Physico-Chemical and Rheological Properties of Date Fruits Extract During Concentration

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ABSTRACT

Sewi date extract was extracted at high pressure and temperature and then concentrated under vacuum to 72.5 °Brix. Some physical, chemical and rheological properties of date extract were studied during concentration steps.

Moisture, acidity and reducing sugars contents gradually decreased during concentration, while total soluble solids (TSS), carbonyl compounds and pH values increased. Specific heat, thermal conductivity and thermal diffusion values decreased with increasing the TSS content. Also, colour attributes of date extract was found to be effected by concentration process. Whereas, lightness (L^*), yellowness (b^*), chroma, hue angle and whiteness index values decreased, while redness (a^*) values varied during concentration.

Rheological parameters were measured by Brookfield digital viscometer at temperature of 5-70°C. Three rheological models (Bingham, IPC Paste and Power law) were used to calculate the relationship between shear stress and shear rate. The flow behaviour of date extract changed during concentration from shear thickening behaviour at 7.5 to 40 °Brix ($n > 1$) to shear thinning (pseudoplastic) behaviour at concentration higher than 40 °Brix ($n < 1$). The plastic viscosity, yield stress, consistency coefficient and 10 rpm viscosity values gradually increased during concentration. The effect of temperature on viscosity was very well correlated with the Arrhenius equation ($r^2 > 0.90$).

Key words: date extract, colour, rheological properties, concentration process, chemical properties

INTRODUCTION

Date fruits (*Phoenix dactylifera*) are an important crop in many Arab countries. Date palm has emerged as an important commercial crop in the producing countries with significant increase in yield by adopting latest biotechnological application. Egypt is one of the largest date producers in the world. Egyptian production represents about 17.6% (1.13 million tons) of the total production of date in the world, which reaches about 6.4 million tons (FAO, 2008).

Most of the produced date fruits are consumed directly at their *Khalal*, *Rutab* and *Tamr* stages, with little or no further processing. Recently, the date producing countries gave more attention to the improvement and development of date processing. Many of date products like paste, syrup, dip, honey, jam, vinegar, bars, beverages, jelly, sheets and date-jutter are successfully marketed (Sumainah & Al-Nakhal, 1984; Yousif *et al*., 1987; Yousif *et al*., 1996, Mostafa *et al*., 2002).

Rheology of foods is crucial for improving the quality of food products and as many problems encountered in manufacturing including mixing, pumping and atomization during spray drying. Most concentrated structured fluids exhibit strong viscoelastic behaviour at small deformations and their measurement is very useful as a physical probe of the microstructure (Ahmed & Ramaswamy, 2005) and in processing equipment design, products development, storage and transportation and quality control of juices and purees (Oomah *et al*., 1999). The rheological behaviour of fruit juices and concentrates is influenced by their composition, especially type of fruit and the treatment performed in its technological process (Ibarz *et al*., 1996a). In addition, factors such as temperature and concentration influence rheological properties of these products (Rao *et al*., 1984; Ibarz *et al*., 1992, 1994). Presence of pectin substances or/and suspended solid particles cause non-Newtonian behaviour of juices and concentrates.

Colour is considered as an important sensory and quality attribute of food products. Maintaining coloured pigments in thermally processed and stored foods has been a major challenge in food processing (Clydesdale *et al*., 1970, Ihl *et al*., 1998). There are many factors that govern the degradation of colour and pigment during thermal processing of food products, such as non-enzymatic and enzymatic browning and process conditions (pH, acidity, oxidation, packaging material and duration and temperature of storage). Special care must be taken to produce food that retains a bright, attractive colour during food processing (Meyer, 1987). Change in colour during thermal processing may therefore be used as a tool to evaluate the product quality.

Despite the fact that thermal properties for a number of food products may be found in the literature (López-Ramos *et al*., 1993, Denys & Hendrickx, 1999), works on thermal properties of date fruits and date products are scarce. Specific heat, thermal conductivity and thermal diffusion of different date cultivars at three stages of maturity (*Khalal*, *Rutab* and *Tamr*) and date paste were determined experimentally at different moisture contents (Al-Askar, 1999, Hobani & Hassan, 2001). The thermal properties of date paste were found to vary linearly with moisture content.

This work was a trial to trace the changes of the physico-chemical, colour, thermal properties and rheological properties of date extract during concentration, which well be useful to control the quality of the final product. The product can be used as a substitute of black honey and in many food products as a sweetener or colourant material.

MATERIALS AND METHODS

Materials

Five hundred kilograms of Sewi (*Phoenix dactylifera*); semi-dry variety; date fruits at *Tamr* stage were obtained from a private orchard at El-Fayoum Governorate, Egypt. The annual production of this variety reached 145,000 tons, representing about 13% of the total production.

Methods

Preparation of date concentrate

Sewi date fruits were sorted, washed and then extracted by gradient extraction at high pressure (5–10 bars) and temperature (85-170°C) at three stages; the first stage at 85–100°C, 5 bar for 30 min, the second stage at 120–150°C, 8 bar for 120 min and the third stage at 150–170°C, 10 bar for 30 min (IWK Extractor, Industrie-Werke, Karlsruhe, Germany). The extract was centrifugated at 5590xg (Westfalia Separator, Niro, France) and then concentrated by thin layer evaporator (Electricte, Industrielle, Greer SA, Paris) under vacuum at 67°C to 72.5°Brix according to the Patent No. 22650 of El-Samahy *et al*. (2003).

Samples of date extract before and after centrifugation and during the concentration process (105 min.) were collected to study the changes occurred during the process.

Methods of analysis

Moisture, total soluble solids (°Brix), pH value, reducing and total sugars, titratable acidity (as citric acid) and crude pectin contents were determined according to the AOAC (1990). Total carbonyl compounds were determined as described by Lappin (1951).

Colour attributes; lightness (L^*), redness (a^*) and yellowness (b^*) were performed using a Minolta Colour Reader CR-10 (Minolta Co. Ltd., Osaka, Japan). The colour intensity (C^*) was calculated as $C^* = (a^{*2} + b^{*2})^{0.5}$. Furthermore, the hue angle (h_{ab}) was calculated as $h_{ab} = \tan^{-1}(b^*/a^*)$, where $h_{ab} = 0°$ for a red hue and $h_{ab} = 90°$ for a yellow hue (RØrå & Einen, 2003). Whiteness Index (WI) was expressed as: $WI = 100 - [(100-L^*)^2 + a^{*2} + b^{*2}]^{0.5}$ (Bolin & Huxsoll, 1991).

Density (ρ, Kg/m^3) was determined with a pyknometer at 25°C according to AOAC (1990). Specific heat ($C_p = 1.511 + 0.031$ M, KJ/Kg K), thermal conductivity ($k = 0.224 + 0.005$ M, W/m K) and thermal diffusion ($\alpha = k/\rho C_p$, m^2/s) were calculated as described by Hobani & Hassan, 2001, where M is the moisture content.

Rheological properties of extract during concentration process were carried out by the Brookfield digital rheometer model DV-III+. The Brookfield small sample adapter and $Sc_{4\text{-}14}$ and $Sc_{4\text{-}21}$ spindles were used. Data were analyzed using the Bingham plastic, IPC paste and Power Law mathematical models to provide a numerically and graphically analysis of the behavior of data sets (Hegedusic *et al*., 1995). These models are:

$\tau = \tau_o + \eta\gamma$, $\eta = KR^n$ and $\tau = K\gamma^n$, respectively; where: τ = shear stress (N m^{-2}), τ_o = yield stress, shear stress at zero shear rate (N m^{-2}), η = plastic viscosity (mPa.s) for Bingham and 10 rpm viscosity (mPa.s) for IPC paste, γ = shear rate (s^{-1}), K = consistency multiplier (mPa.s) for IPC paste and K = consistency coefficient (mPa.s) for Power Law, R = rotational speed (rpm), n = shear sensitivity factor for IPC paste and flow index for Power Law.

Activation energy and effect of temperature on viscosity were calculated using Arrhenius-type equation as mentioned by Ibarz *et al*., (1996a). The equation is: $\eta = \eta_\alpha \exp (E_a/ RT)$, where: η is the viscosity, $\eta\alpha$ is a constant, Ea is the activation energy, R is the gas constant and T is the absolute temperature in °K.

Statistical analysis

The analysis of variance (ANOVA) and LSD were performed as described by Ott (1984).

RESULTS AND DISCUSSION

Physico-chemical properties of the date extract during concentration

Some important physico-chemical properties related to foods are total soluble solids, total solids, sugars composition, moisture content, and pectin. These parameters could successfully be utilized for product development, quality control, shelf life prediction, packaging and storage.

Changes of some physico-chemical properties of date extract during concentration process are represented in Table (1). It was noticed that, moisture content of date extract did not change significantly (from 92.15 to 92.31%) after centrifugation as a result of removal of a part of non-soluble solids substance. Also, crude pectin, reducing and total sugars contents did not decrease significantly.

As a result of concentration process, the moisture content gradually decreased from 92.31 to 23.52% at the end of concentration process (105 min), while the TSS content increased up to 72.5 °Brix. A significant increase was observed in the pH value at the first 35 min (from 3.80 to 4.53) then it significantly increased to 4.80 for the final concentrate. The total acidity content slightly changed during concentration. It decreased significantly from 0.512% at the beginning of concentration to 0.495% at the end of the process.

During concentration, crude pectin content gradually increased from 1.49 up to 2.92% after 70 min of process then it gradually and significantly decreased to 2.46% at the end of the process. This may be referred to the degradation of pectin to simple sugars during process.

Regarding the total carbonyl compounds (as hydroxymethyl furfural), the results showed a significant increase in their content from 0.229% to 0.411% after 50 min of the concentration time, and then they gradually increased up to 0.599% at the end of the process (105 min). The marked increase at the beginning of the process may be attributed to the higher thermal conductivity at this period and the high effect of heat on sugars. After this period up to the end of the process, the thermal conductivity was found to decrease as a result of removal the water and the low effect of heat on sugars.

Reducing sugars decreased gradually from 72.46% at the beginning of the process to 62.08% at the end of concentration. This may be attributed to the non-enzymatic browning (sugar carmalization or Maillard reaction) occurred during process. The same observation was noticed for total sugars, but they decreased from 86.96 to 84.77% after 50 min of the concentration, then they gradually increased to 87.81% at the end of the process (Table, 1). This may be attributed to the hydrolysis of polysaccharides such as pectin to simple sugars during process.

Changes of colour attributes of the date extract during concentration

Colour is an important sensory quality attribute of food products because it is usually the first property that the consumer observes and minimizing the colour losses during processing and storage is of primary concern to the processor (Ahmed & Ramaswamy, 2006).

The colour values for lightness (L^*), redness (a^*) and yellowness (b^*) significantly increased due to the centrifugation before concentration process (Table, 2). The values increased from 23.9, 3.9 and 5.2 before centrifugation to 27.0, 4.3 and 7.1 after centrifugation for L^*, a^* and b^*, respectively. The colour intensity (C^*) also increased from 6.5 to 8.3 as a result of centrifugation. The hue angle (h_{ab}) increased from 53.1 to 58.8, indicating a yellowish colour of date extract.

During the concentration process, the lightness values (L^*) decreased significantly from 27.0 to 19.1 in the final concentrate (Table, 2). This may be attributed to the non-enzymatic browning and sugar carmalization. Furthermore, the concentration process led to decrease significantly the b^* values from 7.1 at the beginning of the process to 2.0 at the end. This was associated with increasing of a^* values from 4.3 to 7.8 after the first 35 min of process, then the values gradually decreased to 6.2. The relative values of *a*/b** gradually increased during concentration. These results complied with h_{ab} values, which decreased from 58.8 to 17.9, indicating a more reddish colour of the date concentrate.

Whiteness Index (WI) indicates the development of white surface discoloration. The higher the WI scores the more severe the white discoloration. Results represented in Table (2) show that the WI value increased significantly from 23.6 to 26.5 as

Table 1: Changes of physico-chemical properties* of the date extract during concentration process

Concentration time (min)	Moisture Content %	TSS °Brix	pH value	Acidity** % (as citric acid)	Total pectin** %	Total carbony*l*** compounds % (as HMF)	Sugars** % Reducing	Total
0 Before centrifugation	92.15^{a}	7.5^{k}	3.81^{d}	0.512^{ab}	1.53^{f}	0.228^{g}	74.60^{a}	87.21^{ab}
0 After centrifugation	92.31^{a}	7.5^{k}	3.80^{d}	0.512^{ab}	1.49^{f}	0.229^{g}	72.46^{ab}	86.96^{ab}
35	66.50^{b}	33.0^{j}	4.53^{c}	0.519^{a}	2.42^{e}	0.261^{g}	71.69^{abc}	85.36^{bc}
50	60.66^{c}	38.5^{i}	4.60^{bc}	0.512^{ab}	2.42^{e}	0.411^{f}	70.48^{bcd}	84.77^{c}
60	55.47^{d}	44.0^{h}	4.62^{b}	0.510^{abc}	2.88^{a}	0.432^{ef}	70.71^{bcd}	85.32^{bc}
70	50.40^{e}	49.0^{g}	4.62^{b}	0.510^{abc}	2.92^{a}	0.462^{de}	68.56^{cde}	86.99^{ab}
80	45.93^{f}	51.0^{f}	4.65^{b}	0.508^{abc}	2.82^{ab}	0.492^{cd}	67.80^{de}	86.23^{abc}
85	42.24^{g}	55.5^{e}	4.65^{b}	0.508^{abc}	2.72^{bc}	0.504^{cd}	67.56^{de}	87.51^{a}
90	36.32^{h}	60.0^{d}	4.77^{b}	0.490^{cd}	2.67^{cd}	0.541^{bc}	65.89^{e}	87.14^{ab}
95	30.78^{i}	65.0^{c}	4.78^{a}	0.490^{cd}	2.62^{cd}	0.567^{ab}	65.68^{e}	87.57^{a}
100	26.55^{j}	70.0^{b}	4.79^{a}	0.482^{d}	2.61^{d}	0.570^{ab}	65.73^{e}	87.31^{ab}
103	25.61^{k}	70.5^{b}	4.80^{a}	0.497^{bcd}	2.48^{e}	0.598^{a}	62.16^{f}	87.61^{a}
105	23.52^{l}	72.5^{a}	4.80^{a}	0.495^{bcd}	2.46^{e}	0.599^{a}	62.08^{f}	87.81^{a}

* Means of triplicates HMF= Hydroxymethel furfural

** On dry weight basis

Means having the same letter within each property are not significantly different at $P \leq 0.05$

Table 2: Changes of colour attributes* of the date extract during concentration

Concentration (time (min	(Date extract (°Brix	*L	*a	*b	*C	h_{ab}	WI
0	Before centrifugation 7.5	23.9^{c}	3.9^{f}	5.2^{b}	6.5^{f}	53.1^{b}	23.6^{bc}
0	After centrifugation 7.5	27.0^{a}	4.3^{f}	7.1^{a}	8.3^{ab}	58.8^{a}	26.5^{a}
35	33.0	24.9^{b}	7.8^{a}	4.1^{c}	8.8^{a}	27.7^{c}	24.4^{b}
50	38.5	24.0^{c}	7.4^{ab}	3.6^{d}	8.2^{ab}	25.9^{d}	23.6^{bc}
60	44.0	23.4^{c}	7.4^{ab}	3.4^{de}	8.1^{bc}	24.7^{de}	23.0^{c}
70	49.0	23.2^{cd}	7.4^{ab}	3.3^{def}	8.1^{bc}	24.0^{e}	22.8^{cd}
80	51.0	22.5^{d}	7.2^{bc}	3.3^{def}	7.9^{bc}	24.6^{de}	22.1^{de}
85	55.5	22.5^{d}	6.8^{cd}	3.1^{ef}	7.5^{cd}	24.5^{de}	22.1^{de}
90	60.0	21.6^{e}	6.5^{de}	3.1^{ef}	7.2^{de}	25.5^{de}	21.3^{e}
95	65.0	20.3^{f}	6.6^{de}	3.0^{f}	7.2^{de}	24.4^{de}	20.0^{f}
100	70.0	20.1^{f}	6.3^{e}	3.0^{f}	7.0^{def}	25.5^{de}	19.8^{f}
103	70.5	19.9^{fg}	6.4^{de}	2.1^{g}	6.7^{ef}	18.2^{f}	19.6^{fg}
105	72.5	19.1^{g}	6.2^{e}	2.0^{g}	6.5^{f}	17.9^{f}	18.8^{fg}

*Means of ten readings

Means having the same letter within each property are not significantly different at $P \leq 0.05$

a result of centrifugation. During concentration, the WI values decreased significantly from 26.5 to 18.8, indicating a darkness of the date concentrate.

Density and thermal properties of the date extract during concentration

Determination the density is important as it contributes with viscosity and their values are used in calculation of the Renolds number (Re), which is the most important in calculation of friction loss, pressure drop and pump sizing. Also, density, specific heat and thermal conductivity can be used to estimate the thermal diffusion (Figura & Teixeira, 2007).

Density of the date extract during concentration is shown in Table (3). The density non-significantly decreased from 1.0277 to 1.0259 Kg m^{-3} as a result of centrifugation. During concentration, density gradually increased from 1.0259 for date extract (7.5 °Brix) to 1.3572 Kg m^{-3} for the concentrate (72.5 °Brix). These results are in agreement with those obtained by Ramos & Ibarz (1998). They found that density of orange and peach juices increased with increasing the soluble solids concentration.

The specific heat capacity is required in cooling, freezing and heat processing, and for calculation the energy demand. Specific heat used in the estimation of Prandtl group, which is important in process calculation and energy application. Specific heat of the date extract decreased gradually and significantly with increasing the soluble solids content. It decreased from 4.3726 KJ/Kg.K for date extract (7.5 °Brix) to 2.2401 KJ/Kg.K for the final concentrate (72.5 °Brix). The same observation was noticed for the thermal conductivity (k) and thermal diffusivity (α). They significantly decreased from 0.6856 W/m.k and 0.1528 m2/s at the beginning of the concentration process to 0.3416 W/m.K and 0.1124 m2/s at the end of the process, respectively (Table, 3). Generally, specific heat, thermal conductivity and diffusion increased consistently with increasing moisture content. These results are in good agreement with those reported by several investigators for similar high sugar foods (Ramaswamy & Tung, 1981, Rahman, 1995).

Changes of rheological properties of the date extract during concentration

The rheological properties of Sewi date extract were studied at different total soluble solids at 20°C during the concentration process and data are presented in Table (4).

As the viscosity is depending upon the intermolecular distances and when the TSS increase the intermolecular distances decrease, it was normally to watch the increment in the plastic viscosity and/

Table 3: Changes* of density (ρ), specific heat (C_p), thermal conductivity (k) and thermal diffusion (α) of the date extract during concentration

Concentration time (min)	Date extract (°Brix)	ρ (Kg/m³)	C_p (KJ/Kg. K)	k (W/m. K)	α (m²/s)
0	7.5 Before centrifugation	1.0277^{i}	4.3677^{a}	0.6848^{a}	0.1526^{a}
0	7.5 After centrifugation	1.0259^{i}	4.3726^{a}	0.6856^{a}	0.1528^{a}
35	33.0	1.1408^{h}	3.5725^{b}	0.5565^{ab}	0.1365^{ab}
50	38.5	1.1682^{g}	3.3915^{bc}	0.5273^{abc}	0.1331^{abc}
60	44.0	1.1967^{f}	3.2306^{bcd}	0.5014^{abc}	0.1297^{bcd}
70	49.0	1.2225^{e}	3.0734^{bcde}	0.4760^{bc}	0.1267^{bcd}
80	51.0	1.2327^{e}	2.9348^{cdef}	0.4537^{bc}	0.1254^{bcd}
85	55.5	1.2582^{d}	2.8204^{defg}	0.4352^{bc}	0.1226^{bcd}
90	60.0	1.2836^{c}	2.6369^{efgh}	0.4056^{bc}	0.1198^{bcd}
95	65.0	1.3124^{b}	2.4652^{fgh}	0.3779^{bc}	0.1168^{bcd}
100	70.0	1.3423^{a}	2.3341^{h}	0.3568^{bc}	0.1139^{cd}
103	70.5	1.3448^{a}	2.3049^{h}	0.3521^{c}	0.1136^{cd}
105	72.5	1.3572^{a}	2.2401^{h}	0.3416^{c}	0.1124^{d}

*Means of three calculations
Means having the same letter within each property are not significantly different at $P \leq 0.05$

Table 4: Changes of rheological properties* (at 20°C) of the date extract during concentration

Concentration time (min)	Date extract (°Brix)	Plastic viscosity (η)	Yield stress (τ_0)	Consistency coefficient (k)	Flow index (n)	Viscosity at 10 rpm
0	7.5 Before centrifugation	0.88[l]	0.00	0.09[l]	1.13[a]	2.16[l]
0	7.5 After centrifugation	0.73[l]	0.00	0.05[l]	1.22[a]	1.35[l]
35	33.0	7.98[k]	0.00	0.43[k]	1.15[a]	6.07[k]
50	38.5	16.20[j]	0.05[h]	1.74[j]	1.00[b]	17.30[j]
60	44.0	25.30[i]	0.14[g]	4.27[i]	0.90[cd]	33.90[i]
70	49.0	36.90[h]	0.24[f]	8.72[h]	0.85[de]	54.70[h]
80	51.0	50.20[g]	0.38[e]	13.20[g]	0.86[de]	81.60[g]
85	55.5	79.60[f]	0.45[e]	15.40[f]	0.89[cd]	113.5[f]
90	60.0	139.60[e]	0.67[d]	23.90[e]	0.96[bc]	186.90[e]
95	65.0	402.70[d]	0.63[d]	48.90[d]	0.81[def]	464.60[d]
100	70.0	678.60[c]	3.17[c]	222.60[c]	0.79[ef]	1995.0[c]
103	70.5	1199.00[b]	9.00[b]	406.30[b]	0.73[fg]	2812.00[b]
105	72.5	1780.00[a]	12.50[a]	484.90[a]	0.64[g]	3947.00[a]

K= mPa.s, n= Dimensionless, η= mPa.s τ_0= N m^{-2}, viscosity at 10 rpm = mPa.s
*Means of triplicates
Means having the same letter within each property are not significantly different at $P \leq 0.05$

or viscosity at 10 rpm (mPa.s) by increasing the concentration (Table, 4). The increment was more pronounced after the concentration 65 °Brix. Where, the viscosities increased from 0.73 and 1.35 mPa.s to 79.60 and 113.5 mPa.s when the concentration increased from 7.5 to 55.5°Brix and to 1780.0 and 3947.0 mPa.s when the concentration increased up to 72.5°Brix in case of plastic viscosity and viscosity at 10 rpm, respectively.

Regarding yield stress (τ_0) data (Table, 4), there was a little bit increase (from 0.0 to 0.63 Nm^{-2}) till the concentration reached 65°Brix, after that there was a pronounced increase (from 0.63 to 12.5 Nm^{-2}) till it reach 72.5 °Brix. Yield stress is related to the existence of the reticulated structure, which is generally due to the interaction between colloidal particles or the formation of links between the long chain molecules. The yield stress value in products is related to the factors, influencing gel formation, such as pH, sugar and pectic contents (Alonso *et al.*, 1995).

The consistency coefficient (k) values increased with increasing the total soluble solids. Whereas, they increased from 0.05 mPa.s for the date extract (7.5°Brix) to 484.90 mPa.s for the concentrate (72.5°Brix).

Concerning the flow index (n) values, they decreased gradually and significantly from 1.22 to 1.00 when the concentration changed from 7.5 to 38.5 °Brix. Then, they decreased to 0.64 for the final concentrate (72.5°Brix). This means that, the flow behaviour of the date extract changed during the concentration process from shear thickening behaviour (dilatent; $1 < n < \infty$) at low concentration (<40°Brix) to shear thinning behaviour (psedoplastic; $0 < n < 1$) at high concentration (>40°Brix). These results are in agreement with those obtained by Ibarz & Pagan (1987) and Juszczak & Fortuna (2003). They found that the consistency coefficient (k) of raspberry and strawberry juices increased with increasing the soluble solids content, whereas flow index (n) tended to decrease.

Effect of temperature on viscosity of the date extract during concentration

The change in apparent viscosity of Sewi date extract during concentration with temperature (5 –70°C) can be described by an Arrhenius-type equation. The parameters of this equation; activation energy (E_a) and viscosity constant (η_α), are shown in Table (5).

The activation energy of the flow was related to some fundamental thermodynamic properties of the Newtonian fluids. For example ΔE_a was found to be approximately equal 1/3 or 1/4 the heat of vaporization, depending on the shape and binding of liquid molecules (VanWazer *et al.*, 1963).

Table 5: Parameters* of Arrhenius equation of the date extract during concentration (temperature range 5-70°C)

Concentration time (min)	Date extract (°Brix)	Ea (KJ/Kmol)	η_α (mPa.s)	Coefficient of correlation (r^2)
0	7.5 Before centrifugation	4226.96[m]	2.0×10^{-9}[c]	0.94
0	7.5 After centrifugation	4763.24[l]	2.2×10^{-9}[c]	0.95
35	33.0	15130.55[k]	1.6×10^{-3}[bc]	0.97
50	38.5	17080.55[j]	2.5×10^{-3}[bc]	0.98
60	44.0	19379.20[i]	3.6×10^{-3}[bc]	0.95
70	49.0	21712.06[h]	9.7×10^{-3}[a]	0.91
80	51.0	24863.38[g]	4.0×10^{-3}[b]	0.94
85	55.5	27020.14[f]	2.0×10^{-3}[bc]	0.97
90	60.0	28721.26[e]	1.9×10^{-3}[bc]	0.95
95	65.0	32536.74[d]	7.0×10^{-4}[c]	0.92
100	70.0	40321.51[c]	1.0×10^{-4}[c]	0.95
103	70.5	41591.95[b]	1.1×10^{-4}[c]	0.97
105	72.5	46364.42[a]	2.0×10^{-5}[c]	0.94

*Means of triplicates
Means having the same letter within each property are not significantly different at $P \leq 0.05$

The activation energy (E_a) increased by centrifugation from 4226.96 to 4763.24 KJ/Kmol as a result of removing some of the suspended particles. During concentration, the E_a values gradually increased up to 46364.42 KJ/Kmol for the final concentrate.

Viscosity constant (η_α) did not change significantly by centrifugation, but it significantly increased from 2.2×10^{-9} for date extract (7.5 °Brix) to 9.7×10^{-3} mPa.s for the 49.0 °Brix concentrate. Then, it significantly decreased to 2.0×10^{-5} in the final concentrate. Ibarz *et al*. (1996b,c) reported that the E_a of sloe and toquat juices increases with increasing the sugar content and decreases with increasing the pulp content. On the other hand, the η_α increases with increase in total solids and pectin content (Manohar *et al*., 1990).

In conclusion, concentration process of date extract had a pronounced effect on most quality properties of the final date concentrate. Controlling the concentration conditions can minimize the undesirable effects on quality parameters of the product.

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الخصائص الفيزيوكيماوية والريولوجية لمستخلص ثمار البلح أثناء التركيز

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تم تحضير مستخلص ثمار البلح السيوي علي ضغط ودرجة حرارة مرتفعين ثم تم التركيز تحت تفريغ الي ٧٢,٥°بركس. وتم دراسة بعض الخصائص الطبيعية، الكيماوية والريولوجية للمستخلص أثناء مراحل عملية التركيز.

أوضحت النتائج انخفاض محتوى المستخلص من الرطوبة، الحموضة والسكريات المختزلة أثناء عملية التركيز بينما حدث ارتفاع في المواد الصلبة الذائبة الكلية، المركبات الكربونيلية وقيم الـ pH. انخفضت قيم الحرارة النوعية، التوصيل الحراري والانتشار الحراري بزيادة محتوى المواد الصلبة الذائبة الكلية. أيضا تأثرت خصائص اللون بعملية التركيز حيث انخفضت قيم وضوح اللون (L*)، درجة الاصفرار (b*)، كثافة اللون (C*) و WI بينما اختلفت قيم درجة الاحمرار (a*).

تم تقدير الخصائص الريولوجية للمستخلص أثناء التركيز عند درجات حرارة من ٥ – ٧٠°م باستخدام جهاز بروكفيلد. وتم تحليل البيانات المتحصل عليها باستخدام ثلاثة أنماط من المعادلات لتوضيح العلاقة بين إجهاد القص ومعدل القص وهي: بنجهام، IPC paste وقانون الأس وتم تقدير الثوابت الريولوجية ذات الأهمية التطبيقية في التصنيع الغذائي. واتضح من خلالها تغير سلوك انسياب المستخلص أثناء التركيز من الديالاتينت عند التركيزات من ٧,٥ الي أقل من ٤٠° بركس الي الزودوبلاستيكي (البلاستيكي الكاذب) عند درجات التركيز الأعلى من ٤٠°بركس. وقد ازدادت قيم اللزوجة البلاستيكية، إجهاد الخضوع، معامل القوام واللزوجة عند ١٠ لفات أثناء التركيز.

كما تم دراسة تأثير درجة الحرارة علي اللزوجة باستخدام معادلة أرهينيوس. وأوضحت النتائج المتحصل عليها من خلال المعادلة أن للحرارة تأثيراً واضحاً علي لزوجة المستخلص أثناء التركيز حيث كانت قيمة r^2 أكبر من ٠,٩٠.