Effect of Gibberellic Acid (GA_3) on the Physical and Mechanical Properties for Some Potato Varieties

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Abstract

Prediction of the potato tuber characteristics is important due to its effects on crop price and marketing. This study was conducted during 2010-2011 seasons at the experimental station, Faculty of Agriculture, Cairo University, Egypt to investigate the effect of gibberellic acid GA_3 on physical and mechanical properties of three potato varieties (Diamant, Nicola and Lady Rosetta). The physical properties included mass (m), dimensions (Length, L – Width, W – Thickness, T), volume (V) and density (ρ_s). The mechanical properties included static friction coefficient (μs) with different surfaces, firmness (F_{ness}), modulus of elasticity (E), bioyield stress (σb) and rupture stress (σr).

The most important results of this study showed that no significant differences of GA3 concentrations on the physical properties, but the effect of GA3 concentration on the mechanical properties was significant. A regression method was derived for each variety for expressing "m", "V", "L", "W", "T", " " and "μs" as a function of GA3 concentration (C), the other regression could be used in predicting the "E", "σb" and "σr" as a function of "C" and "F_{ness}".

Keyword: Potato, GA3, Physical -Mechanical property, Firmness, Modulus of elasticity, Bioyield stress, rupture stress.

1. Introduction

Predicting the change in physical and mechanical properties of various potato tubers affect on the quality of the products processed from the tubers and important for designing mechanical systems for optimal harvesting and handling capacities and other process with minimum damage to tuber. The change can be doing by management practices to optimize yield and grade from that tuber.

In Egypt, potato crop (Solanum tuberosum L.) is one of the major vegetable crop, as it is grown each year, the cultivated area is about 123 ×103 Ha and quantity production is 3201 ×103 ton (FAO Statistical Yearbook, 2009).

Shape and physical dimensions are important in screening solids to separate foreign materials and in sorting and sizing of fruits and vegetables. Quality differences in fruits, vegetables, grain and seeds can often be detected by differences in density (Stroshine, 1998). Mechanical properties of tubers, beside the size and shape, are important factors of cultivar classification for such technological destinations as chips, French fry strips, and cooked potato (Dale and Mackay, 1994).

During harvest and transport, potato tubers are exposed to impact damage which ranges from internal black spot bruising through shatter bruising and finally tissue cracking (Mathew and Hyde, 1997). The extent of damage can be primarily attributed to physiological changes which affect structural components (Thybo et al., 1998), tissue turgor and temperature affecting failure properties of tubers (Alvarez and Canet, 2002; Bajema et al., 1998). Thus, the recognition of the mechanical characteristics of potato tubers permits improvement of harvesting and handling equipment and operations aimed at reducing economic losses.

The quality of potato tubers, as in all horticultural produce, is closely connected to the chemical and structural characteristics of plant tissues and varies widely in relation to different factors such as climate, growing conditions, cultivar and maturity at harvest and harvesting method (Bentini et al., 2006).

Agricultural practices which may increase yield and improve fruit quality are also the application of plant growth regulators, especially gibberellic acid at full bloom, to increase fruit set during fruit let growth to increase fruit size (Agusti et al., 2002; Chao and Lovatt, 2010).

Paleg (1965) defined gibberellins as compounds having a gibberellane structure and that stimulate either cell division or cell elongation. Gibberellic acid (GA3) is the first highly active and commercially available gibberellin to be purified from a culture medium of Gibberella fujikuroi (Sponsel, 1990).

Fidelibus et al. (2002) found that orange was treated with GA3 treatment before color break considerably increased shear and tensile properties of the peel and slightly increased fruit puncture force but generally did not affect modulus of elasticity.

Sweet cherry fruits treated with GA3 were significantly firmer than fruits not treated; there were no differences between single and multiple GA3 treatments (Kappel and Mac- Donald, 2002). The use of GA3 increased fruit firmness at harvest, decreased the rate of fruit softening and delayed fruit maturity for the late-maturing genotypes, but had no significant effect on early-maturing fruits (Choi et al., 2002)

The duration of tuber dormancy is affected by the environmental conditions that exist during tuber development on the mother plant and during storage, where temperatures lower than 10 ◦C delay dormancy breakage and sprout development (Burton, 1989). Breakage of dormancy may be achieved by the application of gibberellin (GA3) during tuber growth on the mother plant (van Ittersum and Scholte, 1993), but the efficacy of this method depends on the stage of plant and tuber development at the time of GA application (Alexopoulos et al., 2006).

This study was conducted to investigate the effect of gibberellic acid GA3 on physical and mechanical properties of three potato varieties (Diamant, Nicola and Lady Rosetta). Also, predicting the physical and mechanical properties of potato tuber ad affecting by the GA3 concentration.

2. Material and methods

2.1. Experiment preparation:

The field experiment was carried out at experimental station, faculty of agriculture, Cairo University during two successive summer seasons 2010 and 2011, to study the effect of GA_3 on the physical and mechanical properties of potato (*Solanum tuberosum*). This experiment included 12 treatments; three varieties (viz., Diamant, Nicola and Lady Rosetta); and four GA_3 concentrations; no acid, 1, 3 and 5 mgl^{-1}. Seed tubers were immersed in growth regulator for 5 minutes and air-dried for 20 minutes. Seed tubers were but in room temperature in indirect light and planted after 15 days from application. The planting date was on 15 February at both seasons. A complete randomized block design (CRB) with three replications was adopted. Each plot unit consisted of 2 ridges with 4 m long and 0.7 m wide. Seed tubers were sown on one side of ridges at 25 cm apart. The tests were carried out in the laboratory with temperature and relative humidity kept constant at 23 ^{o}C and 60% respectively throughout the experiment.

2.2. Physical properties

2.2.1. Tuber dimensions

The potato tuber, in terms of the three principal axial dimensions, that is (in mm): length (*L*), width (*W*), and thickness (*T*) were measured using a vernier caliper with an accuracy of 0.01 mm. Figure (1) shows the three dimension of potato tuber.

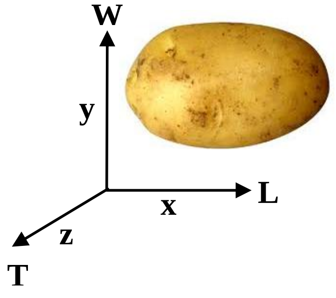


Figure (1): The three major dimensions of potato tuber, where x-axis is length (*L*), y-axis is width (*W*) and z-axis is thickness (*T*).

2.2.2. Tuber mass

The mass (m) of Potato tuber was recorded by using a digital balance, with an accuracy ±0.01 g.

2.2.3. Tuber volume

In order to determine fruit volume (***V***) a simple technique which applies to large objects such as fruit and vegetables is the platform scale (Fig. 2). The liquid volume is computed by determining the mass of the displaced water and dividing by the known density of the water. The mass of the displaced water is the scale's reading with the object submerged minus the mass of the container and water. Weight of the displaced water which will be used in the following expression to calculate volume (*Mohsenin, 1986)*:

$$\text{Volume (cm}^3) = \frac{\text{Weight of displaced water (cm}^3)}{\text{Water density (gm/cm}^3)} \quad \textbf{(1)}$$

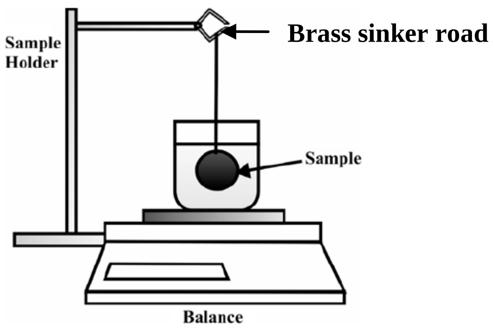


Figure (2): Platform scale for measurement of volume

2.2.4. Tuber density

The tuber density (ρ_s) was calculated from eq. (2) (*Mohsenin, 1986; Joshi et al., 1993*)

$$\rho_s = \frac{M}{V} \quad \textbf{(2)}$$

Where

ρ_s **:** Tuber density, g/cm^3;

M **:** Tuber mass, g ;

V **:** Tuber volume, cm^3.

2.3. Mechanical properties of potato tubers

2.3.1. Static friction coefficient

Static friction coefficient of is the ratio of force required to start sliding the sample over a surface divided by the normal force, i.e. the weight of the object (*Bahnasawy, 2007*). The static coefficient of friction of potato tuber against different materials, namely plywood, plastic, steel and rubber was determined. A device was designed and fabricated, and used for the determination of the coefficient. The device that used is shown in figure (3) (*Ibrahim, 2008*). The static coefficient of friction was calculated as follows:

$$\mu_S = \frac{F_T - F_E}{W} \quad \textbf{(3)}$$

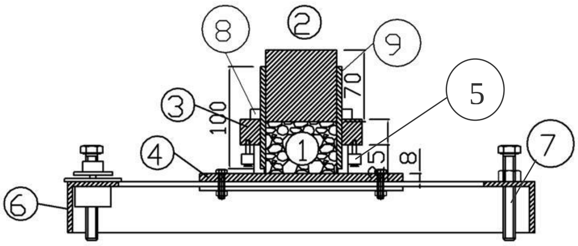
Where

μ_S **:** Static friction coefficient;

F_T **:** Force required starting motion of filled wooden frame, N;

F_T **:** Force required to start motion of empty wooden frame, N;

W **:** Weight of the object, N.



1-Sample	**2**- Piston	**3**- Carriage
4- Sliding surface	**5**- Rolling wheels	**6**- Base
7- Adjustable screw	**8**- Adjustable nut	**9**- Cylinder

Figure (3): The designed device for measuring the friction force.

2.3.2. Firmness

The firmness (F_{ness}) of tuber can express by the force of dynamometer (Model WAGNER, 20 kg – Force Dial FDK 40 – Italy) that penetrate the tuber, tester that used a steel probe of 6.4 mm (or 1/4") diameter. The firmness was measured in three positions: upper and down potato tuber in the X-axis (length), third position in the minor dimension (width) at right angles to the longitudinal axis (thickness) (*Mohsenin et al., 1986)*.

2.3.3. Compression uniaxial test

2.3.3.1. Sample dimensions

Cylindrical samples with a diameter of 25.4 mm were cut from the centre of the potatoes using a cork borer and then trimmed to a height of 25 mm. These sizes were chosen because the height of the specimen should be equal to or less than its diameter, otherwise reproducibility and reliability of compression tests will decrease due to buckling (*Shaw & Young, 1988*). The core samples were taken perpendicular to the major axis of the tubers and from the central region (*Alvarez & Canet, 1998*).

2.3.3.2. Compression test

The test was carried out by placing a cylindrical specimen on a flat platform with a compression platen (90 mm in diameter), compressed at room temperature (20–21^{o}C). The test was carried out between the standard Instron stainless steel polished platens of a model Instron Universal Testing Machine (Instron, USA) using a 1 kN load cell and a 70 mm diameter flat compression plunger (It was fabricated). Experiments were carried out at constant displacement rate (20 mm min^{-1}). The load–displacement behaviour was recorded with Instron recorder.

The load–displacement data were converted into compressive stress and strain. The following parameters were identified: the modulus of elasticity (*E*), bioyield stress (*σb*) and rupture stress (*σ*r).

The Young's modulus of elasticity (*E*) for compressive stress is expressed by equation (2).

$$E = \frac{\sigma}{\varepsilon_a} = \frac{\mathrm{F}/\pi(\mathrm{D_o}/2)^2}{\Delta\mathrm{L}/\mathrm{L_o}} \qquad \textbf{(4)}$$

Where

- E : Young's modulus of elasticity;
- σ : Compressive stress;
- ε_a : the absolute value of loading direction strain (axial strain), mm/mm;
- F : normal load;
- D_o : original diameter before sample compression;
- ΔL : length deformation;
- L_o : original length before sample compression.

2.4. Statistical analyses

Data were analyzed according to procedures outlined by Steel and Torrie (1980). For comparison among means, LSD was applied.

3. Results and discussion

Table (1) shows the average values of combined analysis for physical and mechanical properties that measured and determined for three varieties with different GA_3 concentrations in seasons 2010- 2011, where "*C*" is concentration of gibberellic acid (GA_3): C_0 (no acid) – C_1 (1 mgl^{-1}) – C_3 (3 mgl^{-1}) – C_5 (5 mgl^{-1}).

3.1. Physical property

3.1.1. Tuber mass (*m*)

The average values of tuber mass (*m*) are shown in table (1). It's clear that the average values of *m* ranged from 61.08 to 73.16 g, from 49.18 to 68.43 g and from 32.3 to 52.23 g for Diamant, Nicola and Lady Rosetta respectively. Figure (4) shows the effect of GA_3 concentration on tuber mass (*m*) for different varieties.

Figure (4) shows that, for Diamant the "*m*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*m*" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "*m*" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "*m*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*m*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*m*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*m*" value was increased by increasing the concentration of GA_3 from C_3 to C_5.

Statistical analysis showed that, for Diamant no significant differences of GA_3 on "*m*" with C_0 and C_1 but significant differences between C_1 and C_3. For Nicola, it is no significant differences of GA_3 on "*m*" with C_0, C_1 and C_5 but significant differences between C_3 comparing with C_0 and C_1. For Lady Rosetta, it is no significant differences of GA_3 on "*m*" with C_1, C_3 and C_5 but significant differences between C_3 comparing with C_1.

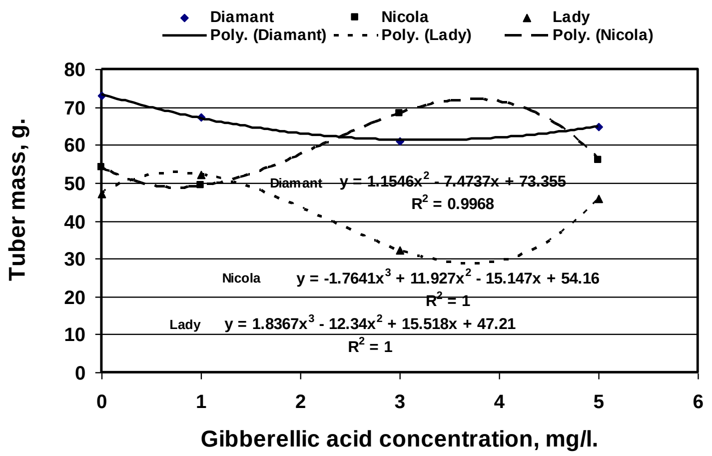


Figure (4): Effect of GA_3 concentration on tuber mass.

3.1.2. Dimensions

Tuber length (*L*)

The average values of tuber length (*L*) are shown in table (1). It's clear that the average values of "*L*" ranged from 65.88 to 69.87 mm, from 61.03 to 72.75 mm and from 37.33 to 46.92 mm for Diamant, Nicola and Lady Rosetta respectively. Figure (5) shows the effect of GA_3 concentration on tuber length (*L*) for different varieties.

TABLE 1: Combined analysis of physical and mechanical properties of three potato cultivars with different GA_3 concentrations.

		Diamant				Nicola				Lady Rosetta			
		C_0	C_1	C_3	C_5	C_0	C_1	C_3	C_5	C_0	C_1	C_3	C_5
		Physical properties											
Mass, g		73.16ab	67.41a	61.08bcd	64.93abc	54.16cd	49.18cd	68.43ab	56.07bcd	47.21e	52.23cd	32.30e	45.89de
Volume, cm^3		66.16ab	60.54ab	57.31b	59.09ab	46.31b	44.46a	63.52ab	52.89b	43.08b	47.75b	28.14b	41.86b
Length, mm		67.46ab	67.53ab	65.88abc	69.87ab	61.80c	61.03bc	72.75a	66.41ab	41.75d	46.92d	37.33d	45.56d
Width, mm		46.28ab	45.57a	42.85abc	42.12cd	41.55d	41.62c	44.06ab	39.95cd	44.56de	45.78ab	38.86e	42.87c
Thickness, mm		39.33ab	37.51ab	36.22abc	35.57bc	35.35bc	33.99bc	37.60ab	34.42bc	42.41a	39.08ab	33.70c	38.51abc
Density, g/cm^3		1.12ab	1.10abc	1.09abc	1.10ab	1.10ab	1.08ac	1.08abc	1.08ab	1.09ab	1.10ab	1.09abc	1.08abc
		Mechanical properties											
μ_S	**Wood**	0.36e	0.53c	0.57b	0.42d	0.42d	0.29f	0.63a	0.67a	0.44d	0.27f	0.21g	0.21g
	Plastic	0.38fg	0.46ef	0.61b	0.46de	0.33gh	0.53cd	0.56bc	0.70a	0.44e	0.30g	0.21i	0.21i
	Steel	0.28cd	0.48ab	0.52a	0.39abc	0.23d	0.39bcd	0.50a	0.49a	0.32bcd	0.24d	0.20d	0.21d
	Rubber	0.42cd	0.48bcd	0.67a	0.47bc	0.38def	0.50bcd	0.60ab	0.56a	0.44bcd	0.33ef	0.23f	0.22f
F_{ness}, kg	**Up**	6.75a	6.35a	6.10ab	6.05ab	5.40d	5.00e	5.45d	5.85cd	5.60bc	6.10ab	6.20ab	6.30ab
	down	6.10a	6.20a	5.95ab	6.15a	5.65ab	5.05b	5.70ab	5.95ab	5.55ab	6.40a	6.35ab	6.40a
	Side	6.95a	6.40a	6.05bcd	6.15ab	5.40e	4.95f	5.90bcd	5.75cde	5.70de	6.25ab	6.05cde	6.10bc
E, MPa		3.99a	3.57b	3.42c	3.64ab	3.21d	3.21e	4.06a	3.71cd	3.99cd	4.14ab	3.42e	3.85cd
σb, MPa		1.67a	1.52b	1.43c	1.50ab	1.32d	1.33e	1.64a	1.53cd	1.65ab	1.71cd	1.46e	1.61c
σr, MPa		2.83a	2.45b	2.37c	2.55ab	2.23d	2.25e	2.85a	2.60cd	2.81ab	2.92bc	2.40d	2.70 ab

In each raw, means followed by the same letter are not significantly different.

Figure (5) shows that, for Diamant the "*L*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*L*" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "*L*" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "*L*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*L*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*L*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*L*" value was increased by increasing the concentration of GA_3 from C_3 to C_5.

Statistical analysis showed that, for Diamant no significant differences of GA_3 on "*L*". For Nicola, it is no significant differences of GA_3 on "*L*" with (C_0, C_1) and (C_3, C_5) but significant differences between C_3 comparing with C_0 and C_1. For Lady Rosetta, it is no significant differences of GA_3 on "*L*".

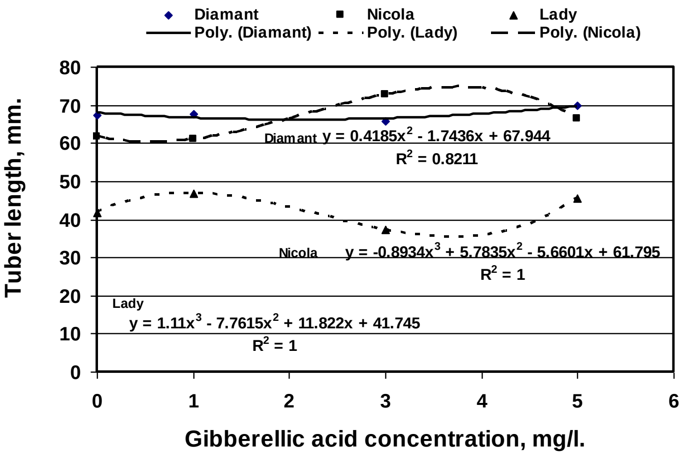


Figure (5): Effect of GA_3 concentration on tuber length.

Tuber width (*W*)

The average values of tuber width (*W*) are shown in table (1). It's clear that the average values of *W* ranged from 42.12 to 46.28 mm, from 39.95to 44.06 mm and from 38.86 to 45.78 mm for Diamant, Nicola and Lady Rosetta respectively. Figure (6) shows the effect of GA_3 concentration on tuber width (*W*) for different varieties.

Figure (6) shows that, for Diamant the "*W*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*W*" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "*W*" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "*W*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*W*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*W*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*W*" value was increased by increasing the concentration of GA_3 from C_3 to C_5.

Statistical analysis showed that, for Diamant no significant differences of GA_3 on "*W*" between C_0, C_1, C_3 but significant differences with C5 comparing with C0 and C1. For Nicola, it is no significant differences of GA_3 on "*W*" with C_0, C_1, C_3 but significant differences between C_3, C_5. For Lady Rosetta, it is no significant differences of GA_3 on "*W*" with (C_0, C_3) and (C_1, C_5), but significant differences between C_0 and C_1 also C_3 and C_5.

Tuber thickness (*T*)

The average values of tuber thickness (*T*) are shown in table (1). It's clear that the average values of "*T*" ranged from 35.57 to 39.33 mm, from 33.99 to 37.6 mm and from 33.7 to 42.41 mm for Diamant, Nicola and Lady Rosetta respectively). Figure (7) shows the effect of GA_3 concentration on tuber thickness (*T*) for different varieties.

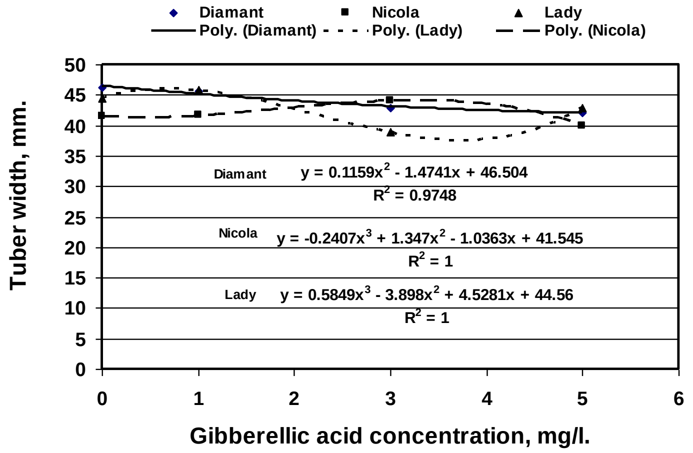


Figure (6): Effect of GA_3 concentration on tuber width.

Figure (7) shows that, for Diamant the "*T*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*T*" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "*T*" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "*T*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*T*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*T*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*T*" value was increased by increasing the concentration of GA_3 from C_3 to C_5.
Statistical analysis showed that, For Diamant and Nicola no significant differences of GA_3 on "*T*". For Lady Rosetta, it is no significant differences of GA_3 on "*T*" between C_0, C_1 and C_5 but significant differences with C_3 comparing with C_0 and C_1.

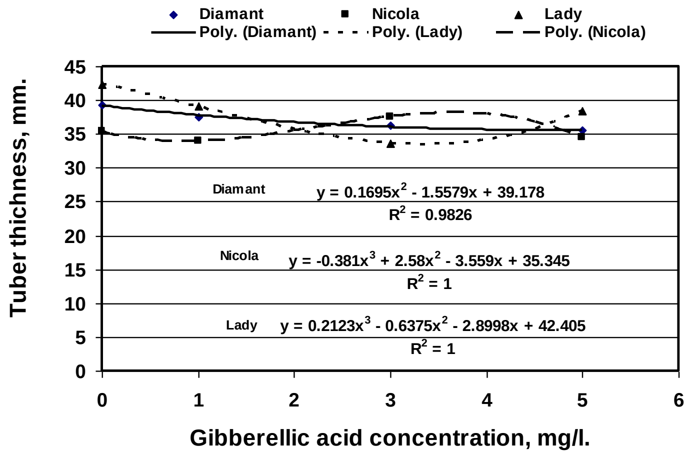


Figure (7): Effect of GA_3 concentration on tuber thickness.

3.1.3. Tuber volume (*V*)

The average values of tuber volume (*V*) are shown in table (1). It's clear that the average values of "*V*" ranged from 57.31 to 66.16 cm^3, from 44.46 to 63.52 cm^3 and from 28.14 to 47.75 cm^3 for Diamant, Nicola and Lady Rosetta respectively. Figure (8) shows the effect of GA_3 concentration on tuber volume (*V*) for different varieties.
Figure (8) shows that, for Diamant the "*V*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*V*" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "*V*" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "*V*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*V*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*V*" value was decreased by

increasing the concentration of GA_3 from C_1 to C_3 and the "*V*" value was increased by increasing the concentration of GA_3 from C_3 to C_5.
Statistical analysis showed that, for Diamant and Lady Rosetta no significant differences of GA_3 on "*V*". For Nicola, it is no significant differences of GA_3 on "*V*" between C_0, C_3 and C_5 but significant differences with C_1 comparing with C_0 and C_5.

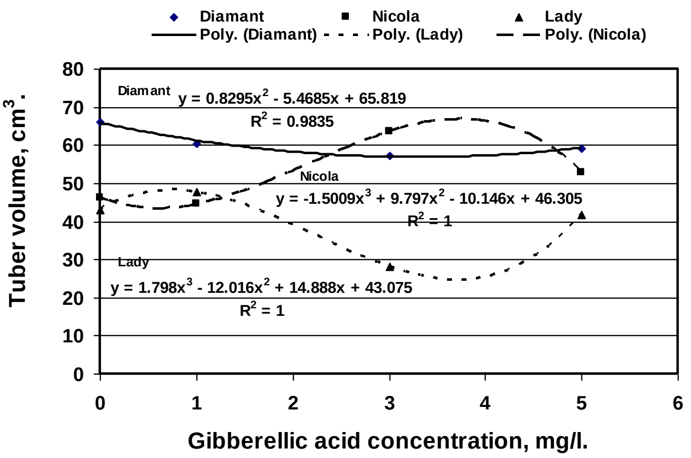


Figure (8): Effect of GA_3 concentration on tuber volume.

3.1.4. Tuber density (ρ_s)

The average values of tuber density (ρ_s) are shown in table (1). It's clear that the average values of "ρ_s "ranged from 1.09 to 1.12 g/cm^3, from 1.08 to 1.1 g/ cm^3 and from 1.08 to 1.1 g/cm^3 for Diamant, Nicola and Lady Rosetta respectively. Figure (9) shows the effect of GA_3 concentration on solid density (ρ_s) for different varieties.
Figure (9) shows that, for Diamant the "ρ_s" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "ρ_s" value was decreased by increasing the concentration of GA_3 from C_0 to C_1, the "ρ_s" value was increased by increasing the concentration of GA_3 from C_1 to C_3 and the "ρ_s " value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "ρ_s" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "ρ" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "ρ_s" value was increased by increasing the concentration of GA_3 from C_3 to C_5. Statistical analysis showed that, for Diamant, Nicola and Lady Rosetta no significant differences of GA_3 on "ρ_s".
In general, No significant differences between gibberellic acid concentrations on the physical properties with three varieties this due to GA_3 increase the number of sprouts so increasing in yield of tuber but the physical properties of tuber did not affected by GA_3. The previous studies in this respect proved that treating tuber seeds with GA_3 (0.5, 1 or 2 mg/l) prior to planting reduced the yield of large tubers and increased the yield of small tuber (*Mikitzel, 1993*).

3.2. Mechanical properties

3.2.1. Static friction coefficient (μ_s)

The average values of static friction coefficient of potato tuber (μ_s) are shown in table (1). It's clear that the average values of "μ_s", for Diamant ranged from 0.36 to 0.57, from 0.38 to 0.61, from 0.28 to 0.52 and from 0.42 to 0.67 with wood, steel, rubber surface respectively. For Nicola**,** the average values of "μ_s" ranged from 0.29 to 0.67, from 0.33 to 0.70, from 0.23 to 0.50 and from 0.38 to 0.60 with wood, steel, rubber surface respectively. With Lady Rosetta, the average values of "μ_s" ranged from 0.21 to 0.44, from 0. 21 to 0.44, from 0.20 to 0.32 and from 0.22 to 0.44 with wood, steel, rubber surface respectively. Figure (10) shows the effect of GA_3 concentration on "μ_s" at different surfaces for different varieties.

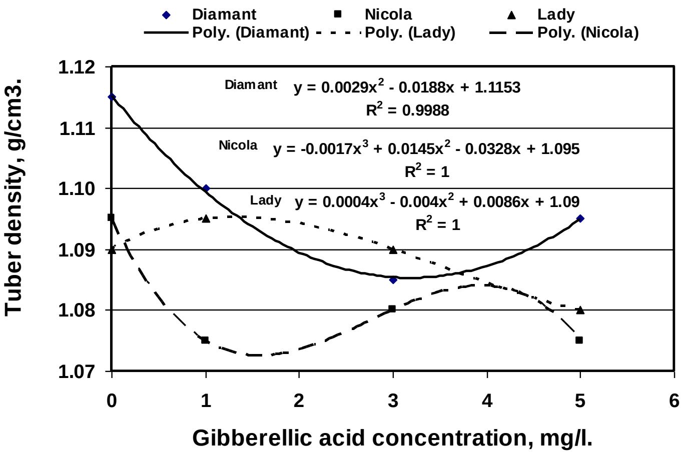


Figure (9): Effect of GA_3 concentration on tuber density.

Wood surface

Figure (10) shows that, for Diamant the "μ_s" value was increased by increasing in the concentration of GA_3 from C_0 to C_3 and the "μ_s" value was decreased by increasing in the concentration of GA_3 from C_3 to C_5. For Nicola, the "μ_s" value was decreased by increasing the concentration of GA_3 from C_0 to C_2, and the "μ_s" value was increased by increasing the concentration of GA_3 from C_2 to C_5. For Lady Rosetta, the "μ_s" value was decreased by increasing the concentration of GA_3 from C_0 to C_5.

Statistical analysis showed that, for Diamant significant differences of GA_3 on "μ_s". For Nicola, it is significant differences of GA_3 on "μ_s" between (C_0, C_1 C_3) and (C_0, C_1 C_5) but no significant differences with C_3 and C_5. For Lady Rosetta, it is significant differences of GA_3 on "μ_s" between (C_0, C_1 C_3) and (C_0, C_1 C_5) but no significant differences with C_3 and C_5.

Plastic surface

Figure (10) shows that, for Diamant the "μ_s" value was increased by increasing in the concentration of GA_3 from C_0 to C_3 and the "μ_s" value was decreased by increasing in the concentration of GA_3 from C_3 to C_5. For Nicola, the "μ_s" value was decreased by increasing the concentration of GA_3 from C_0 to C_5. For Lady Rosetta, the "μ_s" value was increased by increasing the concentration of GA_3 from C_0 to C_5.

Statistical analysis showed that, for Diamant significant differences of GA_3 on "μ_s" between (C_0, C_3, and C_5) but no significant differences between (C_0, C_1) and (C_1, C_5). For Nicola, it is significant differences of GA_3 on "μ_s" between (C_0, C_1, and C_5) but no significant differences between C_1 and C_3. For Lady Rosetta, it is significant differences of GA_3 on "μ_s" between (C_0, C_1 and C_3) and (C_0, C_1 and C_5) but no significant differences with C_3 and C_5.

Steel and rubber surfaces

Figure (10) shows that, for Diamant the "μ_s" value was increased by increasing in the concentration of GA_3 from C_0 to C_3 and the "μ_s" value was decreased by increasing in the concentration of GA_3 from C_3 to C_5. For Nicola, the "μ_s" value was increased by increasing the concentration of GA_3 from C_0 to C_5. For Lady Rosetta, the "μ_s" value was increased by increasing the concentration of GA_3 from C_0 to C_5.

Statistical analysis showed that, for Diamant significant differences of GA_3 on "μ_s" between C_0 comparing with C_1 and C_3 but no significant differences between (C_1, C_3, C_5). For Nicola, it is significant differences of GA_3 on "μ_s" for both C_3 and C_5 comparing with C_0 and C_1 but no significant differences for both (C_0, C_1) and (C_3, C_5). For Lady Rosetta, it is no significant differences of GA_3 on "μ_s" (Steel surface). Otherwise, rubber surface, for Diamant significant differences of GA_3 on "μ_s" with C_3 comparing with C_0, C_1 and C_5 but no significant differences between (C_0, C_1, C_5). For Nicola, it is significant differences of GA_3 on "μ_s" between C_0 and C_3 but no significant differences between C_1, C_3, and C_5. For Lady Rosetta, it is no significant differences of GA_3 on "μ_s" between C_1, C_3, and C_5 but significant differences with C_0 comparing with C_1, C_3, and C_5. The means of coefficient of friction were systematically higher for the treated tuber with GA_3 than for untreated tuber for Diamant and Nicola (Fig. 10),

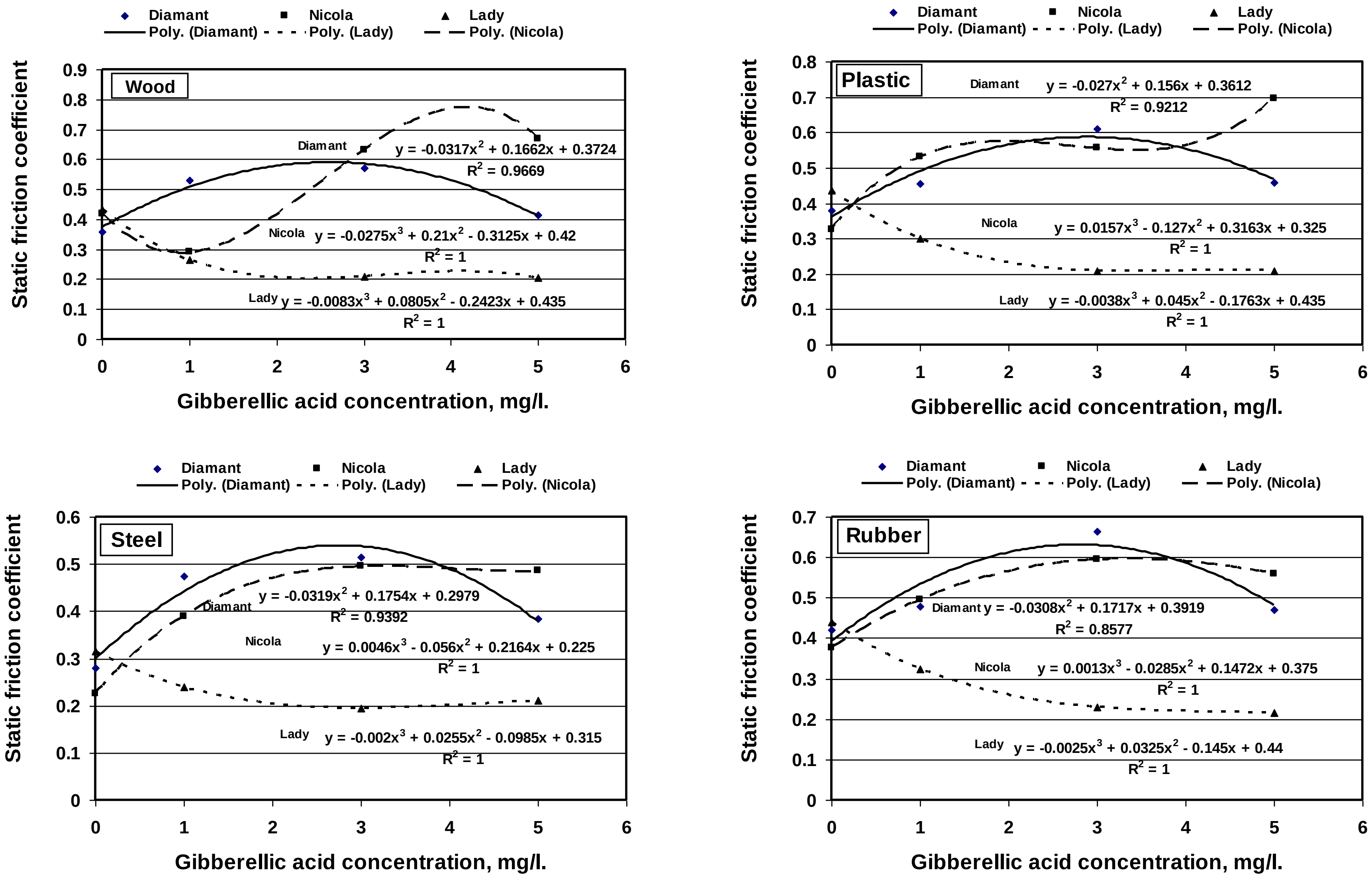


Figure (10): Effect of GA_3 concentration on friction coefficient (with different surfaces).

3.2.2. Firmness (F_{ness})

The average values of firmness of potato tuber (F_{ness}) are shown in table (1). It's clear that the average values of "F_{ness}", for Diamant, ranged from 6.05 to 6.75 kg, from 5.95 to 6.2 kg and from 6.05 to 6.95 kg for up, down and side respectively. For Nicola, the average value of "F_{ness}" ranged from 5 to 5.85 kg, from 5.05 to 5.95 kg and from 4.95 to 5.9 for up, down and side respectively. For Lady Rosetta, the average values of "F_{ness}" ranged from 5.6 to 6.3, from 5.55 to 6.4 kg and from 5.7 to 6.25 kg for up, down and side respectively. Figure (10) shows the effect of GA_3 concentration on the average value of "F_{ness}" up, down and side.

Figure (11) shows that, for Diamant the "F_{ness}" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "F_{ness}" value was increased by increasing the concentration of GA_3 from C_0 to C_5. For Lady Rosetta, the "F_{ness}" value was decreased by increasing the concentration of GA_3 from C_0 to C_1 and the "F_{ness}" value was increased by increasing the concentration of GA_3 from C_1 to C_5. The average values of firmness were systematically higher for the treated tuber with GA_3 than for untreated tuber of Nicola and Lady Rosetta.

Statistical analysis showed that, significant differences of GA_3 on "F_{ness}" for Diamant Nicola and Lady Rosetta.

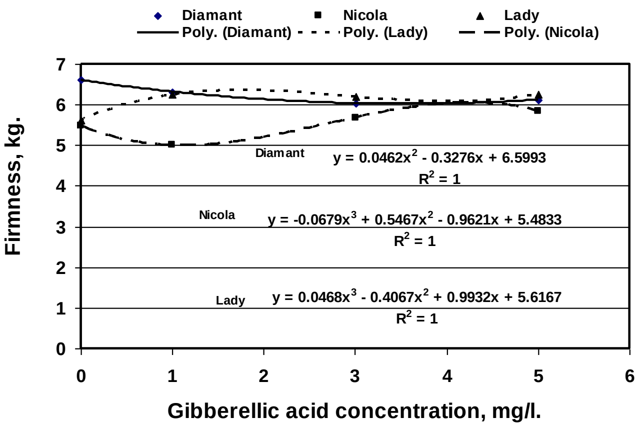


Figure (11): Effect of GA_3 concentration on tuber firmness.

3.2.3. Modulus of elasticity (E)

The average values of modulus of elasticity (E) are shown in table (1). It's clear that the average values of "E" ranged from 3.42 to 3.99 MPa, from 3.21 to 1.06 MPa and from 3.42 to 4.14 MPa for Diamant, Nicola and Lady Rosetta respectively. Figure (12) shows the effect of GA_3 concentration on modulus of elasticity (E) for different varieties.

Figure (12) shows that, for Diamant the "E" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "E" value was increased by increasing the concentration of GA_3 from C_0 to C_3, and the "E" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "E" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "E" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "E" value was increased by increasing the concentration of GA_3 from C_3 to C_5. Statistical analysis showed that, significant differences of GA_3 on "E" for Diamant, Nicola and Lady Rosetta.

3.2.4. Bioyield stress (σb)

The average values of bioyield stress (σb) are shown in table (1). It's clear that the average values of "σb" ranged from 1.43 to 1.67 MPa, from 1.32 to 1.64 MPa and from 1.46 to 1.71 MPa for Diamant, Nicola and Lady Rosetta respectively. Figure (13) shows the effect of GA_3 concentration on bioyield stress (σb) for different varieties.

Figure (13) shows that, for Diamant the "σb" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "σb" value was increased by increasing the concentration of GA_3 from C_0 to C_3, and the "σb" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*σb*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*σb*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*σb*" value was increased by increasing the concentration of GA_3 from C_3 to C_5. Statistical analysis showed that significant differences of GA_3 on "*σb*" for Diamant , Nicola and Lady Rosetta

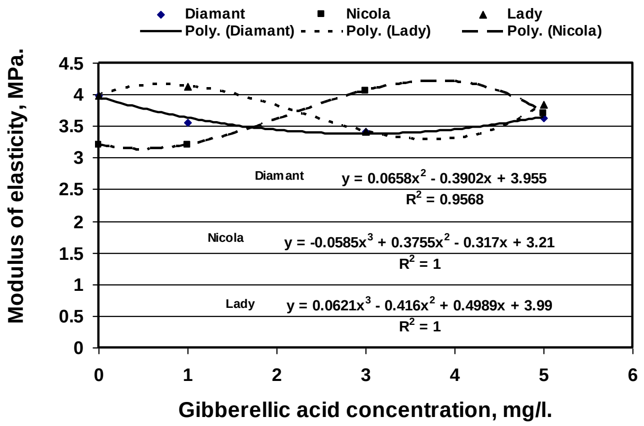


Figure (12): Effect of GA_3 concentration on modulus of elasticity.

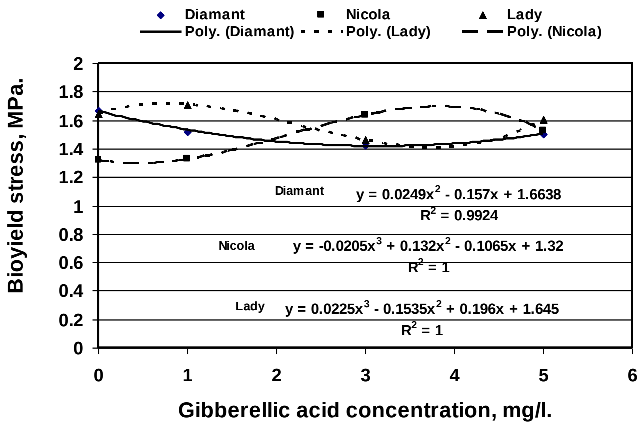


Figure (13): Effect of GA_3 concentration on bioyield stress.

3.2.5. Rupture stress (*σr*)

The average values of rupture stress (*σr*) are shown in table (1). It's clear that the average values of "*σr*" ranged from 2.37 to 2.83 MPa, from 2.23 to 2.85 MPa and from 2.4 to 2.92 MPa for Diamant, Nicola and Lady Rosetta respectively. Figure (14) shows the effect of GA_3 concentration on rupture stress (*σr*) for different varieties.

Figure (14) shows that, for Diamant the "*σr*" value was decreased by increasing in the concentration of GA_3 from C_0 to C_5. For Nicola, the "*σr*" value was increased by increasing the concentration of GA_3 from C_0 to C_3, and the "*σr*" value was decreased by increasing the concentration of GA_3 from C_3 to C_5. For Lady Rosetta, the "*σr*" value was increased by increasing the concentration of GA_3 from C_0 to C_1, the "*σr*" value was decreased by increasing the concentration of GA_3 from C_1 to C_3 and the "*σr*" value was increased by increasing the concentration of GA_3 from C_3 to C_5. Statistical analysis showed that significant differences of GA_3 on "*σr*" for Diamant, Nicola and Lady Rosetta.

In general, it is significant differences between GA_3 concentrations on the mechanical properties with three varieties; it may be due to changing in genotype structure of the potatoes. It may needs to more searches to find the changing in the genotype structure with treated tuber with GA_3.

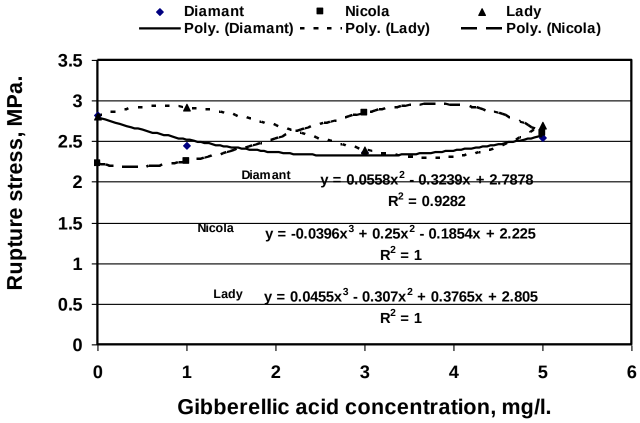


Figure (14): Effect of GA_3 concentration on rupture stress.

3.3. The mathematical expression for the effect of GA_3 concentration (*C*) on the physical and mechanical properties with different varieties by applying the regression approach.

Regression approach was used to find out the value of physical and mechanical properties as a function of GA3 concentration (*C*).

3.3.1 Mathematical expression for the effects of "C" on the value of (m), (*V*), (L), (W), (T), (ρ) and (*μs*).

Multiple regression approach was used to derive a regression equation (5), expressing the effects of "C" on the value of (*m*) in g, (*V*) in cm^3, (*L*) in mm, (*W*) in mm, (*T*) in mm, (ρ) in g/cm^3 and (*μs)* for different varieties. The data of (m), (*V*), (*L*), (*W*), (*T*), (ρ) and (*μs)* in table (1) made relation with GA3 concentrations (*C*). The equations are quadratic (second-order) or third order. Both equations have very high coefficients of determination.

$$Y = a C^3 + b C^2 + d C + e \qquad (5)$$

Where

Y : The value of (*m*), (*V*), (*L*), (*W*), (*T*), (ρ) and (*μs)*.

C : GA_3 concentration, mg/l; ($0 \le C \le 5$).

a, b, d & e : Empirical constants.

Figures (4-10) show the optimal regression for these parameters. The values of the empirical constants (a, b, d and e) and the coefficient of determination of equation (5) are shown in table (2).

3.3.2. Mathematical expression for the effects of "*C*" and "F_{ness}" on the value of "*E*", "σb" and "σr".

The obtained data of table (1) for the "*C*" and "F_{ness}" were used as factors affecting the values of "*E*", "*σb*" and "σr". So, multiple regression approach (by using SPSS software version 14) was used to derive a regression equation (6). Equation (6) expresses mathematical relation, which is linear (first-order).

$$Y = a C + b F_{ness} + d \qquad (6)$$

Where

Y : The value of of "*E*", "*σb*" and "σr", MPa.

C : GA_3 concentration, mg L^{-1}; ($0 \le C \le 5$).

F_{ness} : Firmness, Kg.

Diamant: ($6.03 \le F_{ness} \le 6.60$)

Nicola: ($5.00 \le F_{ness} \le 5.85$)

Lady Rosetta: ($5.62 \le F_{ness} \le 6.27$)

A, b & c : Empirical constants

The values of the empirical constants (a, b and d) and the coefficient of determination of equation (6) are shown in table (3).

TABLE 2: The empirical constants and the coefficient of determination for equation (5).

	Diamant	Nicola	Lady Rosetta
	Mass (g)		
a	-	-1.7641	1.8367
b	1.1546	11.927	-12.34
d	-7.4737	-15.147	15.518
e	73.355	54.16	47.21
R^2	0.997	1	1
	Volume, cm^3		
a	-	-1.5009	1.798
b	0.8295	9.797	-12.016
d	-5.4685	-10.146	14.888
e	65.819	46.305	43.075
R^2	0.984	1	1

	Diamant			Nicola			Lady Rosetta		
	Dimension (mm)								
	L	**W**	**T**	**L**	**W**	**T**	**L**	**W**	**T**
a	-	-	-	-0.893	-0.241	-0.381	1.11	0.5849	0.2123
b	0.4185	0.1159	0.1695	5.7835	1.347	2.58	-7.762	-3.898	-0.638
d	-1.744	-1.474	-1.558	-5.660	-1.036	-3.559	11.822	4.5281	-2.899
e	67.944	46.504	39.178	61.795	41.545	35.345	41.745	44.56	42.404
R^2	0.821	0.975	0.983	1	1	1	1	1	1

	Diamant	Nicola	Lady Rosetta
	Density (g/cm^3)		
a	-	-0.0017	0.0004
b	0.0029	0.0145	-0.004
d	-0.0188	-0.0328	0.0086
e	1.1153	1.095	1.09
R^2	0.998	1	1

	Diamant				Nicola				Lady Rosetta			
	Friction coefficient											
	Wood	**Plastic**	**Steel**	**Rubber**	**Wood**	**Plastic**	**Steel**	**Rubber**	**Wood**	**Plastic**	**Steel**	**Rubber**
a	-	-	-	-	-0.03	0.016	0.005	0.001	-0.01	-0.004	-0.002	-0.003
b	-0.03	-0.03	-0.03	-0.03	0.21	-0.13	-0.06	-0.03	0.081	0.045	0.026	0.0325
d	0.166	0.156	0.175	0.172	-0.31	0.316	0.217	0.148	-0.24	-0.18	-0.099	-0.145
e	0.372	0.371	0.298	0.392	0.42	0.325	0.225	0.375	0.435	0.435	0.315	0.44
R^2	0.967	0.921	0.939	0.858	1	1	1	1	1	1	1	1

TABLE 3: The empirical constants and the coefficient of determination for eq. (6).

	Diamant	Nicola	Lady Rosetta
	Modulus of elasticity (*E*), MPa		
A	0.74	0.084	-0.086
B	1.401	0.431	0.193
D	-05.294	0.986	2.87
R^2	0.952	0.595	0.504
	Bioyield stress, (σb) MPa		
A	0.019	0.036	0.031
B	0.532	0.153	0.094
D	- 1.851	0.532	1.106
R^2	0.991	0.652	0.509
	Rupture stress (σr), MPa		
A	0.070	0.067	- 0.066
B	1.188	0.272	0.163
D	- 5.058	0.832	1.865
R^2	0.923	0.597	0.522

4. Conclusion

The obtained results of physical and mechanical properties of three potatoes varieties affected with GA3 concentration can be summarized as follow:

1. For Diamant, the values of "*m, L, W*, *T*, *V and* ρ_s " were decreased by increasing GA_3 from C_0 to C_5. For Nicola, these values were decreased by increasing GA_3 from C_0 to C_1, these values were increased by increasing GA_3 from C_1 to C_3 and these values were decreased by increasing GA_3 from C_3 to C_5. For Lady Rosetta, these values were increased by increasing GA_3 from C_0 to C_1, these values were decreased by increasing GA_3 from C_1 to C_3, and these values were increased by increasing GA_3 from C_3 to C_5.
2. There are no significant differences between GA_3 concentrations on the physical properties with three varieties, this due to GA_3 increase the number of sprouts so increasing in yield of tuber but the physical properties of tuber did not affected by GA_3.
3. The "μ_s" was increased by increasing in GA_3 concentration from C_0 to C_3, while was decreased from C_3 to C_5 for Diamant at wood and plastic surfaces. For Nicola, The "μ_s" was decreased by increasing GA_3 from C_0 to C_1 "μ_s" and "μ_s" was increased by increasing GA_3 from C_2 to C_5 at wood surface, but with plastic surface the "μ_s" was decreased by increasing GA_3 from C_0 to C_5. For Lady Rosetta, The "μ_s" was decreased by increasing in GA_3 from C_0 to C_5 "μ_s" decreased at wood surface, but with plastic surface the "μ_s" was increased by increasing GA_3 from C_0 to C_5. At steel and rubber surfaces, for Diamant the "μ_s" was increased by increasing GA_3 from C_0 to C_3 and the "μ_s" was decreased by increasing GA_3 from C_3 to C_5. For Nicola and For Lady Rosetta, the "μ_s" was increased by increasing GA_3 from C_0 to C_5.
4. The "F_{ness}, *E, σb* and *σr*" were decreased by increasing GA_3 from C_0 to C_5. For Nicola, "*E, σb* and *σr*" were increased by increasing GA_3 from C_0 to C_3 and "*E, σb* and *σr*" were decreased by increasing GA_3 from C_3 to C_5, but "F_{ness}" was increased by increasing GA_3 from C_0 to C_5. For Lady Rosetta, "*E, σb* and *σr*" were increased by increasing GA_3 from C_0 to C_1, "*E, σb* and *σr*" were decreased by increasing GA_3 from C_1 to C_3, and the "*E, σb* and *σr*" were increased by increasing GA_3 from C_0 to C_1 but "F_{ness}" was decreased by increasing GA_3 from C_0 to C_1 and "F_{ness}" was *increased* by increasing GA_3 from C_1 to C_5.
5. In general, it is significant differences between GA_3 concentrations on the mechanical properties for three varieties; it may be due to changing in genotype structure of the potatoes.
6. The multiple regression technique were derived for each varieties for expressing "m", "*V*", "L", "W", "T", "ρ_s " and "*μs*" as a function of GA_3 concentration "*C*", the other derived regression could be used in predicting the "*E*", "σb" and "σr" as a function of GA_3 concentration "C" in mg/l and tuber firmness (kg).

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