating to get rid-off impurities in between shells, if any.

Drying of shells After the cleaning process completes, the apricot seed shells were spread out uniformly on trays and placed in a convection oven set at 50 °C. The dried seed shells were then allowed to cool down at room temperature and stored in airtight containers to avoid moisture reabsorption and contamination.

Crushing and homogenization of shells

Seed shells were mechanically crushed into smaller uniform pieces. The purpose of uniformly generate particles of a consistent size, between 1–2 mm in diameter to guarantee consistent heat exposure during the pyrolysis process, this size range was selected.

Screening After completion of crushing process, the crushed seed shells were screened using a 2 mm mesh to withdraw any oversized pieces and surety to achieve a homogeneous size distribution.

Measurement of initial and final weight To assess the mass loss during pyrolysis the initial weight of the crushed seed shell particles was measured using a precision analytical digital balance with an accuracy of 0.01 g.

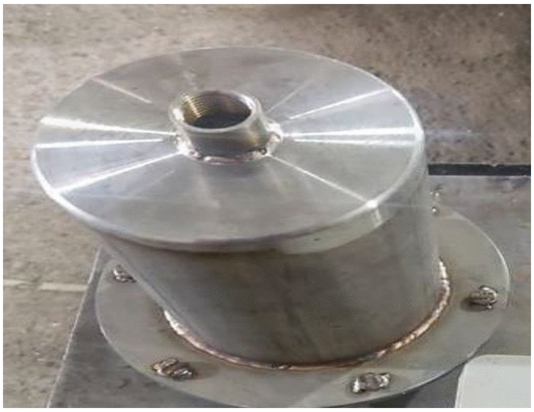


Fig. 1. Description of reactor design.

Fig. 2. Apricot seed shell.

$$\text{Final Weight Percentage Loss} = \frac{(\text{Initial weight} - \text{Final Weight})}{\text{Initial weight}} \times 100$$

Reactor design

Figure 1 shows the image of steel made reactor employed in this research. This steel made self-designed reactor having temperature tolerance range of up to 150° (SS304).This steel made reactor design consists of main body measuring 175 mm × 150 mm, act as the chamber for placing all types of feedstock for biochar materials. Other dimension of main body comprising 25 mm in thickness and 140 mm in height is meticulously designed to accommodate feed stock materials with great efficiency. The bottom side of this steel made reactor is purposely fitted with a bolt of same composition acting a dead knob, facilitating a sophisticated and secure closure. The airtight sealing mechanism ensures airtight inert environmental condition within the reactor for complete pyrolysis of the Apricot seed shell used (Fig. 2).

Biochar synthesis

The uniformly crushed apricot seed shell were loaded into a reactor made up of stainless steel designed to withstand high temperatures up to 1500 °C. After loading shells in reactor was placed inside the muffle furnace. Gradually temperature was raised from room temperature to the predetermined pyrolysis temperature at a rate of 10 °C per minute. After attaining the set temperature, it was maintained for 1 h to ensure complete carbonization of the seed shell particles. This made reactor functionalize under uniform continuous nitrogen supply to ensure a controlled inert and pyrolysis environmental conditions ensuring no chances of combustion during the course. After completion a one-hour heating cycle, the reactor allowed to cool overnight, and the resultant biochar was carefully preserved in airtight plastic bags for subsequent utilization.

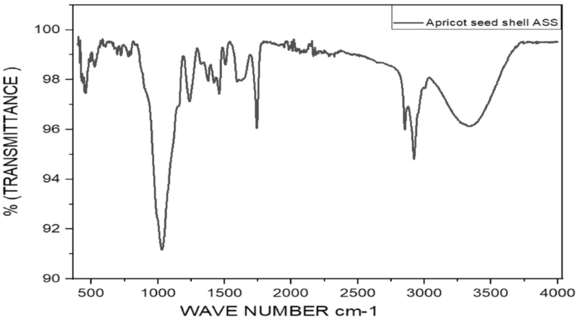


Fig. 3. Apricot seed shell.

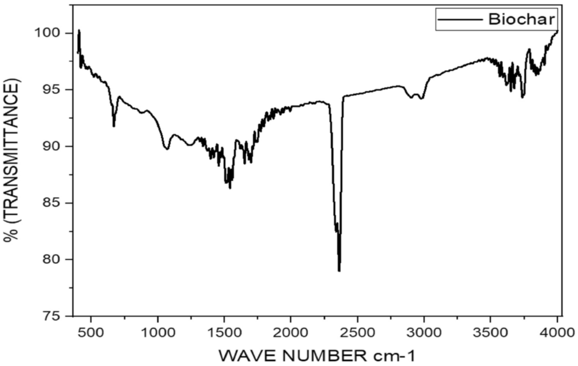


Fig. 4. FTIR–Biochar (apricot shell).

Determining the influence of ASSBC on plant chosen parameters

Vegetation experiment

Soil contained in the experimental jars was inoculated with seeds of vegetables—spinach (Spinacia *oleracea*), mustard (*Brassica rapa*), lettuce (*Lactuca sativa*), and beetroot (*Beta vulgaris)*, and growth parameters were observed. Those soils left untreated (control) seeded with the same number of seeds with similar conditions also run as a blank for comparing to evaluate the effects of incubated biochar on plant growth. This meticulous observational watch remained vigilant during entire course of study to avoid any biasness in results. To determine the effects of biochar application on growth of vegetables under study, color coded botanical jars with two different sections put in place, each set of jars treated with biochar (8% i.e. 8 mg/100 g of soil) and another set of jars left untreated. Other conditions number of seeds sown, watering frequency and all other requirements parameters constantly maintained same for in both the sets. This methodical initiative to biochar synthesis and experimental set up purposefully foundations a stone in assessing the impact of apricot seed shell-derived biochar on the growth in leafy plants.

Results and discussion

Figure 3 illustrates the FTIR analysis of apricot seed shell (ASS) corresponding to respective functional groups. Presence of polysaccharides in the apricot shell is presented by peak 1000 cm^{-1} and is particularly associated with C–O stretching vibrations in cellulose and hemicellulose This peak value specifically 1700 cm^{-1} reflects the C=O stretching vibrations, that shows presence of carbonyl groups in lignin besides availability of few aromatic compounds in the structure of apricot shell. This peak value 3200 cm^{-1} is associated with O–H stretching vibrations, advocating the existence of hydroxyl groups-usual cellulose and lignin, conferring the nature of the material's water solubility. The existence of complicated polymer, skeletal vibrations of the rings lignin is corresponded by 500 cm^{-1}[30].

Figure 4 illustrates the Fourier transform infrared (FTIR) analysis of biochar derived from apricot seed shell (ASSBC) suggesting relevant functional groups. Notably, a strong peak at 2349 cm^{-1} in the 2400–2000 cm^{-1} range associated to O=C=O stretching, revealing presence of carbon dioxide, probably emanating from combustion or oxidation processes. The peaks values bands ranges from 4000 to 3500 cm^{-1} in the FTIR spectrum indicating release of H_2O during the pyrolysis. Peak values ranging from 1440 to 1395 cm^{-1}, a medium peak suggests to O–H bending, specifically related to carboxylic acids, indicating the existence of such functional groups. The peak values fall in the range of 2468 probably because of the carbonyl bonds sample. Moreover, range of value range from 1420 to 1330 cm^{-1} exhibits a medium peak, advocating O–H bending characteristic of alcohols. A strong peak near around 1415–1380 cm^{-1} suggesting to S=O stretching, reflects the presence of sulfate groups, possibly showing interplay with sulfurous compounds or environmental conditions. Lastly, a signal related to

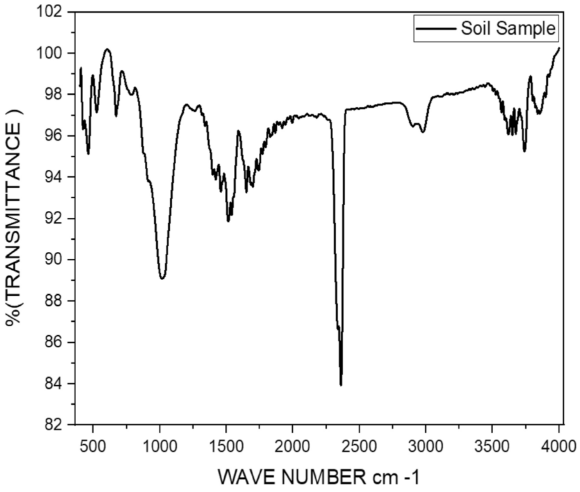


Fig. 5. FTIR soil sample.

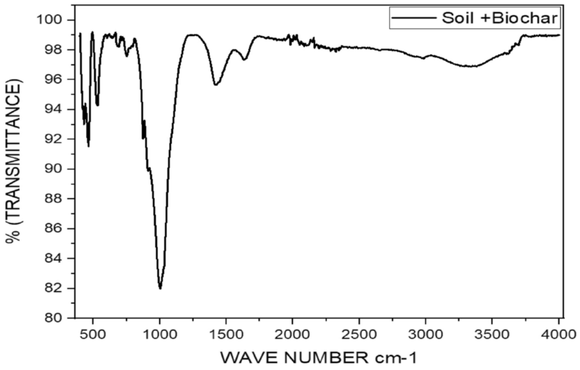


Fig. 6. Soil + biochar.

C=C bending at 995–985 cm^{-1} indicates an existence of mono substituted alkenes. Moreover, an unusual peak at 1600 cm^{-1} demonstrating aromatic C=C stretching in lignin guarantees the existence of biochar. The extensive investigation reveals useful details about the variety of functional groups which are found in the biochar, including the chemical composition and its uses[31].

Figure 5 illustrates the FTIR analysis of soil sample (SS) corresponding to respective functional groups Peak value 1000 cm^{-1} generally respond to the Si–O stretching vibrations indicative of silicate minerals, commonly found in sandy nature soils. This peak values advocates the availability of silicate minerals, quartz SiO_2 that conferring the stability of soil. The outcomes that were collected and reported during the research process coincide with those of[32]. The FTIR analysis's peak value of 1400 cm^{-1} was linked to the bending vibrations of carbon-hydrogen C–H bonds (C–H bonds) in organic materials.

This peak advocates the existence of organic compounds, which can remarkably improve fertility and structure of soil. The findings are in agreement with the present study[33]. The peak value 500 cm^{-1} probably associated with the bending vibrations of oxides of metal or other mineral ingredients of soil, depicting the mineral composition of soil and capability to withstand under harsh conditions[34]. This analytical results coincides with the results of current study. The peak in the range of 2468-is common in the graphs may be due to the carbonyl bonds in the soil sample. Slight difference in the transmissivity can be found in both samples. The strong peaks recorded at 1000 cm^{-1}, 1400 cm^{-1}, and 500 cm^{-1} soil samples attributed to particular vibrational modes related to material's molecular structure. These peaks can be attributed to many factors, including the existence of organic matter and silicate minerals and, which influence the soil's physical and chemical properties.

Figure 6 illustrates the FTIR analysis of soil sample plus biochar (SSBC) corresponding to respective functional groups Strong peaks at 1000 cm^{-1}, 400–600 cm^{-1}, and 1300 cm^{-1} in soil containing biochar are suggestive of certain specific vibration patterns relevant to the chemical and structural features of the constituent components. Functional groups and molecular relationships are crucial to soil characteristics are shown by these peaks values. The Si–O stretching vibrations in silicate minerals, which are very much prevalent in soil and biochar ingredients, are commonly suggested by the peak value at 1000 cm^{-1}[35]. Peaks value near 600 and 400 cm^{-1} associated with bending vibrations of metal–oxygen bonds indicates the presence of clay minerals or metal oxides in the soil-biochar mixture combination. Moreover, it can be evidence of organic substances generated from biochar, which

Parameters	Results
pH	8.25
EC (dS/m)	0.79
OC (%)	3.93
Available nitrogen (Kg/ha)	1080.75
Available phosphorus (Kg/ha)	46.64
Available potassium (Kg/ha)	985.6
Available sulphur (Kg/ha)	38.42
Available calcium (Kg/ha)	344.3
Available magnesium (Kg/ha)	16.9
Available sodium (Kg/ha)	17.95
Zinc (mg/Kg)	2.00
Iron (mg/Kg)	11.27
Manganese (mg/Kg)	4.46
Copper (mg/Kg)	0.87

Table 1. Physicochemical analysis of soil sample.

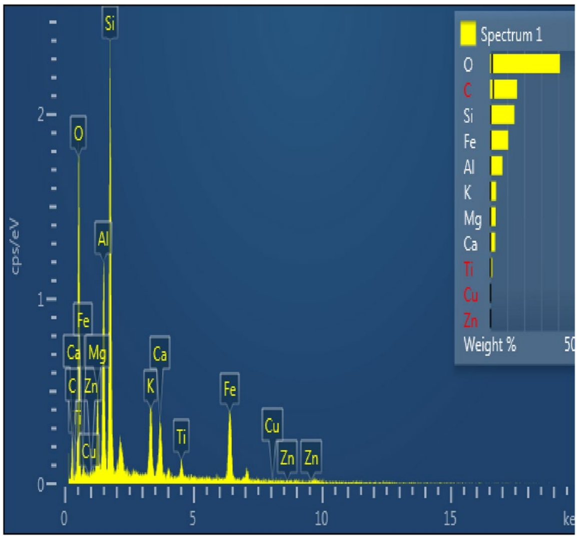


Fig. 7. EDS results of nutrients in soil.

improve the structure of the soil and retention of nutrients[36]. These show how biochar and soil minerals interact to enhance soil fertility and immobilise contaminant[37]. The peak value at 1300 cm^{-1} is associated with C–H bending vibrations, is showing the presence functional groups of organic matter biochar[38]. It states that biochar has the potential ability to boost soil microbial activity and improve soil health in general[39].

In conclusion, an in-depth comprehension of the pyrolysis process evidence the presence of organic substances in the sample, from water release to the identification of particular functional groups in cellulose, hemicellulose, and lignin, are revealed by the careful analysis and interpretation of the FTIR spectra. This helps because biochar with appropriate functional groups may be added to soil to improve soil fertility through lowering nutrient leaching, retaining water, and increasing the specific surface area of soil (see Table 1).

Figure 7 is a scanning electron microscope (SEM) image of soil. It facilitates a highly magnified picture of soil particles, revealing unusual morphology i.e. forms and sizes. The result illustrates a through microscopic insight of the s texture and structure of soil, which is helpful getting information about its compositional properties and qualities (See Fig. 8). This type of picture is unique in it as it illustrate small-scale soil properties that are microscopic to human eye. This useful information is sound and feasible in sectors like geology, agronomy, and environmental science. The findings are tabulated as:

Using EDX (Energy dispersive X-ray spectroscopy) analysis, the chemical composition was determined. Elements of soil sample detected during EDX measurement corresponded to their proportions. Table 2 and Fig. 9 lists the EDX of the sole electron spectra values that are measured in atomic and weight percentages. The Highest value oxygen while lowest value copper (Cu) 0.04 as the lowest value ignoring Zn 0.00. The sole spectral quantity of elemental composition in terms of wt.% comprising distinct components as C 15.78, O 41.09, Mg 3.29, Al 7.23, Si 14.28, K 3.50, Ca 2.98, Ti 1.16, 10.64, Cu 0.04, and Zn 0.00. While EDS shows value of biochar

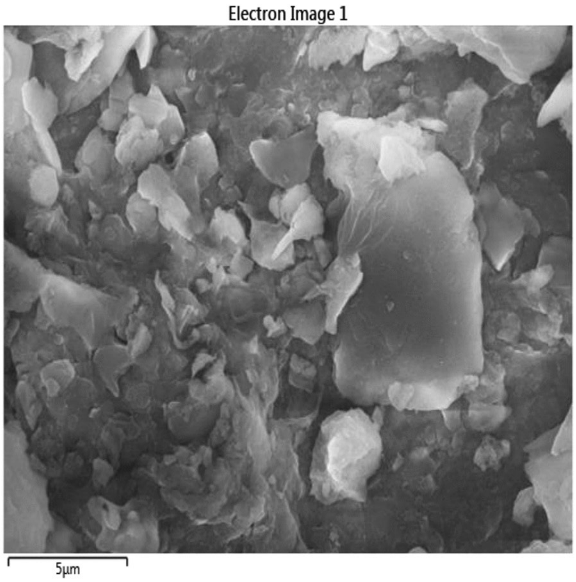


Fig. 8. SEM results of elements in soil.

Spectrum	Wt (%)	Wt (%) Sigma	Spectrum	Atomic %	Spectrum
C	15.78	1.90	C	25.40	C
O	41.09	1.19	O	49.64	O
Mg	3.29	0.21	Mg	2.62	Mg
Al	7.23	0.30	Al	5.18	Al
Si	14.28	0.45	Si	9.83	Si
K	3.50	0.19	K	1.73	K
Ca	2.98	0.19	Ca	1.43	Ca
Ti	1.16	0.16	Ti	0.47	Ti
Fe	10.64	0.47	Fe	3.68	Fe
Cu	0.04	0.26	Cu	0.01	Cu
Zn	0.31		Zn	0.00	Zn
Total	100.00		Total	100.00	Total

Table 2. EDS results of elements in soil.

(Table 3, Fig. 10) in terms of proportionate elements in atomic wt. percentage as C 84.2, O 6.06, Al 0.87, Si 1.72, K0.91, C 1.54, Fe 2.12, Cu 0.80, Zn 1.46.

Figure 10 is a SEM photograph of biochar. The SEM gives a highly enlarged picture of the biochar, demonstrating its porous structure. The surface seems rough and uneven, with varying pore and cavity sizes evident throughout the material. These features are intriguing because they indicate a large surface area, which is important for applications such as water filtration or soil amendment where absorption is critical.

Effect of biochar on growth and development of vegetable plants

Upon the application of biochar, a noticeable and statistically significant enhancement in the growth of all observed plants observed (Table 4, Figs. 11 and 12). The response, however, varied among different plant species, with some exhibiting maximal growth while others displayed moderate responses (Figs. 11 and 12). The assessment of outcome primarily focused on the quantitative aspects, specifically leaf number and leaf size on plants treated with (WB) and without biochar (WOB).

Variability in plant response

Spinacia oleracea emerged as the most responsive species to biochar treatment, displaying remarkable increment in the number of leaves, totaling 45 (Table 4). Conversely, Lettuce (*Lactuca sativa*) exhibited the fewest leaves, numbering only 12, suggesting a more moderate response. Beetroot, on the other hand, demonstrated significant growth. For Spinach, the length of leaves increased from 7 cm without biochar to 20 cm with biochar (Table 4). In terms of leaf length, displaying the longest leaves among the observed plants (35). Lettuce, in contrast, had the shortest leaves among the plants studied, again numbering only 12 (Tables 4, 5).

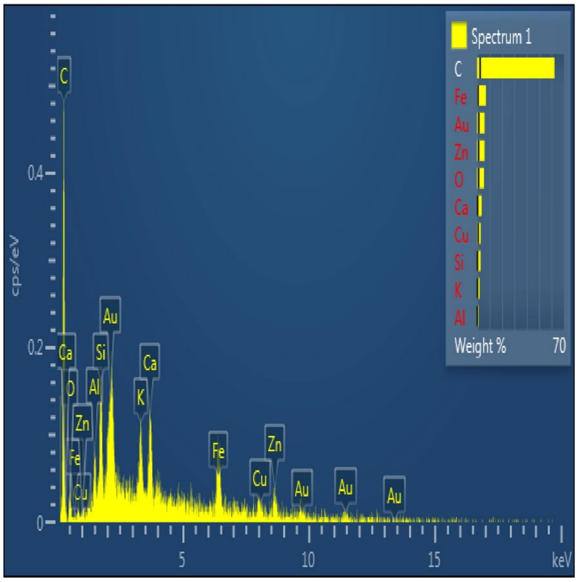


Fig. 9. EDS elements biochar.

Spectrum	Wt%	Wt% sigma	Spectrum	Atomic %	Spectrum
C	84.52	C	C	65.66	2.50
O	6.06	O	O	6.27	1.37
Al	0.87	Al	Al	1.52	0.31
Si	1.72	Si	Si	3.13	0.41
K	0.91	K	K	2.30	0.41
Ca	1.54	Ca	Ca	4.00	0.50
Fe	2.12	Fe	Fe	7.65	0.95
Cu	0.80	Cu	Cu	3.30	1.07
Zn	1.46	Zn	Zn	6.18	1.36
Total	100.00	Total	C	65.66	2.50
C	84.52	C	O	6.27	1.37
Total	100.00		Total	100.00	Total

Table 3. EDS results of elements of biochar.

Interpretation of results

The observed variability in plant response underscores the nuanced impact of biochar on different plant species. Factors such as inherent characteristics of each plant and their specific requirements contribute to the diversity in responses (see Fig. 13). Spinach's prolific leaf production suggests a particularly favorable response to biochar, while the more moderate responses of Lettuce and distinct growth patterns in Beetroot highlight the intricate interplay between biochar and plant physiology.

Conclusion

The comprehensive investigation conducted in this research unequivocally establishes the significant outcome of biochar application on growth and yield of vegetables. Results illustrates noteworthy and visible increment in the growth of plants treated with biochar comparison to those left untreated. The biochar-treated vegetables exhibited a conspicuous and statistically significant increase in growth parameters, notably in terms of both the leaf number and leaf size. This finding holds substantial promise as a sustainable alternative that could potentially replace or diminish the dependence on artificial fertilizers, particularly in ecologically sensitive regions such as Kargil, Ladakh where the adverse environmental impacts of chemical fertilizers are of great concern. The study also unveils a practical solution by utilizing apricot shells, previously discarded as waste, as a valuable alternative source of fertilizer through the biochar production process. This purposeful approach combats issue of waste disposal, improvement in soil quality, ensure winter dry veggies buffer stock besides declares a future window in the field of biochar and ultimately sustainable agricultural practices in these arid clod climatic conditions.

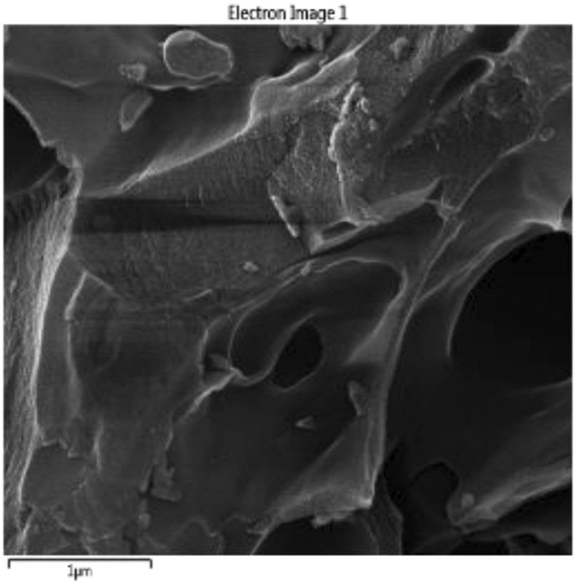


Fig. 10. SEM of biochar.

Name of plant/vegetable	Vase no./color	(1) Length of leaves (without biochar)	(2) Length of leaves (with biochar)	(3) No. of leaves without biochar	(4) No. of leaves (with biochar)
Spinach (*Spinacia oleracea*)	White (1)	7 cm	20 cm	07	45
Root beet (*Beta vulgaris*)	Pink (2)	10 cm	35 cm	33	33
Lettuce (*Lactuca sativa*)	Green (3)	8 cm	12 cm	09	12
Mustard (*Brassica rapa*)	Yellow (4)	11 cm	15 cm	33	35

Table 4. Comparative growth in vegetables with and without application of biochar.

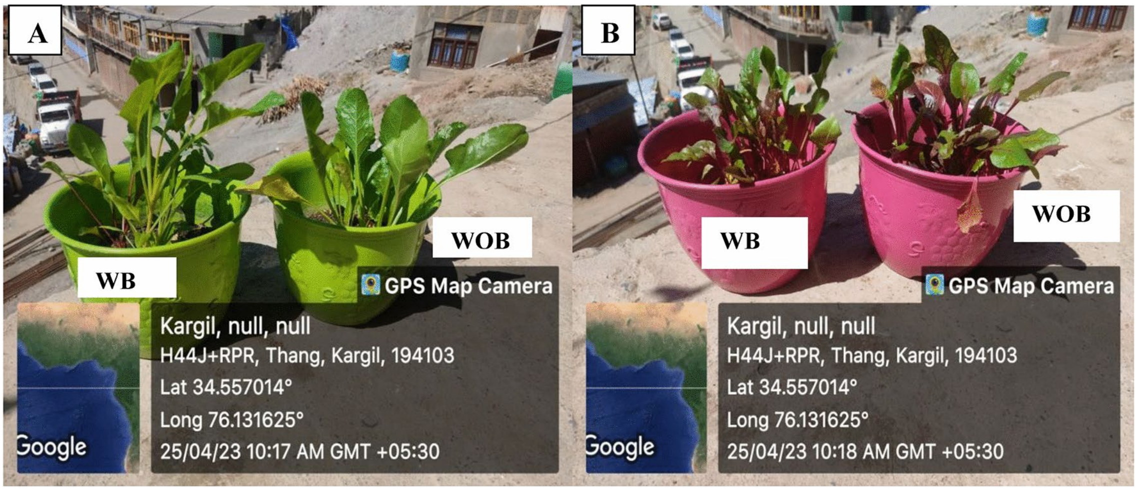


Fig. 11. Showing growth in vegetables Lettuce (**A**) and Root beet (**B**) under observation with and without biochar application. WB stands for with biochar and WOB stands for without biochar.

Implications and future directions

The scope and extension of this research is not only confined to increasing vegetable growth, but this locally sourced apricot biochar seed shell is a window for managing many environmental challenges in ecologically fragile zones of Himalaya region, Kargil Ladakh. This research is a novel approach as all the systematic set

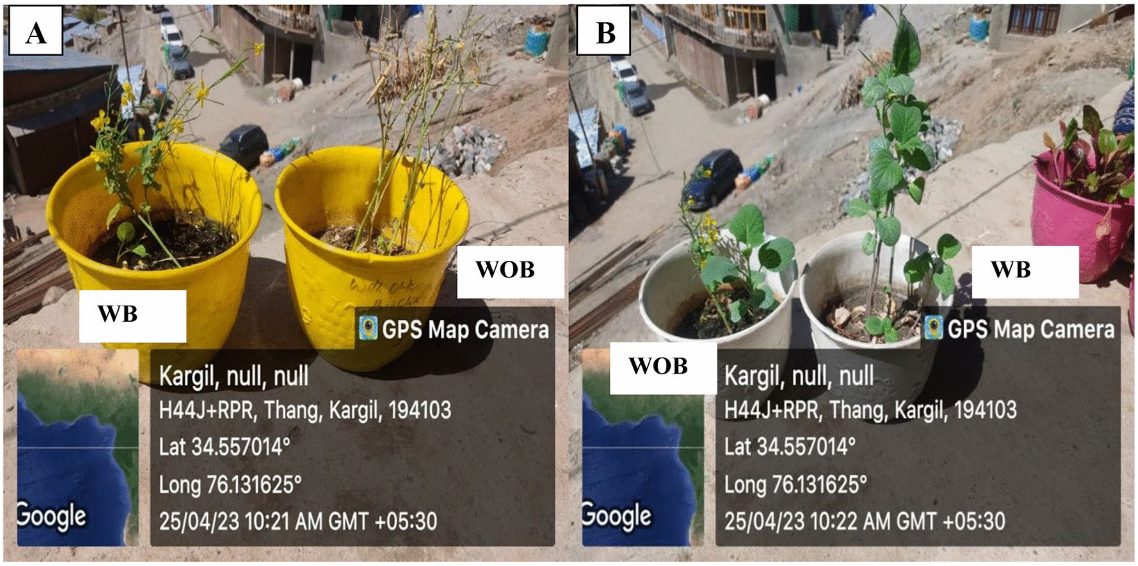
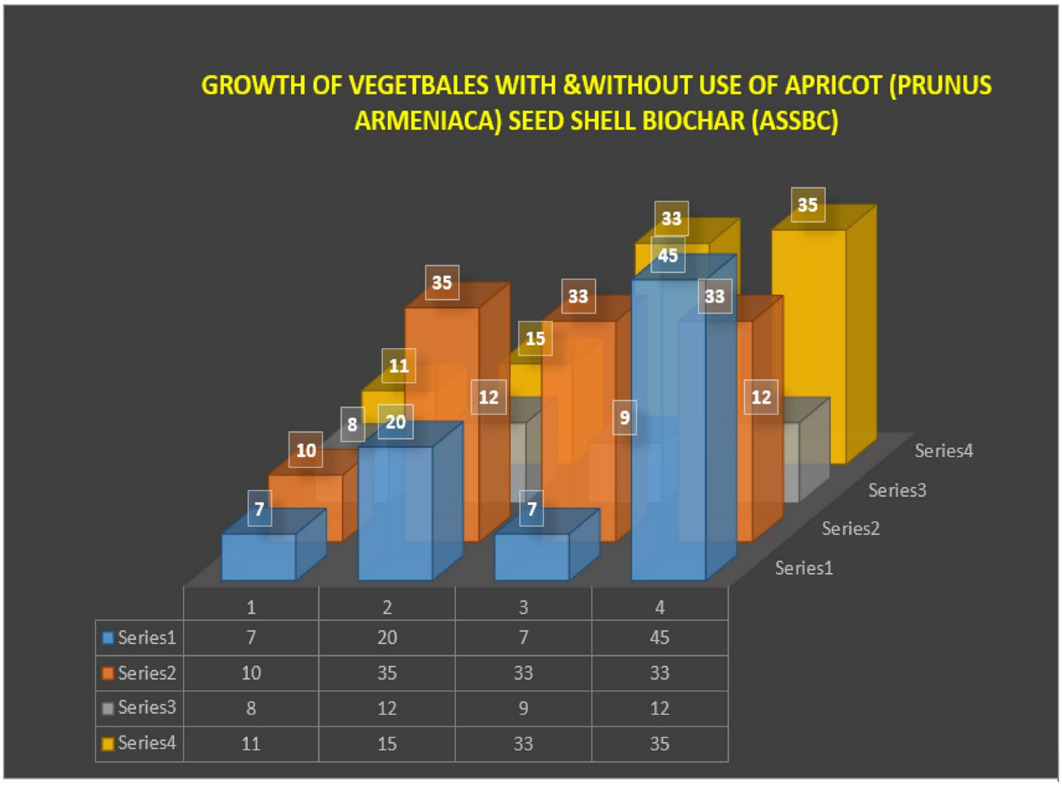


Fig. 12. Showing growth in vegetables Mustard (**A**) and Spinach (**B**) under observation with and without biochar application. WB stands for with biochar and WOB stands for without biochar.

Series 1	Series 2	Series 3	Series 4
Spinach	Root beet	Lettuce series	Mustard

Table 5. Index for vegetable species.



	1	2	3	4
Series1	7	20	7	45
Series2	10	35	33	33
Series3	8	12	9	12
Series4	11	15	33	35

Fig. 13. Comparative growth of vegetables with & without use of Apricot Seed Shell Biochar (ASSBC).

up viz. raw feed stock for biochar, soil study under consideration and leafy vegetable, all are easily accessible indigenously. This will surely going to eradicate or decrease use synthetic fertilizers in such sensitive zones as water is getting contaminated due to urea, phosphate fertilizer, besides helping in carbon sequestration combating global warming boosting economy of farmers in Himalayan region. The study confirms a foundation stone for future endeavors aimed at optimizing biochar applications and radically advancing sustainable agriculture in varied geographic, edaphic and climatic conditions.

Data availability

All data generated or analyzed during this study are included in this article only.

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Author contributions

All authors contributed to the study. Sajad Hussain, Chandrakant Sonawane, Dan Dobrotă: Writing Original preparation of draft, Writing & Editing, conceptualization, Software, Data curation; Final draft writing and editing; Pratima Gajbhiye and Md Irfanul Haque Siddiqui Conceptualization, Supervision, Writing & Editing. All authors have read and approved the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

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