

# Genotypic differences of Cd concentration and nutrition traits of 23 main celery cultivars of China in a Cd contaminated greenhouse

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## Research Article

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# Abstract

Due to the increasing concerns of heavy metal contamination in greenhouse field, safety production of vegetables especially leafy vegetables was largely limited. In this study, the cadmium (Cd) concentration and major nutrition qualities of 23 main celery cultivars of China were compared in a greenhouse experiment. Great genotypic differences in biomass, cadmium accumulation and nutrition traits were observed. The biomass of cultivars HQ, JZ, JH and SQ were significantly higher than those of the others. And Cd concentration in edible part ranged from 0.53 to 2.56 mg·kg<sup>-1</sup> DW, of which SQ exhibited the lowest Cd concentration. In addition, SQ has the lowest Cd transport factor (TF) and bio-concentration factor (BCF), followed by another genotype LF. Simultaneously, they have relatively higher chlorophyll content and vitamin C concentration, lower cellulose content. Therefore, the two genotypes SQ and LF were selected as promising candidates to grow on a mid Cd-contaminated greenhouse field to achieve safety production. Further correlation analysis showed that Cd concentration in edible part is positively correlated with cellulose content, but negatively correlated with vitamin C concentration. The results of celery variety screening provide a safe production strategy of moderately polluted greenhouse vegetable fields.

## Introduction

With the rapid development of cities, atmospheric deposition, mining and smelting activities, wastewater irrigation, sewage irrigation, fertilizer and pesticide application have led to heavy metal pollution in the soil environment and agriculture (Elgallal et al., 2016; Rai et al., 2019; Ma et al., 2020). Cadmium (Cd) is classified as a Group 1 human carcinogen (Cancer IAF0, 2018) and is considered an important pollutant with great concern in agricultural ecosystems due to its high toxicity and bioavailability (Huang et al., 2020; Ma et al., 2021). Plants grown in Cd-contaminated soil readily accumulated Cd in their edible parts, and continuous dietary intake of Cd could result into serious health problems such as prostate, lung cancers and bone disorders (Zhang et al., 2014; Tang et al., 2019a; Yang et al., 2020).

In China, the rapid industrialization and ignorance of environmental protection during the past 30 years led to a serious heavy metal contamination of soil. It is reported that there is about 13000 hectares of Cd polluted land, and the Cd content in the polluted soil is 2.5–23 mg·kg<sup>-1</sup> (Liu et al., 2009). According to the national soil pollution survey, more than one-third of the self-use land and the selected sites around the heavily polluted enterprises exceeded the standard (MEE and MNR, 2014). Therefore, the food safety and related health risks were raising more and more attention. And Cd accumulated most in vegetables and rice fields (Huang et al., 2018). In 2019, China's vegetable planting area reached 20.87 million ha, the output exceeded 700 million tons, the per capita share reached more than 500 kg, and the output value exceeded 2 trillion RMB (Ding et al., 2020). Since vegetable crops play an important role in the dietary structure of Chinese residents, the safe use of heavy metal pollution vegetable land is of great significance to ensure the safety of production and human health (Feng et al., 2018).

The absorption and accumulation of Cd in soil by different kinds of vegetables are obviously different, which are generally manifested as leaf vegetables > root vegetables > fruit vegetables (Zhong et al., 2017). According to the degree and difference of Cd absorption and enrichment of different vegetable crops, the

production can be reasonably arranged. For example, in the heavy metal polluted areas, it is necessary to plant less leafy vegetables which are easy to accumulate heavy metals, and plant weakly enriched fruits and root vegetables. And Cd accumulation mechanism of different leafy vegetables was different, which led to significant differences in cadmium uptake and accumulation of different species (Ding et al, 2013b; Nabulo et al, 2011). Different genotypes of the same leafy vegetables also had different responses to cadmium uptake and accumulation in soil (Xiao et al., 2015; Zhou et al., 2012). Therefore, low accumulation genotype can be screened and used as a major safety production strategy of polluted land (Tang et al, 2016; Tang et al, 2019a; Tang et al, 2019b).

Celery (*Apium graveolens* L.) is a kind of leafy vegetable which is conventionally planted in China with edible stems and leaves (Yan et al., 2020). Celery is rich in vitamins, protein, cellulose and other nutrients (Li et al., 2017). Based on the results of meta-analysis, it was found that celery is not sensitive to cadmium pollution in soil, and can be used as a candidate leaf vegetable for safe production in moderately and slightly polluted vegetable fields (Huang et al., 2020). However, a few reports showed that celery was vulnerable to soil Cd contamination (Ni et al., 2002; Wang et al., 2013; Fang et al., 2019), and long-term ingestion of celery grown in Cd-contaminated field would pose an adverse effect on human health (Yang et al., 2020). As the previous studies of celery were mostly conducted in the form of pot experiments with artificial cadmium addition and few researches were conducted in the field condition, genotypic difference of celery on heavy metal accumulation in mild to mid contaminated field is urgently needed to be studied. Here, 23 main cultivars of China were grown in a natural Cd contaminated greenhouse. The objectives were to compare their (i) growth; (ii) Cd uptake, enrichment, and translocation; and (iii) nutrition qualities, to screen out the Cd low-accumulated celery cultivars for directly large-scale application in local greenhouse.

## Materials And Methods

### Experimental site

A greenhouse experiment was conducted in Guoxiang farm (30°3'16"N and 119° 54' 34"E) in Hangzhou, Zhejiang Province, China. The experimental site is a vegetable greenhouse which has been planting vegetables for decades. The basic soil properties were determined as follows: pH = 5.77 (soil: water = 1: 2.5), total N content 3.24 g·kg<sup>-1</sup>, total P content 2.78 g·kg<sup>-1</sup>, total K content 0.37 g·kg<sup>-1</sup>, available P content 67.35 mg·kg<sup>-1</sup>, available K content 94.62 mg·kg<sup>-1</sup> and total Cd content 0.87 mg·kg<sup>-1</sup>.

### Plant Materials And Experimental Design

A total of 23 cultivated genotypes of celery were purchased from local seed company. The detailed information of the seeds was listed in Table S1. The experiment was carried out with random plot layout, and each genotype was repeated three times. Therefore, there were totally 69 experiment plots of about 6 m<sup>2</sup> (2 m width × 3 m length) each. Seeds were sowed directly in October 2018, followed by the thorough irrigation of the field to facilitate seed germination. After emergence of celery seedlings, about 250 celery plants were left in each plot, and the interval of each celery was about 15 cm. During the whole growing season, regular field management was conducted by the farmers. Plants were sampled at the harvested stage after ten weeks.

## Determination Of Plant Biomass And Chlorophyll Content

For each genotype, plant samples were divided into roots and shoots, then washed with a 20 mM Na<sub>2</sub>-EDTA solution for 20 min followed with deionized water for 3 times. After mixing the cleaned plant samples according to the root, stem and leaf, take out half of the samples and dry them in the oven at 105 °C for 30 minutes, then dry them at 65 °C until a constant weight is obtained.

After harvesting, leaves of fresh samples were collected for chlorophyll content determination. Chlorophyll content was measured according to Wang et al. (2019) using acetone-ethyl alcohol colorimetry. Briefly, 0.50 g fresh leaf sample of different genotypes was collected and put into a mixture of acetone and ethanol (2:1) for dark treatment. After 24 h, the absorbance at 663 nm and 645 nm wavelength by an ultraviolet spectrophotometer (Lambda350V-vis, PerkinElmer, Singapore). Then the chlorophyll content was determined with the equation below:

$$\text{Total chlorophyll content (mg}\cdot\text{g}^{-1}) = 20.2 \times A_{645\text{nm}} + 8.02 \times A_{663\text{nm}}$$

## Determination of soluble protein, soluble sugar, vitamin C and cellulose

Soluble protein concentration in plants were determined using Coomassie brilliant blue colorimetry method (Li, 2000). 1.00 g fresh celery sample, add 2 mL distilled water to grind into homogenate, use deionized water to transfer all to 15 mL centrifuge tube, and let it stand at room temperature for 30 minutes. The suspension was then centrifuged (3500 rpm) for 15 minutes and the supernatant was transferred to a 10 mL volumetric flask. The sample solution (0.1 mL) and Coomassie brilliant blue G-250 protein reagent (5 mL) were shaken and mixed in a test tube with a stopper. After 2 minutes of reaction, the absorbance value was determined at 595 nm wavelength by ultraviolet spectrophotometer (lambda 350V vis, Perkin Elmer, Singapore) Soluble sugar concentration was determined using anthrone-sulfuric acid colorimetry at 620 nm wavelength (Bao, 2008). 1.00 g fresh celery sample was put into a large test tube, added with 15 mL distilled water, and boiled in boiling water bath for 20 min. Then samples were filtered into a 100 mL volumetric flask, washed the residue with distilled water for several times, constant volume to scale, take 1.0 mL of sample extraction solution to be tested, add 5 mL of anthrone reagent, shake and mix quickly, then boil for 10 min in boiling water bath after cooling, the optical density was measured with ultraviolet spectrophotometer (lambda 350V vis, Perkin Elmer, Singapore) at 620nm wavelength. The determination of Vitamin C concentration in plants was performed using 2, 6-dichloro indophenol titration (Tang et al, 2016). 2.00 g fresh celery samples and 3 mL 2% oxalic acid were ground to homogenate in mortar, and then the contents were transferred to a 50 mL volumetric flask containing 1% oxalic acid; 1 mL 30% ZnSO<sub>4</sub> and 1 mL 15% K<sub>4</sub>Fe (CN)<sub>6</sub> were added; after mixing, the suspension was diluted to 50 ml with 1% oxalic acid in the volumetric flask. Transfer 5 mL of sample solution into a conical flask and titrate with 2, 6-dichloroindole phenol (brown burette) until the sample solution turns reddish and does not fade within 15 s. Cellulose concentration was determined using anthrone-sulfuric acid colorimetry at 620 nm wavelength (Tang et al, 2016). Take celery sample (0.10 g, DW) into 60% H<sub>2</sub>SO<sub>4</sub> (30 mL) for 30 min in cold water bath, then dilute with 60% H<sub>2</sub>SO<sub>4</sub> in a volumetric flask to 50 mL, mix evenly, and filter with Buchner funnel. Dilute the filtrate sample (2.5 mL) to 50 mL with deionized water, add 2% anthrone (0.5 mL) and concentrated H<sub>2</sub>SO<sub>4</sub> (2 mL)

and mix well. Let the solution stand for 12 min and cool to room temperature. Measure the absorbance at 620 nm with ultraviolet spectrophotometer ( $\lambda$  350V Vis, PerkinElmer, Singapore).

### **Determination Of Cd Uptake And Accumulation**

The dried plant samples (0.20mg) were weighed into a PTFE digestion tube, and digested at 150°C for 5 h with 1 mL HClO<sub>4</sub> and 5 mL HNO<sub>3</sub>. After filtration to 30 mL, Cd concentrations were determined using an inductively coupled plasma-mass spectrometry (ICP-MS, Plasma Quant, Germany). Plant standard reference material (GBW (E) 100348, the National Research Center for Certified Reference Materials of China) was used for quality control (Bao, 2008).

### **Determination Of Soil PH And Rhizosphere Soil Cd Content**

Shake off the soil that is easy to adhere to the root, and gently brush off the soil that is closely attached to the root with a brush, and collect it as rhizosphere soil.

After harvesting, soil samples were collected from field blocks accordingly. Then soil samples were thoroughly mixed and air-dried in the laboratory, after which soils were ground and passed through 16 and 100 mesh sieves. After 30 minutes of preparation of soil suspension, the pH of soil was analyzed by pH meter in 1:2.5 soil water suspension. 0.20 g soil sample was weighed and digested with 5 mL HNO<sub>3</sub>, 1 mL HClO<sub>4</sub> and 1 mL HF at 180°C for 10 h, and total Cd concentration in soil was determined by ICP-MS (Plasma Quant, Germany) (Bao, 2008). Soil standard reference material (GBW07429) was used as quality control sample.

### **Statistical analysis**

SPSS statistical 20.0 software (SPSS Inc., Chicago, IL, USA) was adopted for data analysis and graphical work was accomplished with Origin Pro 8.5 (Northampton, MA 01060 USA). Data were analyzed using one-way analysis of variance (ANOVA) at a significant level of  $p < 0.05$  indicated by Duncan's test. The correlation was performed using bivariate analysis.

## **Results**

### **Biomass, moisture content and Chlorophyll concentration varied in different genotypes**

After harvesting, biomass of all samples was determined. Our results showed that the biomass in edible part were largely different among all 23 genotypes (Table 1). Edible part biomass ranged from 0.14 (BL) to 1.19 (HQ) g·plant<sup>-1</sup>. Specifically, cultivar HQ, JZ and JH was much heavier ( $> 1.0$  g·plant<sup>-1</sup>) than others, while BL exhibited the lowest biomass. Plant biomass in HQ, JZ and JH was 8.50-fold, 7.36-fold and 7.21-fold of that in BL, accordingly. For moisture content, ranges differed between 94.03% (SQ) and 97.10% (BL) (Table 1).

Table 1

Moisture content, edible part biomass, edible part Cd concentration and Chlorophyll concentration of 23 celery genotypes grown on the cadmium contaminated soil.

Genotypes	Moisture content (%)	Edible part biomass (g·plant <sup>-1</sup> )	Edible part Cd concentration (mg·kg <sup>-1</sup> DW)	Chlorophyll (mg·g <sup>-1</sup> FW)
BL	97.10 ± 1.39a	0.14 ± 0.03g	2.26 ± 0.62ab	1.17 ± 0.09fgh
BLC	96.77 ± 0.74ab	0.49 ± 0.15cdef	1.98 ± 0.18abc	1.32 ± 0.02bcdefgh
BQ	96.93 ± 0.96a	0.76 ± 0.21bc	1.75 ± 0.09abc	1.54 ± 0.20 ab
CF	95.90 ± 0.30abcd	0.63 ± 0.07cd	1.72 ± 0.33abc	1.32 ± 0.02bcdefgh
DW	96.83 ± 0.81ab	0.35 ± 0.15defg	1.44 ± 0.17bcd	1.35 ± 0.08bcdefgh
HH	96.60 ± 1.08abc	0.49 ± 0.05cdefg	1.39 ± 0.28bcd	1.45 ± 0.06bcdef
HL	94.87 ± 0.47de	0.75 ± 0.06bc	1.02 ± 0.02cd	1.18 ± 0.02efgh
HLN	96.93 ± 0.90a	0.50 ± 0.08cdef	1.68 ± 0.694abc	1.42 ± 0.06abcdefg
HQ	94.4 ± 0.70de	1.19 ± 0.04a	1.93 ± 0.28abc	1.13 ± 0.06gh
JH	95.20 ± 0.20bcde	1.01 ± 0.02ab	1.69 ± 0.40abc	1.52 ± 0.04abc
JN	95.63 ± 1.52bcde	0.33 ± 0.12defg	1.60 ± 0.16abcd	1.51 ± 0.06abcd
JZ	95.07 ± 0.38cde	1.03 ± 0.11ab	1.58 ± 0.12abcd	1.23 ± 0.12defgh
LF	96.60 ± 0.78abc	0.76 ± 0.18bc	0.98 ± 0.18cd	1.48 ± 0.11abcde
OQ	95.60 ± 1.41abcde	0.26 ± 0.02efg	2.56 ± 0.33a	1.24 ± 0.06cdefgh
SH	96.67 ± 0.21abc	0.23 ± 0.02efg	1.42 ± 0.04bcd	1.10 ± 0.12 h
SL	96.80 ± 0.87ab	0.82 ± 0.18bc	1.34 ± 0.40bcd	1.26 ± 0.10bcdefgh
SQ	94.03 ± 0.65e	0.83 ± 0.01bc	0.53 ± 0.06d	1.67 ± 0.11 a

Data were presented as means ± standard error (SE) with three replicates. All data were means of three replications. Different letters indicate statistically significant differences at P < 0.05 as detected by Duncan's Multiple Range Test (DMRT).

Genotypes	Moisture content (%)	Edible part biomass (g·plant <sup>-1</sup> )	Edible part Cd concentration (mg·kg <sup>-1</sup> DW)	Chlorophyll (mg·g <sup>-1</sup> FW)
VTL	97.00 ± 1.05a	0.52 ± 0.15cdef	1.61 ± 0.37abcd	1.46 ± 0.04abcdef
XB	95.10 ± 0.26cde	0.53 ± 0.04cde	2.28 ± 0.25ab	1.66 ± 0.10 a
XG	95.60 ± 0.60abcde	0.82 ± 0.14bc	1.48 ± 0.17abcd	0.70 ± 0.06i
XS	96.50 ± 0.50abc	0.30 ± 0.02defg	1.43 ± 0.08bcd	1.36 ± 0.10bcdefgh
ZY	96.67 ± 0.92abc	0.23 ± 0.04efg	1.50 ± 0.05abcd	1.24 ± 0.05cdefgh
ZYX	96.93 ± 0.66a	0.18 ± 0.04fg	1.96 ± 0.64abc	1.22 ± 0.04efgh

Data were presented as means ± standard error (SE) with three replicates. All data were means of three replications. Different letters indicate statistically significant differences at P < 0.05 as detected by Duncan's Multiple Range Test (DMRT).

Chlorophyll concentration among the 23 celery genotypes varied from 0.70 (XG) to 1.67 (SQ) mg·g<sup>-1</sup>FW, with a mean value of 1.33 mg·g<sup>-1</sup>FW. Genotypes SQ, XB, BQ, JH and JN showed relatively higher chlorophyll concentration (> 1.5 mg·g<sup>-1</sup>FW), which was 2.39-fold, 2.39-fold, 2.20-fold and 2.19-fold of XG, respectively (Table 1).

### Cadmium concentration, translocation factor and bio-concentration factor were different in different Genotypes

As shown in Table 1, Cd concentration in edible part among all 23 genotypes ranged from 0.53 (SQ) to 2.56 (OQ) mg·kg<sup>-1</sup> DW, with a mean value of 1.61 mg·kg<sup>-1</sup> DW. Specifically, Cd concentration in genotype OQ, XB and BL were higher (> 2.0 mg·kg<sup>-1</sup> DW) than others, while genotype SQ exhibited a lowest Cd concentration (0.53 mg·kg<sup>-1</sup> DW) (Fig. 4). Cd concentration in genotype OQ, XB and BL was 4.85-fold, 4.33-fold and 4.29-fold of that in SQ, respectively.

The National Standard of the People's Republic of China (GB 2762 - 2017) was used to evaluate the safety of celery grown in Cd-contaminated soils. The maximum permissible concentration (MPC) of Cd for celery is 0.2 mg/kg FW. Cd concentration in edible part among all 23 genotypes ranged from 0.03 (SQ) to 0.11(OQ) mg·kg<sup>-1</sup> FW, with a mean value of 0.06 mg·kg<sup>-1</sup> FW. Cd concentration in edible parts of all genotypes in this field is lower than MPC (< 0.2 mg·kg<sup>-1</sup>FW) (Fig. 1)

Translocation factor (TF) is an important index to evaluate a plant's ability to transport trace elements from roots to shoots. TF was calculated as the ratio of Cd concentration in shoots to the Cd concentration in roots. Cd TF in the celery showed sharp fluctuations among different genotypes (Fig. 2), which varied from

0.40 (SQ) to 1.23 (OQ). In general, Cd TF in genotype OQ, BLC, JH and SH were obviously higher (TF > 1.0), while Cd TF in genotype SQ was the lowest (TF < 0.5) (Fig. 2; Fig. 4).

Bio-concentration factor (BCF) is used to evaluate the ability of celery to accumulate Cd, which is calculated as the ratio of Cd concentration in the shoots (DW basis) to the Cd concentration in the soil. Cd BCF of 23 genotypes fluctuated sharply. Cd BCF in XS, OQ and JH was obviously higher (> 3.0) than others, whereas genotype SQ showed a lowest Cd BCF (< 1.0) (Fig. 2; Fig. 4). Cd BCF in XS, OQ and JH was 6.52-fold, 5.71-fold and 5.03-fold of that in SQ (Fig. 2).

### **Cd concentration of rhizosphere soil and pH of soil varied in different Genotypes**

As shown in Fig. 3, Cd concentration in rhizosphere soil after harvesting of all 23 genotypes ranged from 0.67 (JH) to 0.87 (LF)  $\text{mg}\cdot\text{kg}^{-1}$ , with a mean value of  $0.75 \text{ mg}\cdot\text{kg}^{-1}$ . Specifically, soil Cd concentration in genotype LF was significantly higher than others, while genotype JH exhibited a lowest soil Cd concentration ( $0.67 \text{ mg}\cdot\text{kg}^{-1}$ ). Soil Cd concentration in genotype LF was 1.30-fold of that in JH.

For soil pH, cultivation of SQ induced a reduced pH while BL cultivation resulted in a highest pH value (Fig. 3; Fig. 4). However, tiny differences were detected among all the soil samples.

### **Nutrition Traits Of The Celery Varied In Different Genotypes**

Soluble protein concentrations in edible part ranged from 227.23 (JZ) to 1028.93 (XS)  $\text{mg}\cdot\text{kg}^{-1}$  FW, with a mean value of  $430.99 \text{ mg}\cdot\text{kg}^{-1}$  FW. Genotypes XS, BQ, BL and JN showed higher soluble protein concentration (>  $600 \text{ mg}\cdot\text{kg}^{-1}$  FW) (Table 2; Fig. 4), which was 4.53-fold, 3.51-fold, 2.74-fold and 2.73-fold of JZ, respectively (Table 2).

Table 2

Edible part soluble protein concentration, edible part soluble sugar concentration, edible part cellulose concentration and edible part Vitamin C concentration of 23 celery genotypes grown on the cadmium contaminated soil.

Genotypes	Soluble protein (mg·kg <sup>-1</sup> FW)	Soluble sugar (%)	Cellulose (%)	Vitamin C (mg·100g <sup>-1</sup> FW)
BL	623.60 ± 65.84c	2.17 ± 0.51ef	1.56 ± 0.10bc	4.83 ± 0.14ghij
BLC	519.63 ± 31.10de	0.70 ± 0.04g	1.12 ± 0.05fg	6 ± 0.09cde
BQ	797.97 ± 53.23b	2.23 ± 0.50ef	1.68 ± 0.09ab	7.32 ± 0.43b
CF	259.03 ± 28.07ij	2.38 ± 0.17def	1.73 ± 0.06ab	5.38 ± 0.18defg
DW	547.97 ± 18.26cd	0.55 ± 0.05g	1.39 ± 0.06de	5.85 ± 0.15cdef
HH	229.17 ± 19.05j	2.37 ± 0.043def	0.86 ± 0.07hi	6.33 ± 0.15c
HL	338.40 ± 26.14ghi	3.67 ± 0.30b	0.83 ± 0.058i	7.35 ± 0.51b
HLN	425.60 ± 34.07efg	2.17 ± 0.23ef	1.26 ± 0.06def	3.4 ± 0.22k
HQ	384.17 ± 14.80fgh	5.00 ± 0.086a	1.04 ± 0.09fghi	5.02 ± 0.22fghi
JH	326.77 ± 16.89ghij	2.56 ± 0.15cdef	1.39 ± 0.07cde	3.94 ± 0.09jk
JN	619.50 ± 29.35c	1.90 ± 0.11f	1.45 ± 0.05cd	6.22 ± 0.44cd
JZ	227.23 ± 7.63j	2.46 ± 0.08def	1.07 ± 0.04fgh	5.27 ± 0.19efgh
LF	490.67 ± 26.10de	3.61 ± 0.15bc	1.46 ± 0.07cd	5.25 ± 0.16efgh
OQ	313.67 ± 18.23hij	1.91 ± 0.89f	1.84 ± 0.12a	3.36 ± 0.24k
SH	470.20 ± 32.30def	1.78 ± 0.73	1.10 ± 0.04fg	4.34 ± 0.33ij
SL	378.13 ± 27.94fgh	3.06 ± 0.05bcde	1.15 ± 0.04fg	3.39 ± 0.22k
SQ	338.37 ± 11.32ghi	2.41 ± 0.10def	0.39 ± 0.015j	9.17 ± 0.61a
VTL	232.37 ± 37.27j	3.45 ± 0.08bcd	0.98 ± 0.037ghi	6.48 ± 0.15c
XB	346.90 ± 34.57ghi	2.11 ± 0.15ef	1.69 ± 0.031ab	4.39 ± 0.23hij
XG	280.57 ± 19.02hij	2.34 ± 0.07ef	1.21 ± 0.07ef	5.31 ± 0.24efg

Data were presented as means ± standard error (SE) with three replicates. All data were means of three replications. Different letters indicate statistically significant differences at P < 0.05 as detected by Duncan's Multiple Range Test (DMRT)

Genotypes	Soluble protein (mg·kg <sup>-1</sup> FW)	Soluble sugar (%)	Cellulose (%)	Vitamin C (mg·100g <sup>-1</sup> FW)
XS	1028.93 ± 63.15a	2.68 ± 0.06bcdef	1.16 ± 0.07fg	4.89 ± 0.24ghi
ZY	357.23 ± 9.97ghi	1.84 ± 0.65f	1.26 ± 0.08def	5.34 ± 0.26defg
ZYX	376.67 ± 19.92fgh	0.42 ± 0.04g	1.589 ± 0.11bc	4.2 ± 0.28ijk

Data were presented as means ± standard error (SE) with three replicates. All data were means of three replications. Different letters indicate statistically significant differences at P < 0.05 as detected by Duncan's Multiple Range Test (DMRT)

Soluble sugar concentration in edible part varied from 0.42% (ZYX) to 5.00% (HQ) among the 23 celery genotypes. Soluble sugar concentration in genotype HQ was significantly higher than that in other genotypes, while genotype ZYX exhibited a lowest soluble sugar concentration (Table 2; Fig. 4). Soluble sugar concentration in HQ was 11.81-fold of ZYX (Table 2).

Similarly, edible part cellulose and Vitamin C concentrations were significantly different among the celery genotypes. Cellulose concentration ranged from 0.39% (SQ) to 1.84 % (OQ), with a mean value of 1.27 %. Genotypes OQ, CF, XB and BQ showed relatively higher cellulose concentration (> 1.6%), which was 4.74-fold, 4.47-fold, 4.36-fold and 4.34-fold of SQ, respectively (Table 2; Fig. 4). Moreover, vitamin C concentration was highest in SQ (9.17 mg·100g<sup>-1</sup> FW) while lowest in OQ (3.36 mg·100g<sup>-1</sup> FW), with a mean value of 5.35 mg·100g<sup>-1</sup>FW and a 2.72-fold difference between SQ and OQ (Table 2; Fig. 4).

### Correlation Between Plant Cd Concentration And Nutrition Qualities

Celery biomass was significantly ( $r = 0.637$ ;  $p < 0.01$ ) and positively correlated with soluble sugar concentration in edible part (Table 3). And edible part Cd concentration was significantly ( $r = 0.713$ ;  $p < 0.01$ ) and positively correlated with cellulose concentration in edible part, but significantly ( $r = 0.571$ ;  $p < 0.01$ ) and negatively correlated with Vitamin C concentration (Table 3). While it was negatively correlated with biomass, chlorophyll concentration and soluble sugar concentration ( $r = 0.311$ ,  $0.131$  and  $0.254$ , respectively;  $p > 0.05$ ) (Table 3). Cellulose concentration in edible part was significantly ( $r = 0.540$ ;  $p < 0.01$ ) and negatively correlated with Vitamin C concentration (Table 3).

Table 3

Correlation coefficient between edible part Cd concentration, biomass, chlorophyll concentration, soluble protein concentration, soluble sugar concentration, cellulose concentration and Vitamin C concentration (n = 23).

	Edible part Cd concentration	Edible part biomass	Chlorophyll	Soluble protein	Soluble sugar	Cellulose	Vitamin C
Edible part Cd concentration	1	-0.311	-0.131	0.028	-0.254	0.713**	-0.571**
Biomass		1	0.015	-0.325	0.637**	-0.337	0.197
Chlorophyll			1	0.156	-0.030	0.003	0.289
Soluble protein				1	-0.140	0.208	0.049
Soluble sugar					1	-0.317	0.097
Cellulose						1	-0.540**
Vitamin C							1
Number represents F-values (**) significant at p < 0.01.							

## Discussion

Cd contamination in greenhouse fields has been a large limit for the sustainable production of leafy vegetables. It is reported that plant genotype was the most important plant factor affecting heavy metals uptake of plants (Bhargava et al., 2012). Specifically, heavy metal uptake and accumulation varied among the genotypes of the same species (Ding et al., 2013a; Nabulo et al., 2012). Different Cd accumulation among different genotypes have been investigated in Chinese cabbage (*Brassica pekinensis* L.) (Wang et al., 2015; Tang et al., 2016; Wang et al., 2017), welsh onion (*Allium fistulosum* L.) (Li et al., 2012; Li et al., 2016), spinach (*Spinacia oleracea* L.) (Tang et al., 2019a) and lettuce (*Lactuca sativa* L. var. *ramosa* Hort.) (Dala-Paula et al., 2019). Therefore, growing metal-excluding or low heavy metal accumulating genotypes

of vegetables in the contaminated fields could be a simple but effective strategy to mitigate the transport of heavy metals to edible parts, and further effectively guarantee human health (Feng et al., 2018).

Liu et al. (2009) recommended 4 identification standards of safe genotypes in Cd polluted areas, including (1) the concentration of Cd in the edible part should be lower than MPC; (2) BCF < 1.0; (3) TF < 1.0; and (4) when growing in the polluted soil, the aboveground biomass did not decrease significantly. We observed that there were significant differences in Cd concentration and distribution among 23 celery genotypes (Table 1), which were in consistence with previous literatures (Zhang et al., 2013). The genotypic difference of Cd content in edible parts among different genotypes of celery provides a potential possibility for screening low Cd accumulating celery genotypes. In this study, the content of Cd in the tested soil was  $0.87 \text{ mg}\cdot\text{kg}^{-1}$ , which belonged to moderate pollution soil according to Soil Environmental Quality-Risk Control Standard for Soil Contamination of Agricultural Land (GB15618-2018). However, Cd concentration in edible parts of all genotypes in this field is lower than MPC ( $< 0.2 \text{ mg}\cdot\text{kg}^{-1}\text{FW}$ ), that is all the celery genotypes were quantified with the National Food Safety Standards (GB2072-2017), indicating that celery was a relatively safety leaf vegetable species for moderate polluted greenhouse. Among the 23 genotypes of celery, 19 genotypes had a lower TF than 1.0 (except for SH, JH, BLC and OQ) (Fig. 2), among which only SQ had a lower BCF which was less than 1.0 (Fig. 2). Similar research has reported that celery cultivar/genotype Hongchengsiji was considered a low Cd accumulating genotype due to its low Cd uptake and transport (Zhang et al., 2013). Our results suggested that SQ and LF were suitable to cultivate in Cd-contaminated fields to guarantee food safety.

The growth condition of different genotypes may vary significantly in the same field (Table 1, Table 2). For example, Mi et al. (2019) reported that the fresh weight of 35 Chinese cabbage genotypes showed obvious differences. Another investigation also elucidated that different genotypes of celery showed discrepant growth condition (Golubkina et al., 2020). Similarly, our results showed that the edible biomass of HQ (the largest) was almost 8.30-fold of BL (the lowest), while aforementioned SQ and LF ranked sixth and eighth which is higher than the mean value of celery edible part ( $0.57\text{g}\cdot\text{plant}^{-1}$ ) (Table 1). This could be partly explained by the higher chlorophyll content of SQ and LF (Table 1). Moreover, soluble protein concentration and vitamin C concentration of SQ and LF were higher than the mean value of 23 genotypes, respectively (Table 2), suggesting that SQ and LF maintained a better nutrition level even on Cd-contaminated field. Taken together, due to their larger biomass, slight Cd uptake, lower TF and BCF, together with better performance of nutrition indexes, SQ and LF were therefore selected as promising candidates to grow on a Cd-contaminated greenhouse field to guarantee both the food production and human health.

The contents of vitamin C (Table 2) and cellulose (Table 2) in vegetables are important indexes to evaluate the nutritional quality of vegetables (Adenusi et al., 2015). Vitamin C is one of the most important nutrients to maintain the physiological function of human body. It is a kind of vitamin which human body needs the most and cannot synthesize itself (Ivey et al., 2012). Edible part Cd concentration was significantly and negatively correlated with Vitamin C concentration, Fu et al. (2009) and Hou et al. (2018) also showed that Cd has a significant limit on vitamin C in plants. When people cannot get enough vitamin C and other nutrition through vegetables, eating vegetables contaminated by heavy metals poses a threat to human

health. Under the influence of cadmium pollution in soil, celery growth was inhibited, enzyme activity decreased, lignification accelerated, senescence accelerated, cellulose content increased, celery stem and leaf lignification fibrosis degree increased, which would seriously affect the taste of celery, thereby reducing the quality of vegetables (Dureková et al., 2007; Rahoui et al., 2016). Cellulose is the main component of plant cell wall (Kumar et al., 2016). Studies have shown that plant tissue cell wall plays an important role in cadmium accumulation (Konno et al., 2010; 50. Vatehová-Vivodová et al., 2018; Wu et al., 2020). There was a significant positive correlation between the cadmium content in the edible part of celery and the cellulose content in the edible part of celery (Table 3). It can be inferred that after cadmium enters celery, it might be mainly stored in the cell wall.

## Conclusions

In this study, the biomass, Cd uptake and accumulation and nutrition traits of celery of different genotypes were compared in a greenhouse field experiment. We concluded that more lights should be shed on SQ and LF to be cultivated in Cd-contaminated sites since they had both a heavier biomass and a lower Cd content in the edible part, which provided promising celery resources for safe production and human health of heavy metal polluted areas. Further correlation analysis showed that cadmium content in celery shoot was significantly and negatively correlated with vitamin C, but significantly and positively correlated with cellulose.

## Declarations

**Ethical approval:** Not applicable.

**Consent to participate:** Not applicable.

**Consent to publish:** Not applicable.

**Authors Contributions:** Ying Feng: Perception and experiment design; final approval of the version to be published; Yugen Jiang: Perception and experiment design; Qiyao Zhou: Participation in the whole work; drafting of the article; Qiong Wang: Cultivation of plant material; preparation of the experiment; Lukuan Huang: Participation in part of the work; data analysis; Luyao Ma: Participation in part of data analysis and part draft checking; Yingjie Wu: Assistance in experimental work and data analysis.

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**Competing interests:** The authors declare that they have no competing interests.

**Availability of data and materials:** All data used or analyzed during this study are available from the corresponding author on reasonable request.

## References

- Adenusi AA, Abimbola WA, Adewoga TOS (2015) Human intestinal helminth contamination in pre-washed, fresh vegetables for sale in major markets in Ogun State, southwest Nigeria. *Food Control* 50: 843-849. <https://doi.org/10.1016/j.foodcont.2014.10.033>
- Bao SD (2008) *Soil Agricultural Chemistry Analysis Method*, Third edition. China Agriculture Press, Beijing (in Chinese).
- Bhargava A, Carmona FF, Bhargava M, Srivastava S (2012) Approaches for enhanced phytoextraction of heavy metals. *Journal of Environmental Management* 105:103-120. <https://doi.org/10.1016/j.jenvman.2012.04.002>
- Cancer IAF0 (2018) *Agents Classified by the IARC Monographs, Volumes 1-106*. <http://monographs.iarc.fr/ENG/Classification/index.php>.
- Dala-Paula BM, Custódio FB, Knupp EAN, Palmieri HEL, Silva JBB, Glória MBA (2018) Cadmium, copper and lead levels in different cultivars of lettuce and soil from urban agriculture. *Environmental Pollution* 242 (PT. A): 383-389. <https://doi.org/10.1016/j.envpol.2018.04.101>
- Ding C, Zhang T, Wang X, Zhou F, Yang Y, Huang G (2013a) Prediction model for cadmium transfer from soil to carrot (*Daucus carota* L.) and Its Application To Derive Soil Thresholds for Food Safety. *Journal of Agricultural and Food Chemistry* 61(43):10273-10282. <https://doi.org/10.1021/jf4029859>
- Ding C, Zhang T, Wang X, Zhou F, Yang Y, Yin Y (2013b) Effects of soil type and genotype on lead concentration in rootstalk vegetables and the selection of cultivars for food safety. *Journal of Environmental Management* 122: 8-14. <https://doi.org/10.1016/j.jenvman.2013.02.026>
- Ding H, Fan J, Jia C, Qin C, Yang Y, Zhang H, Zhang F, Wen C, Yu S, Xu Y (2020) Development status and trend of vegetable seed industry in China. *Chinese Vegetable* 09:1-8 (in Chinese).
- Dureková K, Huttová J, Mistrík I, Ollé M, Tamás L (2007) Cadmium induces premature xylogenesis in barley roots. *Plant and Soil* 290: 61-68. <https://doi.org/10.1007/s11104-006-9111-6>
- Elgallal M, Fletcher L, Evans B (2016) Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid zones: a review. *Agricultural Water Management* 177: 419-431. <https://doi.org/10.1016/j.agwat.2016.08.027>
- Fang HW, Li WS, Tu SX, Ding YZ, Wang RG, Rensing C, Li YP, Feng RW (2019) Differences in cadmium absorption by 71 leaf vegetable varieties from different families and genera and their health risk assessment. *Ecotoxicology and Environmental Safety* 184: 109593. <https://doi.org/10.1016/j.ecoenv.2019.109593>
- Feng Y, Ma L, Wang Q, Wu Y, Huang L, Zhou Q, Yang X (2018) Heavy metal pollution in soil vegetable crop system and comprehensive agronomic control technology for safe production in China. *Journal of Agricultural Environmental Science* 37 (11): 2359-2370 (in Chinese).

- Fu Q, Li J, Huang L, Yang H, Lv Y (2009) Effects of soil polluted by cadmium and lead on production and quality of pepper (*Capsicum annuum* L.) and radish (*Raphanus sativus* L.). *Journal of Food, Agriculture and Environment* 7(2):698-702.
- Golubkina NA, Kharchenko VA, Moldovan AI, Koshevarov AA, Zamana SP, Nadezhkin SM, Soldatenko AV, Sekara A, Tallarita AV, Caruso G (2020) Yield, Growth, Quality, Biochemical Characteristics and Elemental Composition of Plant Parts of Celery Leafy, Stalk and Root Types Grown in the Northern Hemisphere. *Plants* 9(4):484. <https://doi.org/10.3390/plants9040484>
- Hou S, Zheng N, Tang L, Ji X (2018) Effects of cadmium and copper mixtures to carrot and pakchoi under greenhouse cultivation condition. *Ecotoxicology and Environmental Safety* 159: 172-181. <https://doi.org/10.1016/j.ecoenv.2018.04.060>
- Huang Y, Wang L, Wang W, Li T, He Z, Yang X (2018) Current status of agricultural soil pollution by heavy metals in china: a meta-analysis. *Science of the Total Environment* 651 (PT.2): 3034-3042. <https://doi.org/10.1016/j.scitotenv.2018.10.185>
- Huang L, Wang Q, Zhou Q, Ma L, Wu Y, Liu Q, Wang S, Feng Y (2020) Cadmium uptake from soil and transport by leafy vegetables: a meta-analysis. *Environmental Pollution* 264: 114677. <https://doi.org/10.1016/j.envpol.2020.114677>
- Konno H, Nakashima S, Katoh K (2010) Metal-tolerant moss *Scopelophila Cataractae* accumulates copper in the cell wall pectin of the protonema. *Journal of Plant Physiology* 167(5): 358-364. <https://doi.org/10.1016/j.jplph.2009.09.011>
- Kumar M, Campbell L, Turner S (2016) Secondary cell walls: biosynthesis and manipulation. *Journal of Experimental Botany* 67(2): 515-531. <https://doi.org/10.1093/jxb/erv533>
- Lewis Ivey ML, Lejeune JT, Miller SA (2012) Vegetable producers' perceptions of food safety hazards in the Midwestern USA. *Food Control* 26(2): 453-465. <https://doi.org/10.1016/j.foodcont.2012.01.065>
- Li H (2000) *Principle and Technology of Plant Physiological and Biochemical Experiment*. Higher Education Press, Beijing (in Chinese).
- Li X, Zhou Q, Wei S, Ren W (2012) Identification of cadmium-excluding welsh onion (*Allium fistulosum* L.) cultivars and their mechanisms of low cadmium accumulation. *Environmental Science and Pollution Research* 19: 1773-1780. <https://doi.org/10.1007/s11356-011-0692-0>
- Li X, Zhou Q, Sun X, Ren W (2016) Effects of cadmium on uptake and translocation of nutrient elements in different welsh onion (*Allium fistulosum* L.) cultivars. *Food Chemistry* 194: 101-110. <https://doi.org/10.1016/j.foodchem.2015.07.114>
- Li M, Hou X, Wang F, Tan G, Xu Z, Xiong A (2017) Advances in the research of celery, an important Apiaceae vegetable crop. *Critical Reviews in Biotechnology* 38 (2):172-183.

<https://doi.org/10.1080/07388551.2017.1312275>

Liu W, Zhou Q, Sun Y, Liu R (2009) Identification of Chinese cabbage genotypes with low cadmium accumulation for food safety. *Environmental Pollution* 157(6): 1961-1967.

<https://doi.org/10.1016/j.envpol.2009.01.005>

Ma L, Wu Y, Wang Q, Feng Y (2020) The endophytic bacterium relieved healthy risk of pakchoi intercropped with hyperaccumulator in the cadmium polluted greenhouse vegetable field. *Environmental Pollution* 264: 114796. <https://doi.org/10.1016/j.envpol.2020.114796>

Ma L, Liu Y, Wu Y, Wang Q, Sahito ZA, Zhou Q, Huang L, Li T, Feng Y (2021) The effects and health risk assessment of cauliflower co-cropping with *Sedum alfredii* in cadmium contaminated vegetable field. *Environmental Pollution* 268 (PT. B):115869. <https://doi.org/10.1016/j.envpol.2020.115869>

MEE and MNR, 2014. The report on the national soil contamination survey (in Chinese).

Mi B, Liu F, Xie L, Zhou H, Wu F, Dai X (2019) Evaluation of the uptake capacities of heavy metals in Chinese cabbage. *Ecotoxicology and Environmental Safety* 171: 511-517.

<https://doi.org/10.1016/j.ecoenv.2019.01.022>

Nabulo G, Black CR, Young SD (2011) Trace metal uptake by tropical vegetables grown on soil amended with urban sewage sludge. *Environmental Pollution* 159(2): 368-376.

<https://doi.org/10.1016/j.envpol.2010.11.007>

Nabulo G, Black CR, Craigon J, Young SD (2012) Does consumption of leafy vegetables grown in peri-urban agricultural pose a risk to human health? *Environmental pollution* 162: 389-398.

<https://doi.org/10.1016/j.envpol.2011.11.040>

Ni W, Yang X, Long X (2002) Differences of cadmium absorption and accumulation in selected vegetable crops. *Journal of Environmental Sciences* 14(3): 399-405.

Rahoui S, Martinez Y, Sakouhi L, Ben C, Rickauer M, Ferjani EF, Gentzbittel L, Chaoui A (2017) Cadmium-induced changes in antioxidative systems and differentiation in roots of contrasted *Medicago truncatula* lines. *Protoplasma* 254: 473-489. <https://doi.org/10.1007/s00709-016-0968-9>

Rai PK, Lee SS, Zhang M, Tsang YF, Kim KH (2019) Heavy metals in food crops: health risks, fate, mechanisms, and management. *Environment International* 125: 365-385.

<https://doi.org/10.1016/j.envint.2019.01.067>

Tang L, Luo W, Tian S, He Z, Stoffella PJ, Yang X (2016) Genotypic differences in cadmium and nitrate co-accumulation among the Chinese cabbage genotypes under field conditions. *Scientia Horticulturae* 201: 92-100. <https://doi.org/10.1016/j.scienta.2016.01.040>

Tang L, Hamid Y, Sahito ZA, Gurajala HK, He Z, Feng Y, Yang X (2019a) Evaluation of variation in essential nutrients and hazardous materials in spinach (*Spinacia oleracea* L.) genotypes grown on contaminated soil

for human consumption. *Journal of Food Composition and Analysis* 79: 95-106.

<https://doi.org/10.1016/j.jfca.2019.03.012>

Tang L, Hamid Y, Zahra A, Sahito ZA, He Z, Hussain A, Gurajala HK, Yang X (2019b) Characterization of fava bean (*Vicia faba* L.) genotypes for phytoremediation of cadmium and lead co-contaminated soils coupled with agro-production. *Ecotoxicology and Environmental Safety* 171:190-198.

<https://doi.org/10.1016/j.ecoenv.2018.12.083>

Vatehová-Vivodová Z, Kollárová K, Malovíková A, Lišková D (2018) Maize shoot cell walls under cadmium stress. *Environmental Science and Pollution Research* 25:22318–22322. <https://doi.org/10.1007/s11356-018-2602-1>

Wang X, Ding W, Nan Z, Liao Q, Wu W (2013) Fraction of cd in oasis soil and its bioavailability to commonly grown crops in Northwest China. *Environmental Earth Sciences* 70: 471-479.

<https://doi.org/10.1007/s12665-013-2374-3>

Wang X, Shi Y, Chen X, Huang B (2015) Screening of cd-safe genotypes of Chinese cabbage in field condition and cd accumulation in relation to organic acids in two typical genotypes under long-term cd stress. *Environmental Science and Pollution Research* 22: 16590-16599. <https://doi.org/10.1007/s11356-015-4838-3>

Wang J, Yu N, Mu G, Shen Z, Shinwari KI, Shen Z, Zheng L (2017) Screening for cd-safe cultivars of Chinese cabbage and a preliminary study on the mechanisms of cd accumulation. *International Journal of Environmental Research and Public Health* 14(4): 395. <https://doi.org/10.3390/ijerph14040395>

Wang Q, Ma L, Zhou Q, Chen B, Zhang X, Wu Y, Pan F, Huang L, Yang X, Feng, Y (2019) Inoculation of plant growth promoting bacteria from hyperaccumulator facilitated non-host root development and provided promising agents for elevated phytoremediation efficiency. *Chemosphere* 234:769-776.

<https://doi.org/10.1016/j.chemosphere.2019.06.132>

Wu X, Song H, Guan C, Zhang Z (2020) Boron alleviates cadmium toxicity in *Brassica napus* by promoting the chelation of cadmium onto the root cell wall components. *Science of The Total Environment* 728:138833. <https://doi.org/10.1016/j.scitotenv.2020.138833>

Xiao Q, Wong MH, Huang L, Ye Z (2015) Effects of cultivars and water management on cadmium accumulation in water spinach (*Ipomoea aquatica* Forsk.). *Plant and Soil* 391:33–49.

<https://doi.org/10.1007/s11104-015-2409-5>

Yan D, Ding K, He Y, Fan L, Jiang X (2020) Strontium uptake and effects in hydroponically cultivated celery. *Water Air and Soil Pollution* 231:279. <https://doi.org/10.1007/s11270-020-04659-y>

Yang L, Liu B, Lu Y, Lu F, Wu X, You W, Huang B (2020) Bioavailability of cadmium to celery (*Apium graveolens* L.) grown in acidic and Cd-contaminated greenhouse soil as affected by the application of

hydroxyapatite with different particle sizes. Chemosphere 240: 124916.

<https://doi.org/10.1016/j.chemosphere.2019.124916>

Zhang K, Wang J, Yang Z, Xin G, Xin J, Huang C (2013) Genotype variations in accumulation of cadmium and lead in celery (*Apium graveolens* L.) and screening for low Cd and Pb accumulative cultivars. Frontiers of Environmental Science & Engineering 7:85–96. <https://doi.org/10.1007/s11783-012-0399-3>

Zhang WL, Du Y, Zhai MM, Shang Q (2014) Cadmium exposure and its health effects: a 19-year follow-up study of a polluted area in China. Science of the Total Environment 470-471: 224-228. <https://doi.org/10.1016/j.scitotenv.2013.09.070>

Zhong T, Xue D, Zhao L, Zhang X (2017) Concentration of heavy metals in vegetables and potential health risk assessment in China. Environmental Geochemistry and Health 40: 313–322. <https://doi.org/10.1007/s10653-017-9909-6>

Zhou Y, Xue M, Yang Z, Gong Y, Yuan J, Huang B (2012) High cadmium pollution risk on vegetable amaranth and a selection for pollution-safe cultivars to lower the risk. Frontiers of Environmental Science & Engineering 7: 219-230. <https://doi.org/10.1007/s11783-012-0469-9>

## Figures

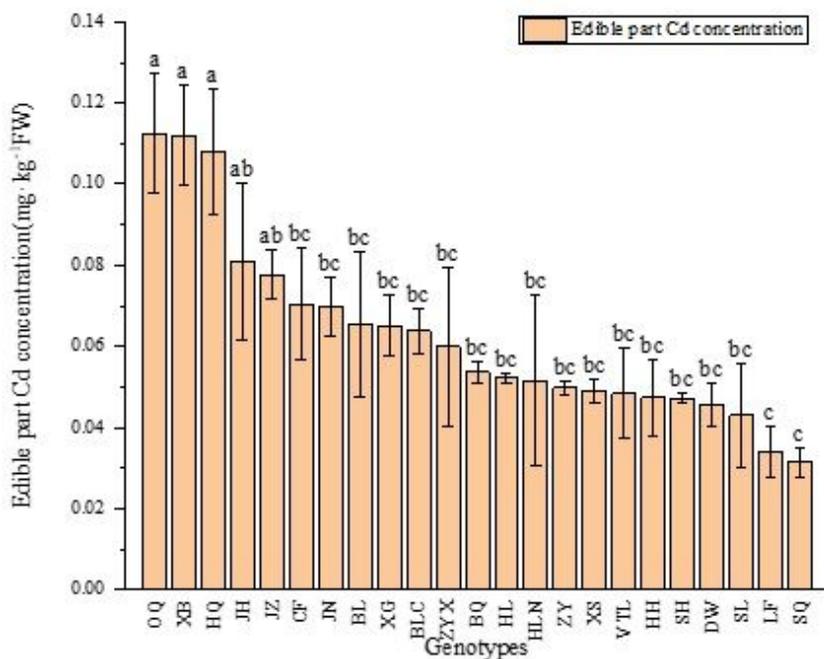
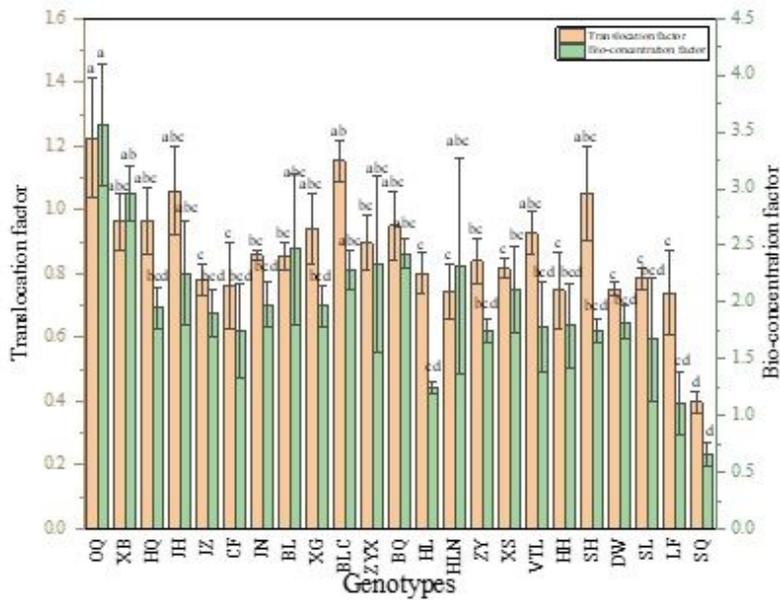


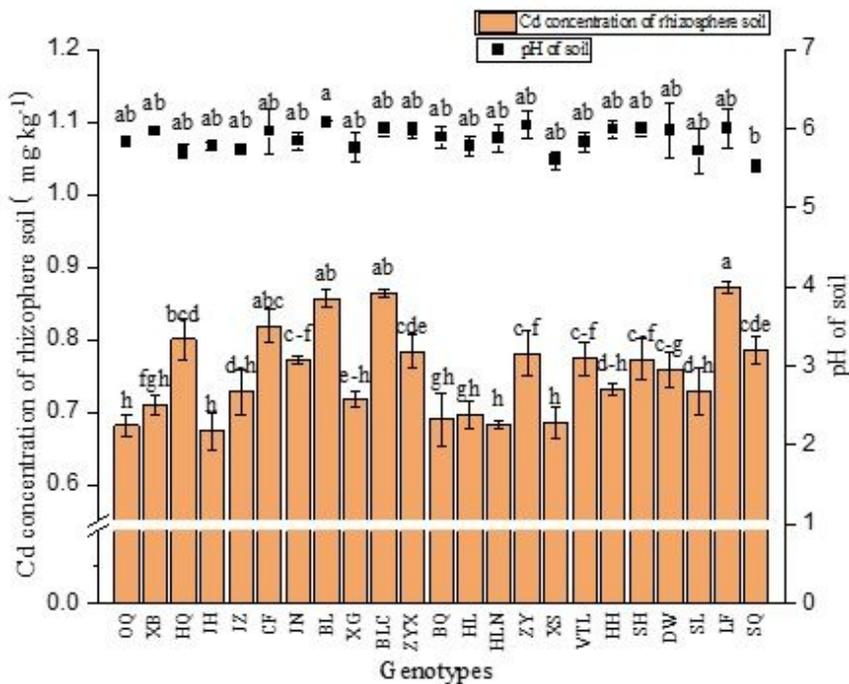
Figure 1

Edible part Cd concentration of 23 celery genotypes grown on the Cd contaminated soil. Data were presented as means  $\pm$  standard error (SE) with three replicates. Bars indicate significant difference at  $P < 0.05$



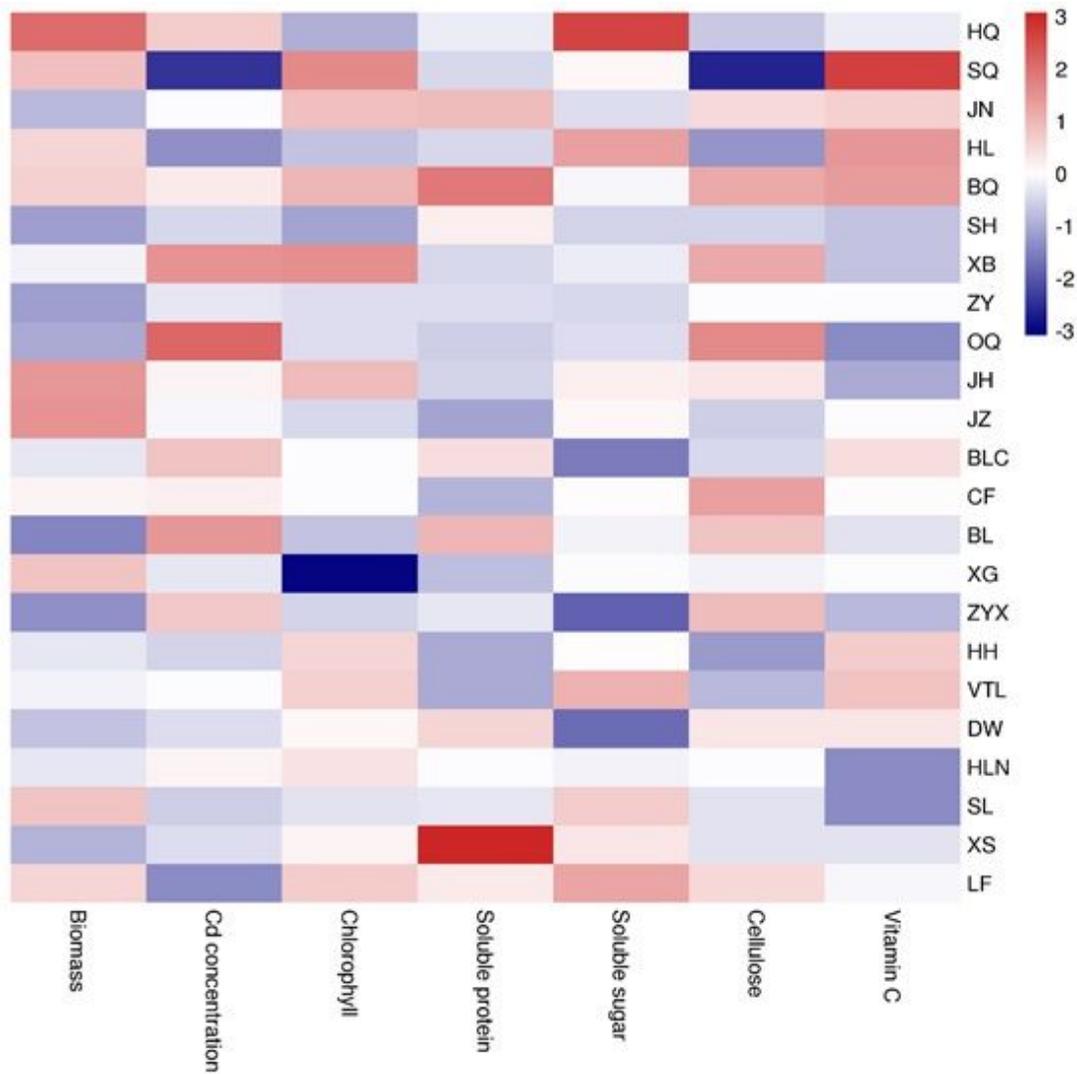
**Figure 2**

Translocation factor and bio-concentration factor of 23 celery genotypes grown on the Cd contaminated soil. Data were presented as means  $\pm$  standard error (SE) with three replicates. Bars indicate significant difference at  $P < 0.05$



**Figure 3**

Cd concentration of rhizosphere soil and pH of soil of 23 genotypes of celery. Data were presented as means  $\pm$  standard error (SE) with three replicates. Bars indicate significant difference at  $P < 0.05$



**Figure 4**

The heatmap overview of all 23 celery respectively. The heatmap drawing was processed using an online platform (<http://www.omicshare.com/tools>).

## Supplementary Files

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