Industrial Crops and Products 76 (2015) 269–274

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Changes in the essential oil content and selected traits of sweet basil (*Ocimum basilicum* L.) as induced by foliar sprays of citric acid and salicylic acid

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ARTICLE INFO

Article history:
Received 26 February 2015
Received in revised form 14 May 2015
Accepted 24 June 2015

Keywords:
Organic acids
Seed mucilage
Seed size
Seed oil content
Leaf/stem ratio

ABSTRACT

The experiment aimed to understand how these organic acids are going to affect on essential oil production in sweet basil. Three concentrations of each citric acid (CA; 0, 4, or 7 mM) and salicylic acid (SA; 0.5 or 1 mM) were applied. We added a standard control for comparison. The first spray was started at 2-leaf stage that was continued with four subsequent sprays in a 15 day interval. The plants were harvested 75 days after sowing the seeds, when they had produced seed. SA in 1 mM concentration caused the maximum of the total essential oil production along with the highest essential oil production by both leaves and stems with an increase of 32.8, 38.3, and 25.8% (respectively) when compared to control treatment. A synergism between 7 mM CA and 1 mM SA was observed in flowering parameters, which yielded the tallest inflorescence in CA_7SA_1 along with the highest inflorescence count per plant and floret count in main inflorescence. Despite these quantitative improvements in flowering parameters, the thousand seed weight was still at its maximum in this combination, as well. The seed mucilage, on the other hand, increased significantly by foliar application of 0.5 mM SA. Seed oil content responded positively to applied CA, while SA effect was negligible. The results show the potential for using these compounds in manipulation of plant growth and metabolism toward the intended final use.

1. Introduction

Sweet basil (*Ocimum basilicum* L.) is an herb from the Lamiaceae family that is used as a favorite fresh vegetable together with many traditional foods, dressings, and salads. The aroma of basil due to its essential oil makes a great contribution to its organoleptic quality as well as the medicinal value.

Salicylic acid (SA) is among the most readily available plant growth regulating agents; it is also effective in other forms of acetyl SA and methyl salicylate in the plant (Raskin, 1992). SA acts as a stress messenger that induces the hypersensitive response (HR), helping the plant to resist invading organisms (Klessig and Malamy, 1994). Interactions have been reported between SA and other natural stress management compounds (Cipollini et al., 2004; Metraux and Durner, 2004; Kachroo and Kachroo, 2007; Zottini et al., 2007; De Torres Zabala et al., 2009). The alternative oxidase enzyme activity in mitochondria could be induced by SA, which is involved in the stress alleviation mechanism in plants (Raskin, 1992; Vanlerberghe and McIntosh, 1997). Beneficial effects by application of lower concentrations (less than 1 mM) has been reported for plant growth (Rivas-San Vicente and Plasencia, 2011). SA caused enhancement (Kiddle et al., 1994; Kang et al., 2004; Wang et al., 2007) or decline (Prithiviraj et al., 2005; D'Onofrio et al., 2009) in specific secondary metabolites of the plant. In sweet basil, increase in the content of essential oil in response to sprays of SA at 0.1 mM is reported (Gharib, 2006). Jafari and Hadavi (2012) tested higher SA concentrations and suggested finding the optimum SA concentration between 0.1 mM and 2 mM.

Citric acid (CA) is a six carbon organic acid, featuring a central role in citric acid cycle in mitochondria that creates cellular energy by phosphorilative oxidation reactions. It is created by addition of imported acetyl-CoA from glycolysis to oxaloacetic acid that is converted in later stages to succinate and malate (Wills et al., 1981). Foliar sprays of CA alone or in combination with Fe salts have been used to recover many plants from the Iron chlorosis (Abadía et al., 2002; Álvarez-Fernández et al., 2004; Eidyan et al., 2014; Mengel et al., 1994; Tagliavini et al., 1995, 2000). Later studies revealed that the CA effect is not just due to pH change and there are a variety of physiological responses to applied CA; foliar use of CA alone or in combinations with SA and malic acid increased the essential

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http://dx.doi.org/10.1016/j.indcrop.2015.06.052
0926-6690/

oil production of Basil (Jaafari and Hadavi, 2012) and Dill (Jafari and Hadavi, 2012). Some physiological parameters were improved in Tuberose by application of foliar CA (Eidyan et al., 2014), Lilium (Darandeh and Hadavi, 2012), and Bean (El-Tohamy et al., 2013). The increase in the vase life of cut rose flowers obtained in the soilless culture system by foliar pre-harvest application of the combinations of SA and CA revealed that the obtained results are not necessarily dependent on soil system (Hajreza et al., 2013). A recent study based on current work confirmed that the combination of 1 mM SA with 7 mM CA caused a significant increase in root acquisition of boron in a soilless culture system (Ghazijahani et al., 2014).

An increase in the exudation of citrate and malate from roots of calcicole plants (plants growing in alkaline soils) enables them to extract P and Fe from such soils (Lopez-Bucio and Nieto-Jacobo, 2000). Jafari and Hadavi (2012), suggested an increase in mineral absorption by elevated exudation of organic acids in response to foliar organic acids as part of mechanism responsible for improved growth parameters. This was confirmed recently by An et al. (2014), and the mediation of these exudates in mineral absorption in the soil medium is well known (Marschener, 1998; Bais et al., 2006; Arcand and Schneider, 2006). In addition, the exudated organic acids are the main carbon source for rhizobacteria (Ohwaki and Sugahara, 1997). Therefore, a much complex interaction and effect size is expected by use of foliar organic acids in a soil culture system as compared to a soilless culture system (Ghazijahani et al., 2014).

There are reports on changes in leaf/stem ratio in response to applied excess nitrogen in Basil (Frabboni et al., 2011), and Mint (Ram and Kumar, 1997). Therefore, making a distinction between their share in essential oil production might be useful to understand how they could interact on total essential oil production in response to applied treatments.

The present experiment was designed mainly to assess the effect of those promising ranges and combinations of SA and CA, which were suggested by earlier reports on essential oil production of sweet basil.

2. Material and methods

This study was conducted during the summer of 2010. The field had a sandy-loam soil with a pH 7.6, a relatively high EC of 5.2 4 dS/m, total organic carbon of 0.6%, total N of 0.55%, dissolved phosphorus of 9.6 mg kg^{-1} and extractable potassium of 314 mg kg^{-1}.

2.1. Plant culture and foliar treatments

Seeds of the *O. basilicum* 'Karaj' accession were directly planted in the field. Seeds were planted in plots (2 m width by 6 m length) with 50 cm line spacing. All field operations were performed manually using local interns. The experiment was conducted in a randomized block design factorial arrangement (2×3) with four replications. CA (0, 4, and 7 mM) and SA (0.5 and 1 mM) were applied in five consecutive sprays starting at two real leaf stage; the sprays were repeated every 15 days. We added a standard control that was sprayed with distilled water as well with four replications for comparison. A commercial wetting agent was added to enhance the wetting effect of the sprays (citogate).

2.2. Essential oil measurement

Dry samples of 50 g from herb were obtained from each replication in day 75 after sowing the seeds and used for essential oil extraction. Essential oil was extracted by hydro-distillation in a Clevenger apparatus according to the method described by Carvalho Filho et al. (2006), with modifications. Samples were placed in round bottomed flasks containing 1.5 L of water and refluxed for 3 h; the oil weight (g) was recorded. The obtained essential oil content (EOC; %) for stem and leaf, were used together with stem dry weight yield (DWY) and leaf DWY to product essential oil yield (EOY) for stem and leaf using following formula: $\text{EoY(kg/ha)} = (\frac{\text{EoC(\%w/w)} \times \text{DWY(kg/ha)}}{100})$. Next, the stem plus leaf EOY yielded in the total EOY. Furthermore, the total EOC was calculated back by the same formula. The ratio of leaf EOY to stem EOY was also calculated.

2.3. Number of inflorescences per plant

Six plants of each plot were randomly selected and the number of inflorescences in each plant was counted and averaged.

2.4. Number of florets in the main inflorescence

Six plants of each plot were randomly chosen and the florets only on the main inflorescence were counted and then averaged.

2.5. Seed oil content

For estimation of seed oil content, 10 g of dry seed was ground thoroughly using pestle and mortar and put in Soxhlet apparatus containing *n*-hexane solvent. The extract was then placed in a rotary evaporator and the remaining oil was weighted.

2.6. Thousand seed weight

A thousand of pure seed were counted and weighted by a 0.0001 digital scale.

2.7. Seed mucilage

Five gram of clean and dry seeds from each treatment were weighed and the equal amount of 100 mL of distilled water was added to each. After 24 h, excess water drained and weighed again. Then the initial weight of 5 g subtracted from each to yield the amount of absorbed water by mucilage. The amount of water absorbed by 5 g sample was indicative of their mucilage content.

2.8. Statistical analysis

Results were analyzed by the GLM module of the SPSS software (version 20, IBM Inc.) and comparison of means was done by the Tukey HSD test ($p < 0.05$). Multiple regression analysis (MRA) was conducted using linear regression component of the same software to test relationship among selected factors and variable.

3. Results

3.1. Essential oil content (EOC)

The results show that the direct effect of CA and SA and the interaction between CA and SA on the total amount of essential oil, essential oil of the leaves and stems were proved to be significant ($p = 1\%$; Table 1).

With constant 0.5 mM SA, an increase of CA to 4 mM caused a slight decrease in the total, leaf, and stem EOC, while increasing the level further to 7 mM caused them to decline further which suggests an antagonism between the two (Fig. 1A). On the other hand, with constant 1 mM SA, all the EOCs declined sharply by an increase of CA to 4 mM, whereas, unlike the previous trend, by increase of the CA level further to 7 mM, the EOC increased.

The mean comparison test showed the greatest increase in the percentage of total essential oil, essential oil of the leaves and stems,

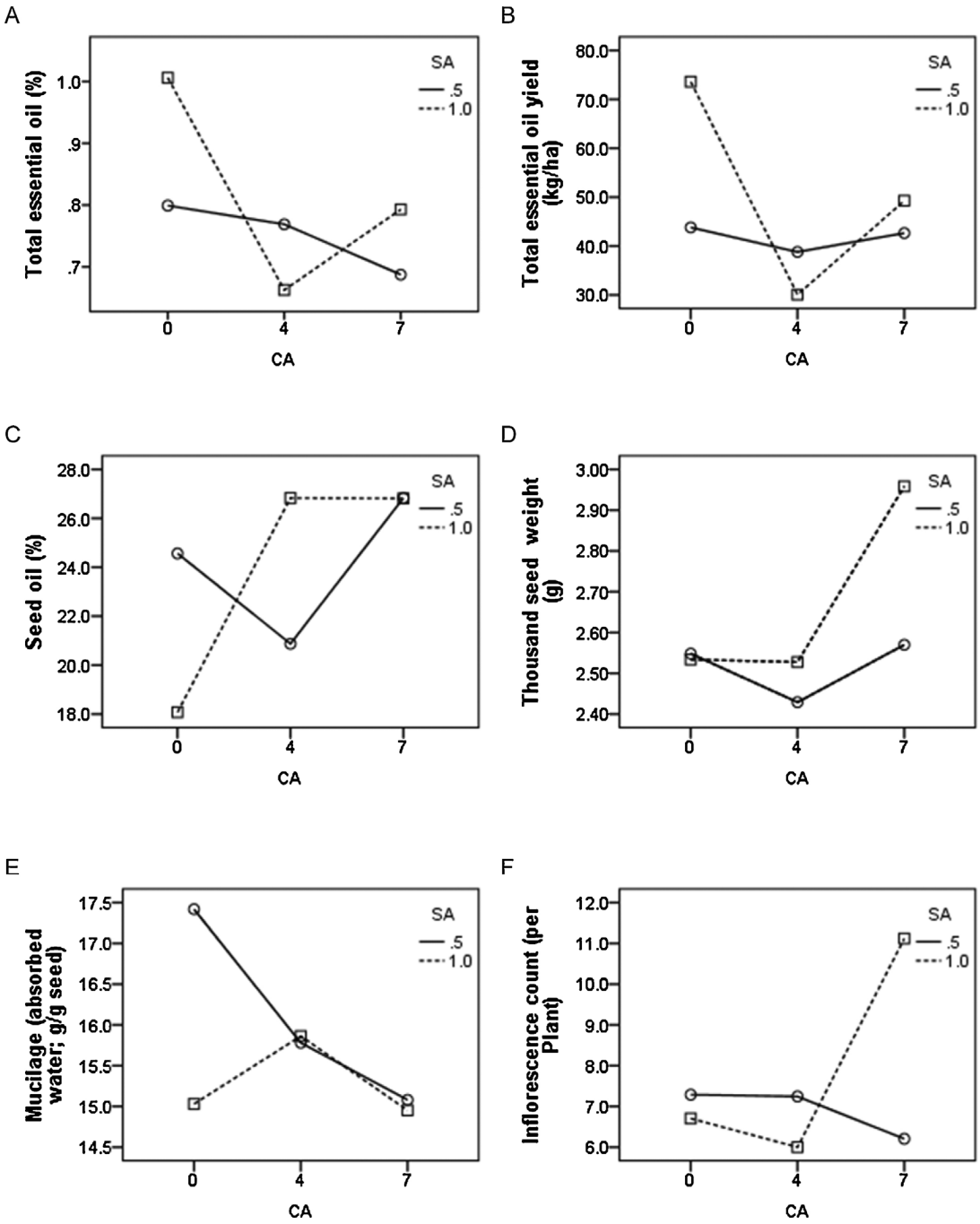

Fig. 1. The interaction of CA and SA on total essential oil content (A), total essential oil yield (B), seed oil content (C), thousand seed weight (D), mucilage content (E), and inflorescence count (F) of sweet basil.

to be respectively, 32.8%, 38.3%, and 25.8% more than the control treatment. However, only the treatment containing 1 mM of SA (CA_0SA_1) caused a significant increase, when compared to the control treatment (Table 1).

3.2. The effect on the essential oil yield (EOY)

The direct effect of CA and SA and their interaction on the total EOY and leaf and stem EOY were significant ($p = 1\%$; Table 1).

With constant 0.5 mM SA, an increase of CA to 4 mM caused a slight decrease in the total and stem EOC while the leaf EOY increased slightly. This trend was reversed by increasing the level further to 7 mM (Fig. 1B). On the other hand, at 1 mM SA, by increase of CA to 4 mM, total EOY, stem and leaf's EOY fell sharply; however, increasing the level to 7 mM CA caused all of them to increase again (Fig. 1B).

Mean comparison test showed the largest increase in total EOY, leaf and stem EOY was recorded in CA_0SA_1 with 157.3, 159.8, and 148.7 percent increase compared with the control group respectively (Table 1).

As it is evident in the Table 1, the ratio of leaf to stem EOY has increased by all treatments when compared to control. We used regression analysis to test the nature of influence of CA and SA on ratio of leaf to stem EOY. The result indicated that SA effect was non-significant while CA explained 34% of variance in ratio of leaf to stem EOY.

Table 1
The effect of foliar citric and salicylic acids on the essential oil, flower and seed parameters of sweet Basil.

Citric acid (mM)	Salicylic acid (mM)	Total essential oil content (%)	Leaf essential oil content (%)	Stem essential oil content (%)	Total essential oil yield (kg/ha)	Leaf essential oil yield (kg/ha)	Stem essential oil yield (kg/ha)	Seed oil content (%)	Ratio of leaf to stem essential oil yield	Thousands seed weight (g)	Mucilage (absorbed water; g/g seed)	Main inflorescence length (cm)	Inflorescence count per plant	Floret count in main inflorescence
0	0.5	0.77[†] b	0.90 b	0.70 bc	42.5 bc	18.7 c	23.7 bc	24.6 b	0.79 cd	2.5 b	17.4 a	22.6 ab	7.3 ab	14.8 a
	1	0.97 a	1.14 a	0.87 a	70.5 a	29.1 a	41.3 a	18.1 d	0.71 cd	2.5 b	15.0 c	22.6 ab	6.7 b	14.3 a
4	0.5	0.76 b	0.86 bcd	0.68 c	38.3 c	19.0 bc	19.3 cd	20.9 c	0.99 a	2.4 c	15.8 b	24.8 ab	7.2 ab	13.3 a
	1	0.63 c	0.77 d	0.55 e	28.7 d	12.8 d	15.9 d	26.8 a	0.80 bcd	2.5 b	15.9 b	23.3 ab	6 b	13.4 a
7	0.5	0.66 c	0.79 cd	0.59 d	41.1 bc	18.3 c	22.7 bc	26.8 a	0.81 bc	2.6 b	15.1 c	23.6 ab	6.2 b	13.9 a
	1	0.78 b	0.88 bc	0.71 b	48.5 b	23.2 b	25.3 b	26.8 a	0.92 ab	3.0 a	15.0 c	25.6 a	11.1 a	16 a
Control		0.74 b	0.83 bcd	0.69 bc	27.9 d	11.2 d	16.6 d	24.9 b	0.68 d	2.5 bc	15.0 c	21.2 b	8.7 ab	14.1 a
Factor significance														
Citric acid		***	***	***	***	***	***	***	***	***	***	ns	ns	ns
Salicylic acid		***	***	***	***	***	***	ns	*	***	***	ns	ns	ns
CA × SA		***	***	***	***	***	***	***	***	***	***	ns	**	ns

ns = non significant, *** = significant ($p = 0.001$), ** = significant ($p = 0.01$), * = significant ($p = 0.05$).
[†] Values in the same column that are followed by the same letter do not differ significantly according to Tukey HSD multiple range test ($p \leq 0.05$).

3.3. Inflorescence parameters

The largest increase in main inflorescence length of 20.7% was in CA_7SA_1, which was significantly different from control but was in a same statistical group with the rest of treatments (Table 1). The interactions between CA and SA on the inflorescence count per plant were significant at 1% probability level, whereas no significant difference was observed in the number of florets (Table 1). Visualized interactions showed that at 0.5 mM SA, 4 mM CA reduced the number of florets per inflorescence, but had little effect on the number of inflorescences per plant, while by an increase in CA level to 7 mM, the number of florets per inflorescences increased and the inflorescence count per plant declined (Fig. 1F). In contrast, with 1 mM SA, when CA increased to concentration of 4 mM, both traits were reduced and further by increasing to 7 mM CA, a synergistic effect was observed, causing both the number of inflorescences per plant and the number of florets per inflorescence increased (Fig. 1F).

The highest number of inflorescence per plant and the floret count were evident in response to CA_7SA_1 which respectively were 27.5 and 13.4 per cent higher compared with the control treatment, although this difference was not significant (Table 1).

3.4. Seed oil content

The results show that the direct effect of CA and CA interactions with SA were effective on seed oil content ($p < 1\%$; Table 1). Review of the interaction chart (Fig. 1C) revealed that at 0.5 mM SA, the increase of CA to 4 mM reduced the seed oil content, while increasing the level of CA to 7 mM had no effect on seed oil content. The interaction of 1 mM SA with increased CA to 4 mM was synergistic, causing a sharp increase in the seed oil content, whereas the increase of CA to 7 mM had no effect on seed oil.

Mean comparison showed the highest increase of 7.6 percent oil content in the $CA_7SA_{0.5}$ treatment; which together with the CA_7SA_1 and CA_4SA_1 treatments, caused a significant increase when compared with the control treatment (Table 1).

3.5. Thousand seed weight

The results show that the direct effect of CA and SA and their interaction on thousand seed weight were significant ($p < 1\%$; Table 1). At 0.5 mM SA, an increase of CA to 4 mM slightly decreased the thousand seed weight and with further increase to 7 mM, the thousand seed weight rose again (Fig. 1D). In 1 mM SA level, the increase of CA to 4 mM caused no mentionable increase in thousand seed weight, while with further increase of CA to 7 mM, a synergism appeared which greatly increased thousand seed weight (Fig. 1D). The mean comparison analysis revealed that largest increase in thousand seed weight was in CA_7SA_1 treatment, which showed a significant (18.4%) increase when compared to control.

3.6. Seed mucilage index

The results showed that the direct and interactive effects of CA and SA on the seed mucilage content were significant ($p < 1\%$; Table 1).

The interaction chart (Fig. 1E), shows that with .5 mM SA, an increase in CA to 4 mM reduced the seed mucilage and by further increase of CA to 7 mM this trend continued suggesting presence of an antagonism effect between the two. On the other hand, in 1 mM SA with an increase of CA to 4 mM the seed mucilage percentage increased but with the further increase of CA to 7 mM the seed mucilage decreased. Mean comparison test showed the greatest increase in mucilage with a 16.4% increase compared with the control group was in $CA_0SA_{0.5}$, which was significantly different from all treatments. In addition, the $CA_4SA_{0.5}$ and CA_4SA_1 treat-

ments had mean mucilage, which were significantly higher than the control.

4. Discussion

4.1. Essential oil parameters

Gharib (2006) showed that 0.1 mM SA caused a significant increase in the EOY of marjoram and basil. An increase in EOC of *Salvia macrosiphon* by application of 1.45 and 2.9 mM SA is reported (Rowshan et al., 2010). On the other hand, Hashmi et al. (2012) reported that 0.1 mM SA was more effective than 1 mM in augmentation of EOY of Fennel. Later, Jafari and Hadavi (2012) noted some positive effects at the applied concentration of 2 mM SA, especially as the result of a synergism with 15 mM CA, therefore, suggested finding the optimum SA concentration between 0.1 mM to 2 mM. Likewise, in another study with concentrations of above 0.5 mM, it was concluded that 1.1 mM SA application was responsible for the increased EOC of Peppermint (Saharkhiz and Goudarzi, 2014). In our experiment, the maximum amount of EOC and EOY was obtained by spraying 1 mM SA; however, still higher SA concentrations than those reported by Gharib (2006) could be considered effective on Basil. Therefore, due to observed inconsistency in reported response from 0.1 mM to 1 mM and higher SA levels among different plants, we suggest incorporating the full concentration range in future studies.

Jafari and Hadavi (2012) reported 73.4 kg ha^{-1} of EOY with application of 5 mM CA comparable with 39.5 kg ha^{-1} in control treatment, when the plants were harvested before flowering. Here, we observed the maximum oil yield of 73.6 kg ha^{-1}, which is comparable to 28.6 kg ha^{-1} in the control treatment, and we harvested the plants after flowering when the seeds were developing. Therefore, we can imagine that the delay in harvest coincided with an increased sink activity of developing flowers and seeds causing metabolites shifting toward flowering. As a matter of fact, In perennial labiates, peak of oil content and yield usually coincides with the flowering phase of the plant (Sangwan et al., 2001). On the other hand, a relationship between seed set and production of oil in the plant is noticeable as an increase in seed weight and seed oil content induced by CA application. We may assume that the increased sink activity in regenerative organs by CA caused less essential oil in our experiment by treatments containing CA. However, further study is needed in order to make a conclusion.

The observed effect on the ratio of the leaf to stem EOY could be compared with previous reports on changes in leaf/stem ratio in response to applied excess nitrogen in Basil (Frabboni et al., 2011), and Mint (Ram and Kumar, 1997). Here, we can guess that similar mechanism could be present in our experiment. Applied CA here, could have created a similar response to nitrogen application by increase of leaf/stem ratio. It is suggested that mineral absorption could be affected by elevated exudation of organic acids in response to foliar organic acids (Jaafari and Hadavi, 2012). However this is confirmed recently by An et al. (2014), and the intervention of these exudates in mineral absorption in the soil is well known (Bais et al., 2006; Arcand and Schneider, 2006; Marschener, 1998).

4.2. Inflorescence parameters

Using combination treatment of 7 mM CA and 1 mM SA caused a significant increase in the main inflorescence length, inflorescence count per plant, floret count in main inflorescence and the thousand seed weight. In our experiment, it appears that the effect of CA on increase of inflorescence length dominated over SA effect. A synergism between 7 mM CA and 1 mM SA was observed which yielded the tallest inflorescence in CA_7SA_1 treatment, as the only one being significantly different from the control. Our results on SA could be considered in accordance with an earlier report by Martín-Mex et al. (2010) that applications of SA have a significant effect on the number of flowers per plant, thought at far lower concentration of 1 μM. Likewise, we noticed a thousand seed weight gain due to foliar CA. A synergism was observed between the concentration of 7 mM CA and 1 mM SA, which caused the highest thousand seed weight in their combined treatment.

4.3. Seed oil

SA had no effect on seed oil content, which corresponded with the results of Hussain et al. (2010) reporting no effect by application of .724 mM SA on the seed oil content of Sunflower (2010). However, Noreen and Ashraf (2010) reported increasing the seed oil content of the sunflower by application of 2.17 mM SA compared to 1.44 and .724 mM concentrations. Kobeasy et al. (2011) also showed that by application of 0.2 mM of SA, peanut seed oil content was increased, which is attributed to increase in the expression of fat carrying proteins that are part of the set response to the viral infection. Here, while no effect by SA was observed, CA increased the content of basil seed oil. The fact that the lowest seed oil was coincided with the highest EOY might suggest that there might be a connection between the two.

4.4. Thousand seed weight

Considering previous result on the effect of CA on thousand seed weight, it appears that CA effect is manifested possibly via elicitation of regenerative sink of plant and especially by elicitation of seed sink, which are evident in increase of inflorescent number and increased carbohydrate storage in seed, respectively. The observed increase in the seed qualitative parameters, could lead to improved seed quality and germination that needs further research.

4.5. Seed mucilage

Test results indicate the potential to increased basil seed mucilage by foliar application of 0.5 mM SA. The seed mucilage content was reduced by CA. We did not find any record of similar results on manipulation of basil seed mucilage content, so our test is raising this possibility for the first time. The extracted mucilage from basil is nominated as an outstanding source for gum production (Razavi et al., 2009). By now, it is used in formulation of dispersible tablets (Sukhavasi and Kishore, 2012), edible coats (Shahiri Tabarestani et al., 2013), and as natural coagulant for removal of dye from textile industry wastewater. Hence, methods to increase the mucilage production would be of interest in the future.

5. Conclusion

Owing to increased inflorescence count, floret count and the thousand seed weight, that are the yield constituents, more seed yield could be expected in CA_7SA_1 treatment that unfortunately, we missed to conduct such a measurement.

A recent study, which was inspired by current work, revealed that the CA_7SA_1 treatment could affect on the acquisition pattern of some minerals from soilless culture condition (Ghazijahani et al., 2014). They found that plants in CA_7SA_1 accumulated more Boron and had higher photosynthetic eficiency. However, further work is needed to understand how basil plants respond to mentioned foliar sprays in more complex growing media.

Regarding SA effect on essential oil production, with a view to accumulated data we can suggest using SA in concentrations around 1 mM to achieve a reasonable increase in EOC of sweet basil. However, due to the synergysm with CA in other traits and previous

results with far lower concentration of 0.1 mM, it sounds reasonable to further fine tune CA and SA concentrations based on the desired traits and intended use.

References

Abadía, J., Lopez-Millan, A.-F., Rombola, A., Abadía, A., 2002. Organic acids and Fe deficiency: a review. Plant Soil 241, 75–86.

Álvarez-Fernández, A., García-Laviña, P., Fidalgo, C., Abadía, J., Abadía, A., 2004. Foliar fertilization to control iron chlorosis in pear (*Pyrus communis* L.) trees. Plant Soil 263, 5–15.

An, Y., Zhou, P., Xiao, Q., Shi, D., 2014. Effects of foliar application of organic acids on alleviation of aluminum toxicity in alfalfa. J. Plant Nutr. Soil Sci. 177, 421–430.

Arcand, M.M., Schneider, K.D., 2006. Plant-and microbial-based mechanisms to improve the agronomic effectiveness of phosphate rock: a review. An. Acad. Bras. Ciênc. 78, 791–807.

Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S., Vivanco, J.M., 2006. The role of root exudates in rhizosphere interactions with plants and other organisms. Ann. Rev. Plant Biol. 57, 233–266.

Carvalho Filho, J.L.S., Blank, A.F., Alves, P.B., Ehlert, P.A.D., Melo, A.S., Cavalcanti, S.C.H., Arrigoni-Blank, M.F., Silva-Mann, R., 2006. Influence of the harvesting time, temperature and drying period on basil (*Ocimum basilicum* L.) essential oil. Rev. Bras. Farmacogn. 16, 24–30.

Cipollini, D., Enright, S., Traw, M., Bergelson, J., 2004. Salicylic acid inhibits jasmonic acid-induced resistance of *Arabidopsis thaliana* to *Spodoptera exigua*. Mol. Ecol. 13, 1643–1653.

D'Onofrio, C., Cox, A., Davies, C., Boss, P.K., 2009. Induction of secondary metabolism in grape cell cultures by jasmonates. Funct. Plant Biol. 36, 323–338.

Darandeh, N., Hadavi, E., 2012. Effect of pre-harvest foliar application of citric acid and malic acid on chlorophyll content and post-harvest vase life of *Lilium* cv. Brunello. Front. Crop Sci. Hortic. 2 (article no. 106).

De Torres Zabala, M., Bennett, M.H., Truman, W.H., Grant, M.R., 2009. Antagonism between salicylic and abscisic acid reflects early host–pathogen conflict and moulds plant defence responses. Plant J. 59, 375–386.

Eidyan, B., Hadavi, E., Moalemi, N., 2014. Pre-harvest foliar application of iron sulfate and citric acid combined with urea fertigation affects growth and vase life of tuberose (*Polianthes tuberosa* L.) 'Por-Par'. Hortic. Environ. Biotechnol. 55, 9–13.

El-Tohamy, W., El-Abagy, H., Badr, M., Gruda, N., 2013. Drought tolerance and water status of bean plants (*Phaseolus vulgaris* L.) as affected by citric acid application. J. Appl. Bot. Food Qual. 86, 212–216.

Frabboni, L., De Simone, G., Russo, V., 2011. The influence of different nitrogen treatments on the growth and yield of Basil (*Ocimum basilicum* L.). J. Chem. Chem. Eng. 5, 799–803.

Gharib, F., 2006. Effect of salicylic acid on the growth, metabolic activities and oil content of basil and marjoram. Int. J. Agric. Biol. 4, 485–492.

Ghazijahani, N., Hadavi, E., Jeong, B.R., 2014. Foliar sprays of citric acid and salicylic acid alter the pattern of root acquisition of some minerals in sweet basil (*Ocimum basilicum* L.). Front. Plant Sci. 5 (article no. 573).

Hajreza, M., Hadavi, E., Zeynanlou, A., Mirzapour, M., Naeini, M., 2013. Effect of different levels of citric acid and salicylic acid at pre-harvesting stage on vase-life of rose (*Rosa hybrida* L.) cut flower. J. Sci. Technol. Greenhouse Culture – Isfahan Univ. Technol. 4, 99–109.

Hashmi, N., Khan, M.M.A., Idrees, M., Aftab, T., 2012. Exogenous salicylic acid stimulates physiological and biochemical changes to improve growth, yield and active constituents of fennel essential oil. J. Plant Growth Regul. 68, 281–291.

Hussain, M., Farooq, M., Jabran, K., Wahid, A., 2010. Foliar application of glycinebetaine and salicylic acid improves growth, yield and water productivity of hybrid sunflower planted by different sowing methods. J. Agron. Crop Sci. 196, 136–145.

Jaafari, N., Hadavi, E., 2012. In: Carlen, C., Baroffio, C.A., Vouillamoz, J.F. (Eds.), Growth and Essential Oil Yield of Basil (*Ocimum basilicum* L.) as Affected by Foliar Spray of Citric Acid and Salicylic acid, 955. Z. Arznei – Gewurzpflanzen, pp. 80–83.

Jafari, N., Hadavi, E., 2012. In: Carlen, C., Baroffio, C.A., Vouillamoz, J.F. (Eds.), Growth and Essential Oil Yield of Dill (*Anethum graveolens*) as Affected by Foliar Sprays of Citric Acid and Malic Acid, 955. Acta Hortic., pp. 287–290.

Kachroo, A., Kachroo, P., 2007. Salicylic acid, jasmonic acid and ethylenemediated regulation of plant defense signaling. Genet. Eng. 28, 55–83.

Kang, S.M., Jung, H.Y., Kang, Y.M., Yun, D.J., Bahk, J.D., Yang, J., Choi, M.S., 2004. Effects of methyl jasmonate and salicylic acid on the production of tropane alkaloids and the expression of PMT and H6H in adventitious root cultures of *Scopolia parviflora*. Plant Sci. 166, 745–751.

Kiddle, G.A., Doughty, K.J., Wallsgrove, R.M., 1994. Salicylic acid-induced accumulation of glucosinolates in oilseed rape (*Brassica napus* L.) leaves. J. Exp. Bot. 45, 1343, http://dx.doi.org/10.1093/jxb/erj022

Klessig, D.F., Malamy, J., 1994. The salicylic acid signal in plants. Plant Mol. Biol. 26, 1439–1458.

Kobeasy, M.I., El-Beltagi, H.S., El-Shazly, M.A., Khattab, E.A., 2011. Induction of resistance in *Arachis hypogaea* L. against Peanut mottle virus by nitric oxide and salicylic acid. Physiol. Mol. Plant Pathol. 76, 112–118.

Lopez-Bucio, J., Nieto-Jacobo, M.I., 2000. Organic acid metabolism in plants: from adaptive physiology to transgenic varieties for cultivation in extreme soils. Plant Sci. 160, 1–13.

Marschener, H., 1998. Role of root growth, arbuscular mycorrhiza, and root exudates for the efficiency in nutrient acquisition. Field Crops Res. 56, 203–207.

Martín-Mex, R., Vergara-Yoisura, S., Nexticapán-Garcés, A., Larqué-Saavedra, A., 2010. Application of low concentrations of salicilyc acid increases the number of flowers in *Petunia hibrida*. Agrociencia 44, 773–778.

Mengel, K., Planker, R., Hoffmann, B., 1994. Relationship between leaf apoplast pH and iron chlorosis of sunflower (*Helianthus annuus* L.). J. Plant Nutr. 17, 1053–1065.

Metraux, J.P., Durner, J., 2004. The role of salicylic acid and nitric oxide in programmed cell death and induced resistance. In: Sandermann, H. (Ed.), Molecular Ecotoxicology of Plants. Springer-Verlag, Berlin, Heidelberg and New York, pp. 111–150.

Noreen, S., Ashraf, M., 2010. Modulation of salt (NaCl)-induced effects on oil composition and fatty acid profile of sunflower (*Helianthus annuus* L.) by exogenous application of salicylic acid. J. Sci. Food Agric. 90, 2608–2616.

Ohwaki, Y., Sugahara, K., 1997. Active extrusion of protons and exudation of carboxylic acids in response to iron deficiency by roots of chickpea (*Cicer arietinum* L.). Plant Soil 189, 49–55.

Prithiviraj, B., Bais, H., Weir, T., Suresh, B., Najarro, E., Dayakar, B., Schweizer, H., Vivanco, J., 2005. Down regulation of virulence factors of *Pseudomonas aeruginosa* by salicylic acid attenuates its virulence on *Arabidopsis thaliana* and *Caenorhabditis elegans*. Infect. Immun. 73, 5319.

Ram, M., Kumar, S., 1997. Yield improvement in the regenerated and transplanted mint *Mentha arvensis* by recycling the organic wastes and manures. Bioresour. Technol. 59, 141–149.

Raskin, I., 1992. Role of salicylic acid in plants. Ann. Rev. Plant Biol. 43, 439–463.

Razavi, S., Mortazavi, S.A., Matia-Merino, L., Hosseini-Parvar, S.H., Motamedzadegan, A., Khanipour, E., 2009. Optimisation study of gum extraction from Basil seeds (*Ocimum basilicum* L.). Int. J. Food Sci. Technol. 44, 1755–1762.

Rivas-San Vicente, M., Plasencia, J., 2011. Salicylic acid beyond defence: its role in plant growth and development. J. Exp. Bot. 62, 3321–3338, http://dx.doi.org/10.1093/jxb/erj022

Rowshan, V., Khosh Khoi, M., Javidnia, K., 2010. Effects of salicylic acid on quality and quantity of essential oil components in *Salvia macrosiphon*. J. Biol. Environ. Sci. 4, 77–82.

Saharkhiz, M.J., Goudarzi, T., 2014. Foliar application of salicylic acid changes essential oil content and chemical compositions of peppermint (*Mentha piperita* L.). J. Essent. Oil Bear. Plants 17, 435–440.

Sangwan, N., Farooqi, A., Shabih, F., Sangwan, R., 2001. Regulation of essential oil production in plants. J. Plant Growth Regul. 34, 3–21.

Tabarestani, H.S., Sedaghat, N., Pooya, E.S., Alipour, A., 2013. Shelf life improvement and postharvest quality of cherry tomato (*Solanum lycopersicum* L.) fruit using basil mucilage edible coating and cumin essential oil. Int. J. Agron. Plant Prod. 49 (9), 2346–2353.

Sukhavasi, S., Kishore, V.S., 2012. Formulation and evaluation of fast dissolving tablets of amlodipine besylate by using Fenugreek seed mucilage and *Ocimum basilicum* gum. Int.Curr. Pharm. J. 1, 243–249.

Tagliavini, M., Abadía, J., Rombolà, A., Abadía, A., Tsipouridis, C., Marangoni, B., 2000. Agronomic means for the control of iron deficiency chlorosis in deciduous fruit trees. J. Plant Nutr. 23, 2007–2022.

Tagliavini, M., Scudellari, D., Marangoni, B., Toselli, M., 1995. Acid- Spray Regreening of Kiwifruit Leaves Affected by Lime-induced Iron Chlorosis, Iron Nutrition in Soils and Plants. Springer, pp. 191–195.

Vanlerberghe, G.C., McIntosh, L., 1997. Alternative oxidase: from gene to function. Ann. Rev. Plant Biol. 48, 703–734.

Wang, Y.D., Wu, J.C., Yuan, Y.J., 2007. Salicylic acid-induced taxol production and isopentenyl pyrophosphate biosynthesis in suspension cultures of *Taxus chinensis* var. mairei. Cell Biol. Int. 31, 1179–1183.

Wills, R., Lee, T., Graham, D., McGlasson, W., Hall, E., 1981. Postharvest. An Introduction to the Physiology and Handling of Fruit and Vegetables. CAB International, Willingford.

Zottini, M., Costa, A., De Michele, R., Ruzzene, M., Carimi, F., Lo Schiavo, F., 2007. Salicylic acid activates nitric oxide synthesis in Arabidopsis. J. Exp. Bot. 58, 1397, http://dx.doi.org/10.1093/jxb/erj022.