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Yield and physicochemical properties of inulin obtained from Iranian chicory roots under vermicompost and humic acid treatments

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ABSTRACT

Chicory (*Cichorium intybus* L.) is a valuable medicinal plant and belongs to the family Asteraceae. Both chicory and Jerusalem artichoke are used in the production of inulin at industrial levels. Meanwhile, the extraction of inulin from chicory is more commonly considered. In this research, different levels of vermicompost and humic acid were used in order to study the effects on Iranian chicory roots, their growth and the physicochemical properties of their inulin. Treatments were vermicompost (0, 5, 7.5 and 10 tons/ha) and commercial humic acid (0, 0.3, 0.6 and 0.9 kg/ha). In this study, the growth parameters of roots were measured, including their fresh and dry weights, the depth of the root network and root volume. Furthermore, several phytochemical parameters were measured, including total sugars, reducing sugars, percent of inulin and the average degree of polymerization (DPn). Results showed that the combined application of vermicompost 7.5 tons/ha + humic acid 0.9 kg/ha significantly increased the fresh weight of roots (by 50.7%), the dry weight of roots (by 51.47%), depth of the root network and root volume compared to the control. In the same manner, the combination of vermicompost 10 tons/ha + humic acid 0.9 kg/ha significantly increased the fresh weight of roots (by 45%), the dry weight of roots (by 48.5%), depth of the root network and root volume compared to the control. All of the three concentrations of humic acid significantly increased the yield of inulin. The highest level of vermicompost (10 tons/ha) caused the highest amount of inulin (71.87%) which was 8.99% more than the control. The reducing sugars were not influenced by humic acid and vermicompost. However, all concentrations of humic acid as well as the highest level of vermicompost (10 tons/ha), significantly increased the total sugar content compared to the control. The application of 10 tons/ha vermicompost caused the highest value of Dpn (28.67).

1. Introduction

Humic acid is a natural product. It contains phosphorus (0.2–1%), nitrogen (4–6%) and organic carbon (51–57%) which make humic acid able to improve the yield of crops and their growth characteristics. It is therefore capable of supplying nutrients and can improve the biological and physicochemical properties of soils (Sharif et al., 2002). Vermicompost is able to increase the availability of nitrogen and phosphorus for plants by nitrogen fixation and by dissolving phosphorus, without producing any unpleasant odors while being free from any pathogen. It is therefore a suitable material for applications in sustainable agriculture. In addition, vermicompost enhances soil quality and nutritional conditions, thereby assisting the growth of crops (Mcginnis et al., 2003; Prabha et al., 2007).

Chicory (*Cichorium intybus* L.) is a valuable medicinal plant and belongs to the family Asteraceae. The genus *Cichorium* includes six species, i.e. *Cichorium intybus*, *C. endivia*, *C. bottae*, *C. spinosum*, *C. calvum* and *C. pumilum*. The most popular species, however, is *C. intybus*. The available scientific literature suggests that *C. intybus* L., *C. endivia* L. and *C. pumilum* Jacq. are species that have received considerable scientific attention (Kisiel et al., 2004).

So far, more than 100 pharmaceutical compounds have been identified and extracted from the chicory. Polysaccharides such as inulin, chicoric acid, sesquiterpene lactones, coumarins, flavonoids and vitamins are the most important of these compounds (Malarz et al., 2002; Velayutham et al., 2006). Studies have shown that this plant has various medicinal properties. It is antioxidant (Cavin et al., 2005; Heimler et al., 2009), anti-cancer (Ahmed, 2009), antimicrobial (Kim et al., 1999), antifungal (Nishimura and Satoh, 2006), anti-inflammatory (Hassan, 2008), anti-malarial (Bischoff et al., 2004), anti-allergy

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(Gazzani et al., 2000), anti-hepatotoxicity (Ahmed et al., 2003) and antidiabetic (Petrovic et al., 2004; Pushparaj et al., 2007). It is also used in preventing the reproduction of the Herpes Simplex Virus (HSV) (Ziai et al., 2007) and in protecting liver cells from oxidative damage (Zafar and Ali, 1998). It can be used as a diuretic (Kaur and Gupta, 2002), laxative (Sugatani et al., 2004) and neuroprotective agent (Marteau et al., 2011). Furthermore, it has anti-testicular toxicity effects (Chopra et al., 1956).

Nowadays, most studies on chicory are focused on the properties of inulin in roots. Both chicory and Jerusalem artichoke are used for inulin production in the industry, but the extraction of inulin from chicory is more prevalent (Franck, 2000). Inulin is a blend of fructan chains that are found in many plants, and it can function as storage carbohydrates. In fact, it is the most abundant carbohydrate after starch and cellulose that naturally exist in plants (Flickinger et al., 2003).

According to the length of the chain and the degree of polymerization (DPn), inulin can be divided into three categories: Fructo Oligo Saccharides (DPn = 2–10, with an average of 4), inulin with long chains (DPn = 10–65, with an average of 25) and standard inulin which is extracted from the roots of chicory and comprises an equal ratio of long and short chains of inulin (DPn = 2–65) (Kaur and Gupta, 2002; Roberfroid, 2004; Meyer et al., 2011).

Physicochemical characteristics of the extracted inulin depend on the extraction method, plant genetics, post extraction processes, harvest time and climate factors. The application of inulin in the pharmaceutical industry has been developed intensively; inulin is capable of reducing the production of fat and triglycerides in the blood, and can facilitate stool production and fecal excretion (Roberfroid, 2004). The nutritional properties of inulin is widely recognized by the food industry. For instance, it is applied in the production of coffee, bitter drinks and dairy products. Furthermore, it could be used in combination with synthetic sweeteners such as sucralose and aspartame (Darjani et al., 2015). The combination of inulin with gel formatting materials like gelatin, alginate and carrageenan can improve the emulsion characteristics of products such as ice cream, sauces and desserts. It also enhances the sustainability of these products. These features signify a high degree of polymerization in the chains of inulin (Franck, 2000). Variations in the yield and physicochemical properties of inulin deserve further investigations to determine how external factors may affect the properties and production of inulin. This study was conducted to determine the effects of the application of different levels of vermicompost and humic acid on the growth of chicory's roots and the physicochemical properties of inulin extracted from the roots.

2. Materials and methods

A 4 × 4 factorial experiment, arranged in a randomized complete block design with three replications, was conducted at the research field of Agricultural Faculty (35° 52′E, 38° 29′N and 1810 m above sea level), Shiraz University, Iran. Meteorological data of the field during the research period were recorded (Table 1). Treatments were vermicompost (0, 5, 7.5 and 10 tons/ha) and commercial humic acid (0, 0.3, 0.6 and 0.9 kg/ha as HUMAX 95-WSG containing 80% humic acid, 15% fulvic acid and 12% K2O). The physicochemical properties of the soil and vermicompost characteristics are shown in Table 2 and 3, respectively. Soil was collected from the surface horizon (0–30 cm). The soil samples were air-dried. Then, they were passed through a 2-mm sieve and mixed uniformly. Physical and chemical characteristics of the soil were measured by standard methods. The soil texture was determined by the hydrometric method (Gee and Bauder, 1986). Soil pH was measured in saturated soil paste using a glass electrode pH meter (Thomas, 1996) and the electrical conductivity (ECe) of the saturated extract (Rhoades, 1996) was measured by an EC meter. Organic matter (OM) content was quantified according to a method used by Nelson and Sommers (1996). Cation exchange capacity (CEC) was determined by the sodium acetate method (Sumner and Miller, 1996). The available amount of phosphorus was measured using the method of Watanabe and Olsen (1965). The total amount of nitrogen was analyzed by the Micro-Kjeldahl method (Bremner, 1996). Potassium was estimated by a flame photometer (Helmke and Sparks, 1996). Micronutrients such as Zn, Fe, Cu and Mn were extracted by diethylenetriaminepenta acetic acid (DTPA) (Lindsay and Norvell, 1978) and their concentrations were measured by atomic absorption spectrophotometry (Shimadzu AA-670 G). The vermicompost in this study was prepared in the agricultural station at Shiraz University. The vermicompost was air-dried and passed through a 2-mm sieve. Then, it was mixed uniformly and its characteristics were determined. Vermicompost: water suspension (1:5 ratio) was used in order to measure the pH (Thomas, 1996) and EC (Rhoades, 1996). Total N by the Micro-Kjeldahl method (Bremner, 1996) and P by Chapman and Pratt method (1961) were determined. The concentrations of micronutrients such as Zn, Fe, Cu and Mn were measured by the dry ash method and atomic absorption spectrophotometry (Shimadzu AA-670G) (Chapman and Pratt, 1961).

Vermicompost treatments were incorporated into the top 15 cm layer of the soil. To avoid direct contact of the vermicompost with seeds, the beds were covered with 1 cm of soft soil and then covered with black polyethylene mulches to control the weeds. The space between every two rows was 150 cm. In each row, holes were dug every 30 cm, and 3 seeds were sowed per hole. Seeds of the *C. intybus* were collected from a certified herbal garden at Jahrom University and were sown on April 22, 2015. Standard agricultural practices were preformed and the drip irrigation system was employed. Aqueous solutions of humic acid were prepared and poured into each hole immediately after sowing. Applying the humic acid was repeated twice a week until the roots were harvested. After drying the areal parts of plants (early in November), the roots were harvested (Fig.1) and several growth parameters of roots were evaluated, including fresh and dry weights, network depth and root volume. Furthermore, several phytochemical parameters were measured, including total sugars and reducing sugars, percent of inulin and the average degree of polymerization (DPn). Photos of the root systems were taken and evaluations of the root network depth and root volume were performed via the "GiA Roots" software (Galkovskyi et al., 2012). The dry weight of the root was recorded after being left to dry in the shade for 12 days.

Table 1
Meteorological data of the field during research period (2015).

Month	Monthly temperatures (°C)			Sunshine duration (h/day)	Evaporation (mm/day)	Precipitation (mm)	Relative humidity (%)		
	Mean	Maximum	Minimum				Mean	Maximum	Minimum
March 21–April 20	10.3	18.6	2.01	8.16	3.72	1.08	43.16	68.48	17.84
April 21–May 21	17.62	27.69	7.54	10.5	6.02	0.2	33.81	57.26	10.35
May 22–June 21	20.3	32.08	8.53	11.96	10.61	0	27.29	44	10.58
June 22–Julay 22	25.29	36.25	14.32	10.93	10.87	0	25.05	37.3	12.81
Julay 23–August 22	25.27	35.37	15.17	10.33	10.16	0	27.51	42.41	12.61
August 23–September 22	21.91	32.39	11.43	10.43	9.27	0	28.87	44.19	13.55
September 2–October 22	16.93	28.3	5.55	10.96	7.4	0	35.76	54.35	17.17
October 23–November 21	12.4	23.83	0.97	8.76	5.8	0.01	33.68	54.63	12.72