Numerical messages of plants under different stresses

M. Teuma Mbezi[1,2,*], Ambang Zachée[3], H. Ekobena Fouda[1] and C. Kofané Timoleon[4]

[1]Laboratory of Biophysics, Department of Physics, Faculty of Sciences, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon
[2]National Advanced School of Posts, Telecommunications and Information and Communication Technologies, P.O. Box 8950, Yaoundé, Cameroon
[3]Laboratory of Phytopathology, Department of Biology and Vegetal Physiology, Faculty of Sciences, University of Yaoundé I, P. O. Box 812, Yaoundé, Cameroon
[4]Laboratory of Mechanics, Department of Physics, Faculty of Sciences, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon

Electrical behaviour of plants under different conditions is studied. It is obvious that electrical response of these plants is characteristic of their physiological state. The present study was conducted to first provide numerical and possible alphabetic messages corresponding to the physiological state of plants under different stresses. Secondly, to calculate and compare their entropies. We used electrical conductance values obtained during the study of electrical behaviour of *Solanum lycopersicum* and *Spinacia oleracea* under different stresses to construct the probabilities tables of symbols appearance. Using Huffman coding, we constructed dictionaries and deducted the numerical and alphabetic messages. For each plant stress, the entropy was calculated. The entropy of infected *S. lycopersicum* was higher than healthy plants. Numerical and alphabetic messages of healthy *S. lycopersicum* are '000111110010110010111011101100111010001-01001011000110000' and 'Holy *lycopersicum*' respectively. For the infected plants they are '110011-11101010 100010110101110011101000010 10010000 0110001' and 'leaf infected up so' respectively. Numerical and alphabetic messages of lit *S. oleracea* and unlit *S. oleracea* were respectively, '100101-010011110000001111110001', 'up *oleracea*' and '001100 0100111101011110001101111', 'of *Spinacia*'. This study goes beyond the electric characterization of plants under stress and tries to establish a communication between plants under stress and human beings. The approach may lead to the design of a sensor to translate messages coming from plants under stress.

Keywords: Entropy, numerical messages, *Solanum lycopersicum*, *Spinacia oleracea*, stress.

INCREASE the number of connected things through the LTE-M is one of multiple purposes of the long-term evolution 4 generation (LTE 4G)[1,2]. In the category of connected things, we have the connected plants. Electrical models are usually used to study electrical behaviour of internal plant components[3–6]. The electrical response of plants subjected to various biotic as well as abiotic stresses has been studied[7–9]. Recently, comparative studies have been conducted on the electrical response of diseased and healthy *Solanum lycopersicum* plants[8]; as also *Spinacia oleracea* plants lit by a source of 1000 W/m^2, and others kept in the dark[9].

The Huffman coding is a lossless data compression algorithm[10]. It uses a variable length code to represent a symbol of the source (for example a character in a file).

In information theory, the entropy of a system represents the amount of information that it contains. Using the probabilities tables of symbols appearance[8,9] and Huffman coding[10], we provide numerical and alphabetic and then calculate entropies of infected and healthy *S. lycopersicum* plants as well as *S. oleracea* plants under light and darkness.

Abiotic stress was produced by illuminating *S. oleracea* with high light intensity. In fact, at 36°C, in front of a 1000 W/m^2 light source, *S. oleracea* was successively in darkness during the first 10 sec and lighted during the other 10 sec. During the passage of *S. oleracea* from darkness state to the lighted state, a short pause was observed to avoid the electrical transition values.

The electrical parameters were measured starting from the electrical assembly (Figure 1). A digital multimeter (Smart UT71.A) was programed to automatically detect the extra chlorophyll space resistance (at zero frequency) and deduce electric conductance. All the values measured by the multimeter were instantly transferred to a laptop to be analysed. The data were analysed using software such as XLSTAT and Matlab[9].

Biotic stress was caused by tomato late blight disease due to the pathogen, *Phytophthora infestans*. To carry out

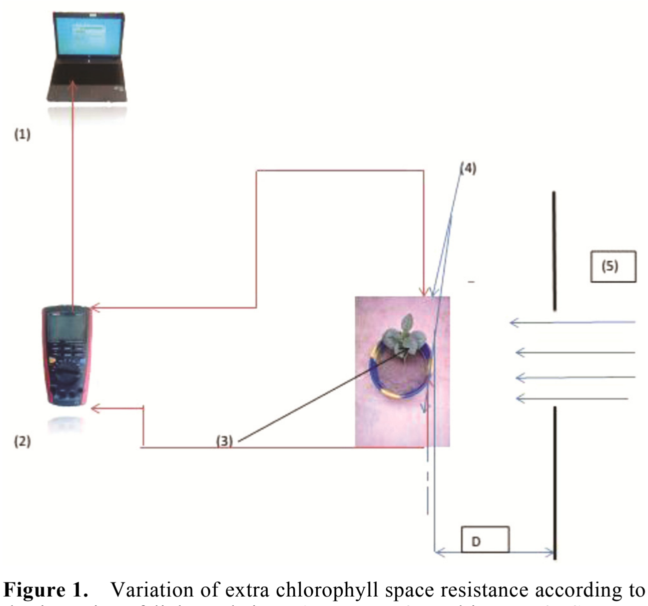

Figure 1. Variation of extra chlorophyll space resistance according to the intensity of light and time. 1, Laptop; 2, multimeter; 3, *Spinacia oleracea* plant leaves; 4, electrodes; 5, source of light. *D* is the distance between the source of light and *S. oleracea* plant leaves[9].

*For correspondence. (e-mail: 3michelteuma@gmail.com)

Table 1. Probability of appearance of x_i symbol of healthy and infected *Solanum lycopersicum*

Healthy *S. lycopersicum*													
Symbol x_i	0.625	1.111	0.666	0.357	0.555	0.5	0.312	0.303	0.344	0.322	0.384	0.37	
$P(X = x_i)$	2/16	2/16	2/16	1/16	2/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	
Infected *S. lycopersicum*													
Symbol x_i	0.45	0.83	0.31	1.0	0.43	0.58	0.27	0.71	0.30	0.20	0.24	0.22	0.16
$P(X = x_i)$	1/16	1/16	2/16	1/16	3/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16

Table 2. Probability of appearance of x_i symbol of unlit and lit *Spinacia oleracea*

Unlit *S. oleracea*								
Symbol x_i	1.26	1.31	1.36	1.39	1.38	1.37	1.35	1.33
$P(X = x_i)$	1/10	1/10	1/10	2/10	1/10	1/10	2/10	1/10
Lit *S. oleracea*								
Symbol x_i	1.55	1.59	1.57	1.60	1.62	1.56	1.52	1.48
$P(X = x_i)$	1/10	1/10	1/10	2/10	1/10	1/10	1/10	2/10

Table 3. Healthy and infected *S. lycopersicum* dictionary

Symbols	Numerical correspondence	Alphabetic correspondence
Healthy *S. lycopersicum*		
x_1 (2)	100	l
x_2 (2)	101	y
x_3 (2)	110	c
x_4	0110	p
x_5 (2)	111	o
x_6	0111	e
x_7	0100	r
x_8	0101	s
x_9	0010	i
x_{10}	0011	u
x_{11}	0000	m
x_{12}	0001	h
Infected *S. lycopersicum*		
x_1	1100	l
x_2	1101	a
x_3 (2)	010f	
x_4	011s	
x_5 (3)	111e	
x_6	1010	t
x_7	1011	n
x_8	1000	i
x_9	1001	u
x_{10}	0010	d
x_{11}	0011	c
x_{12}	0000	p
x_{13}	0001	o

Table 4. Lit and unlit *S. oleracea* dictionary

Symbols	Numerical correspondence	Alphabetic correspondence
Lit *S. oleracea*		
x_1	100	u
x_2	101	p
x_3	010	o
x_4 (2)	110	e
x_5	011	l
x_6	000	r
x_7 (2)	111	c
x_8	001	a
Unlit *S. oleracea*		
x_1	010	s
x_2	011	p
x_3	101	n
x_4 (2)	110	i
x_5	000	c
x_6	001	o
x_7	100	f
x_8 (2)	111	a

measurements of extracellular space resistance and deduce electric conductance, the plants were gathered in two groups as follows: the first group consisted of leaflets infected by tomato late blight which is also called *S. lycopersicum* mildew, while the second group consisted of healthy leaflets[8].

The electrical parameters were measured using the same electrical assembly represented in Figure 1, and replacing *S. oleracea* by *S. lycopersicum* plants.

In order to obtain numerical messages, we first construct tables of probabilities of symbols appearance, from the electrical conductance responses of *S. lycopersicum* and *S. oleracea* plants. Secondly, we use Huffman coding to obtain the numerical values of each x_i symbol. Thirdly, we construct plants dictionaries. For each numerical value of x_i symbol, we associate an alphabet. These alphabets are chosen so that they can be used to form words that have meaning. Fourthly, we deduce using the possible dictionaries, the corresponding numerical and alphabetic messages.

Table 5. Numerical and alphabetic message of healthy *S. lycopersicum*, infected *S. lycopersicum*, lit *S. oleracea* and unlit *S. oleracea*

Plants state	Numerical message	Alphabetic message
Healthy *S. lycopersicum*	0001111100101 1001011101110110011101000101001011000110000	Holy *lycopersicum*
Infected *S. lycopersicum*	11001111101010 10001011010111001110100010 10010000 0110001	Leaf infected up so
Lit *S. oleracea*	100101 0100111100000001111110001	Up *oleracea*
Unlit *S. oleracea*	001100 010011110101111000110111	Of *Spinacia*

The quantity of information average is evaluated by entropy as

$$H(X) = -\sum_{i=1}^{N} P_i \log_2(P_i), \quad (1)$$

where P_i is the probability of obtaining *xi* symbol.

The entropy was evaluated for the two states of *S. lycopersicum* and *S. oleracea* plants.

Tables 1 and 2 are respectively, probabilities tables of symbols appearance of healthy *S. lycopersicum*, infected *S. lycopersicum*, unlit *S. oleracea*, and lit *S. oleracea.* The values taken by *xi* in Tables 1 and 2 are electrical conductance of the plants. The entropies $H(X)$ of healthy *S. lycopersicum*, infected *S. lycopersicum*, unlit *S. oleracea*, and lit *S. oleracea* are respectively, 1.520 shannon (sh), 3.577 sh, 4.64 sh and 4.64 sh. Tables 3 and 4 show the proposed dictionaries of *S. lycopersicum* and *S. oleracea*. The figure in parenthesis in Tables 3 and 4 indicate the number of times that the x_i symbol must appear in the message sought. Table 5 presents the different numerical and alphabetic messages of *S. lycopersicum* and *S. oleracea*.

The entropy of healthy *S. lycopersicum* is given by

$$H(X) = -\sum_{i=1}^{N=12} P_i \log_2(P_i) = 1.520 \text{ sh}. \quad (2)$$

The corresponding entropy of infected *S. lycopersicum* is given by

$$H(X) = -\sum_{i=1}^{N=13} P_i \log_2(P_i) = 3.577 \text{ sh}. \quad (3)$$

The quantity of information average of lit *S. oleracea* is given by

$$H(X) = -\sum_{i=1}^{N=8} P_i \log_2(P_i) = 4.64 \text{ sh}. \quad (4)$$

The quantity of information average of unlit *S. oleracea* is given by

$$H(X) = -\sum_{i=1}^{N=8} P_i \log_2(P_i) = 4.64 \text{ sh}. \quad (5)$$

The entropy of infected *S. lycopersicum* is greater than that of healthy plants. This can be explained by the fact that, for the infected plant, the quantity of information increased due to the perturbation of pathogenic agent inside the tissues of the plant. The entropy of lit and unlit *S. oleracea* is the same. This may be due to the fact that light intensity of 1000 W/m^2 may not be enough to produce light stress in *S. oleracea*; that is why lit *S. oleracea* and unlit *S. oleracea* have the same quantity of information.

According to the dictionaries (Tables 3 and 4) each numerical and alphabetic message (Table 5) reveals the physiological state of the corresponding plant.

Here, we go beyond classical studies that characterize the physiological state of plants subjected to some stress either by measuring the conductivity[11], fluorescence[12] or any bioelectrical parameter[7,13]. We have made a statistical and probabilistic analysis of the bioelectrical data obtained to deduce a numerical and alphabetic message corresponding to the physiological state of the plants.

The purposes of this study was to calculate entropy, provide numerical and alphabetic messages of infected and healthy *S. lycopersicum*, and *S. oleracea* plants under light and darkness. The analysis shows that, due to perturbation action of pathogenic agents, entropy of infected *S. lycopersicum* is higher than the healthy plants. However, under unsaturated light intensity, entropy of lit and unlit *S. oleracea* is the same. We observe that each alphabetic message is related to the physiological state of the plants.

In future studies, it will be interesting to repeat the same experiment several times under the same conditions in order to determine the probability of occurrence of a message.

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Infusing microbial consortia for enhancing seed germination and vigour in pigeonpea (*Cajanus cajan* (L.) Millsp.)

K. Raja[1,*], R. Anandham[2] and K. Sivasubramaniam[3]

[1]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[2]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[3]Agricultural College and Research Institute, Tamil Nadu Agricultural University, Kudumiyanmalai 622 104, India

Use of plant growth promoting bacteria for seed treatment is in trend nowadays as it is beneficial to the plants and environment. But, carrier-based inoculants have short shelf life and difficult to use for large quantities of seed. Therefore, in the present study we used liquid microbial cultures for seed infusion in pigeonpea and assessed their compatibility with seed treating chemicals. The results showed that the soaking of pigeonpea seeds in liquid cultures like pink pigmented facultative methylotroph (PPFM) @ 1 : 100 dilution for 3 h or *Rhizobium* or phosphobacteria @ 1 : 50 dilution for 4 h have showed increased germination and vigour. In the microbial infused seeds, *Rhizobium* (13×10^4 cfu g^{-1} of seed) and phosphobacteria (20×10^4 cfu g^{-1} of seed) populations observed, were slightly reduced during three months storage. Nevertheless, the population was drastically reduced in PPFM (11×10^4 to 2×10^4 cfu g^{-1} of seed). Conversely, PPFM has performed better in seed quality enhancement amongst cultures. Also, consortia of *Rhizobium* @ 1 : 50 dilution + PPFM @ 1 : 100 dilution (1 : 1) for 3 h increased seed vigour with better microbial populations (14×10^4 and 2×10^4 cfu g^{-1} of seed). Also, seed infusion with PPFM liquid culture @ 1 : 100 dilution for 3 h followed by polymer coating @ 5 ml kg^{-1} + carbendazim treatment @ 2 g kg^{-1} of seed recorded increased germination and vigour with the PPFM population of 1×10^4 cfu g^{-1} of seed.

Keywords: Pigeonpea, PPFM, phosphobacteria, *Rhizobium*, seed germination, vigour.

SEED is an important input in agriculture and the quality of the seed alone contributes 20% yield increase. Quality of the seed can be improved by pre-sowing seed management techniques. Among the pre-sowing seed management techniques, seed treatment with the plant growth promoting bacteria (PGPB), viz. biofertilizers or biocontrol agents, is one of the important methods by which the yield can be improved by 5% to 30% (ref. 1). Use of these effective microorganisms as a pre-sowing seed treating agent is considered to be ecologically sound and beneficial to both seed and environment. Application of inoculum to the seeds of host plants is still in vogue with carrier-based bacterial inoculants[2]. Sometimes, in order to improve stickiness on the seed, adhesive is added[3]. However, carrier-based inoculants have a short shelf life, poor quality and the production and application procedure for most of these inoculants were found to be time consuming and difficult when used for large quantities of seed.

Alternatively, liquid inoculants were developed for seed treatment as they are easy to use, spread well, mix easily and need no additional water supply[4]. The liquid rhizobial inoculant for pea and lentils resulted in yield equal to or better than those obtained for the peat inoculant[5]. However, treating the pulses seed in liquid culture will lead to cracking injury which ultimately affects the storability. Therefore, care should be taken to treat the seed with liquid inoculants. Also, the fungicides are non-specific in their lethal action against the organisms. The responses of seed treating chemicals such as captan, thiram, mancozeb, ridomil, benlate and vitavax, etc. have been studied on the survival of *Rhizobium* and

*For correspondence. (e-mail: kraja_sst@rediffmail.com)