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# Effect of adding Melatonin and Biochar on some Growth Characteristics of *Ocimum Basilicum* L. CV. Cinnamon

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**Abstract.** The study was carried out in one of the fields of the Department of Horticulture and Landscaping at the College of Agriculture / University of Anbar for the growing season 2022 from 31/3 to 1/11 at the geographical location longitude 33.4274 N and latitude 43.3331 east. To study the effect of four levels of melatonin (0, 25, 50, and 75) mmol and four levels of Biochar (0, 250, 500, and 750) gm pot<sup>-1</sup>, respectively. The experiment was carried out according to a randomized complete block design with three replications. The results showed that melatonin outperformed at the level of 75 mmol in plant height (48.03 cm), stem diameter (5.04 mm), number of branches (5.25 branches plant<sup>-1</sup>), leaf area (10.56 cm<sup>2</sup> leaf<sup>-1</sup>), number of leaves (129.70 leaf plant<sup>-1</sup>) and fresh leaves weight. (159.68 gm), the dry weight of the leaf (17.13 gm), and the percentage of dry matter (10.65%). It can conclude that spraying aromatic basil plants with melatonin and adding biochar has improved the growth stimulation of this medicinal crop effectively. Therefore, these materials can be used to stimulate the growth of this crop or other crops.

**Keywords:** Aromatic basil, Melatonin, Biochar, Vegetative growth traits, Dry weight.

\*Part of MSc thesis of 1st author

## 1. Introduction

Basil (*Ocimum basilicum* L.), belongs to the Lamiaceae family, which includes a large number of widespread leafy and aromatic plants [1]. The genus contains a number of varieties and species, followed by many varieties spread in the regions of Asia, Africa and the tropics, as it is considered the center of original [2]. In view of the importance of this crop, which is an important source of volatile oils with (aromatic) properties that differ in their content and components according to the cultivation environment [3].

Basil contains flavonoids and phenolic acids, such as Caffeine, Cinnamic acid, and Ferulic acid. The importance of these compounds is that they are powerful antioxidants in curbing free radicals and mineral chelates [4]. It is used in cooking, treating infections, fever, swelling, and constipation as an antibacterial and antifungal [5]. Due to its richness in phenolic compounds, it is marketed as dry and



fresh herbs [6, 7]. Melatonin has diverse functions in vascular plants [8], as it reduces the inhibitory effect of stress on carbon metabolism [9]. Yu et al. [10] indicated that it works to increase the production of some metabolites, including antioxidants, which in turn contribute to increasing the activity of plants completely, which is reflected in their productivity [11]. It is a powerful endogenous molecule that possesses antioxidant properties [12]. Melatonin is involved in various processes starting with root growth [13], and flowering development, fruit ripening, carbon assimilation, and leaf senescence [14, 15]. Over the years, the improvement of soil fertility for agricultural production has become limited to the use of chemical fertilizers, which leads to a decrease in organic matter in the soil, soil acidity and physical deterioration. Therefore, Biochar has been suggested as one of the effective options in order to reduce the impact of climate change on agricultural soils, increase crop yield, improve nutrient holding, and moisture in the soil [16]. Also, Behera et al. [17] indicated that plant growth improves by improving the physical and chemical soil characteristics such as cation exchange capacity, element holding capacity, soil permeability, bulk density, and biological properties. He also noticed that if it stays for the longest period in the soil, it contributes to the great benefits of the crop for several seasons. This medicinal plant undergoes the reduced leaves yield because some factors affect its bioprocesses. Due to the previously mentioned scarcity of studies on the effect of spraying melatonin as a growth regulator on the growth of aromatic basil and the addition of biochar, so this experiment was conducted in order to study the effect of melatonin on the growth and yield of basil and the effect of Biochar on the growth and yield of basil as well as to study the interaction between them in the growth and yield and the active substance of basil.

## 2. Materials and Methods

### 2.1 Experiment site

The experiment was carried out in the fields of the Department of Horticulture and Landscape Engineering - College of Agriculture - University of Anbar for the growing season 2022 during the month of March, from 31/3 to 1/11 to study the effect of spraying with melatonin and adding Biochar on the growth and leaf yield of basil plant Cinnamon cultivar, at the geographical location longitude 33.4274 N and latitude 43.3331 E.

### 2.2 Experimental design

The experiment was carried out as factorial experiment 4x4 according to a randomized complete block design with three replications, each replicate contains 16 experimental unit.

### 2.3 Study factors

The experiment was conducted with two factors, the first factor, melatonin, at concentrations of (0, 25, 50, 75 mmol.) which are coded as M0, M1, M2 and M3. (The process of spraying melatonin was carried out twice during the growing season, the first at the beginning of the vegetative growth corresponding to 20/5 i.e., 50 days after planting, where the spraying process was done in the early morning before sunrise until the leaves of the plants were completely wet using a 2-liter sprayer. Where for the second spray done 70 days after the first spray, and a Surfactants was used to increase the absorption efficiency, reduce the surface tension of water, and cause complete wetting on the leaves in an amount of 1 ml L<sup>-1</sup>. The second factor was use of Biochar at a rate of (0, 250, 500, 750) gm pot<sup>-1</sup> (which are coded as B0, B1, B2 and B3). The plants were grown in plastic pots weighing 25 kg and having diameters of 40 cm. Each pot represents an experimental unit. It was placed in the field and Biochar was added at the beginning of pot preparation, as the specified quantities were mixed with the soil prepared for planting. Soil properties are shown in table 1.

### 2.4 Service operations

All required service operations were applied throughout the growing season, including hoeing and weeding, and the drip irrigation method was used to irrigate the experimental plants. After germination and development of basil seedlings into complete plants, the data recorded were: plant height (cm), stem diameter (mm), and number of branches (branch plant<sup>-1</sup>), Leaf area (cm<sup>2</sup>, leaf<sup>-1</sup>), number of leaves (leaf plant<sup>-1</sup>), total fresh and dry weight of leaves (gm), and dry weight %.

**Table 1.** Some chemical, mechanical and physical properties of trial soil pre-sowing on 0-0.3 m

Properties	unit	value	properties	unit	value
Sand	g kg <sup>-1</sup>	249	pH	-	7.86
Silt		560	EC	Dm m <sup>-1</sup>	3.4
Clay		191	OM	g kg <sup>-1</sup>	1.64
Texture		Silty loam	CaSO <sub>4</sub>		56.88
Bulk density	Mg m <sup>-3</sup>	1.33	CaCO <sub>3</sub>		167.13
Volumetric moisture under stress (bar)	%	62.76	CEC	mmol kg <sup>-1</sup>	117.7
	0	39.54	N	mg kg <sup>-1</sup>	71.00
	0.33	30.82	P		42.00
	1	22.31	K		143.00
	5	21.77			
	15	17.77			
Available water	%	17.77			

### 2.5 Statistical analysis

The data were analyzed statistically using GenStat program, and the averages of the studied traits were compared using least significant difference (L.S.D) at probability level of 0.05 [18].

### 3. Results and Discussion

The results indicated that there were significant differences between melatonin spray treatments, as the M3 treatment outperformed with the highest value of 48.033 cm, while the M0 treatment gave the lowest value of 44.217 cm (Table 1). The result indicates a significant difference between Biochar levels. The results showed superiority of treatment B3 by with the highest value of 49.067 cm, compared to the lowest value of B0, with 42.883 cm. The results showed that there were significant differences between the interaction treatments, as the M3B3 treatment outperformed with plant height of 51.533 cm, compared to the lowest value for M0B0, which amounted to 41.200 cm.

**Table 1.** Effect of spraying with melatonin and adding and adding Biochar on plant height (cm)

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	41.200	41.600	43.933	44.800	42.883
B1	43.333	45.400	44.800	46.600	45.033
B2	45.133	47.200	48.733	49.200	47.567
B3	47.200	48.267	49.267	51.533	49.067
Mean	44.217	45.617	46.683	48.033	
LSD Melatonin	LSD Biochar		LSD Melatonin* Biochar		
0.18	0.18		0.37		

### 3.1 Stem diameter (mm)

The results indicated that there were significant differences between melatonin spray treatments, as the M3 treatment outperformed with the highest value of 5.038 mm, while the M0 treatment gave the lowest value of 4.372 mm (Table 2). The result indicates a significant difference between Biochar levels. the results showed superiority of treatment B3 by with the highest value of 5.304 mm, compared to the lowest value of B0, with 4.121 mm. The results showed that there were no significant differences between the interaction treatments.

**Table 2.** Effect of spraying with melatonin and adding Biochar on stem diameter (mm)

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	3.93	4.00	4.21	4.34	4.12
B1	4.04	4.73	4.40	4.77	4.48
B2	4.54	4.97	5.12	5.36	4.99
B3	4.97	5.03	5.53	5.69	5.30
Mean	4.37	4.68	4.81	5.04	
LSD Melatonin		LSD Biochar		LSD Melatonin* Biochar	
0.23		0.23		N.S	

### 3.2 Branch number (branch plant<sup>-1</sup>)

The results indicated that there were significant differences between melatonin spray treatments, as the M3 treatment outperformed with the highest value of 5.25 (branch plant<sup>-1</sup>), while the M0 treatment gave the lowest value of 4.57 branch plant<sup>-1</sup> (Table 3). The result indicates a significant difference between Biochar levels, where the treatment B3 outperformed with the highest value of 5.10 branch plant<sup>-1</sup>, compared to the lowest value of B0, with 4.43 branch plant<sup>-1</sup>. The results showed that there were no significant differences between the interaction treatments.

**Table 3.** Effect of spraying with melatonin and adding Biochar on branch number plant<sup>-1</sup>.

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	3.93	4.27	4.33	5.20	4.43
B1	4.53	4.73	4.60	4.87	4.68
B2	4.73	4.53	5.40	5.67	5.08
B3	5.07	5.27	4.80	5.27	5.10
Mean	4.57	4.70	4.78	5.25	
LSD Melatonin		LSD Biochar		LSD Melatonin* Biochar	
0.31		0.31		N.S	

### 3.3 Leaf area (cm<sup>2</sup> leaf<sup>-1</sup>)

The results showed that there were significant differences between the melatonin spray treatments, as the M3 treatment excelled by recording the largest leaf area of 10.56 (cm<sup>2</sup> leaf<sup>-1</sup>) compared to the lowest leaf area recorded by the M0 treatment, with 9.72 (cm<sup>2</sup> leaf<sup>-1</sup>). As for the addition of Biochar, the results indicated that there were significant differences between the Biochar treatments, as treatment B3 outperformed with the largest leaf area of 10.72 (cm<sup>2</sup> leaf<sup>-1</sup>), while treatment B0 recorded the lowest value of 9.37 (cm<sup>2</sup> leaf<sup>-1</sup>). The results also indicated a significant interaction and superiority of the M3B2 treatment with the largest leaf area of 10.91 (cm<sup>2</sup> leaf<sup>-1</sup>), compared to the lowest value recorded by the M0B0 treatment, which amounted to 8.99.

**Table 4.** Effect of spraying with melatonin and adding Biochar on leaf area leaf<sup>-1</sup>.

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	8.99	9.04	9.34	10.09	9.37
B1	9.27	9.80	9.66	10.42	9.79
B2	10.08	10.15	10.86	10.91	10.50
B3	10.53	10.78	10.74	10.82	10.72
Mean	9.72	9.94	10.15	10.56	
LSD Melatonin		LSD Biochar		LSD Melatonin* Biochar	
0.21		0.21		0.43	

### 3.4 Leaf number plant<sup>-1</sup>

Foliar spraying of melatonin had a significant effect on increasing the number of leaves of the plant, where the M3 treatment outperformed with the highest value of 129.700 leaf plant<sup>-1</sup>, while the M0 treatment gave the lowest value of 108.467 leaf plant<sup>-1</sup> (Table 5). The result indicates a significant difference between Biochar levels. The B3 outperformed other levels with the highest number of leaves, amounting to 129,000 (leaf of plant<sup>-1</sup>), compared to treatment B0, which recorded the lowest number of leaves, amounting to 105.517 (leaf of plant<sup>-1</sup>). The results showed that there were no significant differences between the interaction treatments.

**Table 4.** Effect of spraying with melatonin and adding Biochar on leaf number plant<sup>-1</sup>.

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	96.267	103.933	105.000	116.867	105.517
B1	111.333	112.200	113.800	120.133	114.367
B2	106.733	112.667	117.000	129.133	116.383
B3	119.533	122.400	121.400	152.667	129.000
Mean	108.467	112.800	114.300	129.700	
LSD Melatonin		LSD Biochar		LSD Melatonin* Biochar	
8.70		8.70		N.S	

### 3.5 Leaves fresh weight (gm)

The foliar spray treatments of melatonin had a significant effect on this characteristic (Table 6), as the M3 treatment outperformed with largest amount of leaf fresh weight of 160.563 gm, compared to the lowest value for M2, which amounted to 135.972 gm. The results of adding Biochar indicates that treatment B3 outperformed with the largest amount of fresh weight of leaves (159.682 gm), compared to the lowest leaves fresh weight of B0 (127.585 gm). The results showed that there were no significant differences between the interaction.

**Table 6.** Effect of spraying with melatonin and adding Biochar on leaves fresh weight (gm)

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	123.586	124.102	131.848	130.804	127.585
B1	145.404	130.834	118.536	149.600	136.093
B2	139.238	144.729	144.526	181.646	152.535
B3	149.860	159.687	148.977	180.204	159.682
Mean	139.522	139.838	135.972	160.563	
LSD Melatonin		LSD Biochar		LSD Melatonin* Biochar	
18.81		18.81		N.S	

### 3.6 Leaves dry weight (gm)

The foliar spray treatments of melatonin had a significant effect on this characteristic (Table 7), as the M3 treatment outperformed with largest amount of leaf dry weight of 17.128 gm, compared to the lowest value for M0 (14.564 gm). The results of adding Biochar indicates that treatment B3 outperformed with the largest amount of dry weight of leaves (17.116 gm), compared to the lowest leaves fresh weight of B0 (13.109 gm). The results showed that there were no significant differences between the interaction.

**Table 7.** Effect of spraying with melatonin and adding Biochar on leaves dry weight (gm)

Biochar gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	12.513	12.593	13.727	13.603	13.109
B1	14.767	13.497	12.557	15.950	14.193
B2	15.000	15.253	15.637	19.590	16.370
B3	15.977	17.107	16.010	19.370	17.116
Mean	14.564	14.613	14.483	17.128	
LSD Melatonin	LSD Biochar		LSD Melatonin* Biochar		
1.96	1.96		N.S		

### 3.7 Dry matter %

The foliar spray treatments of melatonin had a significant effect on dry matter percentage (Table 8). The M3 outperformed with high percentage of dry matter (10.654 %), compared with lowest dry matter percentage recorded by M1 (10.412 %). The results also showed that the addition of Biochar in B3 excelled with the highest percentage of dry matter (10.736 %), compared to the lowest value recorded in B0 (10.267 %). The results showed that there were no significant differences between the interaction.

**Table 8.** Effect of spraying with melatonin and adding Biochar on dry matter %.

Biochar Gm	Melatonin (mm)				Mean
	M0	M1	M2	M3	
B0	10.121	10.187	10.374	10.386	10.267
B1	10.156	10.259	10.555	10.668	10.410
B2	10.675	10.494	10.776	10.772	10.679
B3	10.703	10.710	10.740	10.791	10.736
Mean	10.414	10.412	10.611	10.654	
LSD Melatonin	LSD Biochar		LSD Melatonin* Biochar		
0.21	0.21		N.S		

Melatonin has many physiological roles in activating some important enzymes in the biochemical processes within the plant, which is reflected in the activity of carbon metabolism, respiration, energy production, and stimulation of some growth regulators that co-encode some enzymes, which contributes to cell division and elongation, so the plant height increases (Table 1), the number of branches (Table 3), the number of leaves (Table 5), and the leaf area (Table 4). This hormone also works to maintain the antioxidant system and stimulate its production, which maintains the permanence of the chemical system inside the cell and its organelles. Thus, it is reflected in the increase in fresh weight (Table 6) and dry weight (Table 7), including the percentage of dry matter (Table 8), Spraying the plant with melatonin also helps to increase the effectiveness of many antioxidant enzymes, especially those associated with stress, such as Catalase, Peroxidase, Superoxide dismutase, and maintaining the water balance and mineral elements within the plant [19]. In addition to its role in physiological processes in stimulating the cells present in the thin layer of plant tissue between the dermis and the phloem and increasing the activity of root hairs and their growth, which generates new adventitious and lateral roots as well as its effective role in the process of organizing and early in the flowering process and reducing its abortion, which speeds up the harvesting process and reduces economic losses [20]. Melatonin plays a major role in the formation of genetic receptors associated with plant stress. In addition to its ability to increase the average photosynthesis and the content of leaves of chlorophyll and regulate the level of auxin, abscisic and Salicylic, and thus its positive effect is reflected on the growth of apical dominance and maintaining the dynamics of hormonal balance, which enhances the speed of plant adaptation to changes in environmental conditions, including abiotic stresses such as heat, cold, and drought [21].

Melatonin has important roles in many physiological and biochemical processes, such as antioxidant functions, photoperiod regulation, chlorophyll protection, metabolism of other hormones, seed germination, root development, senescence, and osmoregulation [22, 23, 24, 25]. According to previous studies, Biochar has been identified as a major source of carbon and as a soil conditioner that can reduce the impact of organic pollutants and toxic elements [26], and improve soil fertility and improve its properties. Many studies have shown that adding Biochar to soil can improve aeration and soil composition [9], and increases their water-holding capacity and availability of nutrient [9], Thereby stimulating crop growth and increasing crop yields [27]. Many benefits have also been recorded after adding biochar to the soil. It has the ability to alter the hydraulic properties of the soil and cause shifts in water holding [28]. The porous structure of biochar can reduce soil bulk density, thus increasing water holding capacity. This feature improves water retention capacity and is applicable in areas where water shortage is a limiting factor for crop production [39]. Crucially, it can influence plant growth by modifying soil hydrological properties [30,31] and nutrient availability [32,33], which will have positive effects on the growth and productivity of crops [34]. These effects on soil chemical and physical properties depend on the biochar amount, pyrolysis temperature, biomass type, and biochar particle size [35, 36]. These positive effects of adding biochar to the soil have been studied by several researchers in Egypt [37,38,39]. The results of adding biochar showed that it can improve the physical, chemical and biological properties of the soil, thus reflecting positively on crop growth.

#### 4. Conclusion

Through the results of this study, it was found that spraying melatonin clearly improved the growth characters of aromatic basil, as spraying aromatic basil at a concentration of 75 mmol was effective and stimulating the growth characters. The addition of biochar to the soil also contributed to the improvement of growth characters at the level of 750 gm pot<sup>-1</sup>. Therefore, the use of such natural materials would improve the growth environment in a sustainable and clean manner. Therefore, it can be recommended to implement these materials on other vegetable and medicinal crops for their ability to raise the crop efficiency to the highest possible level.

#### References

- [1] Paton A. 1992. A synopsis of *Ocimum* L. (Labiatae) in Africa. *Kew Bulletin*, 403-435.
- [2] Lawrence B M, Harley R M, and Reynolds T. 1992. Chemical components of labiate oils and their exploitation. *Advances in Labiate science. Kew: Royal Botanic Gardens*. UK. pp. 399–436.
- [3] Masada Y. 1976. Analysis of essential oils by gas chromatography and mass spectrometry. *John Wiley. New York*. P63.
- [4] Polterait O. 1997. Antioxidants and free radical scavengers of natural origin. *Current organic chemistry*, **1**: 415-440.
- [5] Keramati S, Pirdashti H, Babaeizad V, and Dehestani A. 2016. Essential oil composition of sweet basil (*Ocimum basilicum* L.) in symbiotic relationship with Piriformospora indica and paclobutrazol application under salt stress. *Acta Biologica Hungarica*, **67**: 412-423.
- [6] Bernstein N, Kravchik M, and Dudai N. 2010. Salinity-induced changes in essential oil, pigments and salts accumulation in sweet basil (*Ocimum basilicum*) in relation to alterations of morphological development. *Annals of Applied Biology*, **156**: 167-177.
- [7] Bernstein N, Sela S, Dudai N, and Gorbatsевич E. 2017. Salinity stress does not affect root uptake, dissemination and persistence of salmonella in sweet-basil *Ocimum basilicum*. *Frontiers in plant Science*, **8**: 675.
- [8] Uchendu E E, Shukla M R, Reed B M, and Saxena P K. 2013. Melatonin enhances the recovery of cryopreserved shoot tips of A merican elm *Ulmus americana* L.. *Journal of Pineal Research*, **55**: 435-442.
- [9] Zheng H, Wang X, Luo X, Wang Z, and Xing B. 2018. Biochar-induced negative carbon mineralization priming effects in a coastal wetland soil: roles of soil aggregation and microbial

- modulation. *Science of the Total Environment*, **610**: 951-960.
- [10] Yu H, Zou W, Chen J, Chen H, Yu Z, Huang J, and Gao B. 2019. Biochar amendment improves crop production in problem soils: A review. *Journal of Environmental Management*, **232**: 8-21.
- [11] Arnao M B, and Hernández-Ruiz J. 2015. Functions of melatonin in plants: a review. *Journal of Pineal Research*, **59**(2), 133-150.
- [12] Kołodziejczyk I, Kaźmierczak A, and Posmyk M M. 2021. Melatonin application modifies antioxidant defense and induces endoreplication in maize seeds exposed to chilling stress. *International Journal of Molecular Sciences*, **22**: 8628.
- [13] Zhang H J, Zhang N A, Yang R C, Wang L, Sun Q Q, Li D.B, and Guo Y D. 2014. Melatonin promotes seed germination under high salinity by regulating antioxidant systems, ABA and GA 4 interaction in cucumber (*Cucumis sativus* L.). *Journal of pineal Tan*, **57**:269-79.
- [14] Byeon Y, Park S, Kim Y S, Park D H, Lee S, and Back K. 2012. Light-regulated melatonin biosynthesis in rice during the senescence process in detached leaves. *Journal of Pineal Research*, **53**: 107-111.
- [15] Wang S, Yu M, Jiang J, Zhang W, Guo X, Chang S, and Campbell M. 2017. Evidence aggregation for answer re-ranking in open-domain question answering. *Arxiv Preprint Arxiv*:1711.05116.
- [16] Laird D A. 2008. The charcoal vision: a win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy Journal*, **100**: 178-181.
- [17] Behera U K, Sharma A R, and Mahapatra I C. 2007. Crop diversification for efficient resource management in India: problems, prospects and policy. *Journal of Sustainable Agriculture*, **30**:97-127.
- [18] Al-Muhammadi S, and Al-Mohammadi F. 2012. Statistics and Experimental Design. Osama House for Publishing and Distribution. Ammaan Jordan. Pp: 376.
- [19] Hosseini S, Redhaei M, and Ghasemi N N. 2021. Semiotics of the codes of nationalist poems of Badawi jabal Case study: Aesthetic, temporal and spatial codes, personality psychology. *Rays of Criticism in Arabic and Persian*, **11**: 109-136.
- [20] Arnao M B, and Hernández-Ruiz J. 2018. Melatonin and its relationship to plant hormones. *Annals of Botany*, **121**: 195-207.
- [21] Zhao C, Nawaz G, Cao Q, and Xu T. 2022. Melatonin is a potential target for improving horticultural crop resistance to abiotic stress. *Scientia Horticulturae*, **291**: 110560.
- [22] Ahmad I, and Ahmad S B. 2019. The mediation effect of strategic planning on the relationship between business skills and firm's performance: Evidence from medium enterprises in Punjab, Pakistan. *Opción: Revista de Ciencias Humanas y Sociales*, **24**: 746-778.
- [23] Debnath B, Islam W, Li M, Sun Y, Lu X, Mitra S, and Qiu D. 2019. Melatonin mediates enhancement of stress tolerance in plants. *International Journal of Molecular Sciences*, **20**:1040.
- [24] Hossain M M, Purohit N, Sharma R, Bhattacharya S, McKyer E L J, and Ma P. 2020. Suicide of a farmer amid COVID-19 in India: Perspectives on social determinants of suicidal behavior and prevention strategies.
- [25] Lu J, Li L, Park J B, Sun Y K, Wu F, and Amine K. 2014. Aprotic and aqueous Li-O<sub>2</sub> batteries. *Chemical Reviews*, **114**: 5611-5640.
- [26] Xia S, Song Z, Jeyakumar P, Bolan N, and Wang H. 2020. Characteristics and applications of biochar for remediating Cr (VI)-contaminated soils and wastewater. *Environmental Geochemistry and Health*, **42**: 1543-1567.
- [27] Yu Y, Lv Y, Shi Y, Li T, Chen Y, Zhao D, and Zhao Z. 2018. The role of phyto-melatonin and related metabolites in response to stress. *Molecules*, **23**: 1887.
- [28] Liu Z, Dugan B, Masiello C A, and Gonnermann H M. 2017. Biochar particle size, shape, and porosity act together to influence soil water properties. *Plos one*, **12**: e0179079
- [29] Karhu K, Mattila T, Bergström I, and Regina K. 2011. Biochar addition to agricultural soil

- increased CH<sub>4</sub> uptake and water holding capacity—Results from a short-term pilot field study. *Agriculture Ecosystems & Environment*, **140**: 309-313.
- [30] Githinji L. 2013. Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. *Archives of Agronomy and Soil Science*, **60**: 457-470.
- [31] Herath H M S K, Camps-Arbestain M, Hedley M. 2013. Effect of biochar on soil physical properties in two contrasting soils. *An Alfisol and an Andisol Geoderma*, **209**:188–197.
- [32] Glaser B, and Birk J J. 2012. State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). *Geochimica et Cosmochimica Acta*, **82**: 39-51.
- [33] Dai Z, Zhang X, Tang C, Muhammad N, Wu J, Brookes P C, and Xu J. 2017. Potential role of biochars in decreasing soil acidification—a critical review. *Science of the Total Environment*, **581**: 601-611.
- [34] Lehmann J, and Joseph S. 2009. Biochar for environmental management: *Science and Technology*. Earthscan. London, Sterling.
- [35] Blanco-Canqui H. 2017. Biochar and soil physical properties. *Soil Science Society of America Journal*, **81**: 687-711.
- [36] Wang B, Gao B, Zimmerman A R, Zheng Y, and Lyu H. 2018. Novel biochar-impregnated calcium alginate beads with improved water holding and nutrient retention properties. *Journal of Environmental Management*, **209**: 105-111.
- [37] Ali M M. 2018. Effect of plant residues derived biochar on fertility of a new reclaimed sandy soil and growth of wheat (*Triticum aestivum* L.). *Egyptian Journal of Soil Science*, **58**:93-103.
- [38] Mohamed I, El-Meihy R, Ali M, Chen F, and Raleve D. 2017. Interactive effects of biochar and micronutrients on faba bean growth, symbiotic performance, and soil properties. *Journal of Plant Nutrition and Soil Science*, **180**: 729-738.
- [39] Abdelraouf R E, Essay E F, and Saleh M M S. 2017. Sustainable management of deficit irrigation in sandy soils by producing biochar and adding it as a soil amendment. *Middle East Journal of Agriculture Research*, **6**: 1359-1375