DIELECTRIC PROPERTIES OF POTATO TUBERS RELATED TO STORAGE CONDITIONS

Soliman N. Soliman[1] and Azhar El-WershEl-Sayed[2]

ABSTRACT

The objective of this work is to study the dielectric properties of potato tubers asa criteria for predicting of freshnessfor each of fresh and storage commodity under traditional (Nawala) and cold conditions. Dielectric measurementswere measured using LCZ meter,andwere conducted on fresh and stored tubers, for measuring of capacitance (Farad, f), and conductance (Siemens, S) over a range of frequencies from 10 to 1000 kHz. The measured value were used to calculate permittivity (f/m), conductivity (S/m), relative permittivity, complex permittivity (S.sec/f), complex conductivity (f/m.sec) and dissipation factor or "loss tangent" (tan δ) of potato tuber.

The capacitance,relative permittivitydecreases rapidly with increasing frequency.Dissipation factor Tan (δ) decreases gradually with increasing the storage time. Complex permittivity and Complex conductivity were decreases with the increases of the storage time.

The quality factor Q was expressed as a percentage value of the ratio between conductance at high frequency to that at low frequency (GH/GL) for the stored tissue to that for the fresh tissue to indicate the degree of freshness. The quality factor Q decreases with the increasing ofstorage time, storage temperature and storage load stressand isa fairly goodindication of the loss of freshness. The storage ages of potatoes were predictedwith very sensitive equation using the quality factor, tuber weight and storage temperature.

1. INTRODUCTION

Dielectric properties of agricultural materials and products are finding increasing application, as new technology is adapted for use in agricultureand related industries. These properties are important in explaining or in predicting the interaction of materials with environmental parameter.

1- **Prof. of Food Engineering, Faculty of Agriculture, Alex University.**
2- **Researcher at Agricultural Engineering Research Institute, Agricultural Research Center, Ministry of Agriculture.**

Freshness is one of the most important factors, which determine quality of food (Babbitt 1981, Sakaguchi and Koik, 1992). Various sensory methods have been used to assess the freshness. Electronic methods have the advantage of speed, they are non-destructive and are objective (Babbitt, 1981 and Sakaguchi and Koik, 1992) improved methods for rapidly sensing quality factors of fruits and vegetables, such as moisture content, maturity, defects and blemishes, would be helpful in the harvesting, sorting, and packing operations for these commodities. Rapid sensing techniques that can be adapted on-line processes, such as sorting and grading, can simultaneously save labor costs and provide improvement in the uniformity and quality of the products (Nelson et al, 1995).

Dielectric properties can be defined in terms of complex permittivity (eε). The complex permittivity (eε) is composed of a real part (eε', relative dielectric constant) and an imaginary part (eε'', relative dielectric loss factor) and is given by the equation (Saltiel and Datta, 1999):

$$e\varepsilon = e\varepsilon_o(e\varepsilon' - je\varepsilon'') \text{..............................} (1)$$

Where: $j = (-1)^{0.5}$ and $e\varepsilon_o$ is the permittivity of free space (8.86×10^{-12} F/m), (jω) was changed to (jeε''). Loss tangent (tan δ), a parameter is the ratio of dielectric loss factor (eε'') to the dielectric constant (eε'). A product with a higher loss tangent will heat faster under microwave field as compared to a product with a lower loss tangent (Nelson and Datta, 2001).

The relative permittivity **eε'** and conductivity **eσ** of a material are, respectively, the dipole and current densities induced in response to an applied electric field of unit amplitude. The significance of these quantities were illustrated by considering an ideal parallel plate capacitor, whose plates have surface area A and separation d, the capacitance C and conductance G of the capacitor are then:

$$\boldsymbol{C = e\varepsilon\, e\varepsilon_o A / d} \text{ ....} (2)$$

$$\boldsymbol{G = e\sigma A / d} \text{ ....} (3)$$

At radian frequency ω, the admittance Y of the capacitor can be written:

$$Y = (G + j\omega C) \text{ ....} (4)$$

$$Y = (e\sigma + j\omega\, e\varepsilon\, e\varepsilon_o)\frac{A}{d} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$= \mathbf{e}\sigma^{*}\,\frac{A}{d} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\;(6)$$

$$= J\omega\,\mathbf{e}\varepsilon^{*}\mathbf{e}\varepsilon_o\,\frac{A}{d} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\;(7)$$

Where: C (farad), is the capacitance and G (siemens) is the conductance of the capacitor between the two measuring blades. A (m^2) is the surface area of the electrode, (d)is the separation distance between the two blades per meter, (**e**ε') the relative permittivity, (**e**ε_o) the permittivity of vacuum ($8.85 * 10^{-12}$ F/m), and (**e**σ) the electrical conductivity (Siemens / m). j = $(-1)^{1/2}$, (eσ* = eσ +j ω eεeε_o)is the complex conductivity, and(ε * = ε – jσ/ω εo) is the complex permittivity.

In usual notation eε* = eε' –jeε" where eε", is the loss and tan (e_ε"/e_ε') is the loss tangent. Typically; forsoft tissues at low frequencies, (eσ>ωeε^*eε_o)(Polk and Postow 1996, Joseph and Bronzino, 1995).

The objective of this research is to study the dielectric properties of Lady Rosetta potato tubers variety as a criteria for predicting of potato freshness for each of fresh and storage commodity under traditional (Nawala) and cold conditions.

2. MATERIALS AND METHODS

The samples of two fresh potato varieties "Lady Rosetta" which was planted under sand and black soils, each of 500 kilograms were provided from DaltexCompany in Kafr El-Zaiat.

The fresh potato tubers were manually harvested carefully by hand, cleaned from soiland the damage tubers were excluded manually, and transported in the same day to the laboratory of food engineering faculty of agriculture Alexandria University.

The selected tubers from each size were numbered for preparation and recording the physical measurements, including tuber mass, dimension (length, width and thickness), volume, bulk and particle density, surface area, respiration rate, moisture content and sugar contents which were measured according to Mohsenin1986..

The potato tubers were classifieds into three different size small "tubers mass of 70 to < 100 g", medium "tubers mass of 100 to < 130 g" and large "tubers mass of ≥130 g ", and The tuber dimensions were measure with an accuracy of 0.01 mm.

The traditional storage chamber (Al-Nawalla)andrefrigeration chamber at 8 C^o and 85 % relative humiditywere used for potato storage. The curing treatments of potatoes carriedat 15 C^{o}and 90 % relative humidity for 15 days before storage.

The storage potatoes conductedat three levels of static pressure "0.0, 2.44 and 4.87 kPa, which was exerted on the top of the potato cage. The amount of 36 storage treatments including six potato samples which were subjected for 6 storage conditions were done in five replicates.

2.1Measurements of Dielectric Properties

Dielectric measurements conducted in the Institute of Graduate Studies and Research, Alexandria University using LCZ Meter Model 4277A, figure (1). The meter designed to measure the capacitance and conductance of plant and animal tissues, equivalent series resistance, impedance magnitude and phase of electronic components and devices. Its built-in test signal source covers the frequency range of 10 KHz to 1000KHz and provides 701 spot frequencies. Test frequency resolution is 100Hz (maximum), and frequency accuracy is ± 0.01% of the selected spot frequency. Spot frequencies selected were 10 KHz, 100 KHz, and 1000KHz.Test signal level is selectable at 1V_{ras} (HIGH) or 20 m V_{rms} (LOW). The 4-tenninal pair configuration provides a basic measurement accuracy of 0.1%overawidemeasurement range. The samples of potato tubers connected to the meter by means of an electrode. The electrode consists of two parallel blades knife-edge electrode, which used to allow easy insertion of the electrodes inside the potato tuber tissue. The area of each side is equal to 1.35 cm^2 and the two parallel blades fixed on two opposite surface of a Plexiglas cylinder of 1 cm diameter and 1 cm height as shown in (Figure1).

Capacitance (C) and conductance (G) measured by LCZ meter over a frequency range from 10 kHz to1000KHz. The measured values used to calculate permittivity and conductivity of potato tubers at time intervals during a long storage time. The relative dielectric permittivity (**eε**') and conductivity (**eσ**) are calculated using equations (2, 3) Polk and Postow, 1996.

The imaginary part of complex permittivity (**eε**") and conductivity (**e**σ")were calculated according to the relation (Irimajiri*et al*, 1987, Asami*et al*, 1988).

$$e\varepsilon '' = (e\sigma - e\sigma_L) / 2\pi f e \varepsilon_0 \ldots\ldots\ldots\ldots (8)$$

$$e\sigma '' = 2\pi f e \varepsilon_0 (e\varepsilon - e\varepsilon_h) \ldots\ldots\ldots\ldots (9)$$

Where (**σ_L**) is the low frequency limiting conductivity taken at l0 KHz, and (**ε_h**) is the high frequency limiting permittivity taken at 1000KHz.

2.2 Quality factor (Q)

The ratio of low frequency impedance to high frequency Impedance measured with a wide range a.c. bridge is an indication of the degree of injury to animal and plant tissue (Mohsenin 1986).As it is known conductivity is a reverse of impedance. The ratio between conductivity at high frequency to that at low frequency (G_H / G_L) have a high value for fresh tissue and lower value (approaching zero) for deterioration tissue.

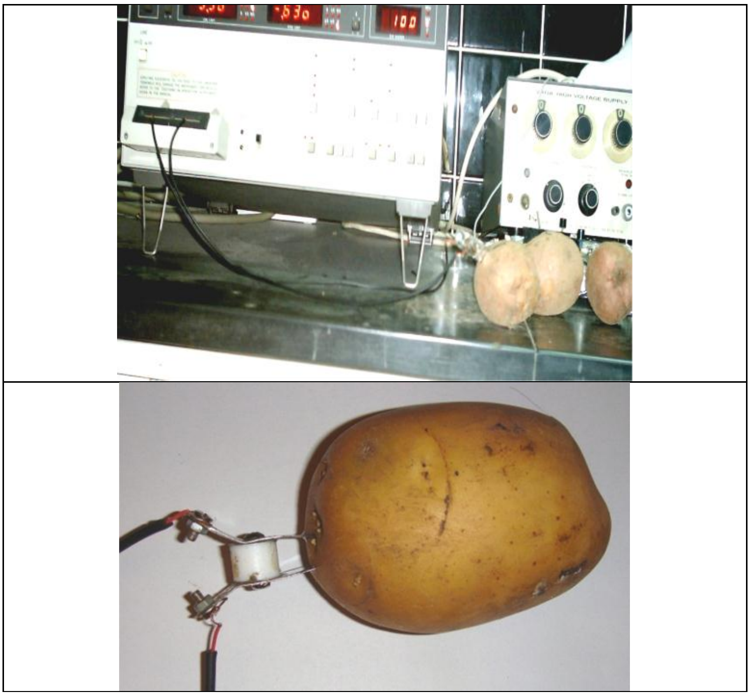

Figure (1) Dielectric apparatus LCZ Meter Model 4227 A

In the present work, a number Q was expressed as a percentage value of the ratio (G_H / G_L) for the stored sample to that for the fresh sample to indicate the degree of freshness. Thus

$$\boldsymbol{Q = \frac{(G_H / G_L)\ stored\ sample}{(G_H / G_L)\ fresh\ sample} * 100} \quad \dots\dots\dots\dots\dots\dots \quad (\mathbf{10})$$

Where: (G_H) conductance measured at the higher frequency,
(G_L) conductance measured at the low frequency.
During all measurements, experimental conditions were kept constant.

3. RESULTS AND DISCUSSION

The dielectric properties of fresh and storage potatoes at cold and traditional conditions, storage period, cultivars' (sand and black soils tubers), tuber size and load stress (0.0, 2.44 and 4.77 kPa) on dielectric properties were investigated. Sample of five tubers randomized selected from each treatment. 288 potato tubers were measured each run including 36 treatments and 8 replicates.
The measured data of dielectric properties are summarized in two parameters as Capacitance C, microfarad (μf) and Conductance G, Siemens (S). The measured parameters are mathematically analyzed into five calculated parameters as Conductivity eσ (S/m), Relative Permittivity eε', Complex Conductivity eσ'' (f/m.sec), Complex Permittivity eε'' (S.sec/f) and Dissipation Factor Tan (δ).

3.1 Capacitance

The dielectric capacitance (C, μf) versus frequency from 10 to 1000 kHz of potato tubers were measured for different storage treatments and are shown graphically in figures (2 and 3). The graphs appear that capacitance decreases rapidly with increasing frequency.
The maximum capacitances (μf) for all data are at 10 kHz and the minimum values at 1000 kHz. The values of capacitances directly proportion with storage time and storage temperature and storage static load stress except at storage time of 200 days, which found that the values of capacitance inversely proportion with static load stress. For sand soil

cultivars, the values of maximum capacitance of fresh potato were 0.01628 μf at 10 kHz and the minimum values was 0.002345 μf at 1000 kHz. For storage potato at cold storage and at 120 and 200 days the values of capacitance were 0.0398 and 1.1939 at 0.0 load; at 2.44 kPa were 0.03356 and 0.4003 and at 4.87 kPa were 0.0503 and 0.01886 respectively. For traditional storage at 120 days the values of capacitance were 0.0318 at 0.0 load; at 2.44 kPa was 0.03078 and at 4.87 kPa was 0.05688. While for black soil cultivars, the values of maximum capacitance of fresh potato were 0.01759 μf at 10 kHz and the minimum values was 0.001733 μf at 1000 kHz. For storage potato at cold storage and at 120 and 200 days the values of capacitance were 0.02957 and 1.4165 at 0.0 load; at 2.44 kPa were 0.06772 and 0.06185 and at 4.87 kPa were 0.05984 and 0.051826 respectively. For traditional storage at 0.0 load and at 120 days the values of capacitance were 0.01755; at 2.44 kPa was 0.017875 and at 4.87 kPa was 0.02673.

Non-linear regression statistical analysis was conducted in order to describe the relationship between capacitance(C,μf) and frequency(f **,**kHz) for all treatments under storage condition. The statistical regression analysis clarify that the power function is the best-fit equation for describing capacitance C= af^b, which a and b are equation constants, and the coefficient of determination is not less than 0.99 for all cases.

Multiple nonlinear regression analysis were conducted to correlate the measured capacitance (C, μf) as a function of soil types (ST, 1 for sandy and 2 for black soil), frequency (f ,kHz) , storage time (D, days), storage temperature (T, C^o), static load stress (SL, kPa) and tuber mass (M, g.). The step wise regression analysis clarify that the correlation of logarithm capacitance as a function of other parameters under study is the best-fit equation. The statistical regression equations were as follow:

$$Ln\ C\ (\mu f) = -1.1176\ ST - 0.00287\ f + 0.000785\ D - 0.0165\ T - 0.11527\ SL - 0.01426\ M \ldots\ldots R^2 = 0.946,\ STDE = 1.126 \ldots\ldots (11)$$

The equation shows that Ln (Capacitance) negatively affected by each of soils type, storage temperature, static load stress, frequency and tuber mass but directly proportion with storage time.

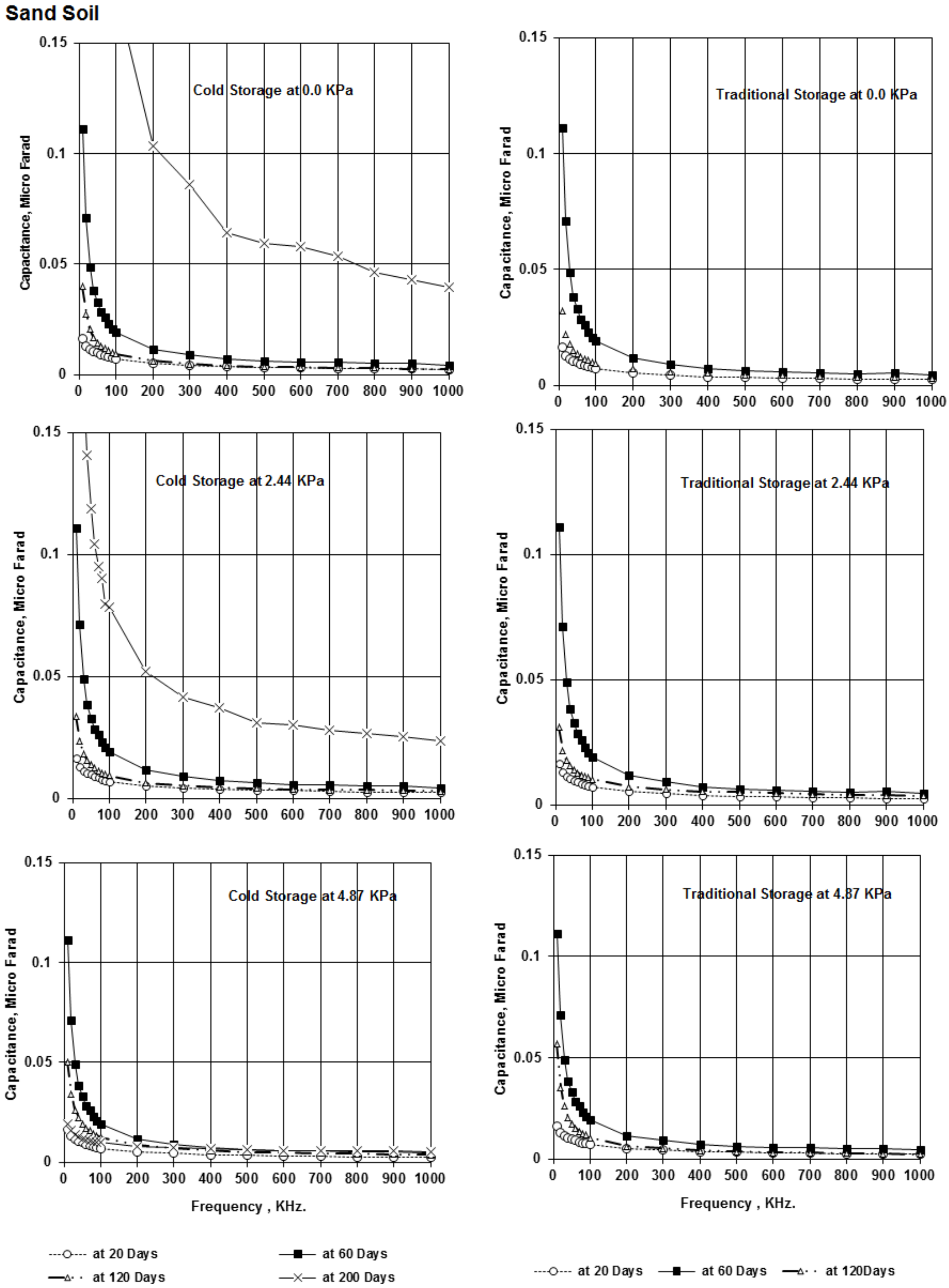

Figure (2): Dielectric Capacitance of Stored Sand Soil Potato Tubers.

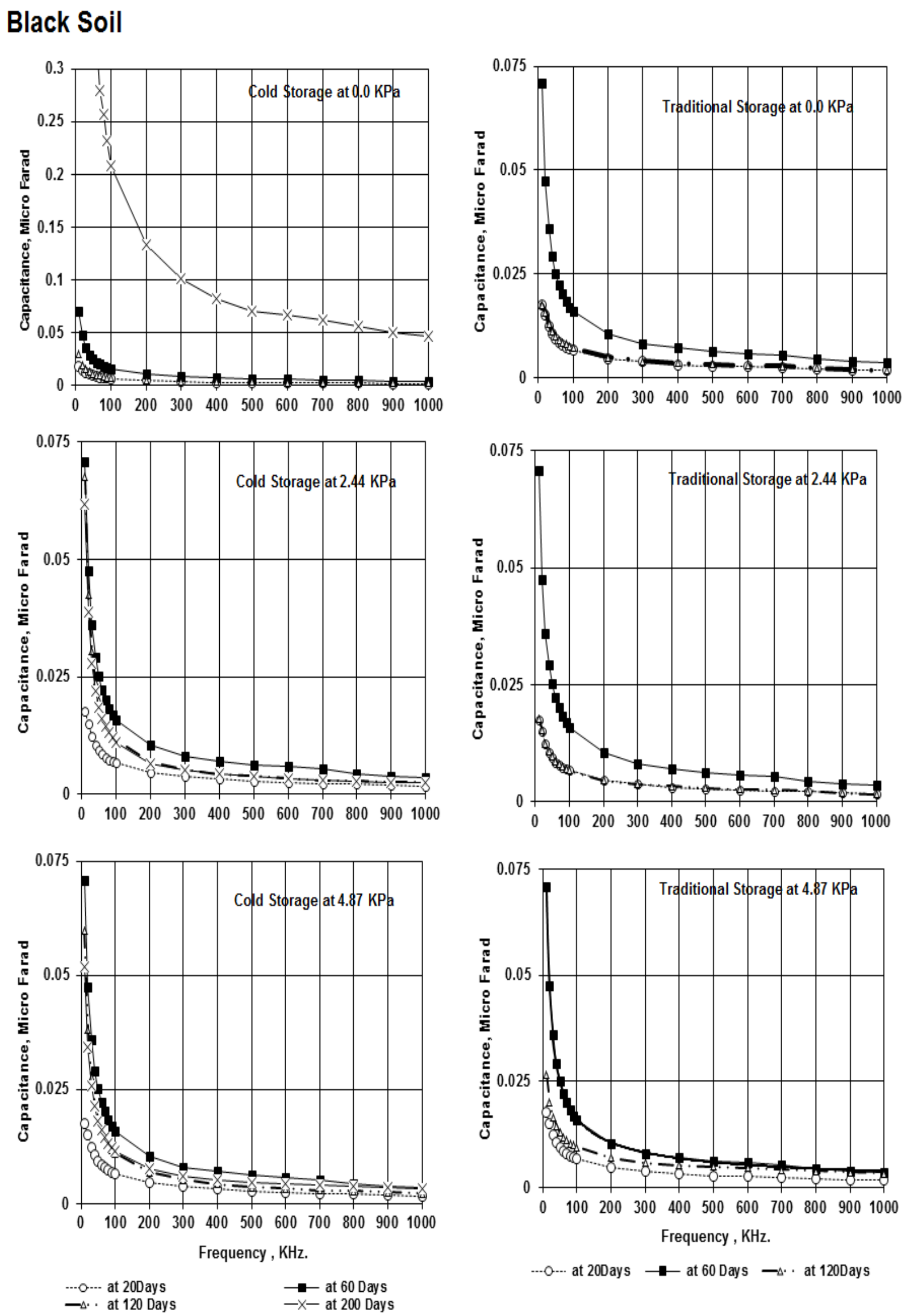

Figure (3): Dielectric Capacitance of Stored Black Soil Potato Tubers.

3.2 Conductance

The dielectric conductance in Siemens, (G, S) versus frequency of potato tuber at different treatments are shown in figures 4 and 5 as a samples of typical graphs. The graphs appear that conductance increases gradually with increasing frequency**.**

The maximum conductance (G,S) for all data are at 1000 kHz and the minimum values at 10 kHz. The values of conductance are directly proportion with storage time and storage temperature and storage static load stress except at storage time of 200 day, which found that the values of conductance inversely proportion with static load stress.

For Fresh potato's, the sand soil cultivars have the maximum conductance values of 0.02375 (S) at 1000 kHz and the minimum values of 0.0008167 (S) at 10 kHz. For black soil cultivars, the values of maximum conductance were 0.0177015 S at 1000 kHz and the minimum values was 0.00135S at 10 kHz.

For cold storage potato, the sand soil cultivars have the maximum conductance value at 120 and 200 days were at 0.0 kPa load 0.02833 and 0.069753; at 2.44 kPa were 0.02109 and 0.06274 and at 4.87 kPa were 0.01691and 0.012849 respectively. For black soil cultivars, the maximum conductance values at 120 and 200 days were at 0.0 kPa load were 0.01929 and 0.10153; at 2.44 kPa were 0.0172 and 0.01486 and at 4.87 kPa were 0.01933 and 0.01502 respectively.

For traditional storage and for the sand soil cultivars at 120 days the maximum conductance values at 0.0 kPa load was 0.03044; at 2.44 kPa was 0.027288 and at 4.87 kPa was 0.028267. For black soil cultivars at 120 days the values of conductance at 0.0 load was 0.02399; at 2.44 kPa was 0.023377 and at 4.87 kPa was 0.0172.

Non linear regression statistical analysis was conducted to describe the relationship between conductance (G,S) and frequency (f ,kHz) for all treatments under storage condition. The statistical regression analysis clarify that the power function is the best-fit equation for describing conductance**,** $\mathbf{G = c}\, f^{\mathbf{d}}$, which c and d are equation constants, and the coefficient of determination is not less than 0.98 for all cases.

Sand Soil

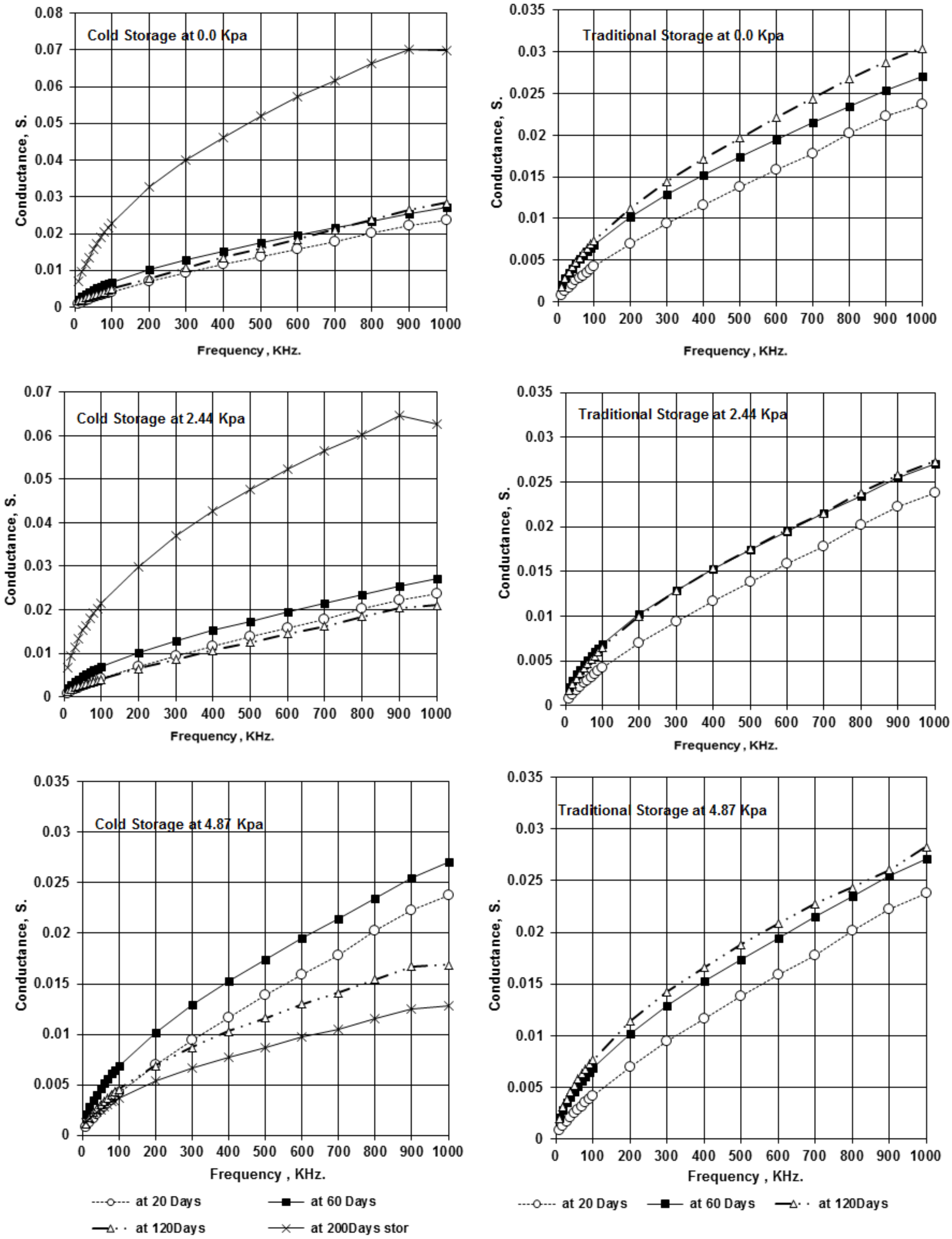

Figure (4): Dielectric Conductance of Sand Soil Potato Tubers.

Black Soil

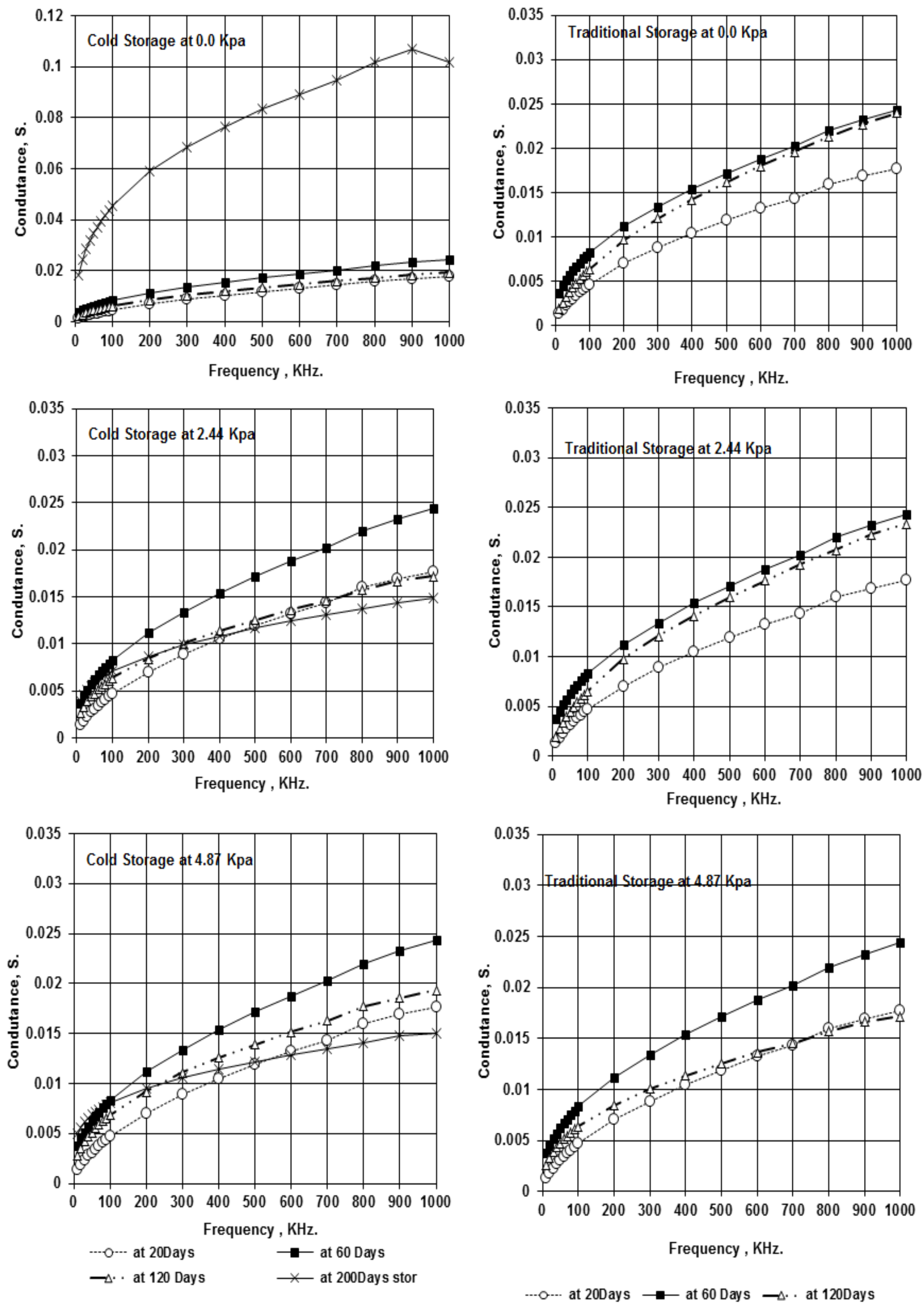

Figure (5): Dielectric Conductance of Black Soil Potato Tubers.

Multiple linear regression analysis were conducted to correlate the measured conductance (G, S) as a function of soil types (ST, 1 for sandy and 2 for black soil), frequency (f , kHz), storage time, (D, days),storage temperature(T, C^o), static load stress (SL, kPa) and tuber mass (M, g.).The step-wise regression analysis clarify that the correlation of logarithm conductance as a function of other parameters under study is the best fit equation. The statistical regression equation was as shown:

$$Ln\ G\ (S) = -1.3096\ ST + 0.00153\ f - 0.00387\ D - 0.01621\ T - 0.1573\ SL - 0.02101\ M \ldots R^2=0.93,\ STD= 1.297 \ldots (12)$$

The equation shows that Ln (G) negatively affected by each of type of soils, storage time, storage temperature, static load stress and tuber mass but directly proportion with frequency.

3.3 Quality Factor

Non-linear regression statistical analysis was conducted in order to describe the relationship between Quality Factor (Q, %),and storage time (t, day) for all treatments under storage condition. The regression analysis clarify that the exponential function $\boldsymbol{Q = ne^{xD}}$is the best-fit equation for describing the quality factor, which $\boldsymbol{n}$ and $\boldsymbol{x}$ are constants and the coefficient of determination for this analysis is not less than 0.90 for all cases.

Multiple linear and non linear regression analysis were conducted to correlate the measured Quality Factor (Q, %) as a function of soil types (ST, 1 for sandy and 2 for black soil), storage time (D, days), storage temperature (T, C^o) and static load stress (SL, kPa). The step wise regression analysis clarify that the Quality Factor (Q, %) is linearly and inversely proportion with the other parameters under study. The statistical regression equation was shown as follow:

$$Q\ \% = 102.4726 - 0.0224*ST - 0.2219*D - 0.2760*T - 0.6480*SL \ldots\ldots R^2=0.942,\ STDE= 3.651 \ldots\ (13)$$

The quality factor was decreases with the increasing of storage time, storage temperature and storage load stress. The equation shows that the effect of soil type on quality factor is non-significant.

The Quality Factor is inversely proportion with mass loss (ML, %) during the storage period**.** Mass loss look like other parameters is also inversely proportion with quality factor.

Figure (6) shows the change of quality factor% and mass losses % versus storage time for each of sand soil and black soil potatoes. The quality factor % value decreased with increasing the storage time but the mass losses are increasing. Therefore, it may be assumed that the increasing permeability of the cell walls is caused by the enzymatic and bacterial action that causes deterioration since both give rise to decomposition of proteins. This is a good indication of the loss of freshness.

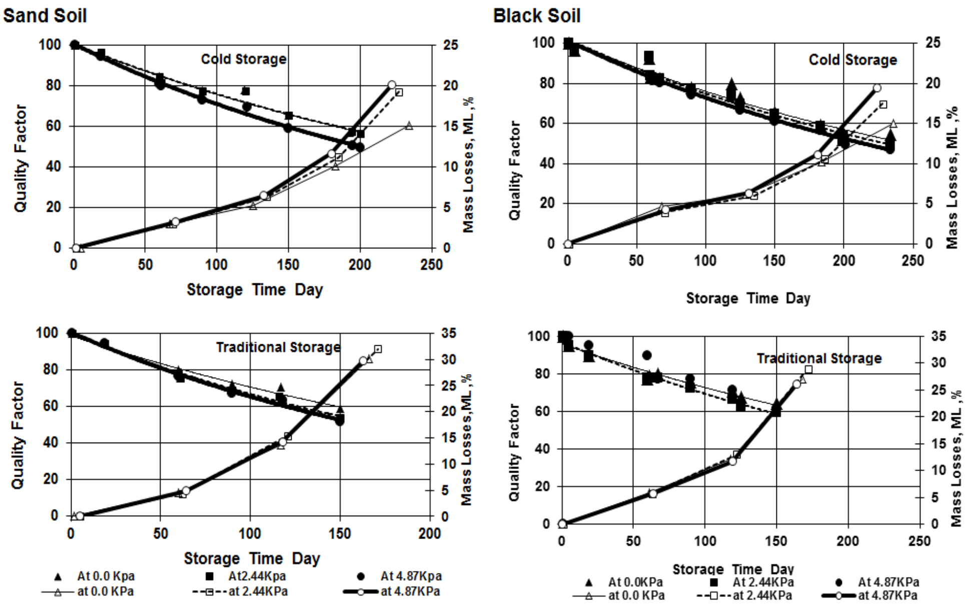

Figure (6): Quality Factors and Mass Losses of Potato Tubers Versus Storage time.

The Quality Factor(Q, %) shows that the values of Q are inversely proportion with all parameters. The quality factor decreases with the increasing of storage time, storage temperature and storage load stress. Mass loss look like other parameters is also inversely proportion with quality factor, therefore the quality factor is a good indication of the loss of freshness.

The prediction of storage periodof potato tubers is one of the important demands for potato industry. Multiple regression analysis was conducted to predict the storage time of potato tubers (D, days) as a function of final tuber weight (FW,g), Storage temperature (T,ºC) and quality factor (Q, %). The statistical regression equations were as follow:

For Sand Soil

Predicted Storage day,(D) = 463.4417+0.020261*FW-1.77971*T-.46864*Q

. . . . . R^2=0.951, STDE=16.299.. (14)

For Black Soil

Predicted Storage day,(D) = 479.8327 + 0.04726*FW- 1.0678*T - 4.8606*Q

. . . . . . R^2=0.958 STDE=15.102..(15)

Figure (7) presented the predicted storage time, which calculated using equations (14 and 15) versus the actual storage time. The trend line show an inclination of about 45º that is mean a very sensitive relationship between storage time and quality factor, storage temperature and final weight. This equation can be used for industrial processing of potato tubers.

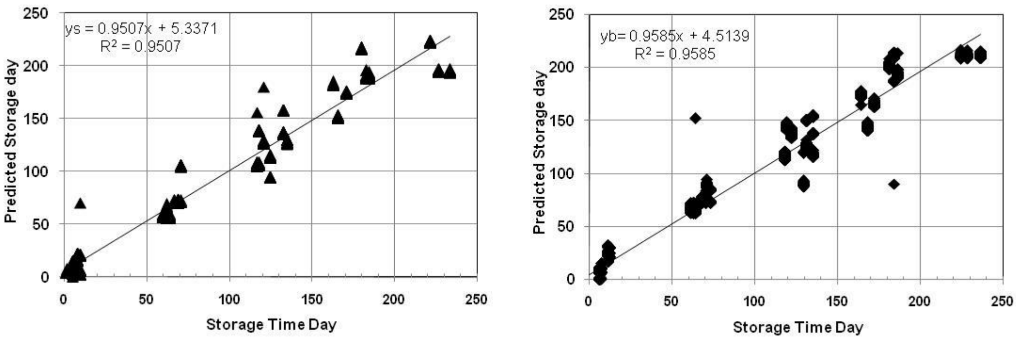

Figure (7): Predicted storage time versus actual storage time of potato tubers.

4- SUMMARY AND CONCLUSION

The electrical insulation tests were carried out on potato tubers to study the relationship between the storage conditions and the electrical insulation properties, which can be taken as a measure of the freshness of the tubers and as a guide to the quality of the potato tubers. The measurements were used to calculate permeability, conductivity, composite permittivity, composite conductivity and Loss tangent for potato above the frequency range of 10-1000 kHz. The results showed that the electrical conductivity log (G, S) is inversely proportional to storage time, storage temperature, static load stress and tuber weight but directly proportional to the frequency level.

The quality factor Q was expressed as a percentage value of the ratio between conductance at high frequency to that at low frequency (GH/GL) for the stored tissue to that for the fresh tissue to indicate the degree of freshness. The quality factor Q decreases with the increasing of storage time, storage temperature and storage load stress and is a fairly good indication of the loss of freshness. The Quality Factor is inversely proportion with mass loss (ML, %) during the storage period**.** This is a good indication of the loss of freshness. The statistical analysis appeared a very sensitive relationship between quality factor and each of storage time, storage temperature and final weight. The quality factor equations can be applied in industrial processing for predicting of storage ages of potatoes with a high sensitivity.

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الملخص العربى

الخواص الكهربية لدرنات البطاطس والمرتبطة بظروف التخزين.

أ.د. سليمان نصيف سليمان[١] و د.أزهار الورش السيد[٢]

تم اجراء اختبار العزل الكهربي علي درنات البطاطس باستخدام جهاز LCZ بهدف دراسة العلاقة بين ظروف التخزين وخصائص العزل الكهربي والذي يمكن أخذة كمقياس لمدي طزاجة و نضارة الدرنات وكدليل لجودة درنات البطاطس. تم اختيار صنف البطاطس"ليدي روزيتا"والذي يتميزبكثافة نوعية ومادة جافة عالية ومحتوى سكري منخفض ويعتبر من أهم الأصناف لتصنيع رقائق الشيبسى في مصر. تم قياس كل من السعوية (C,Farad) والتوصيلية (G, Siemens)لدرنات البطاطس فوق مدي التردد من ١٠-١٠٠٠ كيلو هيرتز. ولقد تم حساب كل من النفاذية (eε, farad/m) و الموصلية (eσ, Siemens/m) والنفاذية النسبية (eε') و النفاذية المركبة Complex Permittivity (eε",S.sec/f) والتوصيلية المركبة Complex Conductivity eσ",f/m.sec ومعامل الفقد (Loss tangent, Tan δ) لدرنات البطاطس.

أوضحت النتائج ان اقصي سعوية (C, farad)عند ١٠ كيلو هيرتز وتقل السعوية مع زيادة التردد لكل من درنات التربة الرملية والطينية. وكانت أقصي توصيلية (G , Siemens) لدرنات البطاطس عند ١٠٠٠ كيلو هيرتز لمحصولي التربة الرملية والطينية.

ولقدأوضح التحليل الإحصائي للنتائج أن لوغاريتم التوصيلية الكهربية (G,S) تتناسب عكسياً مع كل من زمن التخزين، درجة حرارة التخزين، إجهاد التحميل الاستاتيكى و وزن الدرنات و لكن تتناسب طرديا مع مستوي التردد.

١- أستاذ هندسة التصنيع الزراعي بقسم الهندسة الزراعية والنظم الحيوية - كلية الزراعة جامعة الإسكندرية.

٢- باحث بمعهد بحوث الهندسة الزراعية – مركز البحوث الزراعية الدقي الجيزة.

تم استنباط معامل للجودة (Q, %) وذلك بأخذ خارج قسمة التوصيلية عند تردد ١٠٠٠khz علي التوصيلية عند تردد ١٠khz للدرنات المخزنة نسبة الي الدرنات الطازجة وهذا القياس يعتمد علي قياس التغير في خواص التوصيل والعزل الكهربي للدرنات الطازجة وأثناء تخزينها واستنتاج معامل لقياس جودة الدرنات أو درجة الطزاجة Freshness. ووجد ان دليل الجودة قيمتة تتناسب طرديا مع درجة طزاجة الأنسجة.

ولقد اوضح التحليل الإحصائي لدليل الجودة كدالة في العوامل تحت الدراسة انة يتناسب عكسياً مع كل من زمن التخزين و درجة حرارة التخزين وحمل التخزين ولقد بينت النتائج ان نوع التربة ذات تاثير غير معنوي علي دليل الجودة وهي عموما اقل للتربة الطينية عنها للتربة الرملية.

وأوضحت النتائج أيضاً أن قيمة دليل الجودة تقل مع زيادة الفقد الوزني للدرنات مع زمن التخزين ويعتبر هذا مؤشر جيد تماما لفقد الطزاجة وذلك لافتراضنا ان النفاذية تزيد لجدران الخلايا بسبب النشاط الأنزيمي والبكتيري والتى يتسبب في تدهور الدرنات. ولقد تم الإستعانة بمعامل الجودة ووزن الدرنات ودرجة حرارة التخزين للتنبؤ بزمن التخزين للدرنات بحساسية عالية جداً و يمكن استخدامة علي المستوي التجاري لتحديد عمر التخزين لدرنات البطاطس.