Plant Physiology and Biochemistry 116 (2017) 127–138

Contents lists available at ScienceDirect

Plant Physiology and Biochemistry

journal homepage: www.elsevier.com/locate/plaphy

Research article

Improved quinoa growth, physiological response, and seed nutritional quality in three soils having different stresses by the application of acidified biochar and compost

Pia Muhammad Adnan Ramzani [a], Lin Shan [b], Shazia Anjum [a], Waqas-ud-Din Khan [c], Hu Ronggui [b], Muhammad Iqbal [d,*], Zaheer Abbas Virk [d], Salma Kausar [e]

[a] Cholistan Institute of Desert Studies, The Islamia University of Bahawalpur, 63100, Pakistan
[b] Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River), Ministry of Agriculture, College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China
[c] Sustainable Development Study Center, Government College University, Lahore 54000, Pakistan
[d] Department of Environmental Sciences and Engineering, Government College University, Faisalabad 38000 Pakistan
[e] Soil and Water Testing Laboratory, Bahawalpur, 63100, Pakistan

ARTICLE INFO

Article history:
Received 1 March 2017
Received in revised form
9 May 2017
Accepted 9 May 2017
Available online 10 May 2017

Keywords:
Quinoa
Stress
Thiobacillus thiooxidans
Acidification
Essential nutrients
Anti-nutrients
Antioxidants

ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) is a traditional Andean agronomical resilient seed crop having immense significance in terms of high nutritional qualities and its tolerance against various abiotic stresses. However, finite work has been executed to evaluate the growth, physiological, chemical, biochemical, antioxidant properties, and mineral nutrients bioavailability of quinoa under abiotic stresses. Depending on the consistency in the stability of pH, intended rate of S was selected from four rates (0.1, 0.2, 0.3, 0.4 and 0.5% S) for the acidification of biochar and compost in the presence of *Thiobacillus thiooxidans* by pH value of 4. All three soils were amended with 1% (w/w) acidified biochar (BC_A) and compost (CO_A). Results revealed that selective plant growth, yield, physiological, chemical and biochemical improved significantly by the application of BC_A in all stressed soils. Antioxidants in quinoa fresh leaves increased in the order of control > CO_A > BC_A, while reactive oxygen species decreased in the order of control < CO_A < BC_A. A significant reduction in anti-nutrients (phytate and polyphenols) was observed in all stressed soils with the application of BC_A. Moreover, incorporation of CO_A and BC_A reduced the pH of rhizosphere soil by 0.4–1.6 units in all stressed soils, while only BC_A in bulk soil decreased pH significantly by 0.3 units. These results demonstrate that BC_A was more effective than CO_A to enhance the bioavailability, translocation of essential nutrients from the soil to plant and their enhanced bioavailability in the seed.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a native plant of the Andean region and has been used as a staple food crop for thousands of years (Martinez et al., 2015). United Nations (UN) has declared the year 2013, as an international year of quinoa due to its important role in food security at the event of focusing global attention on nutrition and poverty eradication (FAO, 2013). Quinoa is most famous for being one of the only food plants that are an excellent source of essential amino acids, micronutrients, vitamins, phenolic compounds and minerals, and having the high total antioxidant capacity (FAO, 2013; Tang et al., 2015; Nowak et al., 2016). Additionally, quinoa is an attractive crop used for agricultural diversification due to its extraordinary adaptability to various environmental stresses such as soil salinity, low temperature, drought soils having poor nutritional status (Rosa et al., 2009; Ruiz et al., 2014; Razzaghi et al., 2015).

About 1.5 billion people depend on degraded land for food and 795 million people face hunger on daily basis including 780 million people in the undeveloped regions of the world (FAO, 2014). The major reason of degradation in existing agricultural land is due to various abiotic factors including drought, salinity, and heavy metals contamination (Hirich et al., 2014; Amini et al., 2016). The solubility

---

* Corresponding author.
E-mail address: iqbal.farhad@gmx.at (M. Iqbal).

http://dx.doi.org/10.1016/j.plaphy.2017.05.003
0981-9428/

Abbreviations

BC_A	acidified biochar
CO_A	acidified compost
S	elemental sulfur

and mobility of many nutrients in salt-affected, metal contaminated and drought stressed soils are the major reasons for their reduced bioavailability to plants. Unfortunately, this reduced bioavailability of essential nutrients can imply a serious problem for crop production. Soil salinity is one of the major factors limiting plant growth, as plant growth decreases significantly due to salinity in the soil and/or irrigation with saline water (Koksal et al., 2016). Plants grown in salt-affected soils have limitations in morphological, physiological, chemical, biochemical and metabolical processes which reduces stomatal opening and photosynthetic rate, leading towards low plant growth, crop yield and quality (Parida and Das, 2005; Petropoulos et al., 2017). Similarly, soil contamination with Ni is a serious concern for the production of quality food due to decline in plant growth and yield by hampering a number of plant physiological and biochemical processes (Fourati et al., 2016; Ramzani et al., 2016a).

The use of organic amendments like biochar and compost from plants and animals origin has the advantage of eco-friendly recycling of soil nutrients and soil remediation (Lim et al., 2016; Ramzani et al., 2016a). Enormous studies have confirmed the positive influence of biochar on biological and chemical properties of salt-affected and Ni contaminated soils (Hammer et al., 2015; Ramzani et al., 2016a). The application of biochar in soil enhances plant growth by improving water retention, soil organic carbon, and nutrient availability via increasing root density (Kappler et al., 2014; Ramzani et al., 2016a). Improvements in the soil water holding capacity, aggregate stability and enhanced crop productivity by the application of compost have already been confirmed in different studied (Hernández et al., 2016; Xin et al., 2016). Further, it has also been reported that compost provides a specific substrate for intracellular and extracellular enzymatic activities in soil (Garcia-Ruiz et al., 2012; Hernández et al., 2016).

Bioavailability of nutrients exclusively micronutrients (Fe, Zn) is a serious problem in soils having high pH which ends in crops yield to decline and ultimately can lead to malnutrition in humans (Ramzani et al., 2016b). It has already been discussed in our previous literature (Iqbal et al., 2012; Ramzani et al., 2016a,b,c) that bioavailability of nutrients to crop plants can be complemented by sulfur (S) mediated reduction in soil pH. However, major constraints involved in the application of elemental sulfur in soil are its high cost and labor involved (Carrión et al., 2008; Lucheta and Lambais, 2012). Alternatively, acidified amendments like preparation of biochar at high temperature (Silber et al., 2010) and mixing of $FeSO_4$ with granite powder and compost (Paradelo et al., 2016) are some alternate solutions for enhancing the solubility of nutrients in the soil.

We hypothesized that acidified biochar (BC_A) and compost (CO_A), by *Thiobacillus thiooxidans* mediated oxidation of elemental sulfur (S) may solubilize and enhance nutrients status in quinoa seed grown on three stressed soils (salt, Ni, and drought stress). Till yet, the response of quinoa crop grown on Ni-contaminated, saline, and drought stress soils conditioned with CO_A and BC_A has not been investigated. Therefore, the main purpose of this study was to evaluate the effect of BC_A and CO_A on the growth, physiology, antioxidant activity and nutrient availability to quinoa plant in three soils having different stresses. This study may also provide useful information in relation to promote plant growth and human health by efficient solubilization and utilization of soil nutrients.

2. Materials and methods

2.1. Collection of experimental soils and their physicochemical analysis

Three types of soils including Ni-contaminated [industrial area near Lahore (Ramzani et al., 2016a)], salt-affected (Proka, Faisalabad) and the soil used for drought stress (research area, Government College University Faisalabad, Pakistan) were used in this experiment. Prior to use in the pot experiment, soils were air-dried, passed through 2-mm sieve to remove stones, and homogenized. A subsample of each soil was analyzed for the determination of different physicochemical properties by adopting various standard methods. Soil texture was determined by using hydrometer method (Gee and Bauder, 1986). The pH of soil was measured in a saturated soil paste with a standardized pH meter (JENCO pH meter, 671 P model) after shaking the soil/water suspension for 1 h. Similarly, the contents of organic matter in experimental soils were determined by walkley-black method (Jackson, 1962). The total $CaCO_3$ content was determined by the method presented by Allison and Moodie (1965) (treating the samples with HCl 1N, then titrating with NaOH 1N).

Plant available Fe, Zn, and Ni were extracted by 0.005 M DTPA (Lindsay and Norvell, 1978) while (Jones and Case, 1990) method was used for determination of total soil Ni. The available phosphorus was extracted and determined by using Olsen method (Watanabe and Olsen, 1965). Similarly, nitrogen was determined by following the method presented by Bremner and Mulvaney (1982). Similarly, extractable potassium and ASR was determined by following Richards (1954) method. Sulfur was measured as described by Tabatabai (1982). Properties of experimental soil are given in Table 1.

2.2. Culturing of Thiobacillus thiooxidans

Thiobacillus thiooxidans (ATCC 8085) was cultured by the method described by Suzuki et al. (1999). *T. thiooxidans* was stationary grown for four (4) days at 28 °C on S in Starkey's medium 1 (pH 2.3, adjusted with H_2SO_4). Under suction, the S was removed from cultures by filtering it through Whatman no. 1 filter paper. Later, the cells were collected by centrifugation at 8000 × g for 10 min, washed once in glass-distilled water adjusted to pH 2.3 with H_2SO_4 and suspended in the same pH 2.3 water at a concentration of 50 mg (wet weight) of cells per ml. The suspension containing cells was stored at 4 °C before mixing with biochar and compost.

2.3. Preparation of biochar and compost

Biochar used in our experiment was prepared at a low pyrolysis temperature (350 °C) by using maize cob as feedstock. Similarly, the compost was prepared by using maize plants in a locally manufactured composter (Ahmad et al., 2006). The maize plants were oven dried in an oven (Tokyo Rikakikai, Eyela WFO-600 ND, Tokyo, Japan). Later on, the dried maize plants were ground to 2 mm size with the help of an electrical crusher. The crushed material was transferred to composting unit consisting of a vessel (500 kg capacity) having controlled temperature and aeration (shaking at 50 rev min-1). During composting process, the moisture level of 40% (v/w) was maintained by the addition of water. The temperature in the composting vessel rose up from 35 to 70 °C during the 2nd and 3rd day of composting process and later, gradually reduced to 35 °C