Effects Of Rice Husk Biochar On Nutrient Uptake And Yield Of Leafy Vegetables: A Review

Mehnaz Mosahrrof[1], Siti Hasma[2], Md Kamal Uddin[2]*, Sm Shamsuzzaman[1], Md. Hasan Mahmud[3], Md Rafiqul Islam[4], Ahmed Abubakar[5], Nasir Adam Ibrahim[6] and ABM Sharif Hossain[6]

Abstract

Green leafy vegetables have been used since ancient times as a food source because they contain many nutrients and minerals that help for growth and maintaining human health. The objective of this study is to sumarize the effect of rice husk biochar on the selected leafy vegetables. The selected leafy vegetables are spinach (*Spinacia oleracea* L.), cabbage (*Brassica chinensis* L.), lettuce (*Lactuca sativa* L.), Chinese cabbage (*Brassica rapa chinensis*),Amaranth (*Amaranthus viridis* L.). Day by day the demand of leafy vegetables is increasing due to consume by many people. To fulfill this demand, the production of leafy vegetables should be increased. Various organic amendments such as rice husk biochar (RHB) can be used to increase the yield. RHB is one of the soil amendments that contain nutrients which is important for soil health and crop production. Although characteristics of RHB are also related to other factors such as pyrolysis heating rate and residence time, its performance for specific applications (e.g. carbon sequestration, pH amendment) can be manipulated through adjustingthe pyrolysis temperature. Recent studies show the success of multi-application of biochar that affect the soil chemical and physical properties, plant growth and yield of vegetables. This review summarizes nutrient uptake and yield of some leafy vegetables which were influenced by rice husk biochar.

[1,] Soil Resources Development Institute, Dhaka Bangladesh
[2,]*Faculty of Agriculture, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3]Bangladesh Agricultural Research Council
[4]Faculty of Agriculture, Bangladesh Agricultural University
[5]Faculty of Forestry and Environment, University Putra Malaysia, 43400 Serdang, Selangor,Malaysia
[6]Department of Biology, College of Science, Imam Mohammad Ibn Saud Islamic University, Riyadh, Kingdom of Saudi Arabia.

***Corresponding author**: Md Kamal Uddin
*Faculty of Agriculture, University Putra Malaysia,43400 Serdang, Selangor, Malaysia.

Introduction

Leafy vegetables hold an important place in well-balanced diets. It provides adequate amounts of many vitamins and minerals for humans (Kamble & Jadhav, 2013). They are rich source of vitamins like beta-carotene, ascorbic acid, riboflavin, folic acid and minerals like calcium, iron, phosphorous (Kumar *et al.* 2020). The lack of knowledge especially on the nutritive value of these green leafy vegetables among the public in general is the maindrawback in their lower consumption (Ashok Kumar *et al.* 2013). Green leafy vegetablesrepresent an important proportion of foods with medicinal value (Kumar *et al.* 2013).

Biochar is a biomass that is burned at very high temperature in the absence of oxygen (Asadi Zeidabadi *et al.* 2018). Biochar is simply a fine-grained and porous form of charcoal that is made to improve soil as it can help to boost soil health via its positive benefits towards plant growth and disease resistance alike (Kumari & Rajan 2016). It has been the centre of many research activities recently for its potential to support the reduced use of fertilizer and irrigation yet indirectly increasing yield (Clough *et al.* 2013; Faloye *et al.* 2019). It is thus a valuable soil amendment due to its ability to support the higher-level microbial populations (Bhuvaneshwari *et al.* 2019). Moreover, it is stable in the soil and so is a good investment for long-term fertility (Jyoti *et al.* 2018). Biochar as a soil amendment has potential benefits to improve the chemical characteristics of soils (Mulyati *et al.* 2019).

Rice husk biochar (RHB) application can reduce the bioavailability of herbicides and heavy metals in contaminated soils, reduce greenhouse gas (GHG) emissions and decrease nutrient leaching from soil (Faloye *et al.* 2019). The dominant mechanism for immobilization of pollutants in the soil by biochar depends on the pollutant type, soil type, RHB type and application rate (Faloye *et al.* 2019). By biochar application, the pollution risk of herbicides is reduced, which is beneficial for environment, but the efficiency of herbicides is also reduced, whichis an economical concern (Asadi *et al.* 2021). Rice husk biochar (RHB) has an important adsorption capacity for ammonium and nitrate and therefore can reduce their leaching when applied to soil (Bashir *et al.* 2018; Asadi *et al*. 2021).

The co-application of biochar and lime showed a promising effect on nutrient availability and on reducing CO_2 emission by increasing soil pH in acidic soils (Mosharrof *et al*. 2021a). Atoptimum pH (6.5 to 7.5), organic carbon mineralization increased, causing higher CO_2 emission and reducing the Al and Fe toxicity (Mosharrof *et al.* 2021a). Therefore, applying these amendments to agricultural land can be a potential agronomic practice to enhance soil fertilityand crop productivity. Biochar with lime treatment increased soil pH, available P, and decreased exchangeable Al. The emission of CO_2 was lower in the rice husk biochar treatedsoil than oil palm empty fruit bunch (EFB) biochar treated soil, which dictates that the effect of biochar and lime on soil fertility and crop productivity may vary with biochar properties and different pyrolysis temperatures (Mosharrof *et al*. 2021b). Leafy vegetables represent an important part of foods with medicinal and nutritional value. Limited information is available on the properties of nutrient uptake and the yield of leafy vegetables. As a result, there was a need to study leafy vegetables in response to RHB. This review focuses on the role and function of rice husk biochar on soil as well as its effect on yield, and nutrient uptake of some selected leafy vegetables.

Benefits of leafy vegetables

Spinach is one of the most nutritious foods available, as it is low in calories and high in vitamins; spinach is one of the most nutrient-dense foods in existence. It is packed with vitamins A and C, as well as foliate. Heat reduces the green's oxalate content, freeing up its dietary calcium, cooked spinach gives you more nutrition than raw, but is excellent eaten raw in salads (Trumbo *et al*. 2001).Cabbage is an excellent source of vitamin C and vitamin K, containing more than 20%of the daily value for each of these nutrients per serving. Cabbage is also a good source of dietary fiber, vitamin B6 and folate, with no other nutrients having significant content per 100 gram serving (Colonna *et al.* 2016).

Okra mucilage has medicinal applications when used as a plasma replacement or blood volume expander. The mucilage of okra binds cholesterol and bile acid carrying toxins dumpedinto it by the liver (Gemede, 2015; Hafeez *et al*. 2020). Okra seeds are source of oil and protein.Okra seeds have been used on a small scale for oil production (Anwar *et al.* 2010). It can be also used as non- caffeinated substitute for coffee (Singh *et al*. 2014). Okra seeds may be roastedand ground to form a caffeine-free substitute for coffee (Singh *et al.* 2014). The bioactive carbohydrates, proteins, carotenoids, flavonoids, anthocyanins, phenolic acids and minerals arediverse nutrients present in the leaves and roots of sweet potato contain essential minerals of Na, Mg, P, Ca, and K. Leaves of sweet potato hold niacin, vitamins B6, B2, B1, C, E, pantothenic acid, β-carotene, and biotin, having higher contents of vitamins B2, C, E, biotin, and β-carotene than the plant's stems and stalks (Hoang *et al.* 2021).

Lettuce (*Lactuca sativa* L.) is one of the most popular green vegetables worldwide (Kimet al., 2016). Lettuce contains several dietary minerals important for human health such as Phosphorus (P), Magnesium (Mg), Potassium (K), Calsium (Ca), Zinc (Zn), Iron (Fe), andManganese (Mn), but essentially no protein or fat. In general, leaves contain Vitamin A,Vitamin C, Minerals, water and fiber (Buturi *et al.* 2021). In addition, lettuce also containslactocin and lactucopicrin that can be improved sleep. Also contain antioxidants, thecompounds inhibit the formation of carcinogenic substances in the body (Mulyati *et al.* 2019).

The fresh and tender leaves and stems of amaranth are delicious when cooked like otherfresh leafy vegetables (Alegbejo 2014). The leaves and tender stems of the amaranth are rich in protein, minerals, vitamin A and vitamin C (Sarker *et al.* 2020). Dry matter content of amaranths showed positive correlation with crude fiber and phosphorus content at all the stagesof harvest (Biel *et al*. 2017).

Production of biochar

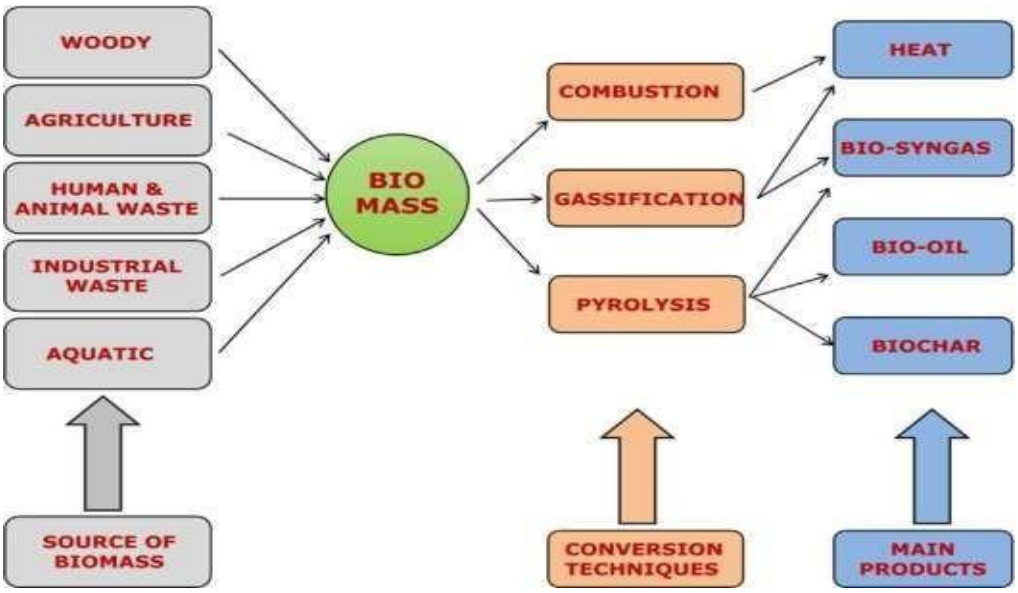

Fig. 1. Conversion techniques of biomass obtained from different sources and their products.

Most commonly, pyrolysis and hydrothermal carbonization are used to make biochar, howeverpartial gasification (thermo-oxidative pyrolysis) and microwave-assisted pyrolysis are also occasionally used (MAP). Slow pyrolysis, the most used technique, calls for heating rates less than 1 ^{0}C per second, moderate temperatures (below 600 ^{0}C), lengthy residence durations, andcoarse feed particle size distributions (PSD) (Seo *et al.*

2022). In order to get the most energy at the lowest cost while simultaneously keeping environmental concerns in mind, it is crucial to select the right process for converting biomass into energy and various value-added products.

Composition of RHB biochar

The main constitute of RHBs include C, hydrogen (H), oxygen (O), N, P, K and silicon (Si). C content of RHBs usually increases by increasing of pyrolysis temperature (Eduah *et al*. 2019). Additionally, research have shown that the C content of RHB is not dependent on thetemperature ofpyrolysis. Most importantly, however, is that compared to RH, C is mostly found in more stable forms in RHB (Abrishamkesh *et al*. 2015). Additionally, as the surface area of biochars expands, so does their ash content (Rajapaksha *et al*. 2015). There are also reports that show the independency of C content from pyrolysis temperature in RHB (Abrishamkesh *et al.* 2015). However, most importantly, C in RHB is mainly in more stable forms compared to RH. In addition, the ash content of biochars increases with the increase in their surface area (Enders *et al.* 2012; Rajapaksha *et al*. 2015).

Characteristics of biochar

The Scanning Electron Microscopy (SEM) analysis showed that the rice husk biochar (RHB) had the best pores development and better-defined pores (Zaitun *et al.* 2022). Coconutshell biochar had larger developed pores and good defined pores (Hao *et al.* 2018). The woodshavings waste biochar had bigger pores than coconut shell biochar and rice husk biochar, less defined and less uniform compared with the pores developed by coconut shell biochar and rice husk biochar (Zaitun *et al*. 2022). Low-temperature pyrolysis produced a higher biochar yield and enriched volatile-matter composition than the high-temperature pyrolysis (Jindo *et al.* 2014). The biochar yields and volatile contents gradually diminished as the pyrolysis temperature increased (Sun *et al.* 2017). Moreover, the type of feedstock also affected the biochar yields and the volatile-matter content (Jindo *et al.* 2014).

The biochars derived from rice material showed a high assh content at all temperature ranges, and this may be the cause of the partial change in the composition promoted by a possible interaction between organic and inorganic constituents during the feedstock pyrolysis in the biochars that contain an amount of ash larger than 20% (Tomczyk *et al.* 2020).The characteristics of RHB had very high in organic C, total N, P and K also were very high (VarelaMilla *et al.* 2013). It seems that, this characteristics of biochars would improve the soil characteristics including soil physical, chemical and biological, and should be maintained the sustainable agriculture production (Abujabhah *et al.* 2016). Therefore, there were important implications to improve the soil quality (Mulyati *et al.* 2019). Sarah *et al*. (2013) stated that when incorporated into soil substrate in pot trials, biochar and local organic fertilizers altered the soil physical structure (bulk density) and modified the soil chemical properties (pH, CEC and nutrient supply) and the impact extended over three cropping cycles.

Table 2. Effect of different biochar's on soil physical, chemical, and biological performance of different soil.

Biochar	Soil Type	Chemical	Physical	Biological	References
Biochar	Loamy soil/Sandy clay loam	Net CO2 flux; NH4+-N and NO3--N	Soil aggregate size classes	Enzymatic activity	(Awad et al., 2018; Solaiman et al., 2010)
Corn straw derived Biochar	Cultivated brown soil Field	SOC; TN;TP; K;	-	-	(Gao et al.,2018)
		SAN; SAK, and SAP			
Rice husk derived Biochar	Loamy soil/ Sandy clay loam	Soil pH, base cations	Soil loss rate	-	(Ahmadi et al., 2020; Mosharr of et al., 2021)
Rice husk derived Biochar	Silt clay	Soil pH; TC; TN	-	Microbial diversity/ Biological nitrogen fixation	(Rafiq et al., 2020; Mia et al., 2014)
Rice straw derived Biochar	Paddy soil/Loamy sand	Soil pH; SOC; TN; C/N ratio	Soil porosity; Soil air permeability coefficient	Enzymatic activity; microbial biomass carbon; and nitrogen	(Zheng et al., 2019; Blackwell et al., 2015)
Oil palm Empty fruit bunch biochar	Sandy clay loam	Soil pH; SOC; TN; C/N ratio, base cations	-	-	(Rabileh et al., 2015; Mosharr of et al., 2021)

Function of biochar

Biochar effects on soil depend on feedstock type, heating temperature, and residence time (Ronsse *et al.* 2013). Biochar can enhance plant growth, retain nutrients, provide habitat for microorganisms (Siddiqui *et al.* 2016), improve soil water holding capacity (Kammann etal. 2012), soil water availability (Baronti *et al.* 2014) and hydraulic conductivity (Buss et al.2012). Biochars can reduce net Greenhouse Gas (GHG) emissions from agricultural soil through mechanisms that are still not clear (Mukherjee & Lal 2013). Biochar is found to be apotential input to agriculture (Barrow 2012). Its effectis mostly observed in low fertile, acidic and degraded soil. The decrease in soil bulk density, large surface area in soil, presence of exchangeable cations and nutrient elements, increase in availability of nutrients and preventionof nutrients leaching are some of the major benefits of biochar contributing towards increasein crop productivity through improvements in soil properties (Kandel *et al*. 2021).

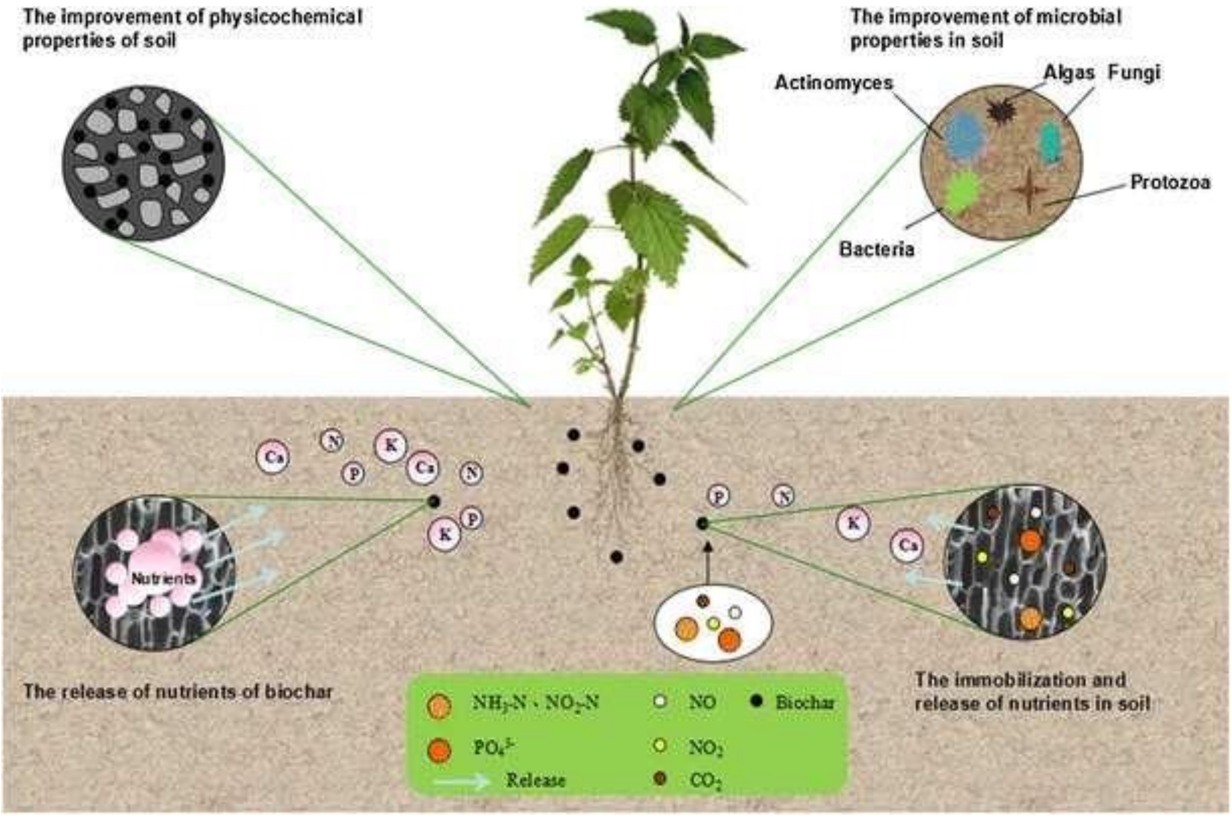

Figure 1. The function of biochar on soil

Rice Husk Biochar (RHB)

The RHB generation from paddy rice husk and its application with beneficial microbial in noculants may be a sustainable crop residue waste management option to enhance the nutrient status, microbial community and paddy productivity of nutrient poor agriculture soils.Rice husk biochar, having large surface area, pore size and nutrient elements provide favourable soil conditions for the growth and multiplication of microbial communities and consequently higher soil microbial biomass (SMB) levels, in nutrient deprived paddy agriculture soil (Singh *et al*. 2018). Rice Husk Biochar has the potential to enhance plant nutrient uptake while providing pest resistance, making it a gateway to achieve agriculture sustainability, especially in rice paddies (Singh Karam *et al*. 2022). Due to its large surface area, high silicon content, enhanced water holding capacity, improvement to soil physical structure and various other positive attributes, RHB can be used to improve soil fertility (SinghKaram *et al.* 2022). Besides, RHB is a carbon-rich, porous substance with multiple-functional groups that has the potential to increase nutrient retention, which improves the effectiveness offertilizers (Vendra *et al.* 2020; Singh Karam i 2022).

In general, RHB application increases the contents of soil organic carbon (SOC), soil pH, CEC, bulk density and microbial activity, available P, available K and total N (Asadi *et al.*2021; Rahman *et al*. 2021). However, there are some inconsistencies in effects of RHB application due to the diverse properties of different soils and RHBs produced under different pyrolysis conditions (Asadi *et al.* 2021). Mosharrof *et al.* (2022) conclude that in tropical acidic soil, amending with the combined application of different rates of RHB, dolomitic limestone, and chemical P fertilizer can enhance nutrients availability to the plant by increasing soil pH, available P, base cations, and reducing exchangeable acidity while reducing the toxicity of Aland Fe. Compared to control and NPK treatments, combined application of lime and RHB increased P bioavailability with the largest increase in the greater P application rate.

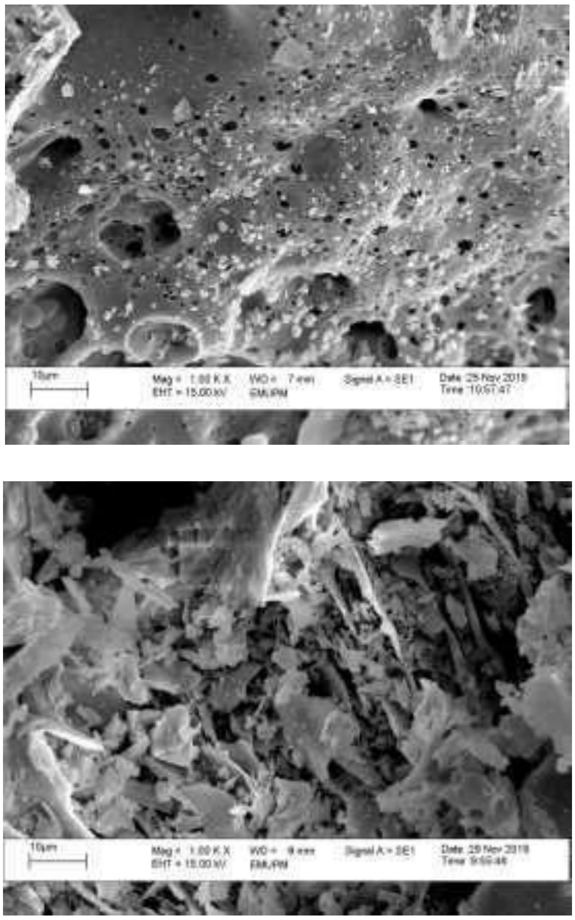

Figure2. Micrograph of RHB used in the study by scanning electron microscopy at 1000 × magnification (Haque, 2021)

Characteristics of RHB

Higher pyrolysis temperatures result in RHBs with a lower hydrogen/carbon ratio, which means more aromatic carbon molecules are present. The manufacturing of RHBs has a larger ash content, a lower yield, and a higher surface area as a result of the rise in pyrolysis temperature. Comparatively to biochars made from other feedstocks under the same pyrolysisconditions, RHB often contains more silicon, ash, and carbon. Although it depends on the kindof soil, RHB treatment can increase the soil's bulk density, microbial activity, accessible K concentration, cation exchange capacity, and organic carbon content (Asadi *et al.* 2021).

Effects of rice husk biochar (RHB) on yield of leafy vegetables Effects of RHB on Spinach yield

The rice husk biochar (RHB) rates giving the tallest plants were 20 g pot^{-1} for 0 week of incubation (WOI),10 g pot^{-1} for 4 and 8 WOI, and 20 g pot^{-1} for 12 WOI (Ebido *et al.* 2021). Thus, in terms of spinach height, the optimum rates of RHB were 10 and 5 g pot^{-1} for soil-biochar incubation lengths of 4 and 8 WOI (Ebido *et al.* 2021). The shorter plants in the control compared to the rest only for the 8 WOI. Despite the fact that, averaged across RH rates, this 8 WOI apparently gave the tallest plants among the four incubation lengths (Ebido *et al.* 2021).Variance only prevailed for 8 and 12 WOI where 10 and 20 g pot^{-1} showed number of leaves per plant different from the rest (Ebido *et al.* 2021). For 12 WOI where the number of leaves was higher in 10 and 20 g pot^{-1} than the rest of the treatments. Statistically that for 8 WOI, aswith 12 WOI, the number of leaves was equally higher in 10 and 20 g pot^{-1} than the rest (Ebido*et al.* 2021). Rice husk biochar (RHB) application at the rates of 3.0 - 4.0 kg/m^3 increased the stem size and leaf length of water spinach (Varela Milla *et al.* 2013).

Effects of RHB on Chinese cabbage yield

The biochar was added to the soil at 0, 1, 3, and 5% by weight, which represent about 0, 18, 54, and 90 t ha^{-1}, respectively (Oh et al. 2017). The treatments were arranged in a randomized complete block design with 3 replications. The Chinese cabbage was grown for 49days in a glasshouse in pots filled with sandy loam soil. Experimental results showed that the residual-wood biochar used for the experiment was slightly alkaline (pH 7.5). The fresh weights of Chinese cabbage were 86.22 g, 84.1 g, 63.23 g and 70.87 g, respectively, for biocharapplications at 0, 18, 54, and 90 t ha^{-1}. Compared with the control (No biochar), biochar application increased soil pH and electrical conductivity (EC). Addition of biochar (54 and 90t ha^{-1}) to sandy loam soil had no effect on growth of Chinese cabbage. This might be due to excessive increase of soil pH from the biochar application, leading to reduced availability of plant nutrients. Based on these results, an excessive addition of biochar may have negative effects on the healthy growth of Chinese cabbage (Taek Keun *et al.* 2017).

Effects of RHB on Cabbage yield

Biochar addition to non-fertilized soils (0) significantly increased all the plant growth indicators for both lettuce trials, except for below ground biomass for the second lettuce crop (Carter *et al.* 2013). In fertilized soils (CS), CS + B50 and CS + B150 showed increases forone or both of the lettuce crops for all plant growth indicators (Figure 2). With the addition of25 g kg^{-1}biochar to the same soil (CS), no significant increases were seen in the lettuce crop growth indicators (Sarah *et al.* 2013)

Effects of RHB on Lettuce yield

For all three cycles of lettuce and cabbage production, above ground biomass increased with biochar addition (Carter *et al*. 2013; Kyei *et al*. 2019). The greatest increase relative to the control was 90.3%, with the addition of 150 g kg^{-1} biochar to non-fertilized soil (Carter *et al.* 2013). In each cycle the lowest above ground biomass was from the non-fertilized and non-biochar amended soil and the highest above ground biomass was in the treatment with fertilizer addition and highest level of biochar application (Carter *et al*. 2013).

Effects of RHB on Amaranth yield

Biochar application generally increased plant growth compared to that with no application (Bioenergy *et al.* 2017). The plant height generally increased as the biochar application rate increased (Bioenergy *et al*. 2017). Biochar amended amaranth plants generallyhave larger stem diameter compared to those with no application (Sun *et al.* 2016). The highest mean plant height, number of leaves, fresh weight and dry weight reflects the better uptake ofnutrients (Eyheraguibel *et al*. 2008). Also, higher shoot and root dry weights were found in the biochar amended plants compared to the control (Brennan *et al*. 2014).

Effects of RHB on nutrient uptake Effects of RHB on N nutrient uptake

There was no significant polynomial trend detected for the effect of biochar rate on total N concentration of the soil. However, polynomial contrast analysis indicated that the existence of a biochar rate × fertilizer interaction was mainly due to a significant difference in the linear part of total N responses to biochar rate at different fertilizer rates. Application of biochar without fertilizer addition increased total N concentration of the soil, but significant differences over controls ($mean_{bt} = 0.17$ g kg^{-1}) were only detected at the highest application rate of 15 g kg^{-1} ($mean_{bt} = 0.398$ g kg^{-1}). However, the total N concentration in fertilized soil showed a decreasing trend with the lowest value recorded in soil treated with the highest application rate at 15 g kg^{-1}biochar ($mean_{bt} = 0.215$ g kg^{-1}) (Shuhada 2016).

Effects of RHB on P nutrient uptake

Biochar also has the potential of improving P fertilizer effectiveness especially in acidic soils (Schneider & Haderlein 2016; Filho *et al.* 2019). Effects of RHB and that of P are independent of one another. Soil pH increased with an increase in the rate of RHB without combining with phosphorus. RHB form insoluble complex with high available phosphorus present in the soil causing fixation and not leaving enough calcium to counter H^+ and $Al3^+$ concentrations and hence reduction in the pH (Okon *et al.* 2005). Application of biochar and chicken manure in soil could potentially improve P availability and affect P uptake by ryegrassand maize plants. (Yuan *et al.* 2011). Seripong (1988) concluded that P and RHB improved nodulation, yields, the soil pH, organic matter content, and cation exchange capacity (CEC) ofthe Thailand acid soils.

Effect of RHB on soil fertility

In general, RHB application increases the contents of soil organic C (SOC), soil pH, CEC, available P, available K and effects of RHB application due to the diverse properties of different soils and RHBs produced under different pyrolysis conditions. Biochars are generally enriched in nutrients and usually increase soil fertility when applied to soil (Feng *et al*. 2017). Masulili *et al* (2010) examined the effect of RHB on the properties of acid sulfate soil, and observed increases in SOC, CEC, soil P, K and Ca contents, and decreases in soil exchangeable Al and soluble Fe. However, Mg and Na contents are remained unaffected by RHB amendment. Singh *et al* (2018) reported significant increases in water holding capacity, total C, N and P contents,as well as soil moisture content following RHB application. Ghorbani and Amirahmadi (2018) also reported that RHB significantly increases the N content and bioavailable K in the amended soils. However, the reported results are contradictory for P. Abrishamkesh *et al* (2015) reported that P content of the soils amended with 0.4%, 0.8% and 3.3% RHB is significantly lower thanthat of the unamended control soil. Ghorbani and Amirahmadi (2018) also observed a decreasein P content by RHB application. Significant improvement in soil bioavailable P content as a result of charcoal application has long been reported in sandy and loamy soils (Tryon 1948).

Effect of RHB on nutrients bioavailability

The growth of different crops is also enhanced by application of RHB. RHB addition to soil can immobilize heavy metals and herbicides and reduce their bioavailability. RHB application shows a significant capacity in reduction of nitrate leaching, although its magnitude depends on the biochar application rate and soil biogeochemical characteristics. Use of RHB, especiallyin paddy fields, shows a promising mitigation effect on greenhouse gas (CH4, CO2 and N2O)emissions. Although RHB characteristics are also related to other factors such as pyrolysis heating rate and residence time, its performance for specific applications (e.g. carbon sequestration, pH amendment) can be manipulated by adjusting the pyrolysis temperature (Asadi *et al.* 2021).

Conclusion

Leafy vegetables grown using rice husk biochar showed positive results. We can observe that nutrient absorption can be increased and produce nutrient-rich vege-tables due tothe biochar use. It can increase the size of the leaves, fruit and root produced is larger than thatof vegetables not grown using rice husk biochar. In addition, rice husk biochar helps green vegetables absorb nutrients better. The high content of nutrient such as silica, N, P and K inbiochar have help a lot to improve the soil condition. The soil structure, water availability, CEC also increases in the soil for using biochar. Thus, the production of the crop increase with a good quality. Although, the use of rice husk biochar has showed positive result, there still more research can be done to proof the effectiveness, because there is more space to do research on other aspect. There is suggestion to research on soil aggregation to determine the exactoptimum rate of RHB alongside the minimum time interval between addition and sowing inthe production on leafy vegetables. So that the effectiveness and the function of biochar can beincrease which can help to improve soil property. Further studies are needed to understand itsactual mechanisms for those variations before recommending it to large-scale level as a soilamendment.

REFERENCES

1. Abrishamkesh S, Gorji M, Asadi H, Bagheri-Marandi G H, Pourbabaei A A. 2015. Effects of rice husk biochar application on the properties of alkaline soil and lentil growth. Plant Soil Environ, 61(11): 475-482.
2. Abujabhah, I. S., Bound, S. A., Doyle, R., & Bowman, J. P. (2016). Effects of biochar andcompost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. Applied Soil Ecology, 98, 243–253. https://doi.org/10.1016/j.apsoil.2015.10.021
3. Alegbejo, J. (2014). Nutritional Value and Utilization of Amaranthus (Amaran-thus spp.) – AReview. Bayero Journal of Pure and Applied Sciences, 6(1), 136 – 143. https://doi.org/10.4314/bajopas.v6i1.27
4. Anwar, F., Rashid, U., Ashraf, M., & Nadeem, M. (2010). Okra (Hibiscus esculentus) seed oil for biodiesel production. Applied Energy, 87(3), 779–785. https://doi.org/10.1016/j.apenergy.2009.09.020
5. Asadi, H., Ghorbani, M., Rezaei-Rashti, M., Abrishamkesh, S., Amirahmadi, E., Chengrong, C., & Gorji, M. (2021). Application of Rice Husk Biochar for Achieving Sustainable Agriculture and Environment. Rice Science, 28(4), 325–343. https://doi.org/10.1016/j.rsci.2021.05.004
6. Asadi Zeidabadi, Z., Bakhtiari, S., Abbaslou, H., & Ghanizadeh, A. R.

(2018). Synthesis, characterization and evaluation of biochar from agricultural waste biomass for use in building materials. Construction and Building Materials, 181, 301–308. https://doi.org/10.1016/j.conbuildmat.2018.05.271

7. Ashok Kumar CK, Divya Sree MS, MOhana Lakshmi S, & Satheesh Kumar D. (2013). a Review on South Indian Edible Leafy Vegetables. Journal of Global Trends in Pharmaceutical Sciences, 4(4), 1248–1256.
8. Barrow, C. J. (2012). Biochar: Potential for countering land degradation and for improving agriculture. Applied Geography, 34, 21–28. https://doi.org/10.1016/j.apgeog.2011.09.008
9. Bashir, S., Salam, A., Chhajro, M. A., Fu, Q., Khan, M. J., Zhu, J., Shaaban, M., Kubar, K.
10. A., Ali, U., & Hu, H. (2018). Comparative efficiency of rice husk-derived biochar (RHB) and steel slag (SS) on cadmium (Cd) mobility and its uptake by Chinese cabbage in highly contaminated soil. International Journal of Phytoremediation, 20(12), 1221–1228. https://doi.org/10.1080/15226514.2018.1448364
11. Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. N. (2019). Crop residue burning in India: Policy challenges and potential solutions. International Journal of Environmental Research and Public Health, 16(5), 1–19. https://doi.org/10.3390/ijerph16050832
12. Biel, W., Jendrzejczak, E., Jaroszewska, A., Witkowicz, R., Piatkowska, E., & Telesiński, A.(2017). Nutritional content and antioxidant properties of selected species of Amaranthus L. Italian Journal of Food Science, 29(4), 728–740.
13. Bioenergy, G. C. B., Xiang, Y., Deng, Q. I., Inventory, F., Botany, A., Ecology, W., Garden, W. B., Academy, C., Sciences, B., Provincial, J., Ecosystems, D., & Ecohydrology, W. (2017). Effects of biochar application on root traits : a meta-analysis. Bioenergy, 1563–1572. https://doi.org/10.1111/gcbb.12449
14. Brennan, A., Jiménez, E. M., Puschenreiter, M., & Alburquerque, J. A. (2014). Effects of biochar amendment on root traits and contaminant availability of maize plants in a copper and arsenic impacted soil. Plant Soil, 379, 351–360. https://doi.org/10.1007/s11104-014-2074-0
15. Buturi, C. V., Mauro, R. P., Fogliano, V., Leonardi, C., & Giuffrida, F. (2021). Mineralbiofortification of vegetables as a tool to improve human diet. Foods, 10(2), 1–23. https://doi.org/10.3390/foods10020223
16. Carter, S., Shackley, S., Sohi, S., Suy, T. B., & Haefele, S. (2013). The Impact of Biochar Application on Soil Properties and Plant Growth of Pot Grown Lettuce (Lactuca sativa) and Cabbage (Brassica chinensis). Agronomy, 3, 404–418. https://doi.org/10.3390/agronomy3020404
17. Clough, T. J., Condron, L. M., Kammann, C., & Müller, C. (2013). A review of biochar and soil nitrogen dynamics. Agronomy, 3(2), 275–293. https://doi.org/10.3390/agronomy3020275
18. Ebido, N. E., Edeh, I. G., Unagwu, B. O., Nnadi, A. L., Ozongwu, O. V, Obalum, S. E., & Igwe, C. A. (2021). Rice-husk biochar effects on organic carbon , aggregate stability and nitrogen-fertility of coarse-textured Ultisols evaluated using Celosia argentea growth. SAINS TANAH – Journal of Soil Science and Agroclimatology, 18(2), 177–187.
19. Eduah J O, Nartey E K, Abekoe M K, Breuning-Madsen H, Andersen M N. 2019. Phosphorus retention and availability in three contrasting soils amended with rice husk and corn cob biochar at varying pyrolysis tempera-tures. Geoderma, 341: 10-17.
20. Eyheraguibel, B., Silvestre, J., & Morard, P. (2008). Effects of humic substances derivedfrom organic waste enhancement on the growth and mineral nutrition of maize. Bioresource Technology, 99, 4206–4212. https://doi.org/10.1016/j.biortech.2007.0

8.082

21. Faloye, O. T., Alatise, M. O., Ajayi, A. E., & Ewulo, B. S. (2019). Effects of biochar and inorganic fertiliser applica-tions on growth, yield and water use efficiency of maize under deficit irrigation. Agricultural Water Manage-ment, 217(February), 165–178. https://doi.org/10.1016/j.agwat.2019.02.044
22. Gemede, H. F. (2015). Nutritional Quality and Health Benefits of Okra (Abelmoschus esculentus): A Review. Journal of Food Processing & Techno-logy, 06(06), 29–37. https://doi.org/10.4172/2157-7110.1000458
23. Hafeez, M., Mona Hassan, S., Sharif Mughal, S., Raza Ayub, A., Yasin, M., Nasir MehmoodKhan, M., Mushtaq, M., & Kamran Khan, M. (2020). Evaluation of Biological Characteristics of Abelmo-schus esculentus. International Journal of Biochemistry, Biophysics & Molecular Biology, 5(2), 44–51. https://doi.org/10.11648/j.ijbbmb.20200502.15
24. Hao, Z., Wang, C., Yan, Z., Jiang, H., & Xu, H. (2018). Magnetic particles modification of coconut shell-derived activated carbon and biochar for effective removal of phenol from water. Chemosphere, 211, 962–969. https://doi.org/10.1016/j.chemosphere.2018.08.038
25. J. Y. Seo; D. Tokmurzin; D. Lee; S.H. Lee; M. W. Seo; Y. K. Park. 2022. Production ofbiochar from crop residues and its application for biofuel production processes – An overview. Bioresource Technology. 361, 127740.
26. Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A., & Sonoki, T. (2014). Physical and chemical character-ization of biochars derived from different agricultural residues. Biogeosciences, 11(23), 6613–6621. https://doi.org/10.5194/bg-11-6613-2014
27. Kamble, V. S., & Jadhav, V. D. (2013). Traditional Leafy Vegetables: A Future HerbalMedicine. International Journal of Agricultural and Food Science, 3(2), 56–58.
28. Kandel, A., Dahal, S., & Mahatara, S. (2021). A review on biochar as a potential soil fertility enhancer to agricul-ture. Archives of Agriculture and Environmental Science, 6(1), 108–113. https://doi.org/10.26832/24566632.2021.0601014
29. Kim, M. J., Moon, Y., Tou, J. C., Mou, B., & Waterland, N. L. (2016). Nutritional value, bioactive compounds and health benefits of lettuce (Lactuca sativa L.). Journal of Food Composition and Analysis, 49, 19–34. https://doi.org/10.1016/j.jfca.2016.03.004
30. Kumar, D., Kumar, S., Gochar, C. S., Rampur, M., Saharanpur, M., Pradesh, U., Corresponding, I., & Shekhar, C. (2020). Nutritional components in green leafy vegetables: A review. Journal of Pharmacognosy and Phytochemistry, 9(5), 2498–2502. www.phytojournal.com
31. Kumari, A., & Rajan, R. (2016). Implication of Biochar in Fruit Crop Production. MARUMEGH, 4(1), 23–27. www.marumegh.com
32. Kyei, E., Manka, A. D., Bernd, N., Werner, S., & Ha, V. (2019). Agronomic effects of biochar and wastewater irrigation in urban crop production of Tamale, northern Ghana. Nutr Cycl Agroecosyst, 231–247. https://doi.org/10.1007/s10705-018-9926-6
33. Mosharrof, M., Uddin, M. K., Jusop, S., Sulaiman, M. F., Shamsuzzaman, S. M., & Haque, N. A. (2021a). Changes in acidic soil chemical properties and carbon dioxide emissiondue to biochar and lime treatments. Agriculture (Swit-zerland), 11(3), 1–20. https://doi.org/10.3390/agriculture11030219
34. Mosharrof, M., Uddin, M. K., Sulaiman, M. F., Mia, S, Shamsuzzaman, S. M., Haque, A. N. A. (2021b). Combined Application of Biochar and Lime Increases Maize Yield and Accelerates Carbon Loss from an Acidic Soil. Agronomy, 11, 1313. https://doi.org/10.3390/agronomy1107131

3
35. Mosharrof, M., Uddin, M. K., Mia, S, Sulaiman, M. F., Shamsuzzaman, S. M., Haque, A. N. A. (2022). Influence of rice husk biochar to reduce lime and phosphorus application rate in acid soil: A field trial. Sustainability, 14, 7418. https://doi.org/10.3390/su141274
36. Mukherjee, A., & Lal, R. (2013). Biochar impacts on soil physical properties and greenhouse gas emissions. Agronomy, 3(2), 313–339. https://doi.org/10.3390/agronomy3020313
37. Oh, T., Lee, J., Kim, S., & Lee, H. C. (2017). Effect of biochar application on growth of Chinese cabbage (Brassica chinensis). PLANT & FOREST, 44(September), 359–365.
38. Rajapaksha A U, Vithanage M, Ahmad M, Seo D C, Cho J S, Lee S E, Lee S S, Ok Y S.2015. Enhanced sulfamethazine removal by steam-activated invasive plant-derived biochar. J Hazard Mater, 290: 43-50.
39. Rahman, M. M., Uddin, S., Mofizur, M., & Jahangir, R. (2021). Integrated Nutrient Management Enhances Producti-vity and. Plants, 1–21.
40. Ronsse, F., van Hecke, S., Dickinson, D., & Prins, W. (2013). Production and characterization of slow pyrolysis biochar: Influence of feedstock type and pyrolysisconditions. GCB Bioenergy, 5(2), 104–115. https://doi.org/10.1111/gcbb.12018
41. Sarker, U., Oba, S., & Daramy, M. A. (2020). Nutrients, minerals, antioxidant pigments and phytochemicals, and antioxidant capacity of the leaves of stem amaranth. Scientific Reports, 10(1), 1–9. https://doi.org/10.1038/s41598-020-60252-7
42. Schneider, F., & Haderlein, S. B. (2016). Geoderma Potential effects of biochar on theavailability of phosphorus — mecha-nistic insights. Geoderma, 277, 83–90. https://doi.org/10.1016/j.geoderma.2016.05.007
43. Siddiqui, A. R., Nazeer, S., Piracha, M. A., Saleem, M. M., Siddiqi, I., Shahzad, S. M., &Sarwar, G. (2016). The produc-tion of biochar and its possible effects on soil properties and phosphate solubilizing bacteria. Journal of Arid Agriculture and Biotechnology, 1(1), 27–40.
44. Singh Karam, D., Nagabovanalli, P., Sundara Rajoo, K., Fauziah Ishak, C., Abdu, A., Rosli,Z., Melissa Muharam, F., & Zulperi, D. (2022). An overview on the preparation of rice husk biochar, factors affecting its properties, and its agriculture application. Journal of the Saudi Society of Agricultural Sciences, 21(3), 149–159. https://doi.org/10.1016/j.jssas.2021.07.005
45. Singh, P., Chauhan, V., Tiwari, B. K., Singh Chauhan, S., Simon, S., Bilal, S., & Abidi, A. B.(2014). An overview on okra (Abelmoschus esculentus) and it's importance as a nutritive vegetable in the world. International Journal of Pharmacy and BiologicalSciences, 4(2), 2230–7605. www.ijpbs.comorwww.ijpbsonline.com
46. Sun, J., He, F., Pan, Y., & Zhang, Z. (2017). Effects of pyrolysis temperature and residence time on physicochemical properties of different biochar types. Acta Agriculturae Scandinavica Section B: Soil and Plant Science, 67(1), 12–22. 315 https://doi.org/10.1080/09064710.2016.1214745
47. Sun, J., He, F., Shao, H., Zhang, Z., & Xu, G. (2016). Effects of biochar application on Suaeda salsa growth and saline soil properties. Environmental Earth Sciences, 75(630),318 1–6. https://doi.org/10.1007/s12665-016-5440-9
48. Tomczyk, A., Sokołowska, Z., & Boguta, P. (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Reviews in Environmental Science and Biotechno-logy, 19(1), 191–215. https://doi.org/10.1007/s11157-020-09523-3
49. Varela Milla, O., Rivera, E. B., Huang, W. J., Chien, C. C., & Wang, Y. M. (2013). Agronomic properties and characterization of rice husk and wood biochars and their effect on the growth of

water spinach in a field test. Journal of Soil Science and Plant Nutrition, 13(2), 251–266. https://doi.org/10.4067/S0718-95162013005000022

50. Vendra, S., Chaturvedi, S., Dhyani, V. C., & Kasivelu, G. (2020). Bioresource Technology Pyrolysis temperature influences the characteristics of rice straw and husk biochar and sorption / desorption behaviour of their biourea composite. Bioresource Technology, 314 (April), 1–9. https://doi.org/10.1016/j.biortech.2020.123674
51. Zaitun, Z., Halim, A., Sa'Dah, Y., & Cahyadi, R. (2022). Surface morphology properties of biochar feedstock for soil amendment. IOP Conference Series: Earth and Environmental Science, 951 (1), 1–6. https://doi.org/10.1088/1755-1315/951/1/012034