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CREEP-RECOVERY BEHAVIOR FOR EIGHT DATES CULTIVARS AT TWO DIFFERENT MATURITY STAGES

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ABSTRACT

Creep-recovery characteristics of some selected Saudi dates cultivars, namely *Barhi, Khudari, Khlass, Serri, Sukkari, Suffri, Saqie*, and *NubotSaif* were investigated at two maturity stages that is, Khalal and Rutab. The results revealed the significant effect of date cultivar and stage of maturity on the creep-recovery behavior for the dates. At the end of creep period, the strain values ranged from 0.02-0.09 mm/mm for *Saqie* and *Barhi* cultivars, respectively at Khalal stage, and from 0.36-0.64 mm/mm for *Saqie* and *Khlass* cultivars, respectively at Rutab stage. Burgers four-element model was used to predict experimental data and it was highly satisfactory in predicting experimental data with determination coefficients ranged from 0.920- 0.994. *Barhi* cultivar showed great susceptibility for deformation and medium ability to recover it regardless of its high toughness.

KEYWORDS: Viscoelastic, Creep-Recovery, Date Cultivars, Burgers Model, Maturity Stage

INTRODUCTION

The date palm (*Phoenix dactylifera* L.) is one of the oldest fruit trees in the world and it is closely associated with the sustenance and culture of the people in the Middle East and North Africa regions since ancient times (Al-Qarawi *et al.*, 2003). Fruits and vegetables including dates exhibit viscoelastic behavior when subjected to external loading. The viscoelastic properties of solid food materials are vital indicators of the usefulness of food for various applications. They are important with respect to the engineering design of continuous process, development of new products, and quality control during processing (Dolz *et al*., 2008).

Many researchers studied modeling of creep-recovery behavior for foodstuff. Moreira *et al.* (2013) used Burgers model to fit creep compliance experimental data for Chestnut flour dough that dried at different temperatures. Myhan *et al.* (2012) developed a mathematical model describing the rheological properties of food materials. The model was verified logically and empirically based on the results of creep tests. Additionally, Karaman *et al.* (2012) simulate the viscoelastic behavior of ketchup, processed cheese and their mixture as a function of processed cheese concentration and temperature, Burgers model successfully describe the effect of these factors. Van Bockstaele *et al.* (2011) used creep-recovery measurements to analyze the non-linear viscoelastic properties of 17 pure wheat cultivars. The Burgers model was fitted to the creep and recovery curves. Several research works investigated the creep-recovery characteristics of various food and pharmaceutical materials (Ma *et al.*; 2012; Kumar *et al.*, 2012; Stathopoulos *et al.*, 2009; Sozer, 2009; Onyango et al., 2009; Olivares *et al.*, 2009; Martinez *et al.*, 2005; Jackman and Stanley, 1995; Mouquet *et al*., 1992; Mittal *et al*., 1987; Ahmed and Fluck, 1972; Somers, 1965). It seems that so far there is limited literature reported on creep-recovery characteristics of date fruits. In view of that the present study was undertaken to describe the creep-recovery characteristics of eight popular Saudi date cultivars at their Khalal and Rutab stages of maturity, investigating the effect of maturity stage on the creep recovery properties and to fit the obtained data to Burgers four-element model.

MATERIALS AND METHODS

Sample Preparation

Eight popular Saudi date cultivars at Khalal and Rutab stages of maturity, namely *Barhi, Khudari, Khlass, Serri, Sukkari, Suffri, Saqie,* and *NubotSaif* were obtained from the educational farm of King Saud University.

Date fruits at each maturity stage were sorted to discard the damaged fruits, and immediately kept for less than 24 h in a cold store at 5 °C. The moisture content was determined for the flesh of date fruits using the AOAC procedures (AOAC, 2005). While the water activity was measured using an Aqua-lab (Model CX-2T, Decagon Devices Inc., Washington).

Creep and Recovery Test

Creep recovery tests were performed at room temperature 25 °C using the Stable Micro Systems TA. HDi texture analyzer Surrey, England. The device was operated with the use of Texture Expert Exceed (v. 2.64) software which supports fast calibration, test parameter setting, data gathering, analysis, visualization and reporting. For each test, ten replications were implemented with the following settings; maximum compressive force 9.8 N; head speed 1.5 mm s^{-1} and duration of creep and recovery test 120 s for each.

The percentage of the recovered strain was calculated using the following equation:

$$EP_{rec}\,(\%) = \left(1 - \frac{E_{rec}}{E_{cr}}\right) \times 100 \tag{1}$$

Where:

EP_{rec} = percentage of the recovered strain (%),

E_{rec} = strain at the end of recovery phase (mm/mm), and

E_{cr}= strain at the end of creep phase (mm/mm).

Creep and Recovery Modelling

The four-component Burgers model, which is reported to be one of the most commonly used models (Dolz *et al.* (2008); Van Bockstaele *et al.* (2011); Karaman *et al.* (2012)), presented mathematically as:

$$J = J_0 + J_1\left[1 - e^{\left(\frac{t}{\tau_{ret}}\right)}\right] + \left(\frac{1}{\eta_N}\right) \tag{2}$$

Where:

J = the compliance at time (t) (kPa^{-1});

J_0= instantaneous compliance (kPa^{-1});

J_1= retarded compliance (kPa^{-1});

τ_{ret} = retarded time (s);

η_N = Newtonian Viscosity (kPa. s); and

t = time (s).

Statistical Analysis

All needed analyses were performed using the IBM SPSS software package (IBM SPSS 2010), and data resented as means ± SE with a level of significance of 5%. Duncan comparison test were carried out to establish statistical differences between the calculated means at each experimental condition tested. Experimental data and parameters of models were analyzed by means of one-factor analysis of variance (ANOVA). Non-linear regression analysis was used to predict the constants of Burgers model.

RESULTS AND DISCUSSIONS

Moisture Content & Water Activity

The mean values of moisture content on wet basis (MC_{wb}) and water activity (a_w) of the eight date cultivars at the Khalal and Rutab stages of maturity are shown in Table 1. The values of MC_{wb} and a_w at Khalal maturity stage for all tested cultivars are higher than those at the Rutab maturity stage.

The results indicated that at the Khalal maturity stage there were significant differences in the ($MC_{wb)}$ between all cultivars, except *Saqie* and *Suffri.* The water activity at this maturity stage ranged from 0.963 ±0.001 to 0.985 ±0.002. There was no significant difference between *Khlass, Khudari, NubotSaif* and *Suffri* cultivars on the (a_w) values. At the Rutab maturity stage, *Barhi, Khlass, NubotSaif, Serri and Suffri* cultivars differ significantly from *Khudari, Saqie* and *Sukkari* based on MC_{wb} values. Likewise, *Barhi, NubotSaif, Khlass* and *Suffri* had no significant differences based on their (a_w) values. The variation in moisture content and water activity between the cultivars and between the maturity stages beside other chemical changes has great effect on their physical and mechanical properties including viscoelastic behavior (Moresi *et al*., 2012).

Creep-Recovery

The obtained creep and recovery curves for the eight date cultivars at both Khalal and Rutab stages are shown in Figures 1 and 2, respectively.

Creep-recovery behavior of all tested dates cultivars at Khalal maturity as shown in (Figure 1) and at Rutab stage in (Figure 2) didn't deviates from the classical pattern forms of the curves of creep-recovery for many viscoelastic materials. The curves, however, indicate the existence of clear differences in the change of strain values with time during creep-recovery stages for the eight date cultivars.

Creep Phase

The data obtained at the Khalal stage of maturity showed that the strain values at the end of the creep period for *Barhi*, *NubotSaif*, *Suffri* and *Khudari* cultivars were the highest. The values were equal to 0.095 ±0.002, 0.061 ±0.003, 0.052 ±0.004 and 0.052 ±0.002 (mm/mm) respectively, followed by *Sukkari* 0.048 ±0.002, *Serri* 0.029 ±0.003, *Khlass* 0.024 ±0.001 and *Saqie* 0.020 ±0.003 (mm/mm). In contrast, the strain values at the end of the creep were very high at the Rutab stage compared to Khalal maturity stage. They ranged from maximum 0.64 ±0.08 mm/mm for *Khlass* to 0.36 mm/mm for *Saqie*. The strain values for the other cultivars at the Rutab stage were 0.57 ±0.09 for *Barhi*; *NubotSaif 0.56* ±0.08; *Suffri* 0.52 ±0.07; *Khudari* 0.51 ±0.04; *Sukkari* 0.48 ±0.07 and 0.43 ±0.08 for *Serri*. These changes are due to the fact that the accumulation of reducing sugars in fruit slightly increased during development with a vast increase during maturation and ripening mainly due to gains in sugars and loss of moisture (Baliga *et al*., 2011; Rastegar *et al*., 2012).

Recovery Phase

The values of the percentage of the recovered strain that were calculated from equation 2 showed the differences between the cultivars. These values were: 8% ±2.1%, 59% ±1.7%, 73% ±2%, 75% ±5.4%, 87% ±2.3%, 75% ±5.1% and 83% ±4.8 for *Barhi, NubotSaif, Khudari, Sukkari, Suffri, Saqie, Khlass* and *Serri* respectively. These results indicate that the cultivar with the highest portability to strain was *Barhi* while the lowest was *Serri*. In other words, *Barhi* has the least ability to retrieve its strain and *Serri* has the highest ability to retrieve its strain.

The ability of the fruits in recovering the strain resulted from creep at the Rutab stage is relatively weaker compared to that at Khalal stage, which ascertain the decrease in fruits elasticity at the Rutab stage resulting from its high proportion of reduced sugars, softness and tenderness of its texture compared to Khalal stage of maturity. This is noticeable from the values of strain at the end of recovery time as well as the percentage of strain recovered, where the values for the eight dates cultivars at Rutab stage were 7.8 ±1.1, 3.5 ±1.2, 5.4 ±1.3, 5.8 ±1.1, 9.8 ±1.8, 10.4 ±1.7, 9.3 ±1.4, and 36.1 ±3.2 (%) for *Khlass, Barhi NubotSaif, Suffri, Khudari, Sukkari, Serri* and *Saqie* respectively. The results disclosed that *Saqie* cultivar at the Rutab stage had the highest elasticity, followed by *Sukkari* and the *Barhi* cultivar ranked last.

Creep and Recovery Modelling

The constants of Burgers four elements model that was used to describe the creep-recovery characteristics of the investigated date cultivars at the two stages of maturity were tabulated in Tables 2 and 3, respectively.

The results of Burgers model constants for the eight date cultivars at Khalal stage described in Table 2 indicate that Burgers model was appropriate in expressing the experimental results of creep tests, where the coefficient of determination (R^2) values ranged in the limits of 0.956 to 0.920 for for *Barhi* and *Khlass* cultivars, respectively.

The values of the instantaneous compliance (J_o) varied in the limits of 69.1×10^{-5} $(kPa)^{-1}$ for *NubotSaif* to 0.7×10^{-5} $(kPa)^{-1}$ for *Saqie*, indicating that *Saqie* is more tough than *NubotSaif*. The values of the retarded compliance (J_1), which represents an inverted modulus of elasticity of the sample was varied within the limits of 9.51×10^{-4} $(kPa)^{-1}$ for *Suffri* to 1.65×10^{-4} $(kPa)^{-1}$ for *Serri* referring to the high elasticity for *Serri* compared *Suffri*. The values of the constant τ_{ret}, which represent retardation time were very small for the eight dates cultivars at Khalal stage and it varied from 1.36 seconds for *Khudari* to 0.28 seconds for *Saqie*. The values of the constant η_N, which represent Newtonian viscosity, ranged from 4.54×10^{6} (kPa.s) for *Saqie* to 0.62×10^{5} (kPa.s) for *Khudari*.

On other hand, Table 3 shows the results of Burgers model constants for the date cultivars at Rutab maturity stage. The values of the instantaneous compliance (J_o) were negative except for Saqie and were ranged from $-4.8\times10^{-4}(kPa)^{-1}$ for *Sukkari* to $-15.43\times10^{-4}(kPa)^{-1}$ for *Barhi*. However, as the instantaneous compliance (J_o) is express the spring element in Burgers model, the negative values can be justified by the tendency of the spring for elongation rather than contraction to represent creep behavior of dates at Rutab stage. It is noted that the values of the determination coefficient (R^2) were high as varied within the limits of 0.994 for *Khlass* to 0.973 for *Saqie*.

In addition, the retarded compliance (J_1) values ranged in the limits of 15.16×10^{-3} $(kPa)^{-1}$ for *Khlass* to $5.46\times10^{-3}(kPa)^{-1}$ for *Sukkari*. The results shown in Table 3 put forward that the elasticity of *Sukkari* and *Saqie* cultivars at the Rutab stage was high compared to the other six cultivars, which were close in the values of modulus of elasticity of the spring element that represents elasticity. The retardation time τ_{ret} values were close for all eight cultivars at Rutab stage and varied from 5.59 seconds for *NubotSaif* to 4.28 seconds for *Suffri*. The Newtonian viscosity η_N had varied for all cultivars except *Barhi* in the range of 5.65×10^5 $(kPa)^{-1}$ for *Sukkari* to 0.7×10^5 $(kPa)^{-1}$ for *Saqie*, while it was high for *Barhi* and equal to 37.83×10^5 $(kPa)^{-1}$, which refers to its high resistance to flow.

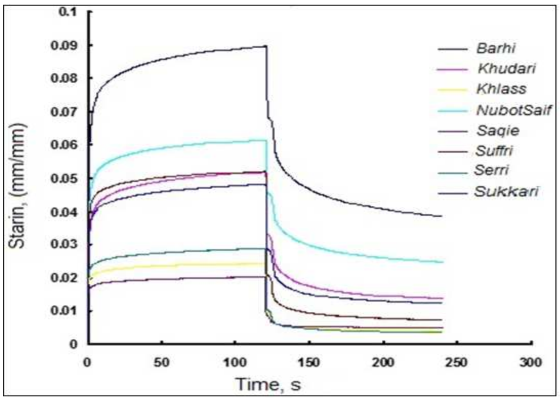

Figure 1: Creep-Recovery at Khalal Stage of Maturity for the Eight Date Cultivars

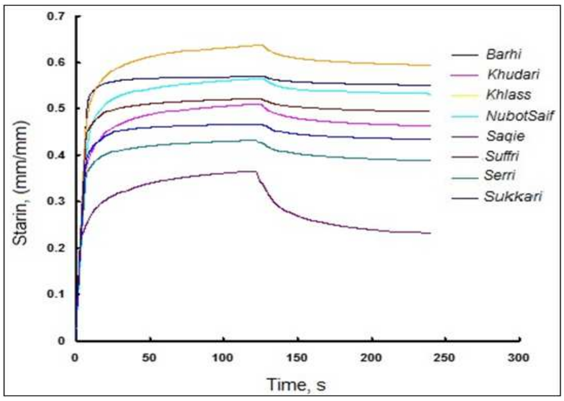

Figure 2: Creep-Recovery at Rutab Maturity Stage for the Eight Date Cultivars

Table 1: The Average Values of Moisture Content on Wet Basis (MC_{wb}, %) and Water Activity (a_w, Decimals) for the Eight Date Cultivars at Two Maturity Stages

Cultivar	Khalal		Rutab	
	MC_{wb},%	aw	MC_{wb},%	aw
Barhi	65.44±1.52	0.963±0.001	41.70± 3.85	0.795±0.011
Khlass	70.87±2.89	0.971±0.003	44.60± 4.32	0.821±0.015
Khudari	66.02±1.02	0.972±0.001	29.26± 3.15	0.729±0.012
NubotSaif	74.59±3.21	0.973±0.009	39.22± 4.41	0.803±0.010
Saqie	72.41±1.45	0.985±0.002	23.67± 5.01	0.658±0.012
Serri	55.63±3.21	0.951±0.008	46.46± 2.24	0.727±0.011
Sukkari	62.57±2.17	0.964±0.002	28.83± 3.33	0.835±0.016
Suffri	72.74±1.11	0.976±0.001	41.22± 1.89	0.820±0.013

Table 2: Burger's Four-Element Model Constants for Creep of Eight Date Cultivars at Khalal Stage

Cultivar	J_0, (kPa)$^{-1}$	J_1, (kPa)$^{-1}$	τ_{ret}, (s)	η_N, (kPa.s)	R^2
Barhi	3.57×10^{-5}	4.52×10^{-4}	1.22	1.53×10^{6}	0.956
Khudari	4.24×10^{-5}	7.73×10^{-4}	1.36	0.62×10^{6}	0.933
Khlass	3.12×10^{-5}	1.89×10^{-4}	0.32	4.09×10^{6}	0.920
Serri,	1.47×10^{-5}	1.65×10^{-4}	0.44	4.34×10^{6}	0.945
Sukkari	4.45×10^{-5}	3.96×10^{-4}	0.82	1.72×10^{6}	0.925
Suffri	1.77×10^{-5}	9.51×10^{-4}	0.60	0.88×10^{6}	0.937
Saqie	0.73×10^{-5}	2.32×10^{-4}	0.28	4.54×10^{6}	0.923
NubotSaif	69.13×10^{-5}	7.01×10^{-4}	1.00	1.03×10^{6}	0.938

Table 3: Burger's Four-Element Model Constants for Creep of Eight Date Cultivars at Rutab Stage

Cultivar	J_0, (kPa)$^{-1}$	J_1, (kPa)$^{-1}$	τ_{ret}, (s)	η_N, (kPa.s)	R^2
Barhi	-15.43×10^{-4}	13.08×10^{-3}	4.47	37.83×10^{5}	0.984
Khudari	-5.09×10^{-4}	10.94×10^{-3}	4.81	0.84×10^{5}	0.992
Khlass	-11.61×10^{-4}	15.16×10^{-3}	5.18	0.85×10^{5}	0.994
Serri,	-8.41×10^{-4}	11.59×10^{-3}	4.30	1.60×10^{5}	0.993
Sukkari	-4.80×10^{-4}	5.46×10^{-3}	4.41	5.65×10^{5}	0.991
Suffri	-14.78×10^{-4}	11.59×10^{-3}	4.28	1.77×10^{5}	0.990
Saqie	6.94×10^{-5}	6.72×10^{-3}	4.49	0.70×10^{5}	0.979
NubotSaif	-12.23×10^{-5}	13.75×10^{-3}	5.59	1.16×10^{5}	0.993

CONCLUSIONS

The results of the creep-recovery experiments gave an objective indicator of the extent of deformation of date fruits when exposed to a sudden constant stress (dead load). Despite high toughness of *Barhi* cultivar, it has shown high susceptibility for deformation and medium ability to recover it. Burgers four-element model was highly satisfactory in predicting experimental data.

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