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ELECTRICAL CONDUCTIVITY OF SOYBEAN SEED CULTIVARS AND ADJUSTED MODELS OF LEAKAGE CURVES ALONG THE TIME[1]

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ABSTRACT - The objective of this work was to study the behavior of ten soybean [*Glycine max* (L.) Merr.] cultivars using the electrical conductivity (EC) test by the comparison of curves of the accumulative electrolyte leakage along the time and to establish the statistical model that allow the best adjust of the curves. Ten soybean cultivars were used and they were mechanically harvested in 2004 in the EEA Oliveros, Santa Fe, Argentina. Measurements of EC were made for 100 individual seeds of each cultivar during 20 hours of immersion at intervals of 1 hour using an equipment that permit an individual seed analysis (Seed Automatic Analyzer SAD 9000S). There were proposed two statistical models to study the EC along the time of the 10 cultivars studied using SAS Statistics Program, to select the model that better allow us to understand the EC behavior along the time. Model 1 allowed to make comparisons of EC along the time between cultivars and to study the influence of the production environment on the physiological quality of soybean seeds. The time to reach the stabilization of the EC must not be lower than 19 hours for the different cultivars.

Keywords: *Glycine max*. Electric conductivity. Vigor.

CONDUCTIVIDADE ELÉTRICA DE SEMENTES DE DIFERENTES CULTIVARES DE SOJA E MODELOS AJUSTADOS DE CURVAS DE LIXIVIAÇÃO AO LONGO DO TEMPO

RESUMO - O objetivo deste trabalho foi estudar o comportamento de dez cultivares de soja [*Glycine max* (L.) Merr.] pelo teste da condutividade elétrica através da comparação de curves de lixiviação acumulativa de eletrólitos ao longo do tempo e estabelecer o modelo estatístico que permita o melhor ajuste das curvas. Foram usados dez cultivares de soja mecanicamente colhidas in 2004 na EEA Oliveros, Santa Fe, Argentina. As medições da condutividade elétrica foram realizadas para 100 sementes individuais de cada cultivar durante 20 horas de imersão a intervalos de 1 hora usando o equipamento que permite uma análise individual das sementes (Seed Automatic Analyzer SAD 9000S). Foram propostos dois modelos estatísticos para estudar a condutividade elétrica ao longo do tempo para os 10 cultivares estudados pelo uso do Programa Estatístico SAS, para selecionar o modelo que melhor permita entender o comportamento da condutividade elétrica ao longo do tempo. O Modelo 1 permitiu realizar comparações da condutividade elétrica ao longo de tempo entre cultivares e estudar a influencia do ambiente de produção sobre a qualidade fisiológica de sementes de soja. O tempo para alcançar a estabilização da condutividade elétrica não deve ser menor que 19 horas para os diferentes cultivares.

Palavras-chave: *Glycine max.* Sementes. Vigor.

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INTRODUCTION

The electrical conductivity (EC) test is known as one of the best evaluation of vigor in soybean seed (ABDUL BAKI; ANDERSON, 1970; YAKLICH et al., 1979; LOEFFLER et al., 1988; MARCOS FILHO, 1990) and it is recommended in the Manual of Vigor Tests (ISTA, 1995). This test is recommended to evaluate vigor in pea seeds (ISTA, 2003; BEDFORD, 1974; TEKRONY; EGLI, 1977; JOHNSON; WAX, 1978; OLIVEIRA et al., 1984; VIEIRA et al., 1999). CE test in soybean seed is more efficient indicator of field emergency than germination test.

Although the EC test is normally conducted by bulk method (GONÇALVES SOUZA, 2009), since some years ago there are equipments that allow the individual measure of seeds (STEERE et al., 1981; HEPBURN et al., 1984; SIDDIQUE; GOODWIN, 1985; HAMMAN et al., 2001). Besides, there are equipments that allow the realization of both methodologies at the same time with the possibility to obtain results that can be expressed in electrical conductivity of individual seeds and per grams by the Automatic Seed Analyzer SAD 9000-S.

EC test of electrolytes leakage for individual seeds indirectly quantifies degradation and disorganization of the cytoplasmic membranes (DELOUCHE; BASKIN, 1973; ROBERT, 1973). The naturally and/or artificially aged or mechanically damaged seeds showed more conductivity than normal healthy seeds (EDGE; BURRIES, 1970; PARRISH; LEOPOLD, 1978; LOEFFLER et al., 1988; HAMPTON, 1995).

There is high correlation between seed deterioration and carbohydrates leakaged from them (KEELING, 1974; POWELL, 1988). All of the cultivated species (rice, soybean, maize, wheat, sunflower, green pea, lupine, cotton, alfalfa, barley, tomato, onion, sugar beet, pepper, dry bean, floral and forestry seeds) could be assayed by this test (ISTA, 1995).

At present, because of high capacity of resolution and reliability of this vigor test and the excellent results obtained with different species, it is recommended for different associations of seed analysts.

From a theoretical point of view, the Seed Automatic Analyzer SAD 9000S could assay all cultivated species. It is indispensable a standardization of the test in order to compare and repeat the analysis results between different laboratories, being essential to take into account relative aspects of the vegetal structure to be analyzed, type of water to be used, operation method of the equipment and the material management.

The objective of the work was to study the behavior of ten soybean cultivars with EC test by leakage curves of electrolytes along a certain period of time and to establish the mathematical model that allow to understand their best behavior.

MATERIALS AND METHODS

There were used ten soybean cultivars; Asgrow 5409, Don Mario 57, Asgrow 6001, Fainta 760, Asgrow 6444, Don Mario 4700, Fainta 570, Torcacita, Santafesina and RA 702, mechanically harvested in 2004. Initial seed moisture content (Table 1) was determined according to the described methodology by ISTA (2003).

The EC measurements were taken per 100 individual seeds of each cultivar during twenty hours of immersion at intervals of one hour. The deionized water medium had a conductivity range of 0 to 5 $\mu S.m^{-1}$. The Seed Automatic Analyzer SAD 9000S (Consultar Ingeniería e Informática- Rosario, Argentina), is made basically of a measurement multiple head with 100 electrodes and an electronic card that is installed in the computer. A leakage multiple tray with 100 cells is used like accessory where seeds are individually soaked in a determined volume of deionized water, a doser-shaker module for the exactly cell filling and a washing tray to wash the head electrodes after each measurement.

The use of the equipment required an ordered handling between the samples, strictly equipment time (twenty hours) and the leakage temperature in the cells (20–23 ºC), the volumes of water within each cell (8 mL) and the cleanliness of the material to avoid the electrodes to get dirty and to affect measurements.

There were proposed two statistical models to study the EC along the time of the 10 cultivars studied using the SAS Statistics Program, to select the model that better allow us to interpret the electric conductivity behavior along the time.

Model 1

$$Y = Ai / Bi + X \qquad i = 1, 2,\ldots\ldots,10$$

Model 2

$$Y = Bi\left[1 - e^{-AiX}\right] \qquad i = 1, 2,\ldots,10$$

For each model and cultivar there were calculated the values of determination coefficient (R^2) and the Akaide Information Coefficient (AIC) (Table 2) and R^2, AIC and Adjusted Akaide Information Criteria (AICC) (Table 3) using Statistical Analysis System (STOKES et al., 2000).

Electrical lixiviation curves were adjusted by the Michaelis-Menten Model (Figure 1), being:

$$AIC = n * \ln(SSE/n) + 2p$$

n: number of observations
p: number of parameters

RESULTS AND DISCUSSION

Moisture content of seeds (Table 1) was considered acceptable within the recommended values for the realization of the EC test.

Table 1. Seed moisture content (%) of ten soybean cultivars.

Cultivars	Seed moisture (%)
Asgrow 5409	13.80
Don Mario 57	10.80
Asgrow 6001	13.40
Fainta 760	13.18
Asgrow 6444	14.92
Don Mario 4700	13.00
Fainta 760	12.97
Torcacita	12.10
Santafesina	12.92
RA 702	13.00

The Table 2 shows Akaide Information Coefficient (AIC) for Adjusted Models of Leakage Curves along the time of 10 cultivars of soybean

Table 2. Values of the Akaide Criterion Coefficient (AIC) for Adjusted Models of Leakage Curves along the time of 10 cultivars of soybean seeds.

Cultivar	RCUAD	AIC
	MODEL 1	
Asgrow 6001	99.95	105.60
Asgrow 6444	99.21	151.18
Asgrow 5409	99.97	87.56
Don Mario 4007	99.81	133.28
Don Mario 57	99.21	146.54
Fainta 570	99.21	147.65
Fainta 760	99.85	142.44
RA 702	99.95	92.12
Santafesina	99.97	99.98
Torcacita	99.85	139.43
	MODEL 2	
Asgrow 6001	99.85	127.53
Asgrow 6444	98.98	156.26
Asgrow 5409	99.83	121.59
Don Mario 4007	99.39	156.20
Don Mario_57	98.98	151.62
Fainta 570	98.96	153.00
Fainta 760	99.62	160.46
RA 702	99.97	78.19
Santafesina	99.91	120.96
Torcacita	99.62	157.45

RCUAD: Determination coefficient (R^2)
AIC: Akaide Criterion Coefficient

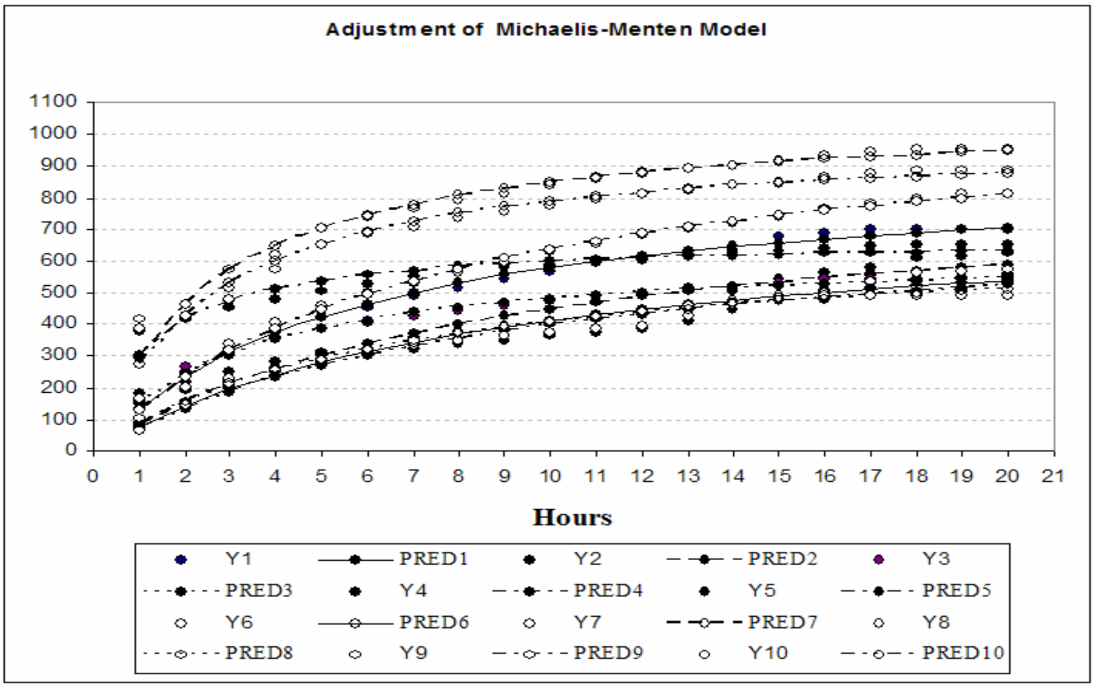

Figure 1. Adjustment of the electrical conductivity measurement (µS. cm^{-1}. g^{-1}) by Michaelis- Menten Model of ten soybean cultivars during twenty hours.

Table 3. Differences in R^2, AIC y AICC (adjusted) for Adjusted Models of Leakage Curves along the time for 10 cultivars of soybean seeds.

Cultivar	DIF R2	DIF AIC	DIF AICC
Asgrow 6001	0.10	-21.93	-21.93
Asgrow 6444	0.23	-5.08	-5.08
Asgrow 5409	0.14	-34.03	-34.03
Don Mario 4007	0.42	-22.92	-22.92
Don Mario 57	0.23	-5.08	-5.08
Fainta 570	0.24	-5.34	-5.34
Fainta 760	0.23	-18.01	-18.01
RA 702	-0.03	13.94	13.94
Santafesina	0.06	-20.97	-20.97
Torcacita	0.23	-18.01	-18.01

AIC: Akaide Criterion Coefficient AICC: Adjusted Akaide Criterion Coefficient

In nine of ten cultivars (Table 3) Model 1 showed the highest R^2 and the lowest AIC and the functional form selected was that corresponded to Model 1.

The Table 4 shows the results of F test estimation to prove that signification of Model 1 proposed was statistical significative ($F= 3972.65$; $P < 0.0001$).

Table 4. F test estimation for Adjusted Model 1 of Leakage Curves along the time of 10 cultivars of soybean seeds.

Cultivars	Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
Asgrow 6001	A	904.1	32.6628	839.6	968.5
Asgrow 6001	B	5.6478	0.5928	4.4781	6.8175
Asgrow 6444	A	859.8	57.0135	747.3	972.3
Asgrow 6444	B	9.1625	1.4034	6.3933	11.9316
Asgrow 5409	A	634.4	21.1531	592.6	676.1
Asgrow 5409	B	3.1944	0.4162	2.3730	4.0157
Don Mario 4007	A	670.8	13.6013	644.0	697.7
Don Mario 4007	B	1.2269	0.1684	0.8947	1.5591
Don Mario 57	A	765.5	57.0145	653.0	878.1
Don Mario 57	B	9.1625	1.5761	6.0525	12.2726
Fainta 570	A	776.7	55.0813	668.0	885.4
Fainta 570	B	8.8464	1.4732	5.9394	11.7535
Fainta 760	A	1071.0	19.2732	1033.0	1109.0
Fainta 760	B	2.6225	0.2066	2.2149	3.0301
RA 702	A	684.9	36.5416	612.8	757.0
RA 702	B	6.7446	0.9529	4.8642	8.6250
Santafesina	A	1115.9	41.5645	1033.9	1197.9
Santafesina	B	7.5064	0.7048	6.1157	8.8971
Torcacita	A	993.5	19.2733	955.5	1031.5
Torcacita	B	2.6225	0.2227	2.1831	3.0619

A: Asymptote
B: Hours to reach A/2

Interpretation of parameters:

Parameter A: it refers to the asymptote of the curve. With the lower values of the asymptote, the lower is the deterioration of the seed.

Parameter B: it refers to the time that is required to reach an EC equal to half of the asymptote. It measures the velocity of ion lixiviation and if the value of this parameter is low, in a short lixiviation time it can be reach an EC equal to the half of the asymptote. Nevertheless, because of the asymptote can differ in the different cultivars it is necessary to consider this value too.

With the objective of comparing the estimated curves for the different cultivars it was calculated the number of hours required to reach the stabilization of the EC. The predicted values for each hour and cultivar were calculated by Model 1. Table 5 shows the time that does not show differences in the response to EC.

Table 5. Hours required reaching Electrical Conductivity Stabilization (µS. m^{-1}. g^{-1}) of 10 soybean cultivars.

Cultivars	Hours
Asgrow 6001	6.99
Asgrow 6444	12.73
Asgrow 5409	11.89
Don Mario 4007	3.59
Don Mario 57	17.25
Fainta 570	15.98
Fainta 760	2.30
RA 702	18.24
Santafesina	6.09
Torcacita	2.66

Although some cultivars stabilized EC within 2 to 3 hours (Fainta 760 y Torcacita 266), most of them achieved it in aproximately 18 hours. This means that the minimum time of lixiviation to reach the stabilization of the seed EC could be of 19 hours, very similar to the usually used in the seed laboratories tests.

The electrolytes lixiviation curves during 20 hours are shown in Figure 1.

The curves differed significative (F= 10.64) p< 0.0000) and they could be joined to determine which one showed similar parameters in magnitude. Group 1 was constituted by the cultivars RA 702; Don Mario 57 and Fainta 570; Group 2 by Fainta 760 and Torcacita; Group 3 by Asgrow 5904 and Don Mario 4007 and Group 4 by Asgrow 6001 and Santafesina.

The three curves of the Group 1 were coincident (F=0.86; p = 0.49).

Curves of Group 2 differed at least in one parameter (F= 16.341; p = 0.00) and the asymptote of them differed significatively. B coefficient that corresponded to the curves of lixiviation velocity was similar for the two cultivars Fainta 760 and Torcacita. For that reason, they showed curves with different asymptotes but similar lixiviation velocity.

Curves of group 3 differed in at least one parameter (F= 193.123; p= 0.00). Asymptotes of the curves were different and the coefficient corresponding to the velocity of lixiviation differed in the curves. For that reason, curves corresponding to EC of Asgrow 5904 and Don Mario 4007 differed in all of their parameters.

Curves of group 4 differed in at least in one parameter (F= 144.02; p= 0.00) and the asymptotes of the curves differed between them. The coefficient corresponding to the velocity of lixiviation differed between the curves and that corresponding to the EC of Asgrow 6001 and Santafesina differed in all of their parameters.

The environmental and soil conditions and insect and microorganisms that attack the crop during the period of seed development defined aspects of importance like grain filling, resistance of the tegument to the mechanical damage (CARBONEL et al., 1992; CARBONEL; KRZYZANOWSKI, 1995), viability, chemical composition and vigor (HADAVIZADEH; GEORGE, 1988). The environmental unfavorable factors interact with seed genotype modifying the physiological quality of their seeds. As a result of this interaction, EC is a variable that could be considered a good estimator of the physiological quality of seeds evaluated as standard germination and vigor. Panobianco e Vieira (1996) established that the EC varied between genotypes in soybean and Vieira et al., 1999 showed significative differences in CE of the different genotypes in soybean of high vigor. Salinas et al., 2001 concluded that the CE is considered a good vigor test to detect indirectly alterations of cytoplasmic membranes, in early stages of seed deterioration. Panobianco et. al., 1999 working with soybean seeds showed that genotypes with different lignin content in their seed coats had a great influence on the EC.

The application of the Model I could be a helpful tool if it is used in the study of EC of different genotypes produced in the same production environment or the same genotypes in different production environments.

CONCLUSIONS

Model 1 allows to make comparisons of electric conductivity along the time between cultivars and to study the influence of the production environment on the physiological quality of seeds;

Incubation time of seeds must not be lower than 19 hours.

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