Journal of Modern Materials
ISSN: 2456-4834
Volume 6, Issue 1, pp. 40-51, 2019
DOI: https://doi.org/10.21467/jmm.6.1.40-51

REVIEW ARTICLE

Multiple Beneficial Effects of Using Biochar (as a Great Organic Material) on Tolerance and Productivity of Rice under Abiotic Stress

Gulaqa Anwari [1,2*], Jin Feng [2], Abdourazak Alio Moussa [2]

[1] Department of Agronomy, Faculty of Agriculture, Kunduz University, Kunduz 3501, Afghanistan.
[2] College of Agronomy, Jilin Agricultural University, Changchun 130118, China.

* Corresponding author email: gulaqa.anwari@gmail.com

Received: 31 October 2019 / Accepted: 23 December 2019 / Published: 31 December 2019

ABSTRACT

Rice as a sensitive crop that usually affected by many harmful environmental stresses. Numerous policies are followed to increase plant growth-tolerance under abiotic-stresses in various plant species. The attempts to improve crop tolerance against abiotic stresses via common breeding method are needed to follow a long-term, and may also be non-affordable, these are due to the existing genetic variability of the plant. Current review analysis existing knowledge gaps, challenges, and opportunities in the biochar application as a beneficial and pyrogenic-C, material. Consequently, a review of the literature with a high focusing on the multiple beneficial effects of using biochar on tolerance and productivity of rice in abiotic stresses is needed. This review provides a summary of those efforts that would be beneficial in reducing inconvenienced abiotic-stresses, and also how using biochar could increase rice tolerance and production through the supporting of plant growth regulator's roles. Accordantly, present review findings showed that biochar is a great amendment and consisting of principally organic rich-C matter, which has multiple benefits on improving soil physicochemical and biological properties as well as increasing rice tolerance and its productivity through enhancing plant hormones roles under abiotic stressed conditions (heat/cold temperature, drought, salinity, heavy metal, and climate change stresses). Nevertheless, it is anticipated that further researches on the benefits of biochar will increase the comprehension of interactions between biochar and plant growth hormones, to accelerate our attempts for improving rice tolerance and productivity, under abiotic-stress conditions.

Keywords: multiple beneficial, biochar amendment, Organic-C, Pyrogenic-C martial, Rice-tolerance, productivity, abiotic- stress.

1 Introduction

Rice (*Oryza sativa L.*) is the second largest under cultivated area crops in the world, which consumes as a staple food by 50% world's population. According to the statistical report on rice intake globally from 2008 to 2017, approximately 47,563 million metric tons have been consumed. Based on the current population growth, many developing countries are facing challenges due to the high demand to have more rice production under raising environmental stresses. China and India have the biggest positions in rice production in the world. Only China has a 20% paddy-field and 31% of all world rice production. Many studies have been described that among other crops, rice is the most and ancient food source for people as well, [1]. Consequently, each kind of stress to this plant can have a dangerous impact on rice production and ultimately result in huge economic losses. While rice is a highly adaptable crop that can as result be grown in a wide variety of environmental and climatic conditions, which is commonly undesirable for the growth of other crops around the globe. Although there has been reported a great increase in rice production during recent years, it still needs to be developed and improved the yielding capacity of its through stress tolerance mechanisms [1, 2].

Biochar addition to effectiveness in soil ameliorate and plant productivity, it also by having a great influence on abiotic stresses that can play a key role in adapting (acclimatize) rice crop through the promoting of plant growth regulators roles. These multiple beneficial effects in different conditions can assist rice plants via the establishment of proportional growth (mediating growth), development promptly and optimal allocation of nutrients (nutrient allocation) [3, 4]. Plant growth regulators move through specific channels in specific regions to achieve a very low concentration of plants in response to harmful-stresses. It should be noted that the whole biological activities of plants are directly or indirectly affected by different plant growth hormones[3]. To session rice agronomic needs, massive abiotic-stresses tolerance is required to develop for the majority of rice-growing areas. Abiotic-stresses such as cold and high-temperatures, salinity, UV-radiations, and drought can be a very serious menace to the productivity of rice plants. Among the mentioned abiotic stresses, salinity and drought stresses are known as the biggest threat and worst rice productivity losses around the world. Rice same to other crops, is most exposed to multiple climatic-stresses that consequently in the combination of the concurrent or consecutive complex of sets stresses, for which the rice crop has developed abilities to respond in several unique ways [5].

Moreover, biochar application as a helpful material that is known to have variable effects on crop production depending on the biochar types and properties, soil conditions and plant types. Several studies have reported the positive impact of biochars prepared from various feedstocks, with and without inorganic and organic fertilizers, on the crop yield both in acidic and alkaline soils. Analyses revealed that overall biochar application increased the crop yield by approximately 10 % under various soil conditions, but in another analysis is found a 25 % increase in crop yield in the tropics area [4]. Biochar by contributing and supporting plant growth hormones roles, which in response to environmental and genetic factors, they are the most important internal factors that regulating growth and development. Where in the process of source formation, the potential of storage and production plays a major role. Also improving rice performance under different stresses mainly related to the effects of biochar types, and plant growth regulators [6]. However, in figure1, it could be seen how biochar produced from Rice-residual to be returned, and it's used again as an affordable material in rice production, as an example [7].

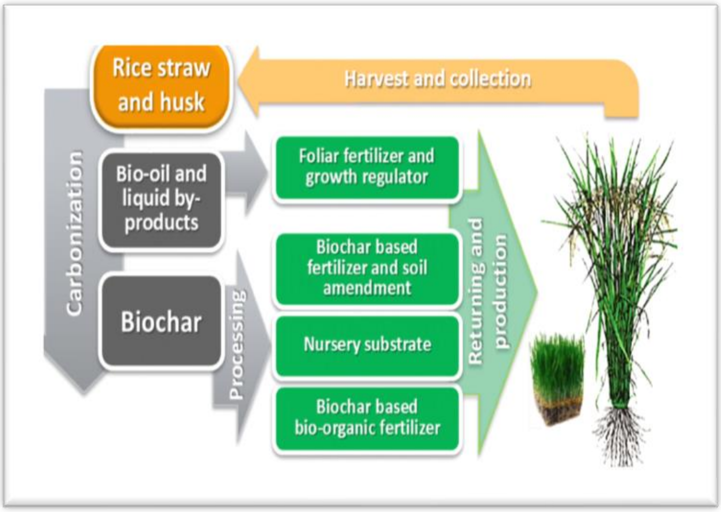

Figure 1: *indicates the returning and production of biochar (Rice-straw and Rice-husk) with multiple beneficial effects on rice productivity through the effectiveness of described such as (i) Foliar-fertilizer and growth regulator, (ii) Biochar based fertilizer and soil amendment, (iii) Biochar based bio-organic fertilizer [7]*

Sine all kinds of abiotic stresses have different effects on the main performance of rice production. The impacts of abiotic stresses with appropriate and effective strategies such as increase rice resistance, and the reduction of the negative effects of various tensions, from biochar as a beneficial agent should be mainly used. But, still providing a clear view of, how multiple positive effects of biochar could be enhanced the effective role of plant growth regulators, how biochar and plant growth regulators may interact with each other, these are the important hypotheses and research questions should be addressed by further studies.

According to previous studies, that the investigating studies on the multiple beneficial effects of biochar application on tolerance and productivity of rice under abiotic stresses have been largely ignored. The general objectives of this review are paying attention to have a deep overview of different environmental-stresses, biochar application effects on rice tolerance and productivity through promoting plant growth hormones, as well as signaling pathways involved and plant's response to them. In the specific objectives present review, will be discussed to:(i) highlight the more dangerous and serious type impacts of abiotic stresses in rice plants growth, (ii) addressing the multiple beneficial effects of biochar application on rice tolerance and productivity under abiotic-stresses (drought, salinity, high temperature, low temperature, heavy metals, and climate change), which widely have influence on growth and morphological changes of rice, and (iii) pointing some useful interaction roles between biochar and plants growth hormones for improving tolerance and rice production through the environmental stresses reduction.

2 Abiotic stresses impact on rice growth and productivity

Abiotic stresses are a package of environmental factors that include drought, salt, hate, low temperature, heavy metal, ozone, and UV stresses, etc. (figure 2), which are stimulated wider negative effects to plant responses for growth hormones [8]. These stresses have a major impact on plant growth and development through physiological and biochemical activities, consequently, reduce crop yield losses worldwide. Therefore, plant growth and performance ability under abiotic-stresses depend on the amount of vegetative growth and plant reproduction [6]. It should mention that in the (figure 2), a summary of the more common impacts of abiotic stresses in rice growth, and its responses to stressed condonations are presented.

2.1 Drought stress impact on rice growth and productivity

Plant growth and development are recognized as a complicated issue to exchange amongst sources and extent of the association between the two main plant organs (root-framework and stem) and the balance of them. Plants are facing water shortages, seriously prevent its growth and development in comparison to some other ecological factors [9]. Whenever rice plants are exposed to agricultural drought, the amount of moisture needed to grow and develop into the supplementary life cycle is not provided to the rice.

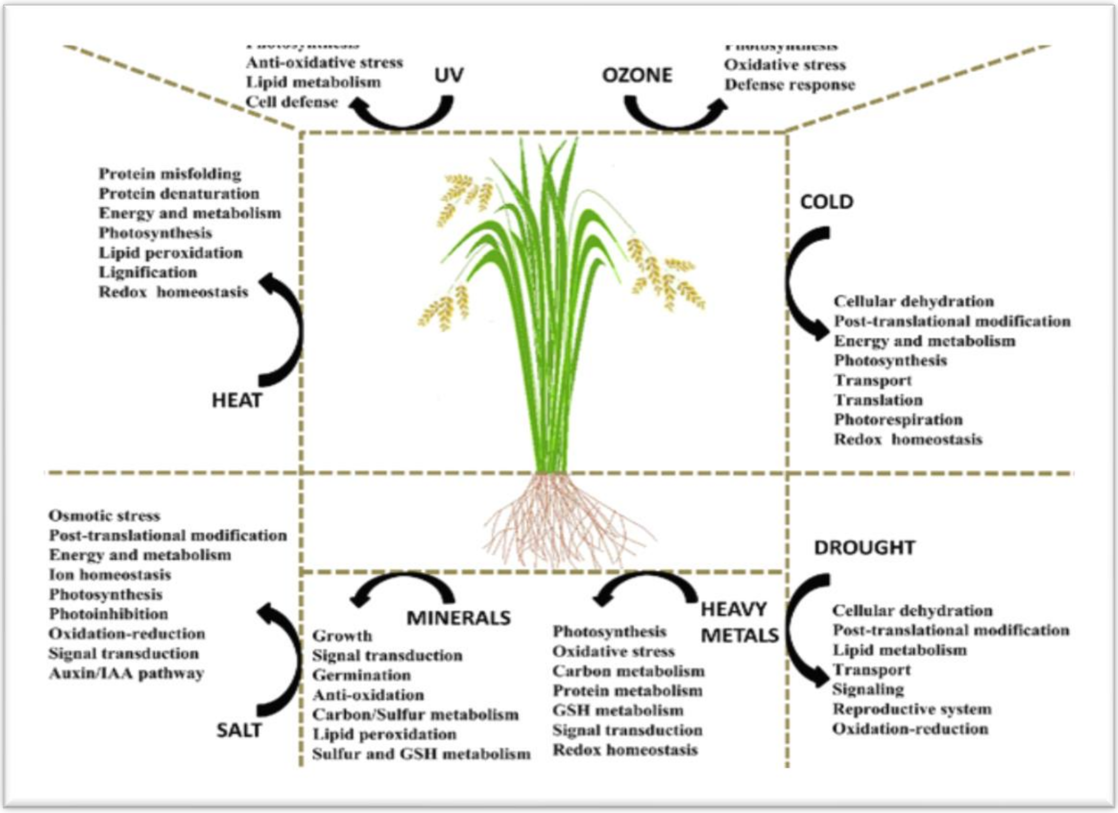

Figure 2: *Common Abiotic Stresses Response in Rice [18]*

Similarly, agricultural droughts lead to biomass accumulation. Nevertheless, the most severe effects of drought stress on rice are: (i) the speed of cell division and expansion, (ii) leaf size, stem elongation, and root proliferation, (iii) disorder on periods of opening and closing stomata, (iv) nutrients and water uptake by plants and their use efficiency (figure 2), [10]. With increasing water shortage and moisture in rice plants increase, the amount of abscisic acid (ABA) biosynthesis which decreases stomatal efficiency and leads by causing problems in the transpiration pathway [11]. However, the comprehension of the rice morphological and physiological compatibility under the impacts of the drought-stress can be very crucial to overcoming that problem [6].

2.2 Salt stress impact on rice growth and productivity

Salinity is a kind of the most dangerous abiotic-stress that exists in a high concentration of salt content in the soil, which causes obstacle impact to plant growth and leads to finally death of plants [6]. On a global scale, and among abiotic stresses, no other toxin matter is as hazardous as salt for growing rice. Salinity is a concern situation because it reduces soil and plant productivity eventually reduces crop yield. It is supposed that 20% of all cropland and almost 50% of all irrigated land areas affected by salinity-stress and reduced productivity less than genetic potential. [12]. There should be worrying that the increase in salt-contaminated soil is due to the lack of irrigation water or its quality and the use of saline water. Influence of high salt stress on rice products can happen in various ways including ion toxicity, nutritional disorders, alteration of metabolic processes, oxidative stress, cytotoxicity, membrane irregularity, reduction of cell division and expansion, as well as water deficit stress (figure 2), [13].

2.3 High-temperature stress impact on rice growth and productivity

Greenhouse gas emissions cause a constant increase in the temperature of the atmosphere. According to the Intergovernmental Panel on Climate Change report, temperatures have increased from 1.8 to 4 degrees Celsius during the 21st century and averaging 0.2 degrees Celsius every 10 years [13]. Since rice is more susceptible to stress during the reproductive and adult stages, intensive stress may even lead to severe damage to the rice plant for several hours. On the other hand, high temperatures during maturity can reduce the quality of straw and seed filling and ultimately decrease crop production (figure 2). The stress of high-temperature and extreme tolerance cause immutably losses to rice performances like yielding, fertility, germination, and grain quality [14]. Therefore, one of the most serious high-temperature stress sensibility in all rice specifically relates to the phonological stages, which have a significant impact on the yield of rice products, the heat- stress at night, in comparison with the day is more affected. High-temperature stress at night causes sudden instability and changes in the germplasm of rice and spike, where even flower buds are unable to absorb carbohydrates during such stress [5]. Though both temperatures extremely cause harm to the rice plant, high-temperatures at the stages of flowering are more severe, thus affecting the fertility of the plant by increasing 1°C in the growing season has decreased rice yields by 15 %, [13, 15].

2.4 Low-temperature stress impact on rice productivity

Cold temperature stress is one of the most common weather stress that can delay the growth of plants abnormally. There are two types of stress at cold temperatures, namely stress cooling/chilling and freezing/frost-stress [8]. Cold temperatures can have a serious effect on cell membrane structure and function, protein synthesis, and cell skeletal structure. In extremely cold temperature, it can result in the membrane phase shifting from a liquid crystalline phase to a solid phase of the gel. These changes can greatly affect membrane permeability [15]. Cold temperatures can also be an obstacle to photosynthesis in both reactions (light and dark). The electron pathways then face the perturbations and preparation of free radical species that can be hazardous to rice crops, causing the membranes to destroy (figure 2). And depending on the temperature, the plant's respiration rate can increase or decrease, short-term stress at low temperatures leads to high respiration, but in long-term stress, the cell is damaged and thus dies, this is due to the reduced rate breathing [6]. According to a report that protein produced under low temperatures can cause cell damage, even fluctuations in the structure of plasma layers and capacities during cooling are important features of plant resistance regulation [16].

2.5 Heavy metals impact on rice growth and productivity

Heavy metals stresses are a major environmental stress that are naturally more than five metals with specific gravitational properties. At optimum concentrations, heavy metals play an important role in plant metabolism, growth, and productivity [17]. The response of rice proteins to stress and toxicity of metals affects related to the kinds and concentration of metals as well as the growth stage and tissue type. Protein studies affecting heavy metals have been performed in rice and other plants (figure 2). These five heavy metals are (Cadmium, Arsenic, Mercury, Copper, Aluminum), which the addressing whole details and the response of the rice plant to them, is out of the reach of this review because of a large amount of information they require to the separate articles [18]. As well, figure1 shows the main rice responses to abiotic stresses. The common reaction and defense systems that are created under conditions of major abnormal stresses (cold, heat, drought, salt, heavy metals, minerals, UV and ozone). All of these abiotic stresses produce ROS (reactive oxygen species). The abundance of ROS-inhibiting proteins and apparent roles of plant growth hormones helps stress plants to detoxify ROS and maintain redox homeostasis within the cell [18].

Overall, the main abiotic-stresses (salinity, drought, heat and cold and heavy) negatively affected in survival, yielding and biomass production of plants by as much as (70%) and threaten food safety around the world. Dryness is the major factor in plant growth, development, and productivity, mainly occurring due to salt, drought and heat stresses. So, when the rice plant is exposed to abiotic stresses, it can face a huge number of problems [19]. Since resistance and tolerance to this problem in plants are of great importance in nature. Although breeders face an enormous challenge in attempting to manipulate new genetic modification in plants to overcome the issue. Conventional plant breeding approaches have limited effectiveness in improving resistance and tolerance to these stresses, but in among the different ways of making tolerance, biochar application also can be a useful and suitable method to mitigate the negative effect of abiotic stresses [20]. Thus, for the approach to this goal, it is needed to use biochar that has a great potential to improve the positive roles of plant growth regulators and rice-producing through stressed reduction (Table 1).

Table 1: *The application of different biochars type amendments effects on the increasing percentage (%) of rice growth and productivity under abiotic stresses.*

Abiotic stresses	*Biochar Type*	*Plant*	*Growth/Yield Increases (%)*	*Reference*
Acidity stress	*Sewage sludge*	*Rice*	148.8-175.1	[37]
Salinity stress	*Bamboos*	*Rice*	20	[38]
Salinity stress	*Rice husk*	*Rice*	12	[39]
Nutrient deficient stress	*Rice straw*	*Rice*	12.3	[40]
Saline-sodic stress	*Wheat straw*	*Rice*	13.4	[25]
Saline–sodic stress	*Peanut shell*	*Rice*	22.45-23.81	[22]
Cold waterlogged stress	*Bamboos*	*Rice*	8.5-10.7	[41]
Nutrient deficient stress	*Rice residues*	*Rice*	16-35	[42]
Cold waterlogged stress	*Bamboo*	*Rice*	8.51	[19]
Nutrient deficient stress	*Rice-husk*	*Rice*	4-10	[43]
Tropical (heat- stress)	*Rice-husk*	*Rice*	5	[44]
High-temperature stress	*Rice-husk*	*Rice*	7	[29]
Cadmium stress	*Rice and maize residues*	*Rice*	3.9	[45]
Cd and Pb stresses	*Wheat straw*	*Rice*	16.6–18.3	[46]

3 Biochar application effects on rice tolerance and productivity under abiotic stresses

3.1 Definition of Biochar based on production and use

Biochars are a form of charcoal or carbon-rich materials that produced through exposing the organic waste matter (such as wood chips, crop residue, or manure) to heat or pyrolysis in a low-oxygen environment, they are used especially as a soil amendment. There are different kinds of biochar based on plant biomass and production methods. The substance, in the below (figure 3), could be indicated the biochar types as an example.

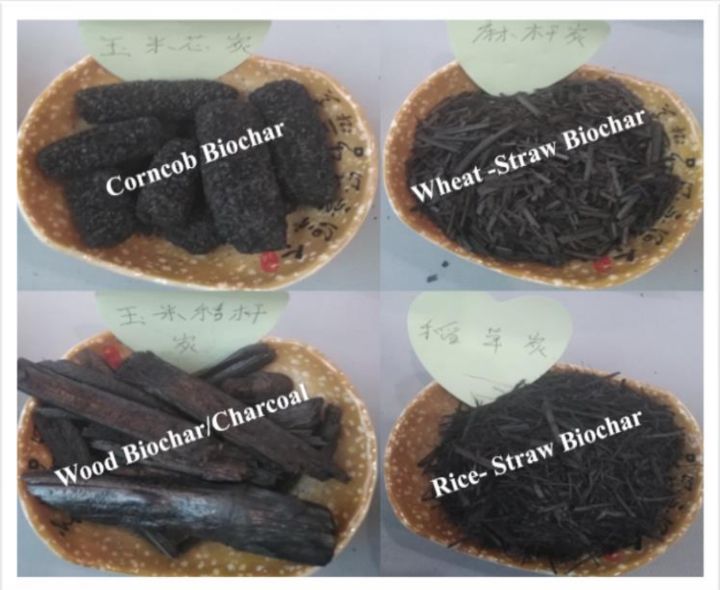

Figure 3: *shows the four types of biochar that were produced from (a) Corncob, (b) Straw of Rice, (c) Woods, and (d) Straw of Wheat. These images have been taken by Assistant Professor Gulaqa Anwari on the day of the international conference "First International Conformance on Biochar Research and Application" on September 20, 2019, in Shenyang Liaoning China.*

However, biochar is thought to be the key component in a carbon-negative strategy to resolve several critical current ecological and energy challenges as well as it has many beneficial effects on soil and plant productivity [21].

3.2 Biochar application effects on tolerance and productivity of rice under drought-stress

Plant development is a complex issue of exchange between resources and the limitations of the relationship between the two main parts of a plant (root framework and stem) and the balance between them. Water deficiency seriously damages plant growth compared to other ecological factors [9]. Many investigated results on the ameliorative effects of biochar on the growth of different plants under drought-stress conditions have shown that the biochars application were caused to improve products' quality and crop productivity via tolerantly and water holding capacity [4]. As, vineyard field increased the vine yield, especially in the years receiving lowest rainfall, however, no significant effects were observed on the grape quality parameters such as brisk, total acidity and anthocyanin's [22]. There is also compelling evidence that biochar could reduce drought stress when applied in combination with microbial inoculants under limited water availability. Similarly, there was found that biochar application influenced the potato leaf area, root biomass, water use efficiency (WUE) and soil pH. However, these effects vary with biochar type, soil characteristics, crop types, and climatic conditions. So biochar application has extensively been linked to increased water use efficiencies and improved water relations under drought stress [23]. This discussion may lead to the fact that biochar application with other bio-resources such as organic amendments and microbial inoculants may reduce drought stress to plants, whereas, these effects vary with biochar type as well, [4].

Agricultural drought-stress cause biomass accumulation. The general impacts of drought tensions on rice crops are summarized in the disturbing plant physiology process through damaging cell biology activities (figure 2), [10]. Therefore, many studies results have shown that the application of biochar positively affected on mitigation of drought stress, such as the rice husk biochar application had a positive impact on growth, water relation traits and yield of maize under drought conditions. Among the doses of rice husk biochar, the rate of 20 t ha^{-1} dose presented the best performance to enhance plant height, leaf water content, and yield of maize and rice [24]. Biochar addition can alter the resistance and resilience of soil microbial properties to drought tensions. This process is mediated by changes in the soil microbial and fungal communities. So biochar application can increase the resistance of both the bacterial and fungal networks to drought conditions [23]. Based on a report that the using of biochar in addition to recovery and increasing absorption withholding the capacity of water in the soil, it also can prompt water holding capacity in all parts of rice plants in comparing to zero biochar traits (Table1), [22, 25]. According to an updated study, it has been reported that biochar application increases plant growth and yield in drought conditions, as well as increased photosynthesis, nutrient uptake and modified gas exchange characteristics in plants under moisture stress. In drought stress, soil moisture, soil water holding capacity and water status of plants increased but decreased sodium absorption through increasing K uptake [26]. Biochar can be a good alternative for arid and semiarid areas because those areas are mostly faced with drought stress conditions. So, for more our understanding will be needed further investigations.

3.3 Biochar application effects on rice tolerance and productivity under salt-tress

Salinity-stress is the most dangerous environmental stress, which the high concentration of salt content in the soil that results in obstacles in rice growth and leads to death in rice plants [12]. Since the leaching is known as a useful method for washing or removing salt from the field, but it is a doubtful issue that the increased salinity in the soil is due to irrigation water shortage, and may also relate to quality and saline water in the rice field [13].

From applied biochar amendment has been found useful in mitigating salt stress to plants modifying soil physical, chemical and biological properties, which directly linked to Na dynamics in the soil solution-phase [4]. The use of biochar for the reclamation of salt-affected lands has been reviewed, which biochar can reclaim salt-affected soils, but the effects are dependent on biochar properties, and interactions between biochar and soil properties need further evaluation. So in the sustainable and profitable use of salt-affected soils by applying biochar is emphasized, and should low-cost methods. For producing biochar are urgently searching, and also reviewed the extensive literature to conclude that biochar improved soil physicochemical and biological properties under salinity stress differential origin [27]. Studied the effects of poultry manure derived biochar compost on soil biological indicators found that biochar enhanced microbial biomass carbon and the activities of urea's, inverters and phosphatase enzymes in saline soil under maize cultivation. Similarly, it also found varying, but positive effects biochar on soil enzyme activities in saline soil depending on the rate of biochar application and incubation conditions[20]. However, the data about the effects of biochar on soil properties under saline conditions is not consistent. For example, biochar the application rate of 30 gm^2 increased soil EC but resulted in non-significant affects soil pH under salt stress. In another study, the application of biochar saline soil condition reduced soil pH and increased SOC contents, CEC and available P,[4]. Similar results were observed when composted biochar was applied to the saline soil, which improved soil organic matter and CEC but reduced the exchangeable Na and soil pH, and these investigations indicate that the biochar amendments can improve soil properties and plant growth under salinity stress [28].

Biochar has multiple binding sites due to the presence/or modification of various functional groups produced during the pyrolysis process depending on the type of feedstock and temperature. After the addition of biochar to salt-affected soils, it was observed that sodium content and soil pH were significantly reduced compared with control treatments [27]. It was also observed that soil organic carbon and available phosphorus increased in biochar amended soils. There was suggested that biochar addition to salt-affected soils could be an alternative solution due to its high adsorption capacity of the Na cell through degrading proteins, enzymes, and nucleic acids [22]. While in parallel to this oxidative stress, the enzymatic [like SOD, CAT, glutathione reductase (GR), guaiacol peroxidase (GPX) and APX] and non-enzymatic [ascorbic acid (ASA) and dehydroascorbate reductase (DIIAR)] components in plants are also produced as defense mechanisms in plant's against heavy metals stress (HMs) stress, but the highest concentrations of these metals in soil suppressed the enzymatic activities in plants [4]. A result of biochar application of saline-sodic soil demonstrated that biochar can significantly mitigate salinity stress due to its high salt sorption capacity, by increasing K^+ availability, rice tolerant, and reclamation saline-sodic paddy-soil, which ultimately improves growth, physiology, and yield of rice (Table1), [25].

3.4 Biochar application effects on rice tolerance and productivity high-temperature Stress

Heat-stress as a type of environmental stress, which has harmful impacts on plant growth and performance, but plants have resistance in primary stress levels. However, rice plants resistance to high-temperature stress can be categorized into three groups: (i) heat escape; this means that the plant completes its reproductive phase before the onset of severe heat stress, (ii) heat avoidance; plant maintain high water status by closing stomata, decreasing leaf area, senility of older leaves, and/or increasing root growth ; and (iii) heat tolerance: plant holds its functions during severe stress or recovers functioning after severe stress [8].

Among abiotic stresses, heat stress is one of the most important stresses which have adverse effects on growth, productivity, and yield crops. Stress is not only affecting morphological, physiological and biochemical attributes but also reduced the nutritional quality of various cereal crops. It has been reported that global wheat production was declined by 6% for each degree Celsius rise in temperature [13]. Though high temperatures are also good for sustainable crop production in some cooler areas around the globe, the overall impacts on global food security are adverse. Rising high temperatures severely disturbed photosynthesis production, proteins, inactivate key enzymes, damage proteins and produced ROS. All these factors are responsible for the reduction of plant growth and favor oxidative damage. Moreover, under high-temperature stress, during seed filling could also result in an accelerated filling, which will further result in poor quality and yield reduction [4]. However, the result of a study on a biochar application protects rice pollen from high-temperature stress is shown that the high-temperature stress significantly reduced spike fertility, pollen fertility, anther dehiscence, germination rate per stigma, pollen count per stigma and the rate of pollen germination, but the biochar application by having a good role, controlled negative effect, and caused to mitigate high-temperature stress (Table1), [29].

3.5 Biochar application effects on rice tolerance and productivity under low-temperature stress

Cold-stresses mainly impact on plant growth and development around the world, plants significantly vary in their capacities to manage freezing temperatures [16]. Plants grown under tropical and subtropical conditions (i.e., maize, cotton, soybean, rice, mango, tomato, etc.) are more sensitive to freezing. Plants grown in a temperate climate can tolerate low temperatures, although the degree of tolerance varies from species to species. According to a report that the amino acid was produced in the low-temperature effect could be harmful to the host cells [20].

Based on the results of biochar leachate has a positive effect on rice seedling cold tolerance, organic molecules in biochar leachates enhance the cold resistance of plants when other interference factors are excluded [30] [19]. There is suggested that the positive impacts of bio-fertilizers on cold tolerance in plants are due to surface organic molecules that may act by entering a plant and interacting with stress-related proteins, and the tensions are related proteins [30]. Meanwhile, it has been reported that a bowl of cold-watered rice refers to a type of low-yielding rice that is caused by relatively low soil temperatures (generally 3–5 °C lower than normal rice paddies in summer and autumn seasons), and long-term saturated water on the soil surface [19]. Cold waterlogged paddies typically have a low and or average crop performance, this may due to high underground-water, poor drainage, a low proportion of soil temperature, poor aeration-system, less availability of nutrient content, especially soil-available phosphorous (P), and massive amounts of soil reducing substances [14]. Similar, it is reported that the biochar amendments which were derived from Rice-straw and Bamboo-residual could regulate the daily fluctuations in soil temperature at a depth of 5cm in cold waterlogged paddy-fields. Both of these biochar amendments caused to decrease in an average of soil temperature fluctuations during the whole rice-growing season, especially in the tillering stage at the end of July. It also has been said that the application of biochar and its practice in the cold waterlogged rice field could increase the amount of biomass and grain yields of rice (Table1), [19].

3.6 Biochar application effects on tolerance and productivity of rice under heavy-metal stress

Heavy metal toxicity is the main universal threat to crops productivity especially rice plants. Rice-field soils contaminated with heavy metal is a danger to food security, food safety, and the whole environment. Since the level of heavy metals or metalloids found in rice grains is increasing, and it can be a serious concern for human health [15].

Hoverer, when heavy metal accumulations extremely increase, this issue leads to a high decrease in growth and rice performance by the reduction of photosynthesis activity[31]. This response is caused by disrupting cellular organelles, the synthesis of protein, the composition of lipid, and nutrient homeostasis owing to the enhanced ROS generation causing oxidative stress, up-and-down regulation of genes involved in antioxidant defenses [32]. Moreover, the use of biochar as a black carbon having exclusive attributes like a large surface area, porous structure, a high CEC, active functional groups and a mineral phase for adsorption of heavy metals. It also has a potential role in the immobilization of heavy metals in the soil [4]. Applying biochar to contaminated soils is remarked that it can alleviate the metal toxicity and add carbon inputs, improves the microbial activities and other factors like soil pH, CEC, and sorption mechanism are primary factors involved in this sorption process of heavy metals [33]. Also, biochar in the soil alleviates heavy metals toxicity via adsorption of heavy metals on surfaces of biochar (Table1). Heavy metal pollutants in soil negatively influence soil properties and functionality through disturbing soil biological and physiochemical attributes like poor soil health (structure and productivity) and low soil microbial activities [31].

Incorporation of a large amount of biochar in the soil improved the habitat for microbial population via increased porosity, biochar can donate or accept electrons in their environments via biological pathways. Biochar is the soil that also promotes microbial electron shuttling processes, analogous to soil organic matter with redox-active functional groups. However, the result of a study has been shown that the biochar of rice-straw can effectively immobilize heavy metals, thereby reducing their mobility and bioavailability in contaminated soils (Table1), [32]. Thus, we can say that the heavy metals contents can transmission to rice grains through agricultural practice and inputs (fertilizers, pesticides, irrigation water, etc.), that they in high concentration were causing seriously in health risks. As these metals have a high persistence, non-degradability, and toxicity[15]. Therefore, several other factors like pH, decreased the solubility of heavy metals, improved allochthonous microbial biomass, and available nutrients, as also contributing to the variation in soil microbial population [4]. Table1 also refers to it.

3.7 Biochar application effects on tolerance and productivity of rice under climate-change tensions

Climate changes from future speculation to the unpleasant reality of the present time have evolved. It has been shown an inseparable linkage in the climate-changes of the agriculture ecosystem, where the impacts of climate change on agriculture and food security have been in the forefront research and policy agenda in recent years[15]. Climatic alteration in wider parts of the globe is becoming fairly perceptible. As a reason, climate change causing to create abiotic stress like high and low temperatures, droughts, salinity, osmotic stress, heavy rains, floods, and frost damages is posing serious threats to rice production and also are detrimental to farmers' earnings in the rice cultivation [34]. Although, rice plant is contributing to climate warming via greenhouse gas emissions like methane gas, by applying biochar on rice cultivation, such effects become decrease. Since the application of biochar as the main amendment can play an important role in increasing the tolerance of rice and having a great effect on water-holding capacities. It can reduce greenhouse gases, managing C-cycle, and increasing the microbial activity in the soil, which is also useful for rice under abiotic stresses [19]. The effectiveness of biochar in the reduction of climate change due to the greenhouse gas effect, which is greenhouse gas emission can be reduced by sequestering carbon, as biochar that stores carbon for hundreds of years or more. With its relative recalcitrance against microbial decay and the slow return of carbon as carbon dioxide to the atmosphere. Biochar has the potential of reducing the carbon footprint of rice production strongly, but the pyrolysis of efficient- energy technique is an important matter [35].

Moreover, some other results are indicated that instead of wasting or burning of crop residues in the field and using those residues for producing biochar in aim application into soils can reduce the climate change impacts in rice plants. This issue can be related to the level of impacts of biochar on CH4 emissions in the paddy-fields. Besides, the moderate reduction of CH4 in studies indicates a significant advantage in reducing CF of rice, which some doubt on the effect of CH4 on greenhouse gas emissions still exist [36]. Thus, being more certain of this hypothesis needs further study.

4 Conclusion

Abiotic-stresses are found all over the world, and the initial restriction on plant growth results in a significant reduction in rice yield, nonetheless, comprehension the biochemical, bio-physiological and molecular responses of rice plants to abiotic stresses on one hand, and other the recognizing of stress regulation remains a big challenge for plant science researchers around the globe. Although significant advances have been made in identifying genetic function during environmental stresses, as a large number of transformed plants have been created (single genes or multiple genes) to alter metabolic pathways to make rice plants more resistant. But they cannot reach the level of production of excellent plants resistant to stress.

Overall, biochar is known as a significant solution material to the problem of soil's ecosystem due to abiotic stresses. Consequently, we can say that this review could contribute to a better understanding of the biochar amendment benefits which is not only an effective but also an affordable substance for improving soil physicochemical and biological properties, rice tolerance and productivity through promoting plant growth hormones roles under abiotic stressed conditions. Future studies should be elevated for giving a better understanding of biochar functionalities and effectiveness. Additionally, new approaches in biochar beneficial including heavy metals adsorption, rice tolerance as well as its effect on plant hormones under environmental stresses, are strongly suggested for further researches.

5 Declarations

5.1 Study Limitations

This review did not provide enough information about biochar interaction mechanisms with plant hormones as well as for each heavy metal pollutants as separately. This is due to the existing huge numbers of data and information that could be enough for writing several review articles or books.

5.2 Acknowledgments

The authors are grateful to Assoc. Dr. Mahmoud Gamal Mohamed Abd El-Rahim, and Mr. Ajmal Mandozai for their assist and advice in this manuscript.

5.3 Competing Interests

The authors declared that no conflict of interest exists in the publication of this work.

How to Cite this Article:

G. Anwari, J. Feng, and A. Alio Moussa, “Multiple Beneficial Effects of Using Biochar (as a Great Organic Material) on Tolerance and Productivity of Rice under Abiotic Stress”, *J. Mod. Mater.*, vol. 6, no. 1, pp. 40-51, Dec. 2019. doi:10.21467/jmm.6.1.40-51

Reference

[1] R. Prasad, Y. S. Shivay, and D. Kumar, "Current status, challenges, and opportunities in rice production," in *Rice Production Worldwide*, ed: Springer, 2017, pp. 1-32.

[2] S. Pan, F. Rasul, W. Li, H. Tian, Z. Mo, M. Duan, *et al.*, "Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (Oryza sativa L.)," *Rice (N Y)*, vol. 6, p. 9, Apr 16 2013.

[3] S. Fahad, L. Nie, Y. Chen, C. Wu, D. Xiong, S. Saud, *et al.*, "Crop plant hormones and environmental stress," in *Sustainable Agriculture Reviews*, ed: Springer, 2015, pp. 371-400.

[4] M. Riaz, M. S. Arif, Q. Hussain, S. A. Khan, H. M. Tauqeer, T. Yasmeen, *et al.*, "18 Application of Biochar for the Mitigation of Abiotic Stress-Induced Damages in Plants," *Plant Tolerance to Environmental Stress: Role of Phytoprotectants*, 2019.

[5] K. Malik, "ABIOTIC STRESS SIGNALING IN RICE CROP," *Advances in Rice Research for Abiotic Stress Tolerance*, p. 551, 2019.

[6] R. Akram, S. Fahad, N. Masood, A. Rasool, M. Ijaz, M. Z. Ihsan, *et al.*, "Plant Growth and Morphological Changes in Rice Under Abiotic Stress," in *Advances in Rice Research for Abiotic Stress Tolerance*, ed: Elsevier, 2019, pp. 69-85.

[7] J. Meng, T. He, E. Sanganyado, Y. Lan, W. Zhang, X. Han, *et al.*, "Development of the straw biochar returning concept in China," *Biochar*, pp. 1-11, 2019.

[8] M. Arif, T. Jan, M. Riaz, S. Fahad, M. S. Arif, M. B. Shakoor, *et al.*, "Advances in Rice Research for Abiotic Stress Tolerance: Agronomic Approaches to Improve Rice Production Under Abiotic Stress," in *Advances in Rice Research for Abiotic Stress Tolerance*, ed: Elsevier, 2019, pp. 585-614.

[9] M. Ijaz, S. Qamar, S. A. Bukhari, and K. Malik, "Abiotic stress signaling in rice crop," in *Advances in Rice Research for Abiotic Stress Tolerance*, ed: Elsevier, 2019, pp. 551-569.

[10] M. Farooq, A. Wahid, N. Kobayashi, D. Fujita, and S. Basra, "Plant drought stress: effects, mechanisms and management," in *Sustainable agriculture*, ed: Springer, 2009, pp. 153-188.

[11] D. Todaka, K. Shinozaki, and K. Yamaguchi-Shinozaki, "Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants," *Frontiers in plant science*, vol. 6, p. 84, 2015.

[12] Z.-H. Ren, J.-P. Gao, L.-G. Li, X.-L. Cai, W. Huang, D.-Y. Chao, *et al.*, "A rice quantitative trait locus for salt tolerance encodes a sodium transporter," *Nature genetics*, vol. 37, p. 1141, 2005.

[13] S. Fahad, A. Rehman, B. Shahzad, M. Tanveer, S. Saud, M. Kamran, *et al.*, "Rice Responses and Tolerance to Metal/Metalloid Toxicity," in *Advances in Rice Research for Abiotic Stress Tolerance*, ed: Elsevier, 2019, pp. 299-312.

[14] K. E. Zinn, M. Tunc-Ozdemir, and J. F. Harper, "Temperature stress and plant sexual reproduction: uncovering the weakest links," *Journal of experimental botany*, vol. 61, pp. 1959-1968, 2010.

[15] S. Fahad, M. Noor, M. Adnan, M. A. Khan, I. U. Rahman, M. Alam, *et al.*, "Abiotic Stress and Rice Grain Quality," in *Advances in Rice Research for Abiotic Stress Tolerance*, ed: Elsevier, 2019, pp. 571-583.

[16] H. A. MacMillan, E. Baatrup, and J. Overgaard, "Concurrent effects of cold and hyperkalaemia cause insect chilling injury," *Proceedings of the Royal Society B: Biological Sciences*, vol. 282, p. 20151483, 2015.

[17] K. E. Giller, E. Witter, and S. P. Mcgrath, "Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review," *Soil biology and biochemistry*, vol. 30, pp. 1389-1414, 1998.

[18] R. Singh and N.-S. Jwa, "Understanding the responses of rice to environmental stress using proteomics," *Journal of proteome research*, vol. 12, pp. 4652-4669, 2013.

[19] Y. Liu, S. Yang, H. Lu, and Y. Wang, "Effects of biochar on spatial and temporal changes in soil temperature in cold waterlogged rice paddies," *Soil and Tillage Research*, vol. 181, pp. 102-109, 2018.

[20] M. Hasanuzzaman, M. Fujita, H. Oku, and M. T. Islam, *Plant Tolerance to Environmental Stress: Role of Phytoprotectants*: CRC Press, 2019.

[21] J. Rawat, J. Saxena, and P. Sanwal, "Biochar: a sustainable approach for improving plant growth and soil properties," in *Biochar-An Imperative Amendment for Soil and the Environment*, ed: IntechOpen, 2019.

[22] C. Ran, A. Gulaqa, J. Zhu, X. Wang, S. Zhang, Y. Geng, *et al.*, "Benefits of Biochar for Improving Ion Contents, Cell Membrane Permeability, Leaf Water Status and Yield of Rice Under Saline–Sodic Paddy Field Condition," *Journal of Plant Growth Regulation*, pp. 1-8, 2019.

[23] C. Liang, X. Zhu, S. Fu, A. Méndez, G. Gascó, and J. Paz-Ferreiro, "Biochar alters the resistance and resilience to drought in a tropical soil," *Environmental Research Letters*, vol. 9, p. 064013, 2014.

[24] M. Shashi, M. Mannan, M. Islam, and M. Rahman, "Impact of Rice Husk Biochar on Growth, Water Relations and Yield of Maize (Zea mays L.) under Drought Condition," *The Agriculturists*, vol. 16, pp. 93-101, 2018.

[25] J. Feng, R. Cheng, A. A. Qul, Q. G. Yan, Y. G. Li, B. L. Jian, *et al.*, "Effects of biochar on sodium ion accumulation, yield and quality of rice in saline-sodic soil of the west of Songnen plain, northeast China," *Plant, Soil and Environment*, vol. 64, pp. 612-618, 2018.

[26] P. Rani, H. Nayar, S. Rai, S. K. Prasad, and R. K. Singh, "Biochar: Moisture stress mitigation."

[27] S. Dahlawi, A. Naeem, Z. Rengel, and R. Naidu, "Biochar application for the remediation of salt-affected soils: Challenges and opportunities," *Science of The Total Environment*, vol. 625, pp. 320-335, 2018.

[28] X. Luo, G. Liu, Y. Xia, L. Chen, Z. Jiang, H. Zheng, *et al.*, "Use of biochar-compost to improve properties and productivity of the degraded coastal soil in the Yellow River Delta, China," *Journal of Soils and Sediments*, vol. 17, pp. 780-789, 2017.

[29] S. Fahad, S. Hussain, S. Saud, S. Hassan, M. Tanveer, M. Z. Ihsan, *et al.*, "A combined application of biochar and phosphorus alleviates heat-induced adversities on physiological, agronomical and quality attributes of rice,"

Plant physiology and biochemistry, vol. 103, pp. 191-198, 2016.

[30] J. Yuan, J. Meng, X. Liang, X. Yang, and W. Chen, "Organic molecules from biochar leacheates have a positive effect on rice seedling cold tolerance," *Frontiers in plant science,* vol. 8, p. 1624, 2017.

[31] C. S. Lwin, B.-H. Seo, H.-U. Kim, G. Owens, and K.-R. Kim, "Application of soil amendments to contaminated soils for heavy metal immobilization and improved soil quality—a critical review," *Soil science and plant nutrition,* vol. 64, pp. 156-167, 2018.

[32] K. Lu, X. Yang, G. Gielen, N. Bolan, Y. S. Ok, N. K. Niazi, *et al.*, "Effect of bamboo and rice straw biochars on the mobility and redistribution of heavy metals (Cd, Cu, Pb and Zn) in contaminated soil," *J Environ Manage,* vol. 186, pp. 285-292, Jan 15 2017.

[33] Y. Xu, B. Seshadri, B. Sarkar, H. Wang, C. Rumpel, D. Sparks, *et al.*, "Biochar modulates heavy metal toxicity and improves microbial carbon use efficiency in soil," *Science of the total environment,* vol. 621, pp. 148-159, 2018.

[34] T. Dabi and V. Khanna, "Effect of Climate Change on Rice," *Agrotechnology,* vol. 7, p. 2, 2018.

[35] Q. Liu, B. Liu, P. Ambus, Y. Zhang, V. Hansen, Z. Lin, *et al.*, "Carbon footprint of rice production under biochar amendment–a case study in a Chinese rice cropping system," *Gcb Bioenergy,* vol. 8, pp. 148-159, 2016.

[36] A. Mohammadi, A. Cowie, T. L. A. Mai, R. A. de la Rosa, P. Kristiansen, M. Brandao, *et al.*, "Biochar use for climate-change mitigation in rice cropping systems," *Journal of cleaner production,* vol. 116, pp. 61-70, 2016.

[37] S. Khan, N. Wang, B. J. Reid, A. Freddo, and C. Cai, "Reduced bioaccumulation of PAHs by Lactuca satuva L. grown in contaminated soil amended with sewage sludge and sewage sludge derived biochar," *Environmental Pollution,* vol. 175, pp. 64-68, 2013.

[38] D. Dong, Qibo Feng, Kim Mcgrouther, Min Yang, Hailong Wang, and Weixiang Wu. "Effects of Biochar Amendment on Rice Growth and Nitrogen Retention in a Waterlogged Paddy Field." Journal of Soils and Sediments 15, no. 1 (2014): 153–62.

[39] W. Jinyang, Xiaojian Pan, Yinglie Liu, Xiaolin Zhang, and Zhengqin Xiong. "Effects of Biochar Amendment in Two Soils on Greenhouse Gas Emissions and Crop Production." Plant and Soil 360, no. 1-2 (2012): 287–98.

[40] A. Kamara, H. S. Kamara, and M. S. Kamara, "Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties," *Agricultural Sciences,* vol. 6, p. 798, 2015.

[41] Y. Liu, H. Lu, S. Yang, and Y. Wang, "Impacts of biochar addition on rice yield and soil properties in a cold waterlogged paddy for two crop seasons," *Field crops research,* vol. 191, pp. 161-167, 2016.

[42] S. Haefele, Y. Konboon, W. Wongboon, S. Amarante, A. Maarifat, E. Pfeiffer, *et al.*, "Effects and fate of biochar from rice residues in rice-based systems," *Field Crops Research,* vol. 121, pp. 430-440, 2011.

[43] M. HUANG, F. Long, L.-g. JIANG, S.-y. YANG, Y.-b. ZOU, and N. Uphoff, "Continuous applications of biochar to rice: Effects on grain yield and yield attributes," *Journal of integrative agriculture,* vol. 18, pp. 563-570, 2019.

[44] K. Kartika, B. Lakitan, A. Wijaya, S. Kadir, L. I. Widur, E. Siaga, *et al.*, "Effects of particle size and application rate of rice-husk biochar on chemical properties of tropical wetland soil, rice growth and yield," *Australian J. of Crop Sci.,* vol. 12, pp. 817-826, 2018.

[45] T. He, J. Meng, W. Chen, Z. Liu, T. Cao, X. Cheng, *et al.*, "Effects of biochar on cadmium accumulation in rice and cadmium fractions of soil: A three-year pot experiment," *BioResources,* vol. 12, pp. 622-642, 2017.

[46] R. Bian, S. Joseph, L. Cui, G. Pan, L. Li, X. Liu, *et al.*, "A three-year experiment confirms continuous immobilization of cadmium and lead in contaminated paddy field with biochar amendment," *Journal of hazardous materials,* vol. 272, pp. 121-128, 2014.