CREEP BEHAVIOR OF POTATO TUBERS DURING STORAGE

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ABSTRACT

The aim of this investigation is to study the creep behavior of Lady Rosetta potato tuber variety of sand and black soil cultivarsunder different storage treatments.

The fresh harvested tubers tend to be very brittle. Four creep apparatuses were develop using a digital micrometer, which enable to feed the data into the computer and instantaneous reading of deformation with time at constant stress (62.45 kPa) during a duration time of 60 minutes. The creep curves were analyzed and the constants related to Burger rheological models were determined. For fresh potato tubers, all rheological model constants were slightly increased with tuber mass, rheological model constants of black soil cultivar were larger than that for sand soil cultivar. The time of retardation of the rheological model was found to be constant around 621 ± 5 seconds for each of sand and black soil cultivars.

1. INTRODUCTION

Potatoes are considered as one of the most important vegetables crops in Egypt, which is one of the largest producers and exporters of potatoes in Africa. Potato is the second most important vegetable crop after tomato. According to the NPC, Jul 2016 (National Potato Council, Washington, D.C., USA), the Egyptian production of potatoes increased from 2.3 million tons in 2006 to 4.8 million tons in 2014) for the total area of 1.77million hectare.

Harvesting, handling and storage of potatoes produces several mechanical injuries. There for the study of mechanical property is very important for improving the technology of these processes. Storage processes produce stresses effect and bring about physiological changes and water loss, which in turn affect the mechanical properties (Burton. 1989).

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Mohesnin (1986) mentioned that mechanical damage in agricultural products is due to external forces and internal forces. External forces affect fruits or vegetables when they subjected to several static and dynamic loads causing mechanical injuries, while internal forces may be a result of physical changes, such as variations in temperature and moisture content, or a result of chemical and biological changes.
Static loading of plant vegetative tissue can result in visco-elastic deformations, as 1989).
The four element model, known as Burger model, which has been used to predict the Creep and stress relaxation are two important phenomena observed in well as structural failure (McLaughlin and Pitt 1984; Pitt Viscoelastic materials of Agriculture Egypt creep behavior in many biological materials. The model is composed of a spring and dashpot in series with another spring and dashpot in parallel.
According to Ashis Datta and Morrow (1983), the total strain at certain time resulting from constant stress σ in Burger model is calculated from the following equation:

$$\varepsilon(t) = (\sigma_o / E_o) + (\sigma_o / E_r) * (1 - e^{(-t'/Tret)}) + (\sigma_o * t' / \mu_o) \quad ......(1)$$

$$\varepsilon(t)/\sigma_o = (1/E_o) + (1/E_r) * (1 - e^{(-t'/Tret)}) + (t' / \mu_o) \quad ....(2)$$

Where:

$\varepsilon(t)$ = strain at time t.

σ_o = constant stress, MPa.,

E_o = Instantaneous modulus of elasticity, MPa.

E_r = retarded modulus of elasticity, MPa.

μ_o = viscosity coefficient of free dashpot, MPa.min

μ_r = viscosity coefficient of Kelvin dashpot, MPa.min

t' = time, min.,

T_{ret} = retardation time, min.= $\frac{\mu_r}{E_r}$

Figure (1) clarifies the creep curve which sectioned into two stages: loading stage, and unloading stage. Every stage was conducted in one hour.

The creep curve (1) was analyzed and the constants related to Burger rheological models were determined.
The objective of this research is to measure the creep properties of fresh and storied potato tubers and study the effect of potato size, storage

conditions and storage times on the change of their creep properties by using creep test, these measurements is indicator of texture strength to withstand mechanical post-harvesting processes.

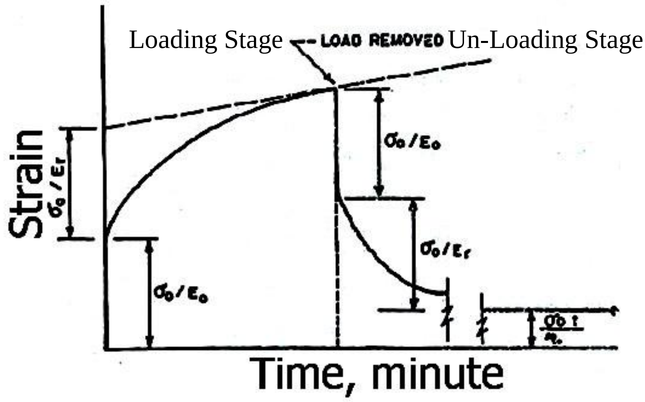

Figure (1) Creep curve for both the loading and the unloading stages.

2. MATERIAL AND METHODS

Two samples of fresh potato variety "Lady Rosetta" which was planted under two different soils sandy soil and black soil, were provided from Daltex company in Kafr El-Zaiat.

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

Two storage chambers were prepared for conducting storage treatments of potato tubers at Agricultural Engineering Department, Faculty of Agriculture, Alexandria University. The first type is traditional storage chamber (Al-Nawalla). The second type is refrigeration chamber which used for each of curing potatoes at 15 ^oC and 90 % relative humidity for 15 days and for long storage of potatoes at 8 ^oC and 85 % relative humidity.

The storage were done under 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 6 potato samples which were subjected for 6 storage conditions were done in five replicates.

2.1 Experimental Measurements

The creep properties tests as a non-destructive test were conducted using four apparatus. The creep test was carried out to establish the change in rheological models constants, E_o, $E_r$in (MPa.) and $\mu_{o,}$ μ_r in (MPa.min.) for each of fresh and stored tubers under different storage conditions.

The controller test was done on about 20 tubers which were selected from each of the three mentioned size grade.

The creep apparatus which were used to perform the creep tests was manufactured by Soliman et al, 1994. This creep apparatus was developed by providing it by an automatic recording unit for time and deformation in the same time. This system was computerized reading system using industrial I/Ocard. The values of time and related deformation were read by an electronic sensor and then transformed into an interface board which collect data from the four sensors and insert them into a computer, by using a computer program to collect the data (time in sec) and the related deformation for each sensor in mm with the accuracy of 0.01 mm. The developed creep apparatus is shown in figure (2).

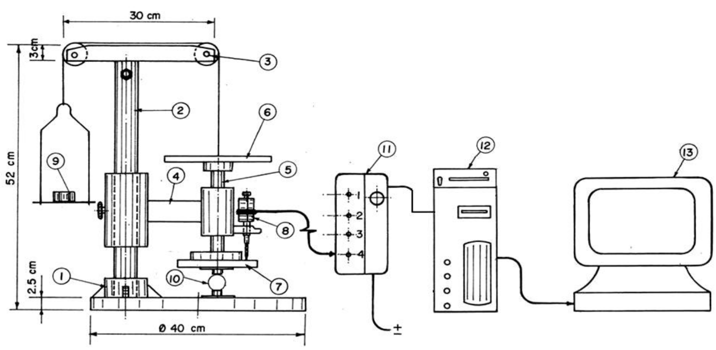

Figure (2): Schematic Diagram of Creep Apparatus

The creep test was done by placing the tuber between two parallel plungers each of two cm diameter and two cm height. The tuber was placed at its rest position (natural position), which the main axes was perpendicular to loading direction, and its maximum thickness in the loading direction under the plunger. The press plunger touched the tuber surface at zero time.

The creep test was conducted during 60 minute of loading and 60 minutes of unloading using a load of two kilograms, which produced a compression stress of 62.4524 kPa and can be considered as a control test for storage treatments. Burger rheological model (four elements model) was used to simulate the creep behaviors of potato tubers, by many authors (Mohsenin, 1986).

The instantaneous time and deformation indicated and recorded in computer file. The deformation of the tuber was continuously measured each second (Through the first fifteen minutes), and each 5 seconds (for the remaining 45 minutes). After an hour elapsed time, the 2 Kg force was removed and the recovered deformation is measured and recorded with time. Figure (3) presented the typical graphs of creep experiment on fresh potato tuber.

Substituting instantaneous compliance D_o for $1/E_o$ retard compliance D_r for $1/E_r$ in equation (2) we get

$$D(t) = (D_o) + (1/D_r) * (1-e^{(-t'/Tret)}) + t' \qquad ....(3)$$

The analysis of creep data was conducted according to Ashis and Morrow (1983).

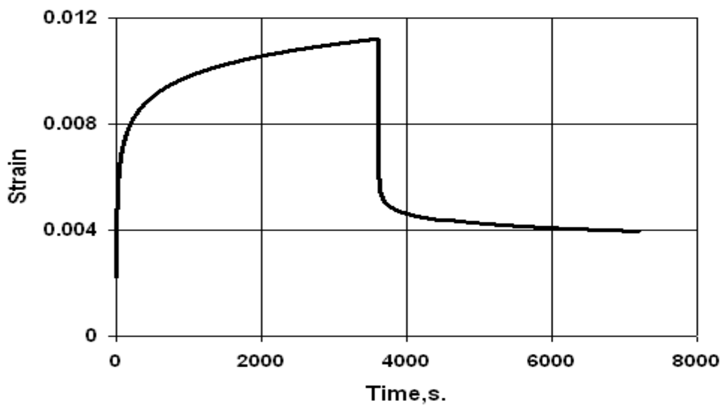

Figure (3) typical Creep and recovery Curve of Fresh Lady Rosetta Potato Tubers.

3. RESULTS AND DISCUSSION

3.1. Creep Behavior of Fresh Potato

The total of 360 creep tests were conducted on fresh potato tubers for a sample of 60 Fresh tubers from each mass groups and each soil cultivars to observe the effect of tubers mass and tubers cultivars (sand or black soils) on the constants of the rheological model, and the strain values of potato tubers.

The rheological model constants of equation (1) for fresh potato tubers were demonstrated in figures (4 and 5) as a function of tuber mass for each of sand and black soils cultivar.

The magnitude of the elasticity parameters E_o ,E_r and viscosity parameters μ_o, μ_r for fresh potato samples were determined for sand soil and black soil cultivars and illustrated in tables (1&2).

The rheological model constants of black soil cultivar were larger than that for sand soil cultivar. In general, all rheological model constants of fresh potato tubers were slightly increases with tubers mass. That is clarifying that the strength of tuber texture structure directly proportion with tuber mass.

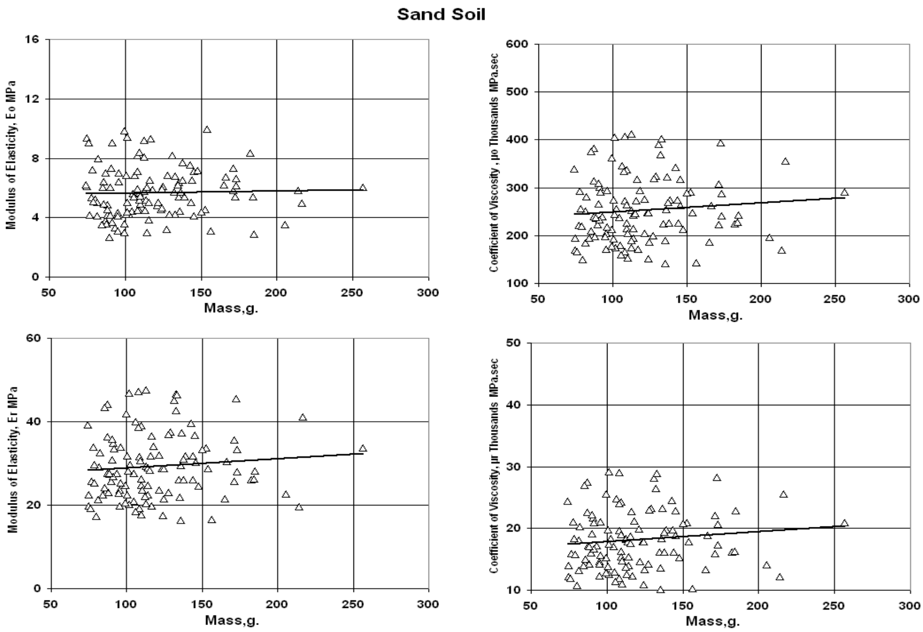

Figure (4): Constants of Burgers Rheological Model of Fresh Sandy-Soil Potato tubers.

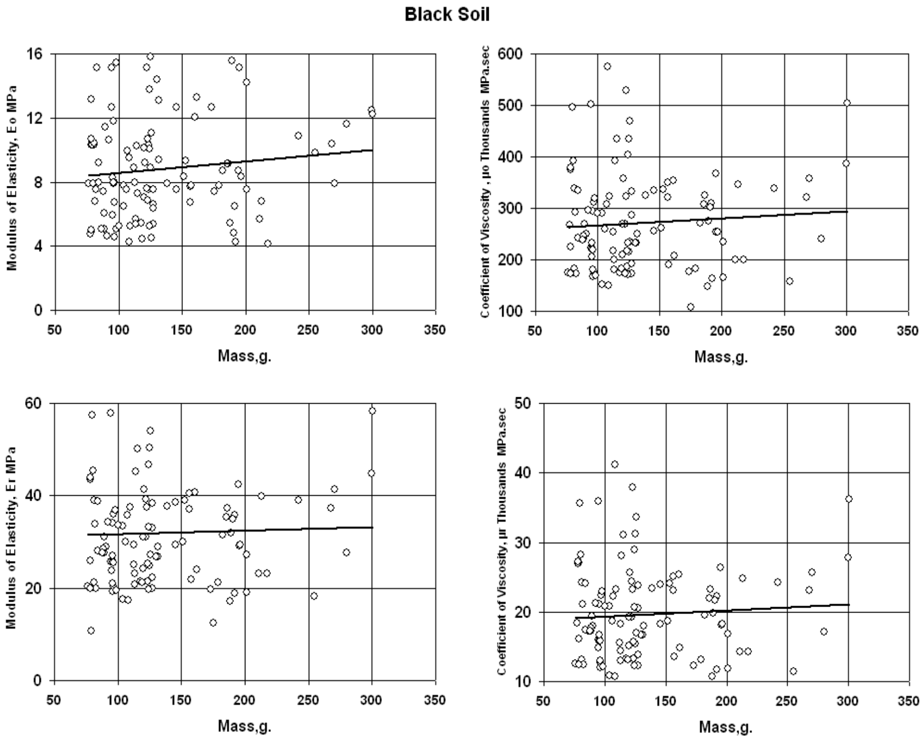

Figure (5): Constants of Burgers Rheological Model of Fresh Black Soil Potato tubers.

The time of retardation of the rheological model for all creep test experiment were calculated and found to be constant around 621 ± 5 seconds for each of sand and black soil cultivars.

Table (1): For Sand Soil Cultivar

Data Analysis	Eo, MPa.	µo, MPa.sec	Er, MPa.	µr, MPa
Mean	5.697	253550.224	29.343	18155.12
Minimum	2.686	141591.805	16.381	10172.688
Maximum	9.937	411916.961	47.655	29133.176

Table (2): For Black Soil Cultivar.

Data Analysis	Eo, MPa.	µo, MPa.sec	Er, MPa.	µr, MPa
Mean	8.806	271492.634	31.959	19614.748
Minimum	4.16123	91828.25	10.6238	6597.417
Maximum	16.994	574787.49	70.983	41182.124

3.2. Creep Behavior of Stored Potatoes

The creep behavior of potato tubers under investigation were measuring during storage period under different conditions. The creep test as a non-destructive test was run several times on the same tuber at different storage time.

The total of 3240creep tests were conducted on storage potato tubers to determine the variation of the rheological model constants with time. The tests including, two cultivars (sand and black soil), two storage conditions (cold and traditional), three mass groups, three load stresses and ten replicates from each treatment. The creep tests were carries several times on the same tuber once each storage period of about 45 days. Figure (6) illustrate the creep compliance [D(t) = 1/E(t)] curves of potato tubers of black soil cultivars at different storage times. It has been reported that the fresh potatoes has a minimum value, and the creep compliance increased with storage time. These changes in the creep properties of potato during storage are due to loss of turgor pressure and other biochemical reactions and returned to change in storage, which affect the cell wall and middle lamella of the tissue.

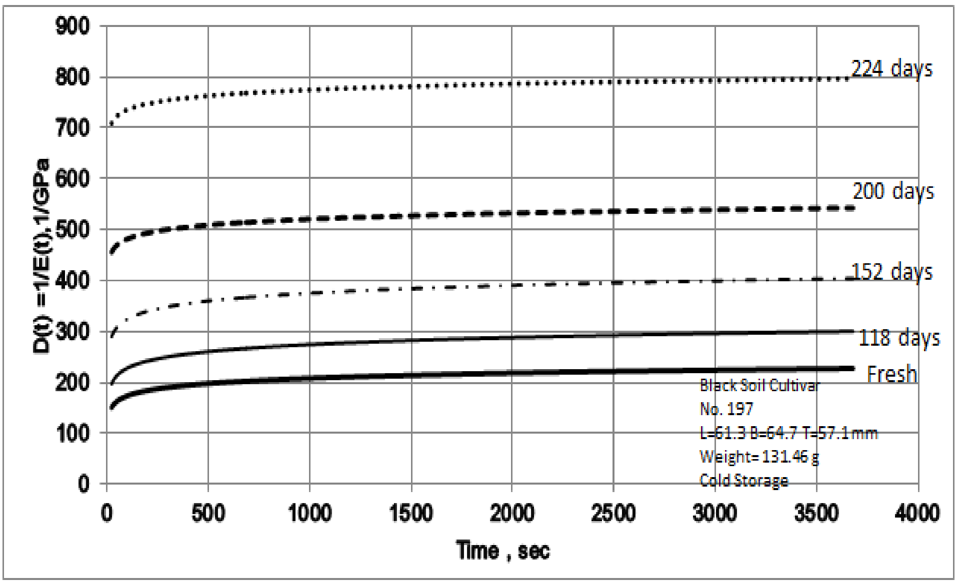

Figure (6) Creep Compliance Curves of Potato Tuber at Different Storage Times.

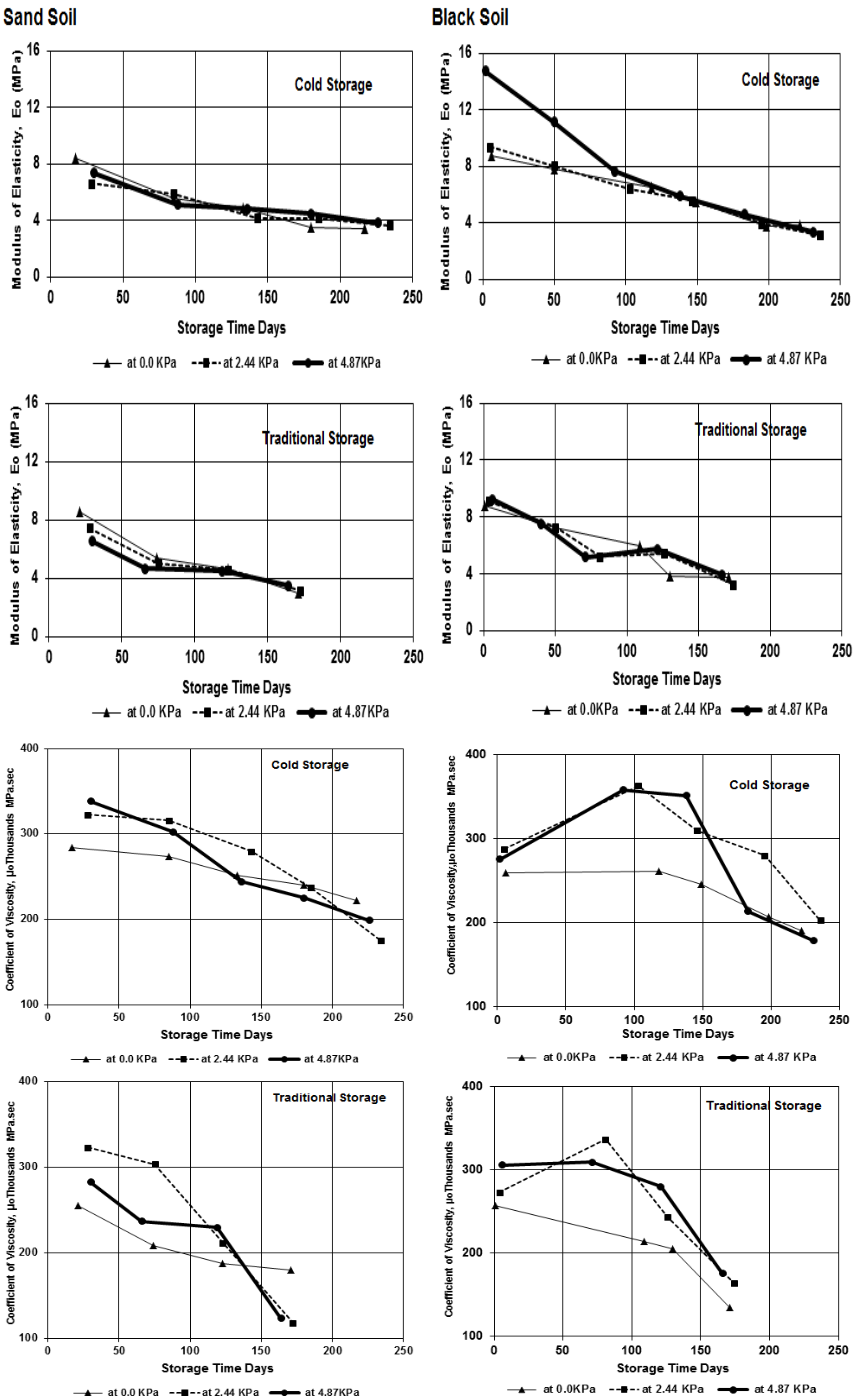

Figure (7): Effect of Storage Time on Elasticity Modulus and Coefficient of Viscosity of Maxwell Group In Burger Model of Creep Test.

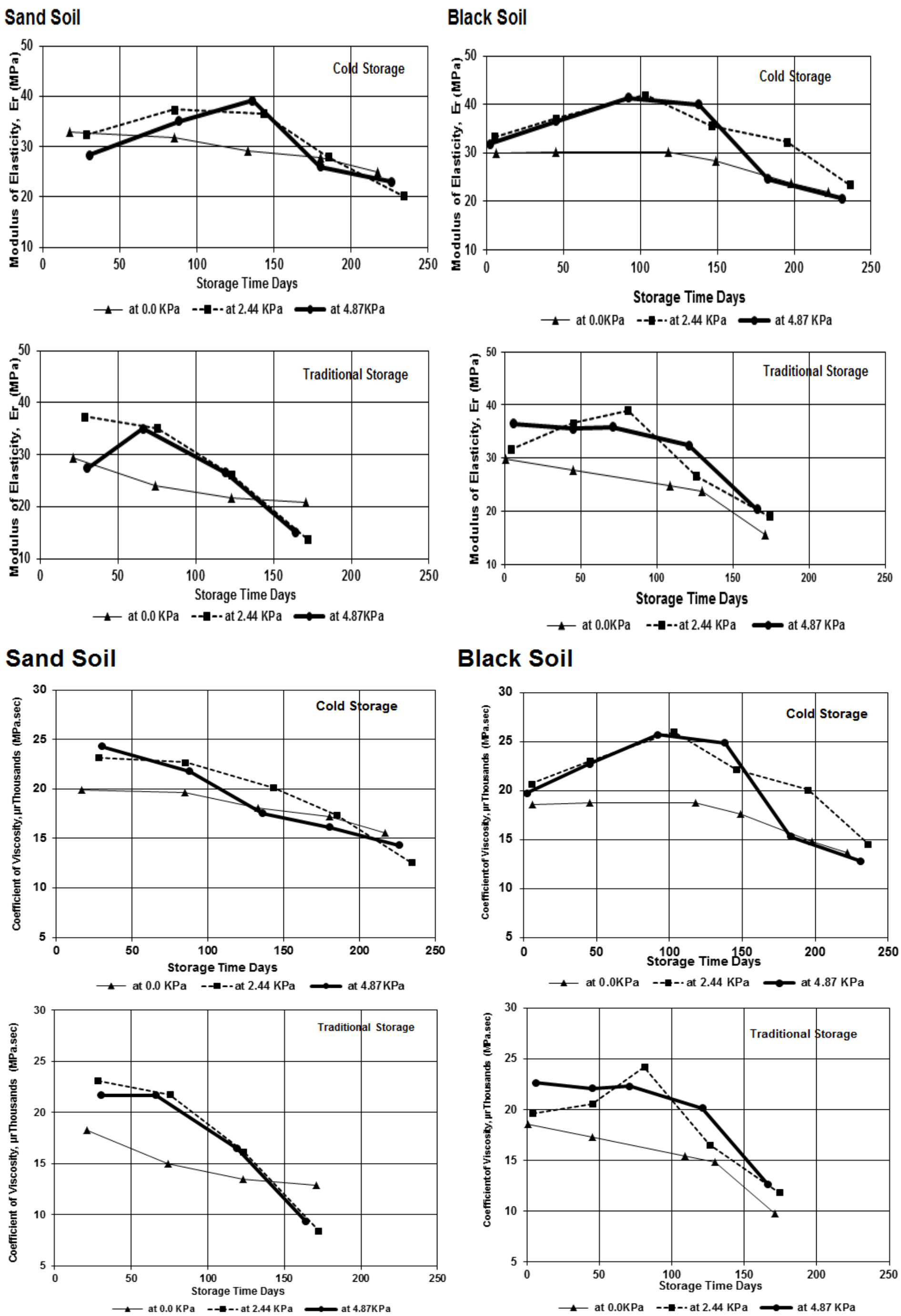

Figure (8): Effect of Storage Time on Elasticity Modulus and Coefficient of Viscosity of Kelvin Group In Burger Model of Creep Test.

The rheological model constants of storage potato including modulus of elasticity (E_o, MPa) and coefficient of viscosity (μ_o, MPa.sec) of Maxwellgroupasfree elements; and retarded modulus of elasticity, (E_r, MPa) and coefficient of retarded viscosity (μ_r, MPa.sec) of Kelvin group demonstrated in figures (7-8) as a function of storage time for each of sand and black soils cultivar.

The graphs appear that instantaneous modulus of elasticity E_o, MPa decreases gradually with increasing storage time**.** The coefficient of viscosity of free dashpot (μ_o, GPa.sec) decreases gradually with increasing storage time for sand soil**.** While the result of black soil show that coefficient of viscosity of free dashpot (μ_o, GPa.sec) increases gradually with increasing storage time up to about 90 day and then the coefficient of viscosity of free dashpot (μ_o, GPa.sec) decreasing gradually with increasing storage time. The retarded modulus of elasticity, (E_r, MPa) decreases gradually with increasing storage time. The coefficient of retarded viscosity (μ_r, GPa.sec), decreases gradually with increasing storage time**.**

The non-linear statistical multiple regression analysis of Burger rheological model constants versus storage parameters including storage temperature (T, ℃), static load stress (SL, kPa), storage periods (t, days) and tubers mass (M, g), for each of sand and black soil cultivars were conducted.

The logarithm of Burger parameters were the best fitting correlation with storage parameters under study.

The statistical regression equations were as follow:

For Sand Soils:

$$LN\ E_{os},\ MPa = 0.0628\ T + 0.0353\ SL + 0.0007\ t + 0.0046M \quad ..……….R^2 = 0.851,\ STD=0.605…\ (3)$$

$$LN,\ \mu_{os},\ GPa.sec = 0.2034\ T + 0.1281\ SL + 0.0104\ t + 0.0113\ M \quad …………R^2 = 0.944,\ STD=1.262…\ (4)$$

$$LN\ E_{rs},\ MPa = 0.1191\ T + 0.0840\ SL + 0.0058\ t + 0.075\ M \quad \ldots\ldots\ldots R^2 = 0.931,\ STD=0.869\ldots\ldots (5)$$

$$LN,\ \mu_{rs},\ GPa.sec = 0.1003\ T + 0.0743\ SL + 0.0048t + 0.0066\ M \quad \ldots\ldots\ldots R^2 = 0.923,\ STD = 0.786\ldots (6)$$

For black Soils:

$$LN\ E_{ob},\ MPa = 0.0628\ T + 0.0353\ SL + 0.0007t + 0.0049\ M \quad \ldots\ldots\ldots\ldots R^2 = 0.851,\ STD=0.605\ldots (7)$$

$$LN,\ \mu_{ob},GPa.sec = 0.1963\ T + 0.1709\ SL + 0.0086\ t + 0.0122\ M \quad \ldots\ldots\ldots\ldots R^2 = 0.954,\ STD=1.186\ldots (8)$$

$$LN\ E_{rb},\ MPa = 0.1155\ T + 0.1213\ SL + 0.0046\ t + 0.0079M \quad \ldots\ldots\ldots\ldots R^2 = 0.943,\ STD=0.794\ldots (9)$$

$$LN,\ \mu_{rs},\ GPa.sec = 0.0975\ T + 0.1103\ SL + 0.0037\ t + 0.0069\ M \quad \ldots\ldots\ldots\ldots R^2 = 0.938,\ STD=0.715\ldots (10)$$

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الملخص العربي

سلوك الزحف لدرنات البطاطس أثناء التخزين.

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يعتبر اختبار الزحف أحد الأختبارات الغير متلفة لدراسة الخصائص الريولوجية للدرنات. ويهدف البحث إلى دراسة سلوك الزحف لدرنات البطاطس أثناء معاملتي التخزين الطبيعي في النوالة والتخزين المبرد في غرفة التبريد عند ٨م° ورطوبة نسبية ٨٥% وعند ثلاث مستويات من التحميل الاستاتيكى (٢.٠،٤.٤٤،٤.٨٧ كيلوباسكال) ومدي ارتباط تغير نتائج الإختبارات بكل من طرق و زمن التخزين تحت الظروف المختلفة. ولقد تم تطويروتصنيع أجهزة قياس خاصية الزحف لتعمل باستخدام الحاسب الألي. وتم قياس وزن الدرنات وإبعاد الدرنة واجراء اختبارات الزحف أكثر من مرة علي نفس الدرنة أثناء تخزينها.

وكانت ثوابت نموذج بارجر الريولوجي والمستنتجة من تحليل اختبار الزحف للدرنات الطازجة تضمن معامل المرونة اللحظي(Eo, MPa) ومعامل لزوجة العنصر الحر الغير مرتد زمنيا (μo,GPa.sec)، معامل المرونة المرتد زمنيا (Er,MPa) و معامل اللزوجة المرتد زمنيا (μr,GPa.sec). وهذة الثوابت تزداد زيادة طفيفة طردياً مع زيادة وزن الدرنات الطازجة. وأوضحت النتائج ان زمن التقاصر للنموذج الريولوجى لكل من الأرض الرملية والطينية عند نفس الزمن علي منحني الزحف هو حوالي ٦٢١ ثانية ولقد أظهرت النتائج أيضاً للدرنات المخزنة أن معامل المرونة اللحظيE_o لكل من درنات الأرض الرملية والطينية يقل تدريجيا مع زمن التخزين وذلك مع كل من معاملات التخزين المختلفة وان هناك علاقة غير خطية متعددة الانحدار لمعامل المرونة اللحظي مع زمن التخزين عند ظروف التخزين المختلفة لكل من الأرض الرملية والطينية. وان لوغاريتم معامل المرونة اللحظيE_o أعطي أفضل معامل ارتداد كدالة للعوامل الأخرى تحت الدراسة. وكذلك أوضحت النتائج إن معامل اللزوجة للعنصر الحر (μo,GPa.sec) للتخزين البارد يقل تدريجيا مع زيادة زمن التخزين خلال فترة تخزين ٢٣٦يوم لكل من محصولي الأرض الرملية والطينية على التوالي. وكذلك خلال فترة تخزين ١٦٦ يوم لكل من محصولي الأرض الرملية والطينية على التوالي للتخزين الطبيعي.

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وأيضا أظهرت النتائج للدرنات المخزنة ان معامل المرونة المرتد زمنياً (Er, MPa) للتخزين البارد لكل من درنات الأرض الرملية والطينية يقل تدريجيا مع زيادة زمن التخزين وكذلك يقل خلال فترة تخزين ١٦٦ يوم للتخزين الطبيعي وكذلك أوضحت النتائج أن لوغاريتم معامل المرونة المرتد زمنيا (Er, MPa) أيضا كدالة في عوامل التخزين الاخري تحت الدراسة هي افضل علاقة خطية. وقد أوضحت النتائج أن لوغاريتم معامل اللزوجة المرتد زمنيا (μr, MPa.sec) يعطي أفضل معامل ارتداد مع عوامل التخزين الاخري تحت الدراسة.