ABSTRACT

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Mechanical and Physiological Properties of Potato Tubers Related to Storage Condition.

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Potato crop is considered as one of the most important vegetable crops in Egypt, especially in the last decade, in which the Egyptian production of potato reached 2,5 million ton and the amount of exporting potato tuber reached 2.76 million tons in 2008. European Union is the most regions, which demand the Egyptian potato.

Potato crop is subjected to various types of different storage condition during storage. The effect of potato cultivars, storage condition, storage period, tuber size and load stress on potato tubers quality were valued.

The main objective of this research is to study the effect of traditional and cold storage condition on physiological and physical quality of potato tubers. The physiological measurements are moisture content, sugar content and respiration rate. The physical characteristics measurements are including dimensions, surface area, volume, spherisity, mass, particle and bulk density. The mechanical properties of fresh and stored potato tubers are conducted and including force deformation, penetration and creep tests. The measurements of dielectric properties of potato can help in predicting the internal condition and degree of deterioration of potato tubers.

Potato variety Lady Rosetta was selected as one of the most important commodity for chips industrials and for exporting, but it is very sensitive for handling and storage and specified by high specific density, high dry matter percent and law sugar content. One ton of fresh potato variety "Lady Rosetta" 500 kilograms for each of sandy soil and black soil cultivars were used.

The fresh received tubers were cleaned and the tubers which have cuts, skinning, splitting, rot, and greenish were discarded. The tubers were then weighed, registered by numbers, recorded and then graded into three sizes based on its mass.

Potato tubers were cured for 2 weeks at 15 C^o and 90% R.H., then the potatoes were divided into two equal samples each of 250 kg of each cultivar for long term storage under aerated natural condition (Nawalla) and under cooling condition at 8 C^o and relative humidity of 85 %.

An Instron machine was used for stress-strain tests. Four creep apparatuses were developed using a digital micrometer which enable to feed the data into the computer and instantaneous reading of deformation with time at constant stress. Dielectric measurements including capacitance, and conductance, were measured using LCZ meter over a frequency range from 10 to 1000 kHz.

The results showed that there are a linear multiple regression relationships between mass loss percent, change of tuber dimensions percent, change of volumes percent, particle and bulk density and each of storage condition (cold and traditional temperature), storage periods up to 200 day, tubers mass and at different static load stress (0.0, 2.44 and 4.87 kPa) for each of sand and black soil cultivars.

Mass loss of tubers increases gradually with increasing storage time which reached (18.173, 17.300) percentage for cold storage and (30.648, 27.305) percentage for traditional storage for each of sand and black soil cultivars, respectively.

The changes percentage of length, width and thickness give the same trend with storage time, for cold storage were (8.267, 7.890), (10.498, 9.588) and (12.037, 10.826) respectively, and for traditional storage were (13.226, 12.802), (15.705, 14.787) and (20.033, 19.403), respectively.

The shrinkage of tubers volumes during storage periods directly proportion with storage time, for cold storage were (22.819, 23.200) and for traditional storage were (34.099, 30.894) respectively.

The particle density kg/m³ of potato tubers were increased directly with storage time, for cold storage were (1100.86, 1163.46) kg/m³ and for traditional storage were (1101.76, 1137.06) kg/m³ respectively.

Tubers bulk density kg/m³ was directly proportion with storage time. The tubers bulk density for cold storage were (609.053, 617.284) kg/m³, and for traditional storage were (611.284, 617.284) kg/m³ respectively.

Respiration rate (mg CO_2/kg.h) of fresh tubers is directly proportion with tuber specific surface area and inversely proportion with tuber mass for all cultivars, for sand soil fresh tubers was changed from 2.4964 up to 7.7679 with an average 5.631 mg CO_2/kg.h and for fresh tubers of black soil was changed from 2.513 up to 11.441 with an average of 7.774 mg CO_2/kg.h.

Sugar content (Brix) positively affected by each of type of soil, storage temperature, static load stress, storage time and tuber mass.

Penetration force (N) of fresh tubers was measured. The penetration force were ranged from 19.080 to 26.389 with an average of 22.306 for sand soil cultivars, while ranged from 18.246 to 32.785 with an average of 24.413 for black soil cultivars, using probe of 3.8 mm diameter.

Creep test optimal condition was suggested to use two parallel plates each of 2 cm diameter, and 2 kilograms load (62.45 kPa) during a duration time of 60 minutes for loading and 60 minutes for unloading, and was carried several times on the same tuber at different storage time. 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 masse; 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.

Force-deformation tests of fresh potato tuber show that the small tubers have a more strength than that for big tubers for each soil cultivars. The fresh harvested tubers tend to be very brittle. Because of their brittleness, potato tubers tissues were cracked under compression test. The results appear that yield force, yield stress, resilience, initial modulus of elasticity and secant modulus of elasticity decreases gradually with increasing storage time. The result appears that yield strain, increases gradually with increasing storage time. Rupture force, rupture strain, rupture stress, and toughness decreases gradually with increasing storage time.

Dielectric properties test were 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 results showed that capacitance and relative permittivity decreases rapidly with increasing frequency. For cold storage sandy soil potato and at 120 and 200 days the values of capacitance were 0.0398 and 1.1939 at 0.0 load; 0.03356 and 0.4003 at 2.44 kPa and 0.0503 and 0.01886 at 4.87 kPa respectively. For black soil potato and at 120 and 200 days the values of capacitance were 0.02957 and 1.4165 at 0.0 load; 0.06772 and 0.06185 at 2.44 kPa and 0.05984 and 0.051826 at 4.87 kPa respectively. For traditional storage sandy soil potato at 120 days the values of capacitance was 0.0318 at 0.0 load; at 2.44 kPa was 0.03078 and at 4.87 kPa was 0.05688. For black soil potato at 0.0 load and at 120 days the values of capacitance was 0.01755; at 2.44 kPa was 0.017875 and at 4.87 kPa was 0.02673.

The conductance of stored sand soil potato at cold storage, and at 120 and 200 days were 0.02833 and 0.069753 at 0.0 load; 0.02109 and 0.06274 at 2.44 kPa and 0.01691 and 0.012849 at 4.87 kPa respectively. For traditional storage at 120 days the maximum conductance at 0.0 load was 0.03044; at 2.44 kPa was 0.027288 and at 4.87 kPa was 0.028267. For storage black soil potato at cold storage and at 120 and 200 days the values of maximum conductance at 0.0 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 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.

Complex permittivity and Complex conductivity were decreases with the increases of the storage time.

The dissipation factor Tan (δ) decreases gradually with increasing the storage time in cold storage.

The quality index 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 index Q decreases with the increasing of storage time, storage temperature and storage load stress. The results show that the effect of soil type on quality index is non significant. Mass loss look like other parameters is also inversely proportion with quality index.

The Quality Index Q value decreased with increasing the storage time this is a fairly good indication of the loss of freshness.

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LIST OF SYMBOLS

Symbol	Meaning , Unit
V_{tuber}	Tuber volume, cm^3.
M_t	Weight of (Tubers + glass vessel + seed) (kg).
M_s	Weight of Seeds
M_g	Weight of the empty glass vessel (kg).
V_g,	empty glass vessel volume, cm^3
V_s	Volume of seeds, cm^3.
ρ_s	density of the seeds
A_P	The largest projected area of object in natural rest position.
A_c	area of smallest circumscribing circle.
r	the radius of curvature of the sharpest corner.
R	the radius of the maximum inscribed circle
n	the total number of corners summed in numerator
d_e	The diameter of a sphere of the same volume as the object.
d_c	Diameter of the smallest circumscribing sphere.
d_i	Diameter of largest inscribed sphere.
M_f	Weight of (tubers + box), kg.
M_i	Weight of empty box, kg.
V_i	Empty box volume, m^3.
MC_{wb}%	Moisture content, percentage.
M_o	Fresh mass of sample before drying, g.
M_1	Dry mass of sample after drying, g.
M	Mass of Potato tuber at measured it, g
ΔM, %	Change of Weight to sample of potato
$(L*W*Th)^{1/3}$	geometric mean diameter, cm.
d_C	major diameter, cm.
ML, %	Mass loss of tuber.
M.C	Moisture Content
S.C.	Sugar Content, Brix
T	Storage Temperature, ^0C
t	Storage Time, day
SL	Static Load stress, kPa
ST	Soil type, 1 for sand or 2 for black soil.
L	Length of Potato Tuber, mm.
ΔL, %	Change of Length of Potato Sample
W	Width, mm.
ΔW, %	Change of Width of Potato to Sample.

Th	Thickness, mm.
ΔTh, %	Change of Thickness of Potato Sample
V	Tuber volume, $cm^{3.}$
ΔV, %	Shrinkage of Volume of Potato Sample
ρ_P	Particle Density of Potato Sample, kg/ m^3
ρ_B	Bulk Density of Potato Sample, kg/ m^3
SG	specific gravity
DM	dry matter
PF	Penetration Force, N.
PS	penetration stresses, MPa.
ε	Total strain.
ε_A	Strain in free spring (Maxwell group).
ε_B	Strain in Kelvin group.
ε_C	Strain in free dashpot (Maxwell group).
σ_o	Total stress (constant stress), MPa
σ_A	stress affecting on free spring, MPa.
σ_B	stress affecting on Kelvin group, MPa.
σ_C	stress affecting on free dashpot, MPa.
E_o	Instantaneous modulus of elasticity, MPa.
E_r	Modulus of Elasticity of Kelvin Model, MPa
μ_r	Coefficient of Viscosity of Kelvin Model, (MPa.sec)
μ_o	Viscosity coefficient of free dashpot, (MPa. Sec)
t	Time of creep, min.
D	plunger diameter, cm
F	force, kg
T_{ret}	retardation time, min.
E_1	Initial Modulus, MPa.
E_2	Secant Modulus, MPa.
F_r	Rupture Force, N
ε_r	Rupture Strain
σ_r	Rupture Stress, MPa.
ε_Y	Strain of Yield Point
σ_Y	Stress at Yield Point, MPa.
WD_r	Toughness or Rupture Work Done, J
WD_Y	Resilience or Yield Point Work Done, J.
F_Y	Yield Force, N
RR	Respiration rate, mg of CO_2 / kg tuber. h.
SSA	Specific surface area, cm^2/g
SA	Surface Area, cm^2
σ_A	Stress affecting on free spring, MPa.
σ_B	Stress affecting on Kelvin group, MPa.
σ_C	Stress affecting on free dashpot, MPa.
ε (t)	Strain at time t
σ_o	Constant stress, MPa.
T_{ret}	Retardation time, min.

t_c	Creep Time of the test , sec
f	Frequency, Hz
f	Farad
C	Capacitance of Sample, farad (f).
G	Conductance of Sample, Siemens (S).
eε	Permittivity, f/m
$e\varepsilon_o$	Permittivity of Vacuum , f/m
eε'	Relative Permittivity of Sample
eσ	Dielectric Conductivity of Sample, S/m
eε"	Complex Permittivity of Sample, S. sec/f
eσ"	Complex Conductivity Sample, f/m. sec
Tan δ	Dissipation Factor or loss tangent of Sample.
eσ*	complex conductivity
Q%	Quality Index
b	The blank titer ml.
a	The sample titer ml.
N	Normality of the standardized acid
E	Equivalent weight of CO_2.
L*W*Th	Tuber dimension, cm.
M	Tuber mass, Kg.
R^2	Determination coefficient.
DYP	dynamic yield pressure
MT	Magness-Taylor
WVPD	water vapor pressure deficit
TPA	texture profile analysis
BM	basic mechanical
VEB	Viscoelastic behavior
UWW	The underwater weight
CPR1	Central Potato Research Institute.
CIPC	Isopropyl N-(3-chlorophenyl) carbamate
CIP	International Potato Center
PTM	Potato Tuber Moth
NSP	National Seed Programme
DS	Dielectric spectroscopy
RF	radio frequency
Δ	Change of parameter, %.
m	meter
Subscript	
s	For sand soil.
b	For black soil.
r	rupture
Y	Yield

p	Particle density
B	Bulk density
A	Probe (A)
B	Probe (B)