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INVESTIGATION OF THE EFFECT OF SOCIAL DISTANCE ON FREQUENCY AND VOLTAGE FLUCTUATIONS ON IDENTICAL *OCIMUM BASILICUM* L. PLANTS INDOORS AND OUTDOORS FOR 24 HOURS USING A MIXED MODEL

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Abstract

Plants play a vital role in environmental cleanliness by reducing harmful gases in the atmosphere. Genus *Ocimum* has a separate prescription due to its ability to clean air toxins in the interior. *Ocimum* has spread commercially all over the world due to its economic importance. Frequency and electrical voltage were measured on the leaves of two identical *Ocimum basilicum* L., plants using an oscilloscope for two consecutive days. Interaction between plants was quantified by standard deviations (SDs) of the average voltage and frequency values. A higher standard deviation for these measures means that the plants interact better with each other for the corresponding position (i.e., adjoining or social distance) and environment (i.e., indoors or outdoors). The most fluctuating average voltage and frequency values were observed outdoors in the social distance position (SD = 5185.44mV) and outdoors in the adjoining position (SD = 3.01Hz). The smallest variations in average voltage values were obtained indoors at the social distance position (SD = 578.78mV). The average frequency values were in line with each other for the adjacent plants indoors (SD = 0.49Hz), the social distance plants indoors (SD = 0.36Hz) and the social distance plants outdoors (SD = 0.40Hz). A mixed-modeling framework was used to investigate the effects of position, temperature, humidity and their interaction on the frequency and voltage values. These variables did not have a significant effect on the frequency and voltage values at the outdoor environment. Social distance had a positive effect on voltage values ($\hat{\beta}_1$ = 0.25, P = 0.033) indoors. Temperature had a negative impact on frequency values ($\hat{\beta}_2$ = -2.09, P = 0.040) and voltage values ($\hat{\beta}_2$ = -2.87, P = 0.005) indoors. Similarly, humidity negatively affected the frequency values ($\hat{\beta}_3$ = -1.26, P = 0.033) and voltage values ($\hat{\beta}_3$ = -1.74, P = 0.003) indoors. The interaction effect between temperature and humidity was positive for both the frequency values ($\hat{\beta}_4$ = 0.04, P = 0.026) and voltage values ($\hat{\beta}_4$ = 0.06, P = 0.003) indoors.

Key words: *Ocimum basilicum* L., Social distance, Electrical voltage, Frequency, Adjoining, Mixed-modeling.

Introduction

*Ocimum*is a popular and fragrant plant in the Lamiaceae family, with leaves ranging from light green to purple and flowers of different colors (white, purple, magenta). *Ocimum* spreads naturally in Asia, Africa and Central America and is mostly found as a cultivated plant in France, Italy and Spain (Ceylan, 1997; Darrah, 1988). *Ocimum* grows in hot and dry environments (Paton *et al*., 1999; Arabaci & Bayram, 2004). *Ocimum basilicum* L., one of the world's essential oil-containing plants, cultivated commercially in many countries (Omidbaigi, 2005). *O. basilicum* L., is also used as a medicinal herb. This antiseptic and antispasmodic plant has gas reducing and phlegm dissolving impacts. It is also used in bee stings, snake bites, cough, worm-lowering, brain fatigue, stomach ailments, diarrhea and urinary tract infection (Baytop, 1984; Akgül, 1989). *Ocimum* contains high levels of phenolic compounds such as rosmarinic, caffeic and caftaric acid. Its essential oil that has aromatic components and features such as insect incontinence, anti-nematodes, antibacterial and antifungal is widely used in food industry (in canned foods, beverages, in the composition of various teas) and perfume industry (Lee & Scagel, 2009; Flanigan & Niemeyer, 2014; Nadeem *et al*., 2019).

Deterioration of clean environment and natural life can cause various biological and psychological diseases in humans. Particularly in winter, since the houses are much less ventilated, the harmful gases inside can reach dangerous levels for people. We can use a wide variety of plants to remove harmful gases from indoor environments. The interactions between plants belong to the same species may occur both at indoor and outdoor environments and these interactions can be measured by means of using frequency and voltage values. The main aim of this study is to examine the frequency and voltage values of two identical *O. basilicum* L., plants in contact with each other (i.e., adjoining position) and at a distance around of 1 meter (i.e., social distance position).

This study focuses onthe effect of social distance on frequency and voltage values of identical *O. basilicum* L., plants in indoor and outdoor environments. The study was designed considering that these frequency and voltage values could act as a language between the plants. For this reason, frequency and voltage measurements were made in *O. basilicum* L., plants for 24 hours (day and night).

Materıals and Methods

Frequency and voltage values of the *O. basilicum* L., plants were measured and recorded hourly for two consecutive days in both indoor and outdoor environments. The identical plants were placed in the adjoining position in both environments on the first day and they are placed in the social distance position at both environments on the second day. Measurement of frequency and electrical voltage values were performed simultaneously by using AA TECH-1022B Digital Storage oscilloscope for each of the 24 hours. A mixed-model was used to inspect the effects of position (P: 1 = adjoining and 2 = social distance), temperature (TE), humidity (H) and their two-way interaction (TE × H) on the outcomes frequency (F) and voltage (V) values. R programming software was used for statistical analysis.

Results

This section elaborates on the interaction between plants in terms of calculating standard deviations of the average frequency and voltage values in different positions (i.e., adjoining and social distance) and environments (i.e., indoors and outdoors) (Fig. 1) displays the first day's measurement of the plants in the adjoining position at the indoor environment. The time-dependent frequency and voltage values (along with the values of temparature and humidity) regarding each plant in this case are presented in (Table 1).

Figure 2 shows the measurement of the plants in the adjoining position at the outdoor environment for which the results are presented in (Table 2).

The next day the frequency and voltage values of the plants in the social distance position were measured at both indoor and outdoor environments. Figs. 3 and 4 show the measurement of the plants in the social distance position at the indoor and outdoor environments, with the results presented in Tables 3 and 4, respectively.

In terms of average voltage values, almost no fluctuationwas observed between 1am and 8am for the adjacent indoor plants (SD = 19.28mV). The outdoor plants better interacted in this time period when compared to the indoor plants (SD = 710.39mV). The indoor plants were interactive between 3pm and 9pm (SD = 1274.50mV) but most interactive between 8am and 11am (SD = 8028.71mV). The outdoor plants were also interactive between 8am and 11am (SD = 1177.53mV), but not as much as the indoor plants (Fig. 5, Tables 1 and 2).

In the case of adjoining position, the humidity ranged between 40-61% indoors and 38-65% outdoors (Fig. 7, Tables 1 and 2).

In the case of social distance position, the average voltage variations were more apparent for the outdoor plants (SD = 5185.44mV) when compared to the indoor plants (SD = 578.78mV). The most obvious differences between the average voltage values for the indoor and outdoor plants were observed at 3am (i.e., 3840mV), 10am (i.e., 24441mV) and 5pm (i.e., 3988.50mV) (Fig. 8, Tables 3 and 4).

The average frequency values of the plants in the adjoining position at indoor and outdoor environments were generally in line with each other, but, at 4pm, the average frequency value of the outdoor plants reached 64.07Hz which was larger than that of the indoor plants, i.e., 50.01Hz (Fig. 6, Tables 1 and 2).

The average voltage variations were the least apparent for the indoor plants at the social distance position (SD = 578.78mV), whereas they were the most apparent for the outdoor plants in the social distance position (SD = 5185.44mV) (Fig. 11, Tables 1, 2, 3 and 4).

There was no visible trend regarding the average frequency fluctuation of *O. basilicum* L., between the indoor and outdoor plants until 3pm. However, in terms of average frequency values from 3pm to 11pm, the indoor plants were slightly more interactive (SD = 0.45Hz) than the outdoor plants (SD = 0.37Hz) (Fig. 9, Tables 3 and 4).

Fig. 1. Frequency and electrical voltage measurement of *O. basilicum* L. (indoor environment and adjoining position).

Fig. 2. Frequency and electrical voltage measurement of *O. basilicum* L. (outdoor environment and adjoining position).

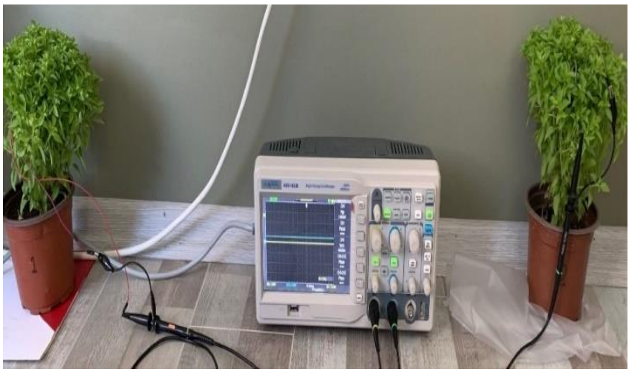

Fig. 3. Frequency and electrical voltage measurement of *O. basilicum* L. in indoor (Social distance position).

Fig. 4. Frequency and electrical voltage measurement of *O. basilicum* L. in outdoor (Social distance position).

Table 1. Time-dependent voltage and frequency variations of *O. basilicum* L. (indoor environment and adjoining position).

Time (hr)	1st plant frequency (Hz)	1st plant Voltage (mV)	2nd plant frequency (Hz)	2nd plant Voltage (mV)	Temperature (Cº)	Humidity (%)
01.00	49.02	40	49.10	50	27	54
02.00	49.22	40	49.20	45	29	53
03.00	50.25	40	50.22	45	28	58
04.00	49.70	40	49.69	45	28	58
05.00	50.22	20	50.15	24	28	57
06.00	49.80	20	49.72	22	28	56
07.00	49.76	60	49.82	66	28	57
08.00	49.55	80	49.42	78	29	56
09.00	50.11	5480	50.25	6700	31	55
10.00	50.82	26000	50.20	11200	29	49
11.00	51.75	7200	49.10	420	29	43
12.00	50.25	800	49.29	800	30	41
13.00	50.57	200	50.19	180	30	40
14.00	50.25	200	50.55	200	30	43
15.00	49.90	200	49.40	260	30	44
16.00	49.90	200	50.12	5000	30	42
17.00	50.12	5880	50.01	510	31	44
18.00	50.02	540	50.80	770	31	47
19.00	50.06	664	50.04	656	30	41
20.00	50.12	2400	49.90	20	30	50
21.00	49.80	6300	50.20	20	29	48
22.00	50.11	20	50.25	30	29	51
23.00	52.11	30	50.99	40	29	56
24.00	50.14	30	50.11	30	28	61

Table 2. Time-dependent voltage and frequency variations of *O. basilicum* L. (outdoor environment and adjoining position).

Time (hr)	1st plant frequency (Hz)	1st plant Voltage (mV)	2nd plant frequency (Hz)	2nd plant Voltage (mV)	Temperature (Cº)	Humidity (%)
01.00	50.00	200	49.74	180	28	54
02.00	50.00	200	50.11	180	28	54
03.00	49.11	400	49.23	420	28	58
04.00	49.23	680	49.44	660	28	58
05.00	51.85	80	51.77	92	28	58
06.00	49.96	1180	49.86	1220	27	59
07.00	50.10	1200	50.98	1150	28	57
08.00	50.00	2100	50.00	2200	30	55
09.00	50.00	2800	50.11	4200	32	43
10.00	49.20	800	50.20	1120	33	38
11.00	50.02	2000	50.06	180	31	39
12.00	49.90	800	50.01	460	31	39
13.00	50.09	800	50.07	800	31	40
14.00	50.07	1400	50.08	1600	30	42
15.00	56.75	200	49.90	100	31	42
16.00	50.88	40	77.25	20	31	40
17.00	50.02	1700	49.80	1400	31	46
18.00	46.96	500	49.56	900	31	47
19.00	50.20	1440	50.00	172	30	46
20.00	50.01	704	50.20	30	29	49
21.00	50.32	2800	50.10	2640	28	52
22.00	49.10	30	49.20	40	48	51
23.00	50.21	30	50.10	40	28	55
24.00	49.10	40	49.20	20	27	65

Table 3.Time-dependent voltage and frequency variations of *O. basilicum* L. (indoor environment and social distance position).

Time (hr)	1st plant frequency (Hz)	1st plant Voltage (mV)	2nd plant frequency (Hz)	2nd plant Voltage (mV)	Temperature (C°)	Humidity (%)
01.40	50.00	200	50.12	181	30	48
02.00	50.12	210	50.07	175	29	52
03.20	50.32	200	50.22	220	30	57
04.40	50.23	20	50.18	25	29	59
05.40	50.10	560	50.17	541	29	60
06.00	49.96	1180	49.88	1230	29	59
07.20	50.21	320	50.17	340	29	60
08.00	49.90	350	49.88	340	29	58
09.00	50.13	400	50.19	380	29	56
10.00	50.21	140	50.26	142	29	56
11.00	49.98	180	49.78	175	31	39
12.30	49.11	1200	49.32	1320	30	48
13.00	49.77	1320	49.66	1280	30	48
14.00	50.21	2000	50.19	1870	31	49
15.00	50.12	1750	50.18	1822	31	47
16.00	49.20	120	49.23	133	31	43
17.00	49.20	80	49.25	77	31	43
18.00	49.43	80	49.38	83	31	46
19.00	50.12	80	50.18	83	32	45
20.00	49.32	88	49.35	85	31	46
21.00	50.11	85	50.16	84	30	48
22.30	50.14	80	50.18	79	30	52
23.00	50.12	84	50.16	82	29	51
24.00	50.23	89	50.18	87	29	51

Table 4.Time-dependent voltage and frequency variations of *O. basilicum* L. (outdoor environment and social distance position).

Time (hr)	1st plant frequency (Hz)	1st plant Voltage (mV)	2nd plant frequency (Hz)	2nd plant Voltage (mV)	Temperature (C°)	Humidity (%)
01.40	50.11	1200	50.19	1190	29	55
02.00	50.21	1320	50.18	1220	29	56
03.20	50.22	-4000	50.19	-3260	30	57
04.40	49.33	240	49.21	220	29	59
05.40	50.13	480	50.11	460	29	61
06.00	49.96	1180	49.88	1250	29	59
07.20	50.12	200	50.18	230	29	58
08.00	50.15	320	50.11	290	30	58
09.00	50.11	320	50.11	340	30	59
10.00	49.34	-24800	49.28	-23800	30	59
11.00	49.32	400	49.30	380	31	39
12.30	49.23	400	49.31	380	31	47
13.00	49.55	1100	49.49	1200	30	51
14.00	50.12	2000	50.17	1900	31	52
15.00	50.17	200	50.18	220	31	47
16.00	50.34	200	50.29	220	31	47
17.00	49.27	-4000	49.25	-3820	32	39
18.00	49.64	1160	49.77	1190	31	46
19.00	50.21	1200	50.26	1180	32	47
20.00	50.17	-200	50.15	-220	32	48
21.00	50.14	320	50.11	311	32	49
22.30	50.43	400	50.45	411	32	49
23.00	50.32	400	50.35	416	31	50
24.00	50.19	380	50.15	382	31	51

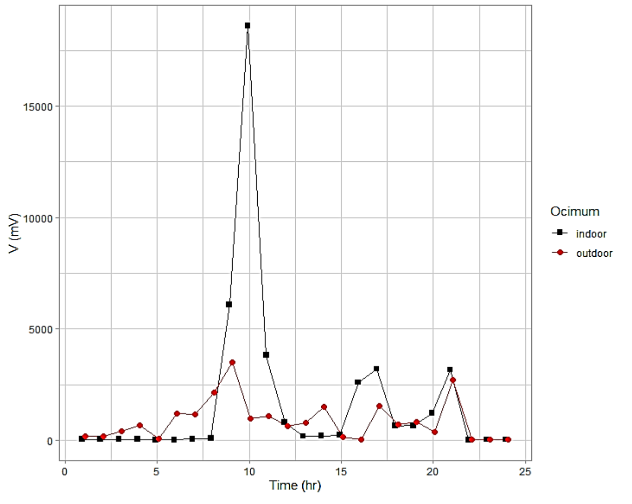

Fig. 5. Time-dependent average voltage variations of *O. basilicum* L. (indoor versus outdoor environment and adjoining position).

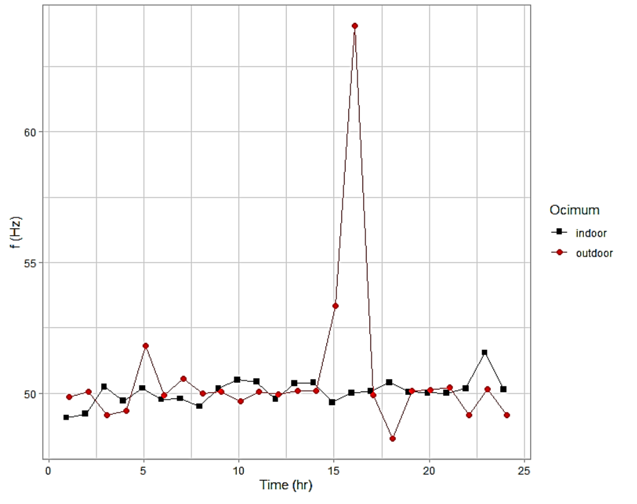

Fig. 6. Time-dependent average frequency variations of *O. basilicum* L. (indoor versus outdoor environment and adjoining position).

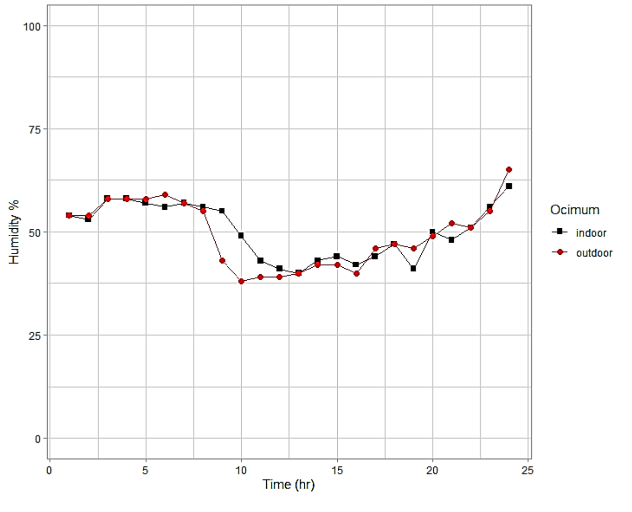

Fig. 7. Time-dependent humidity variations of *O. basilicum* L. (indoor versus outdoor environment and adjoining position).

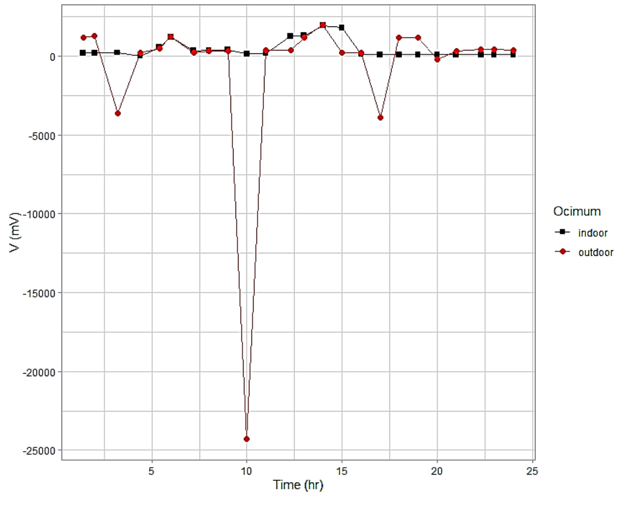

Fig. 8. Time-dependent average voltage variations of *O. basilicum* L. (indoor versus outdoor environment and social distance position).

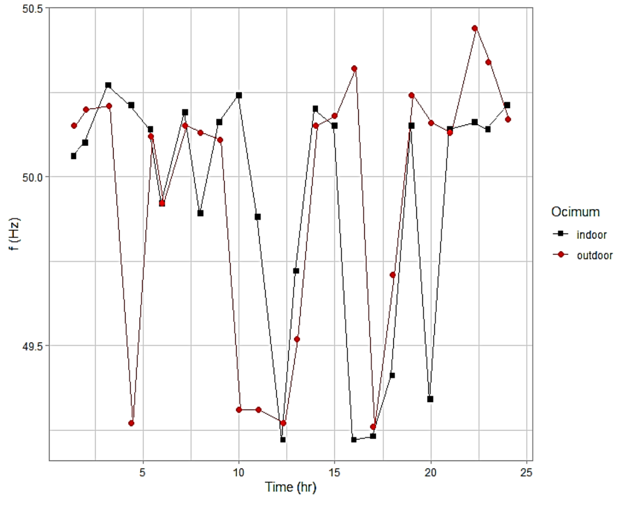

Fig. 9. Time-dependent average frequency variations of *O. basilicum* L. (indoor versus outdoor environment and social distance position).

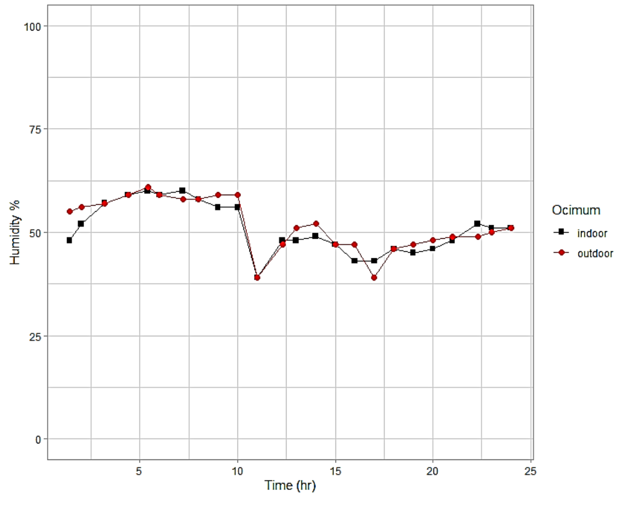

Fig. 10. Time-dependent humidity variations of *O. basilicum* L. (indoor versus outdoor environment and social distance position).

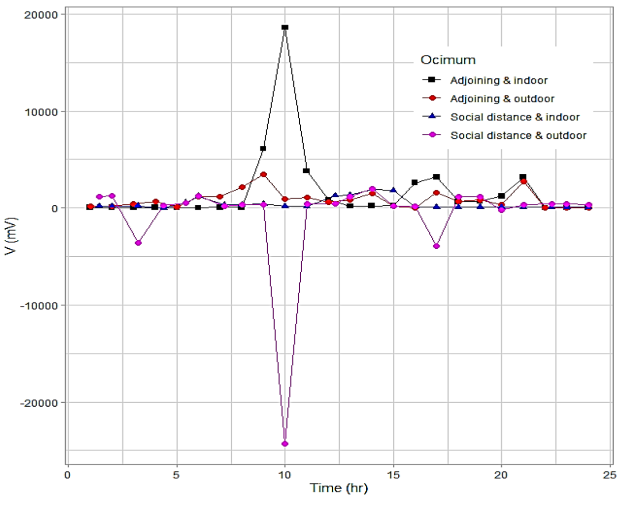

Fig. 11. Time-dependent average voltage variations of *O. basilicum* L. (indoor versus outdoor environment and adjoining versus social distance position).

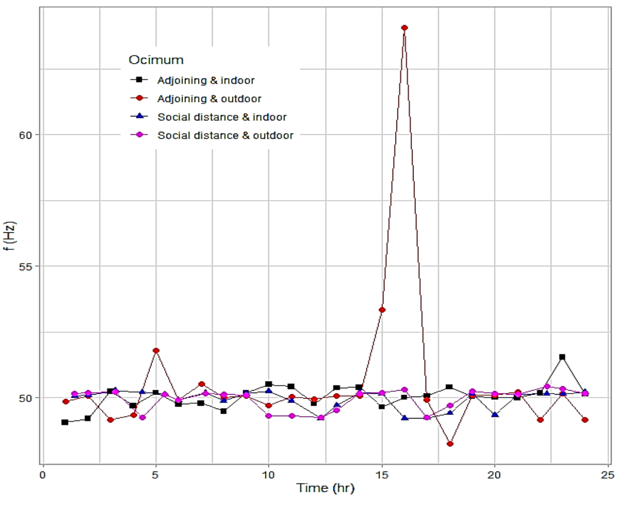

Fig. 12. Time-dependent average frequency variations of *O. basilicum* L. (indoor versus outdoor environment and adjoining versus social distance position).

Table 5. Descriptives of the variables at indoor and outdoor environments.

Environment	Variables	Frequency	Percentage
Indoor	Position		
	Adjoining	48	0.50
	Social distance	48	0.50
Outdoor	Position		
	Adjoining	48	0.50
	Social distance	48	0.50

Environment	Variables	Mean	Standard deviation	Median	Min	Max	Range	Standard error
Indoor	Frequency (Hz)	49.99	0.49	50.11	49.02	52.11	3.09	0.05
	Voltage (mV)	1097.34	3156.68	177.50	20.00	26000	25980	322.18
	Temperature (C°)	29.58	1.08	29.50	27.00	32.00	5.00	0.11
	Humidity (%)	50.52	6.26	50.50	39.00	61.00	22.00	0.64
Outdoor	Frequency (Hz)	50.29	2.92	50.09	46.96	77.25	30.29	0.30
	Voltage (mV)	48.52	3761.53	400.00	-24800	4200	29000	383.91
	Temperature (C°)	30.19	2.37	30.00	27.00	48.00	21.00	0.24
	Humidity (%)	50.62	7.12	51.00	38.00	65.00	27.00	0.73

In environments where the plants were at the social distance position, the humidity ranged between 39-60% indoors and 39-61% outdoors (Fig. 10, Tables 3 and 4).

Variations for the outdoor plants in the adjoining position were more visible than that for the other conditions (SD = 3.01Hz). Average frequency variations for the other cases were in accordance with each other (SD = 0.49Hz for the adjacent plants indoors, SD = 0.36Hz for the social distance plants indoors and SD = 0.40Hz for the social distance plants outdoors) (Fig. 12, Tables 1, 2, 3 and 4).

Analysıs: The influence of social distance, temperature and humidity on the frequency and voltage values of J = 2 identical plants at indoor and outdoor environments were investigated. A mixed-model was used in which the two plants under evaluation constituted a random sample with repeated measures on time having N_j = 24 levels each representing a one hour time period. The outcomes are predicted by categorical variable position (P: 1 = adjoining and 2 = social distance) and continuous predictors temperature (TE) and humidity (H) and their two-way interactions. Table 5 displays the descriptives of the variables at indoor and outdoor environments, respectively.

The mixed-models used to inspect the association between these variables is defined as:

$$F_{ij} = \beta_0 + \beta_1 P_{ij} + \beta_2 TE_{ij} + \beta_3 H_{ij} + \beta_4 TE_{ij} H_{ij} + \mu_{0j} + \mu_{1j} TE_{ij} + \varepsilon_{ij},$$

and

$$V_{ij} = \beta_0 + \beta_1 P_{ij} + \beta_2 TE_{ij} + \beta_3 H_{ij} + \beta_4 TE_{ij} H_{ij} + \mu_{0j} + \mu_{1j} TE_{ij} + \varepsilon_{ij},$$

where

F_{ij} and V_{ij} are the values of outcomes frequency and voltage respectively in the ith time period for the jth plant,

β_0 is the overall intercept, that is, the grand mean of the values of frequency (or voltage) for the two plants at indoor or outdoor,

β_1, β_2, β_3, and β_4 are the coefficients of variables P, TE, H, and the interaction between TE and H, respectively,

$\mu_{0j} \sim N(0, \sigma^2_{\mu_{0j}})$ are the random intercepts at plant level with a mean of zero and variance of $\sigma^2_{\mu_{0j}}$,

$\mu_{1j}\sim$ N(0, $\sigma^2_{\mu_{1j}}$) are the random slopes at plant level for variable **TE** with a mean of zero and variance of $\sigma^2_{\mu_{1j}}$, and$\varepsilon_{ij}\sim$ N(0, σ^2) are the random errors for i = 1, 2, …, 24 and j = 1, 2.

Since the above model contained the interaction term between variables TE and H, we standardized the values of outcomes frequency and voltage in line with the suggestion given by (Gelman, 2008). Table 6 shows the estimates of model parameters and their standard errors (with the corresponding t-statistics and p-values) when predicting the standardized values of outcomes frequency and voltage at the indoor environment, respectively. At the indoor environment, social distance did not exert a statistically significant impact on the outcome frequency ($\hat{\beta}_1$ = 0.20, P = 0.090), while it had a positive influence on the outcome voltage ($\hat{\beta}_1$ = 0.25, P = 0.033). In this case, both the variables temperature and humidity had negative impacts on the outcomes frequency ($\hat{\beta}_2$ = -2.09, P = 0.040 and $\hat{\beta}_3$ = -1.26, P = 0.033) and voltage ($\hat{\beta}_2$ = -2.87, P = 0.005 and $\hat{\beta}_3$ = -1.74, P = 0.003). The interaction term between variables temperature and humidity positively influenced the outcome frequency ($\hat{\beta}_4$ = 0.04, P = 0.026) and voltage ($\hat{\beta}_4$ = 0.06, P = 0.003).

Figures 13 and 14 displayed the effects of temperature and humidity on the outcomes frequency and voltage values, respectively, in the cases of adjoining and social distance for each plant at the indoor environment. Figure 13 showed on the left panel that, at the indoor environment, increasing values of temperature were in relation to the increasing values of frequency for both plants when they are adjocent to each other, while increasing values of temperature are associated with the decreased values of frequency for both plants in the social distance position. Figure 13 on the right panel shows that the values of humidity and frequency are positively associated with each other for both plants in the social distance position, however, this association is not apparent in the adjoining position. Figure 14 shows on the left panel that the values of temperature and voltage are positively related to each other in the adjoining position, while temperature does not exert a significant influence on the values of voltage for neither of the plants in the social distance position. (Fig. 14) on the right panel that the values of humidity and voltage are negatively associated with each other only for the first plant and only for the adjoining position. It seemed that the associations between these variables in the other conditions at the indoor environment were negligible.

Estimates of model parameters and their standard errors and the corresponding t-statistics and p-values in predicting the standardized values of outcomes frequency and voltage at the outdoor environment, respectively are shown in Table 7. No significant effect was observerd between the variables at the outdoor environment (Table 7). Since no significant association between variables was observed at the outdoor environment, the corresponding figures showed the relationships more in detail (not presented here, but, would be made available upon request).

Table 6. The estimates of model parameters, their standard errors, and summary statistics at indoor environment in predicting the standardized values of outcomes frequency and voltage.

Predicting standardized values of the outcome frequency				
Fixed effects	**Estimates**	**Std. Errors**	***t** statistics**	**P**
(Intercept)	59.63	29.99	1.99	0.050*
P (Social distance)	0.20	0.11	1.72	0.090
TE	-2.09	1.01	-2.08	0.040*
H	-1.26	0.58	-2.17	0.033*
TE*HE	0.04	0.02	2.26	0.026*
Random effects	**Variance components**		**Standard deviations**	
(Intercepts)	0.21		0.46	
TE	0.0001		0.03	
Residuals	0.90		0.95	
Predicting standardized values of the outcome voltage				
Fixed effects	**Estimates**	**Std. Errors**	***t** statistics**	**P**
(Intercept)	85.21	29.89	2.85	0.005**
P (Social distance)	0.25	0.11	2.17	0.033*
TE	-2.87	1.00	-2.86	0.005**
H	-1.74	0.58	-3.01	0.003**
TE*HE	0.06	0.02	3.01	0.003**
Random effects	**Variance components**		**Standard deviations**	
(Intercepts)	<0.001		0.015	
TE	<0.001		<0.001	
Residuals	0.90		0.95	

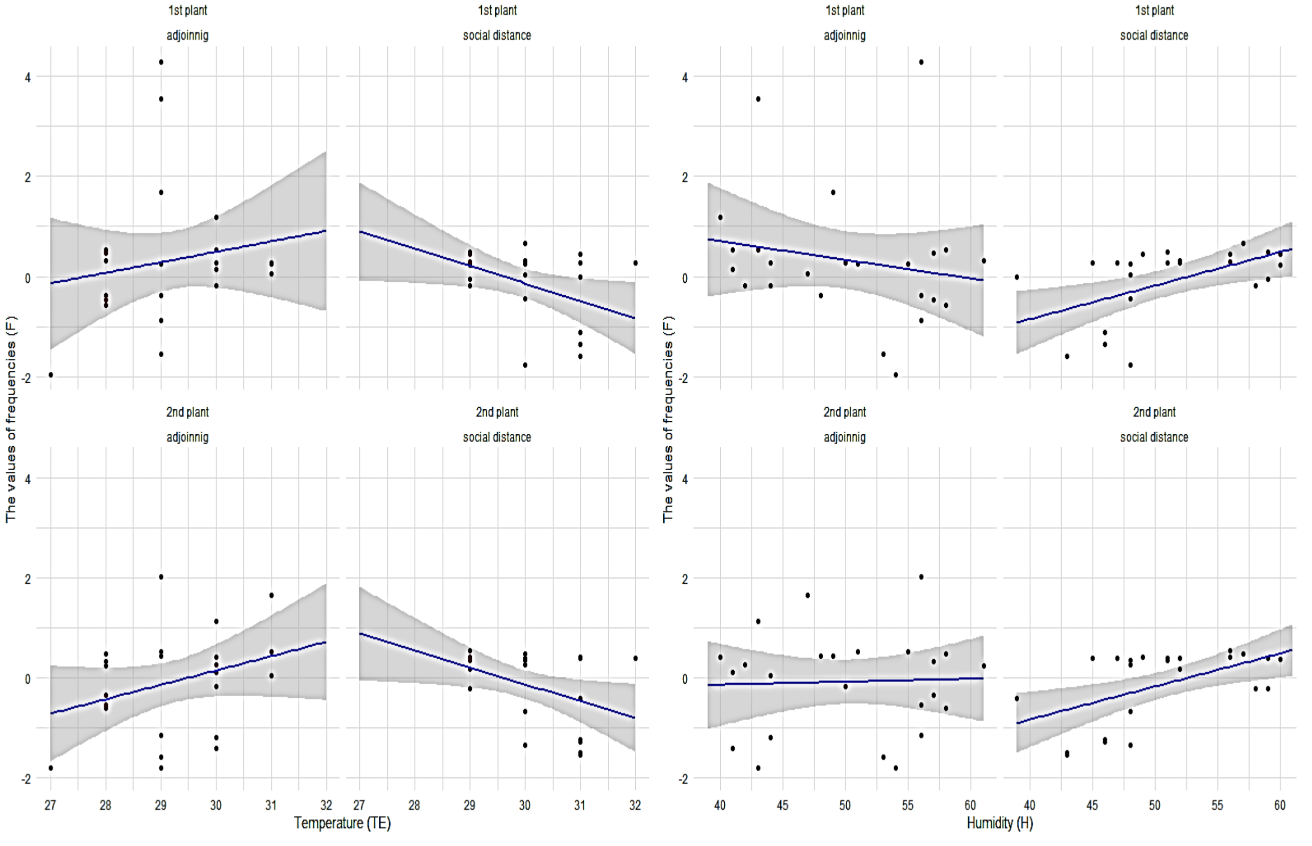

Fig. 13.The effects of temperature and humidity on the outcome frequency in the adjoining and social distance positions for each plant at the indoor environment.

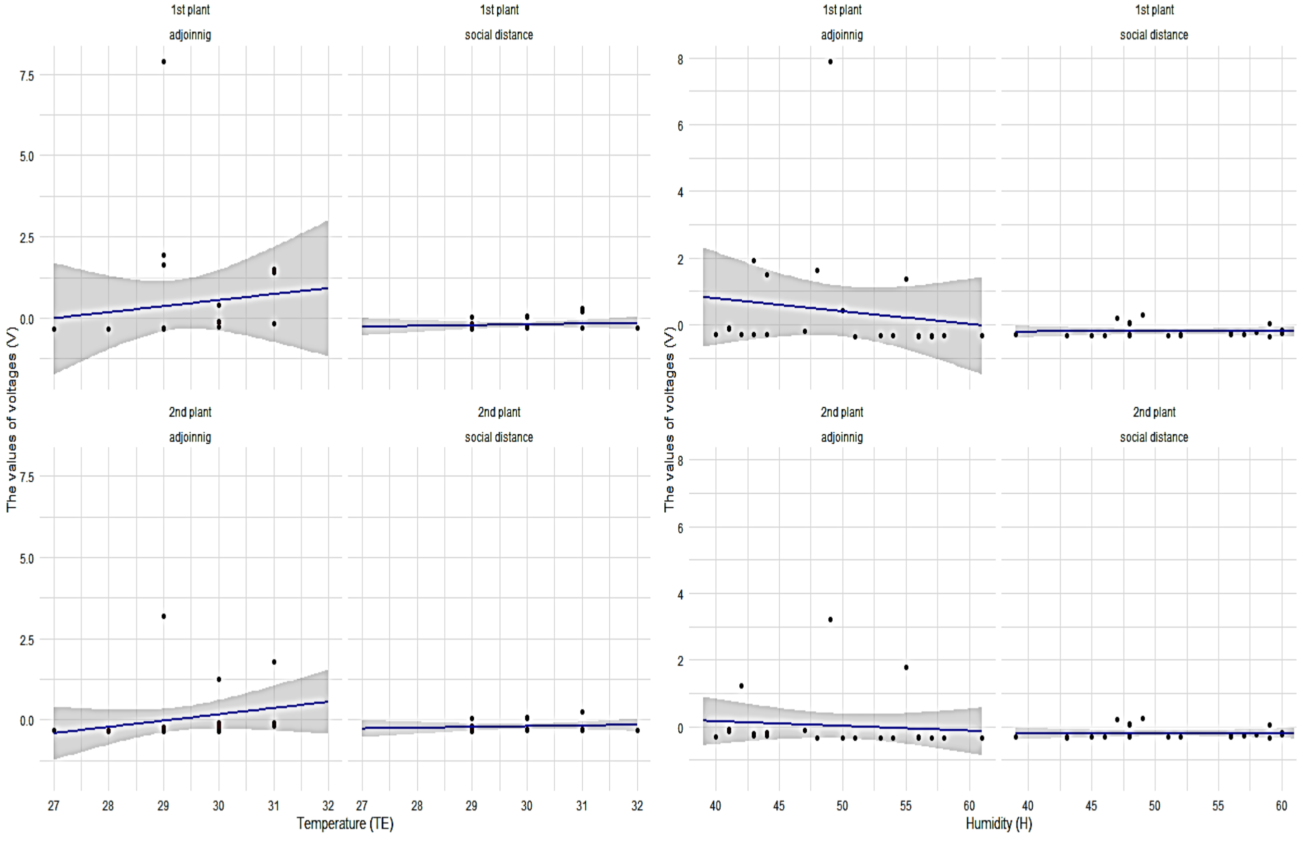

Fig. 14. The effects of temperature and humidity on the outcome voltage in the adjoining and social distance positions for each plant at the indoor environment.

Table 7. The estimates of model parameters, their standard errors, and summary statistics at outdoor environment in predicting the standardized values of outcomes frequency and voltage.

Predicting standardized values of the outcome frequency				
Fixed effects	**Estimates**	**Std. Errors**	**t^* statistics**	**P**
(Intercept)	9.11	18.75	0.49	0.628
P (Social distance)	0.09	0.11	0.83	0.409
TE	-0.26	0.62	-0.42	0.676
H	-0.16	0.36	-0.45	0.651
TE*HE	0.05	0.01	0.38	0.702
Random effects	**Variance components**		**Standard deviations**	
(Intercepts)	<0.001		<0.001	
TE	<0.001		<0.001	
Residuals	1.00		1.00	
Predicting standardized values of the outcome voltage				
Fixed effects	**Estimates**	**Std. Errors**	**t^* statistics**	**P**
(Intercept)	0.08	18.46	0.004	0.996
P (Social distance)	0.18	0.11	1.64	0.105
TE	0.04	0.61	0.06	0.952
H	0.01	0.36	0.04	0.970
TE*HE	-0.001	0.01	-0.11	0.917
Random effects	**Variance components**		**Standard deviations**	
(Intercepts)	<0.001		<0.001	
TE	<0.001		<0.001	
Residuals	0.97		0.98	

Discussion

Studies to measure the response of plants to different environmental conditions are becoming increasingly common (Cha *et al*., 2022; Midgley, 2017; Chapin *et al*., 1987; Mehmood *et al*., 2022; Morello *et al*., 2022). In the literature, there are studies in which voltage measurements are made depending on different environmental settings to produce renewable and sustainable electrical energy both indoors and outdoors (Choo & Dayou, 2013; Sing & Kumar, 2021). Moreover, fluctuations in action potential signals from the plant leaf have been measured (with an oscilloscope) in response to different light modes (Aditya *et al*., 2011) and landslide stimulations (Aditya *et al*., 2013). Although the response of plants to external conditions have been extensively studied in the literature, there are relatively limited studies on measuring the response of plants to these conditions in relation to each other (Chamovitz, 2013; Hemachandran *et al*., 2017).

When plants interact with each other (and other life forms), differences in frequency and voltage values may occur. To the best of our knowledge there was only one study that investigated frequency and voltage values from the leaf of the plant to explore how plants interacted with each other (Bursalioglu, 2019). The author examined frequency and voltage variations to understand whether the adjacent and social distance positions of *Saintpaulia ionantha* (African violet) and *Spathiphyllum* spp., plants had an effect on their interaction (indoors only). The novelty of the present study stems from investigating (average) frequency and voltage variations in plants both indoors and outdoors. For this purpose, time-dependent (average) frequency and voltage variations were obtained for *O. basilicum* L., plants at indoor versus outdoor environment and adjoining versus social distance position. The data were obtained by the Digital Storage oscilloscope and recorded in each of the 24 hours for two consecutive days.

Fluctuations in average frequency and voltage values indoors and outdoors were quantified by calculating their standard deviations. In terms of average voltage values, it was concluded that adjacent indoor plants did not interact much between 1am and 8am in the early morning (SD = 19.28mV), while outdoor plants interacted better than indoor plants in this time period (SD = 710.39mV). The indoor plants in the adjoining position were the most interactive between 8am and 11am (SD = 8028.71mV) (Fig. 5). In the same position, the average frequencies were generally in accordance with each other except at 4pm (SD = 0.50Hz indoors and SD = 0.96Hz outdoors) (Fig. 6). For the social distance position, the most apparent distinction of average voltages between the indoor and outdoor plants were observed at 3am (i.e., 3840mV), 10am (i.e., 24441mV) and 5pm (i.e., 3988.50mV) (Fig. 8). The indoor plants at the social distance position were slightly more interactive (SD = 0.45Hz) than the outdoor plants in the same position (SD = 0.37Hz) in terms of average frequencies between 3pm and 11pm (Fig. 9). The humidity during measurements varied between 40-61% indoors and 38-65% outdoors in the adjoining position (Fig. 7) and 39-60% indoors and 39-61% outdoors in the social distance position (Fig. 10). The largest average voltage and frequency variations for the plants were observed outdoors at the social distance position (SD = 5185.44mV) (Fig. 11) and outdoors in the adjoining position (SD = 3.01Hz) (Fig. 12).

We also investigated the effects of position, temperature, humidity, and the interaction between temperature and humidity on the frequency and voltage values of each plant in both indoor and outdoor environments using a mixed regression model. It was concluded that social distance did not significantly affect the frequency values indoors ($\hat{\beta}_1$ = 0.20, P = 0.090), but positively affected the voltage values ($\hat{\beta}_1$ = 0.25, P = 0.033). In the indoor environment, temperature ($\hat{\beta}_2$ = -2.09, P = 0.040) and humidity ($\hat{\beta}_3$ = -1.26, P = 0.033) had a negative effect and their interaction ($\hat{\beta}_4$ = 0.04, P = 0.026) had a positive effect on frequency values. Similarly, temperature ($\hat{\beta}_2$ = -2.87, P = 0.005) and humidity ($\hat{\beta}_3$ = -1.74, P = 0.003) exerted a negative influence and their interaction exerts a positive influence ($\hat{\beta}_4$ = 0.06, P = 0.003) on voltage values (Table 6). No significant effect of these variables on frequency and voltage values was observed at the outdoor environment (Table 7).

Conclusion

Outdoor plants at the social distance position interacted better than indoor plants at the same position in terms of average voltage values. Adjacent outdoor plants interacted better than plants in other conditions in terms of average frequency values. In this study, mixed-modeling framework was used to examine the effects of social distance, temperature, humidity and temperature versus humidity interaction on voltage and frequency values. The results of the analysis indicated that social distance had a positive effect on the voltage values indoors, but had no effect on frequency values was found. Increasing values of temperature and humidity reduced both voltage and frequency fluctuations indoors. It was observed that social distance, temperature and humidity (and their interaction) had no effect on frequency and voltage values in the outdoor environment.

The present study has three main limitations. (1) Although voltage and frequency measurements were made every hour for 24 hours, the measurements could only be continued for 2 consecutive days. (2) The measurements were obtained for only two identical *O. basilicum* L., plants. Therefore, the average voltage and frequency values in Figures 5, 6, 8, 9, 11 and 12 were calculated based on only two numbers at each hour. Obtaining voltage and frequency values for many *O. basilicum* L., plants will provide more accurate plots in the figures. This will also improve the precision of the estimates obtained for the mixed-model in the analysis section (especially at the outdoor environment for which no significant effect of social distance, temperature and humidity was observed). (3) Measurements were obtained for only *O. basilicum* L., plants. It is not yet known how different plant species will behave in terms of voltage and frequency measurements in environments similar to those in this study. Voltage and frequency measurements can be discussed in more detail in the light of these three factors in future studies.

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