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The Effects of pH-Neutral Electrolysed Oxidising Water on Growth and Development of Chrysanthemums

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ABSTRACT

The aim of the study was to analyse the effects of pH-neutral electrolysed oxidising water (pH-neutral EOW), prepared by using the Envirolyte® system, on the growth and development of chrysanthemums. The experiment included two varieties of potted ('Tonka Blanc', 'Jahou CoCo') and two cut flower varieties of chrysanthemums ('Annecy White', 'Ninja'). The test plants planted in pots were irrigated with three different solutions of pH-neutral EOW (0%, 0.1% and 0.2%). Based on the results of the study, we can confirm that pH-neutral EOW has a significant effect on the growth and development of the studied chrysanthemum varieties. In potted chrysanthemums, we found a significant effect on the increased number and diameter of inflorescences, as well as fresh and dried weight of the plant and inflorescences. Chrysanthemums for cut flowers were taller and more developed, with a greater weight of the aboveground part of the plant. Its effect on the growth and development of the studied varieties depended on the solution of the mixture. Best results were observed with the 0.2% solution of pH-neutral EOW.

Key words: electrolysed oxidising water, chrysanthemums, *Dendranthema* × *grandiflora* Tzvelv., growth, morphological characteristics

INTRODUCTION

Chrysanthemums are one of the most important cultivated ornamental plants in the world, sold as plants for cut flowers, potted plants and as perennials. They are popular because of their wide range of shapes and sizes of flowers, brilliance of colour tones, long lasting florets, and relative ease of cultivation throughout the year. In commercial production, two groups of plants are grown, both for cut flowers and as potted plants (Anderson, 2007; Boodley and Newman, 2009; Dole and Wilkins, 2005).

Water is essential for growing chrysanthemums. The plants need plenty of water to produce high quality flowers. The quality of water is important for irrigating plants as it has an impact on the growth and development of the plant and its health. Parameters that affect water quality are pH, salinity, toxicity of certain ions, alkalinity and hardness, microbiological purity, etc. However, many diseases can occur during the development of chrysanthemum, especially in high soil and air humidity and inadequate ventilation during cultivation in greenhouses (Dole and Wilkins, 2005).

Surface water (rivers, streams, canals, water catchments, artificial lakes, reservoirs, ponds, dams), groundwater (boreholes, wells), rainwater, tap water and treated wastewater are used for irrigation. To remove harmful microorganisms from water, chemicals (such as chlorine, ozone, peracetic acid or hydrogen peroxide) or processes such as UV irradiation and membrane filtration are used (Chen et al., 2017; Dandie et al., 2019; Hai et al., 2014; Mahajan et al., 2014; Markland et al., 2017; Martínez et al., 2011).

Many authors report of advantages of using electrolysed oxidising water (EOW), which is generated through the

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electrolysis of chloride-containing water (generally in the form of sodium or potassium chloride) to form hypochlorous acid and reactive oxygen species ($^{\bullet}OH$, O_3, H_2O_2) that are toxic to micro-organisms (Jeong et al., 2007; Jeong et al., 2009; Rahman et al., 2016; Ogunniyi et al., 2019; Ogunniyi et al., 2021). The various types of EOW described in literature include acidic EOW (pH 2–3.5), slightly acidic EOW (pH 5–6.5), alkaline EOW (pH 10–13), slightly alkaline EOW (pH 8–10), and neutral EOW (pH 7–8) (Rahman et al., 2016). Neutral EOW is used as a disinfectant in soaking and washing fresh vegetables (Abadias et al., 2008) or fruit (Torlak, 2014) and in the seafood (Khazandi et al., 2017) and meat industries (Han et al., 2018; Veasey and Muriana, 2016). It can also be used to mist greenhouses, sterilise equipment and soil, and as an additive to irrigation water. The use of sodium-based salts rather than potassium for generation of the EOW might be of concern in the context of plant production because of the potential problems associated with sodium accumulation in soil, in contrast to the potential benefit of potassium supplementation for crop growth.

Published studies have demonstrated the efficacy of EOW as a disinfectant in the production of vegetables, fruit, seafood and meat. However, there has been no report on its efficacy on plant growth. In this preliminary study, we investigated the effects of neutral EOW in the form of potassium chloride on the growth and development of chrysanthemums. We assume that by disinfecting the irrigation water and adding potassium, the growth of the plants and their resistance to pathogens is improved.

MATERIAL AND METHODS

Plant material

Two varieties of chrysanthemums for cut flowers ('Annecy White' and 'Ninja') and two varieties of potted chrysanthemums ('Jahou CoCo' and 'Tonka Blanc') were included in the experiment conducted in a greenhouse. All varieties have a reaction time of eight weeks. The variety 'Annecy White' is characterised by branched growth and several inflorescences on one stem ('spray' form). The variety 'Ninja' can be grown as a standard variety with one inflorescence per stem or as a branched variety. The variety 'Jahou CoCo' is characterised by the formation of a large number of bright yellow inflorescences, up to 5 cm in diameter, and is categorised in the multiflora group of potted chrysanthemums, growing to a height of 25 cm. The variety 'Tonka Blanc' is used for growing in pots and belongs to group of multiflora chrysanthemums that grow up to 25 cm in height.

Substrate, planting and fertilisation

For planting, the substrate Einheits Erde (type ED 73 + Eisen + pH) produced by the German company (Einheitserde Werkverband e.V) was used, which is intended for cultivation of pot plants and structural plants. The main components of the substrate are white peat and clay. At planting, 140 g of slow-release fertiliser (5–6 months) Osmocote® was added to 70 l of substrate, with the NPK + Mg nutrient content in the ratio 17:9:11(2) (w/w/w/w) with micro nutrients. Chrysanthemums for cut flowers were planted in pots with a diameter of 12 cm, and potted chrysanthemums in pots with a diameter of 14 cm. Each pot was used for a single plant. When plants transitioned to the flowering stage, we used the Ferty® 4 fertiliser at each watering (every 2 to 3 days), with the NPK + Mg nutrient content in the ratio of 8:16:24(4) (w/w/w/w) with micro nutrients in 0.1% solution. Per treatment, 26 plants were planted. The experiment was laid out in three replicates using a random block system. A total of 312 plants were included in the experiment.

Electrolysed oxidising water

A pH-neutral EOW was produced using the Envirolyte® system (Envirolyte Industries International Ltd.). We used the ANK Neutral Anolyte solution, in the form of potassium chloride (KCl), with a pH of 7, active chlorine content of 500 mg/l, and a redox potential of 700 mV. The effect of ANK-Neutral Anolyte was studied for 0% (tap water), 0.1% and 0.2% solutions. Plants were irrigated by hand, with an irrigation shower, using a dispenser to dose the exact concentration of pH-neutral EOW. The plants were irrigated 63 times from planting until evaluation.

Measurements

Evaluation of morphological characteristics of potted chrysanthemums was carried out at two specific time points: in the stage of inflorescence bud formation and in the flower opening stage. Chrysanthemums for cut flowers were evaluated only in the flower bud formation stage. At each evaluation date, 13 plants were selected from each treatment randomly. During the first evaluation (in the stage of inflorescence bud formation), we evaluated the following characteristics: plant height (cm), plant width (cm), plant circumference (cm), number of shoots, fresh weight of aboveground part of plant (g) and dry weight of aboveground part of plant (%) (dried for 48 hours at 50 °C). During the second evaluation, we evaluated the following characteristics of potted chrysanthemums: number of open and closed inflorescences, average circumference of three most open inflorescences (cm), fresh weight of aboveground part of plant (g), dry weight of aboveground part of plant (%) (dried for 48 hours at 50 °C), fresh weight of inflorescences (g) and dry weight of inflorescences (%) (dried for 48 hours at 50 °C).

Data analysis

Data obtained in the experiment were statistically analysed using the statistical programme IBM SPSS Statistics Data Editor (Version 24). The analysis of variance (ANOVA)

was performed for individual analysed morphological characteristics. Significances of differences between means at $P \leq 0.05$ were tested using the Duncan method.

RESULTS

The effects of pH-neutral EOW on morphological characteristics of selected varieties of potted chrysanthemums

In the inflorescence bud formation stage (first evaluation period), the studied plant characteristics in both varieties irrigated with pH-neutral EOW differed significantly from those of control plants (Table 1). In the variety 'Tonka Blanc', we found that the plants irrigated with the 0.2% solution of pH-neutral EOW were significantly higher ($\overline{x}$ = 18 cm) and wider ($\overline{x}$ = 18.1 cm) than control plants and plants irrigated with the 0.1% solution. Plants irrigated with the 0.1% solution were also significantly higher ($\overline{x}$ = 16.2 cm) and wider ($\overline{x}$ = 16.4 cm) than control plants (h = 14.1 cm, w = 14.4 cm). Characteristics related to plant size, number of shoots, fresh weight of aboveground part of plant (FWAGP) and dry weight of aboveground part of plant (DWAGP) were significantly higher in plants irrigated with pH-neutral EOW than in control plants.

In the variety 'Jahou CoCo', we found that plants irrigated with the 0.2% solution of pH-neutral EOW differed significantly from control plants and from plants irrigated with 0.1% solution. They were higher ($\overline{x}$ = 21.9 cm), had a greater circumference, were more branched, and had higher fresh and dry weight. Plant width differed significantly only compared to control plants. Plants irrigated with the 0.1% solution were also significantly higher ($\overline{x}$ = 19.3 cm), wider ($\overline{x}$ = 29.2 cm), had a greater circumference, more shoots, and higher fresh weight than control plants (h = 16.7 cm).

In the second evaluation period, conducted in the flower opening stage, the studied morphological characteristics of plants in both varieties irrigated with pH-neutral EOW also differed significantly from those of control plants (Table 2). In the variety 'Tonka Blanc', we found that the plants irrigated with the 0.2% solution of pH-neutral EOW developed significantly larger flowers ($\overline{x}$ = 5.1 cm) than control plants ($\overline{x}$ = 4.5 cm) and plants irrigated with the 0.1% solution ($\overline{x}$ = 4.8 cm). Values for characteristics related to fresh weight of aboveground part of plant (FWAGP), dry weight of aboveground part of plant (DWAGP), fresh weight inflorescences (FWINF) and dry weight of inflorescences (DWINF) were significantly higher in plants irrigated with pH-neutral EOW than in control plants.

In the variety 'Jahou CoCo', we found that plants irrigated with pH-neutral EOW formed significantly more inflorescences and higher fresh weight of aboveground plant part (Table 2). Inflorescence diameter ($\overline{x}$ = 4.8 cm), dry weight of aboveground plant part ($\overline{x}$ = 15.2 %) and dry weight of inflorescence ($\overline{x}$ = 14.1 cm) were significantly higher when plants were irrigated with the 0.1% solution compared to control plants. When the plants were irrigated

Table 1: Average values of morphological characteristics of potted chrysanthemum varieties 'Tonka Blanc' and 'Jahou CoCo' in the inflorescence bud formation stage, depending on irrigating with pH-neutral EOW

Variety	SEOW (%)	H (cm)	W (cm)	C (cm)	NoS	FWAGP (g)	DWAGP (%)
'Tonka	0	14.1c	14.4c	22.5b	14.7b	102.71b	16.1b
Blanc'	0.1	16.2b	16.4b	25.3a	18.4a	128.43a	22.2a
	0.2	18.0a	18.1a	24.4a	18.5a	143.07a	20.4a
'Jahou	0	16.7c	24.5b	59.3c	13.5c	95.56c	22.9b
CoCo'	0.1	19.3b	29.2a	67.9b	17.8b	129.98b	24.5a
	0.2	21.9a	30.4a	72.9a	19.5a	148.10a	24.4a

SEOW – pH-neutral EOW solution (%); H – plant height (cm); W – plant width (cm); C – plant circumference (cm); NoS – number of shoots (main and side); FWAGP – fresh weight of aboveground part of plant (g); DWAGP – dry weight of aboveground part of plant (%); a, b, c – different characters represent statistically significant differences (Duncan, α- = 0.05)

Table 2: Average values of morphological characteristics of potted chrysanthemum varieties 'Tonka Blanc' and 'Jahou CoCo' in the flower opening stage, depending on watering with pH-neutral EOW

Variety	SEOW (%)	NoINF	DiaINF (cm)	FWAGP (g)	DWAGP (%)	FWINF (g)	DWINF (%)
'Tonka	0	241.7a	4.5c	211.21b[11]	10.3b	96.33b	11.4b
Blanc'	0.1	272.0a	4.8b	266.48a	11.3a	133.36a	11.9a
	0.2	277.0a	5.1a	274.07a	11.0a	115.54a	13.4a
'Jahou	0	137.4b	4.3b	156.99b	14.8c	50.71b	12.3c
CoCo'	0.1	178.5a	4.8a	210.85a	15.2b	72.24b	14.1b
	0.2	189.3a	4.5ab	227.69a	15.9a	122.11a	14.6a

SEOW – pH-neutral EOW solution (%); NoINF – number of inflorescences; DiaINF – diameter of open inflorescences (cm); FWAGP – fresh weight of aboveground part of plant (g); DWAGP – dry weight of aboveground part of plant (%); FWINF – fresh weight of inflorescences (g); DWINF – dry weight of inflorescences (%); a, b, c – different characters represent statistically significant differences (Duncan, α- = 0.05)

Table 3: Average values of morphological characteristics of chrysanthemum varieties for cut flowers 'Annecy White' and 'Ninja' in the inflorescence bud formation stage, depending on watering with pH-neutral EOW

Variety	SEOW (%)	H (cm)	W (cm)	C (cm)	NoS	FWAGP (g)	DWAGP (%)
'Annecy	0	66.1b	7.4b	15.4a	13.5a	88.89b	19.2b
White'	0.1	75.3a	10.9a	20.0a	14.2a	130.54a	19.9a
	0.2	81.6a	12.3a	19.3a	15.5a	134.30a	21.1a
'Ninja'	0	78.8c	11.5a	7.9b	11.9c	121.20c	15.8c
	0.1	85.0b	8.3b	7.4b	15.5b	130.65b	17.5b
	0.2	92.8a	13.6a	17.9a	18.1a	147.91a	19.3a

SEOW – pH-neutral EOW solution (%); H – plant height (cm); W – plant width (cm); C – plant circumference (cm); NoS – number of shoots; FWAGP – fresh weight of aboveground part of plant (g); DWAGP – dry weight of aboveground part of plant (%); a, b, c – different characters represent statistically significant differences (Duncan, α- = 0.05)

with the 0.2% solution, they had significantly higher dry weight of aboveground plant part ($\overline{x}$ = 15.9 %), dry weight of inflorescences ($\overline{x}$ = 14.6 %), and the fresh weight of inflorescences ($\overline{x}$ = 122.1 g) was also significantly higher compared to control plants and plants watered with 0.1% concentration.

The effects of pH-neutral EOW on morphological characteristics of selected varieties of chrysanthemums for cut flowers

Chrysanthemums for cut flowers were evaluated only in the flower bud formation stage (Table 3). In the variety 'Annecy White', we found that plants irrigated with pH-neutral EOW were significantly higher, wider, and formed significantly higher fresh weight and dry weight of the aboveground part of the plant.

In the variety 'Ninja', we found that plants irrigated with the 0.2% solution of pH-neutral EOW differed significantly from control plants and plants irrigated with 0.1% solution in all studied morphological characteristics. Plants irrigated with the 0.1% solution were also significantly higher ($\overline{x}$ = 85cm), wither ($\overline{x}$ = 8.3 cm), had more shoots ($\overline{x}$ = 15.5), higher fresh weight ($\overline{x}$ = 130.65 g), and dry weight ($\overline{x}$ = 17.5 %), of aboveground plant parts than those watered with tap water.

DISCUSSION

Based on the results obtained in the evaluation of morphological characteristics of potted chrysanthemums and chrysanthemums for cut flowers, we can conclude that pH-neutral EOW had a great effect on plant growth and development in all considered varieties and that no harmful effects on plants were found.

Plant habit, fresh weight of aboveground part of plant and dry weight of aboveground part of plant increased significantly at the flower bud formation stage. We also found that both varieties for cut flowers, when irrigated with pH-neutral EOW, had a significantly higher habit at the flower bud formation stage and consequently a significantly higher fresh and dry weight of aboveground part of plant compared to control plants. The growth and development of studied chrysanthemum varieties also depended on the EOW solution used. In the chrysanthemum for cut flowers, the morphological characteristics of the variety 'Ninja', when irrigated with the 0.2% solution of pH-neutral EOW, differed significantly from plants watered with the 0.1% solution. No significant differences were found in the variety 'Annecy White', but a trend of increasing studied morphological characteristics was observed when using the 0.2% solution of pH-neutral EOW. Also, in potted chrysanthemum varieties, the best results were observed with the 0.2% solution of pH-neutral EOW.

We can assume that plant growth and development was affected by the use of pH-neutral EOW in the form of potassium chloride (KCl). The use of potassium-based salts might have potential benefit of potassium supplementation for crop growth. Potassium is required in large quantities for optimum plant growth and productivity (Oosterhuis et al., 2014) since it is essential for completion of various physiological and metabolic functions: maintains cell growth and turgor pressure (Anschütz et al., 2014), hydraulic conductance (Oddo et al., 2011), leaf expansion (Jordan-Meille and Pellerin, 2004), photosynthesis (Pasandi Pour et al., 2021), root elongation (Song et al., 2018), transport of photoassimilates between source and sink organs (Hu etal., 2017), and regulation of stomatal guard cells (Raschke, 1975).

Plant tissue analysis reflects the level of nutritional status of the plant. Particularly, a combination of soil and tissue analyses may provide a better understanding of the role of potassium in the use of pH-neutral EOW in the form of potassium chloride (KCl). As the effects of EOW as a disinfectant in the production of vegetables, fruits, seafood and meat are already established, the impact on pathogenic microorganisms occurring in irrigation water, soil and on chrysanthemum plants should be studied further.

CONCLUSION

The pH-neutral electrolysed oxidising water (pH-neutral EOW) prepared using the Envirolyte® system significantly affects the growth and development of the studied chrysanthemum varieties. Its effect depended on the solution of the mixture and varieties.

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Vpliv pH-nevtralne elektrolizirane vode na rast in razvoj krizantem

IZVLEČEK

Namen raziskave je bil proučiti vpliv pH-nevtralne elektrolizirane vode (pH nevtralne EV), ki smo jo pridobivali s sistemom Envirolyte®, na rast in razvoj krizantem. V poskus smo vključili dve sorti lončnih krizantem ('Tonka Blanc', 'Jahou CoCo') in dve sorti krizantem za rezanje ('Annecy White', 'Ninja'). Rastline, posajene v lonce, smo po potrebi zalivali s tremi različnimi koncentracijami pH nevtralne EV (0 %, 0,1 % in 0,2 %). Na osnovi rezultatov raziskave lahko potrdimo, da ima pH nevtralna EV značilen vpliv na rast in razvoj proučevanih sort krizantem. Pri lončnih krizantemah smo ugotovili značilen vpliv na povečano število in premer socvetij ter svežo maso in suho snov rastline in socvetij. Krizanteme za rezanje so višje in bolj razraščene ter imajo večjo maso nadzemnega dela rastline. Vpliv pH nevtralne EV na rast in razvoj proučevanih sort je odvisen od koncentracije raztopine. Najboljše rezultate smo dosegli z uporabo 0,2 % koncentracije.

Ključne besede: elektrolizirana voda, krizanteme, *Dendranthema* × *grandiflora* Tzvelv., rast, morfološke lastnosti