Rheological Properties of Some Egyptian and European Tomato products

Sharoba, A.M. [*§]*; Senge, B.* [§]*; El-Mansy, H.A.* [*]*; Bahlol, H.EL.M.* [*]
and Blochwitz, R. [§]

The rheological behaviour of tomato juice, puree and paste were measured in shear rate range 0.0 to 100 s^{-1} and Oscillatory tests were studied at a wide range of temperatures (0 - 50 °C) using a Physica UDS 200 rheometer. The results indicated that these tomato juice, puree and paste behave as non-Newtonian fluids (pseudoplastic) and have a definite yield stress. The relationship between (η_{eff}) and temperature of tomato products under investigation was examined. Higher significantly correlation was found between (η_{eff}) and temperature. The η_{eff} decrease with increase in temperature. Oscillatory test data revealed weak gel-like (dispersion structure) behaviour of the tomato products: magnitudes of G´ were higher than those of G´´, and both increased with oscillatory frequencies. The effect of temperature on their viscosity can be described by means of an Arrhenius-type equation. The flow activation energy for viscous flow depends on the chemical composition; the flow activation energy increases with the total solids contents. Chemical and physical tests for tomato products were made.

Key words: Tomato juice puree and paste. Rheological parameters. Flow behaviour. Oscillatory test. Activation energy. Chemical composition

INTRODUCTION

Viscosity is usually considered an important physical property related to the quality of food products. Viscometric data are also essential for the design evaluation of food processing equipment such as pumps, piping, heat exchangers, evaporators, sterilizes filters and mixtures. Many foods of commercial importance, such as tomato paste and tomato puree are concentrated dispersions of insoluble matter in aqueous media. Their rheological behaviour, especially the yield point, is important in the handling, storage, processing and transport of concentrated suspensions in industry, Rao (1987). The viscosity of fluid foods is an important parameter of their texture. It determines to a great extent the overall mouth-feel and influences the intensity of flavour (Thomas *et al.,* 1995). Therefore, for many years, the viscosity of liquid and semi solid foods has been of interest to researchers and industrialists. All the test modes discussed so far involve subjecting the foodstuff to a step change in $\dot{g}$ or τ and measuring the stress as a function of time. A useful procedure in the study of food rheology is to subject the same to a periodic deformation. If the rheological behaviour is studied through a dynamic test, the stress is made to vary sinusoidally with time at a determined frequency (ω). Oscillation is a non-destructive technique for investigating the structure of foods. It is an ideal method for measuring structural formation changes. Form the application of this technique, which is especially valuable for small values of times, several rheological parameters were defined by Bistany and Kokini (1983a,b).

The present work was done to determine the rheological behaviour of tomato products in steady and dynamic shear, with relationship of chemical composition and temperature.

MATERIALS AND METHODS

1. *Materials:*

Tomato products:

Tomato juice Vitafit obtained from Lidl supermarket Schöneberg, Berlin, Germany. Tomato puree (Primadonna) producted in Italia, obtained also from Lidl supermarket Schöneberg, Berlin, Germany. Tomato paste (The read star, Cairo Co., for Food Producition) obtained from local supermarket in Egypt.

2. *Methods:*

2.1. Analytical methods:

Moisture content, total solids, ash, ascorbic acid, starch, were determined according to A.O.A.C. (1995) methods. The pH was measured with a pH-meter Schott CG840. Titratable acidity was determined by titration with NaOH 0.1 N solution using phenolphthalein as indicator according to A.O.A.C. (1995). Total and reducing sugars determined by Shaffer and Hartman method as described in the A.O.A.C. (1995). Total pectic substances contents were determined by the method of Carre and Hayness, which was described by Pearson (1976). Pulp content determined according to El-Mansy *et al.*,(2000a). Colour index of was determined by the method of Meydov *et al.,* (1977). Carotenoids were determined according to Wettestein (1957), while lycopene was determined according to Ranganna (1997). Specific heat (cp) was determined according to Alvarado (1991). Density was determined with a pyknometer at 5 and 30 °C according to A.O.A.C. (1995).

2.2. Rheological measurements:

All measurements: Rotational and Oscillatory measurements have been performed on a Physica UDS 200 rheometer (Universal Dynamic Spectrometer) equipped with an electronically commutated synchronous motor allowing rheological testing in controlled stress and control strain modes.

The instrument allows the individual creation of complex real time tests containing a large number of different intervals in controlled stress and strain control, both in rotational and oscillatory modes. The direct strain Oscillation option based on a real position control as described above has been used for oscillatory testing.

Precise temperature control was done by a Peltier Cylinder temperature system TEZ150P that assures minimal temperature gradients across the measuring gap by a patent protected design.

The data analysed by using Universal Software US200.

The Herschel-Bulkley model: This model describes the flow curve of a material with a yield point and shear thinning or shear thickening behaviour at stresses above the yield in compression with the Casson or Ostwald equations with a higher correlation coefficient.

$\tau = \tau_0 + K \cdot \dot{g}^{\ n}$ (1)

Casson Model: Application for fluids with yield point: the flow behavior beyond yield points often differs from that of ideal-viscous fluids. The Casson dynamic viscosity also useful because it is equivalent to the infinite shear viscosity of shear thinning dispersions Yoo and Rao (1995). Therefore, it can be used to calculate relative viscosity.

$(t)^{0.5} = (t_{0C})^{0.5} + (\eta_C \cdot \dot{g}\,)^{0.5}$ **(2)**

Ostwald Model: Application: Precondition: the viscosity decreases with increasing load. This behavior is a characteristic feature of pseudoplastic substances.

$t = \mathbf{m}\ \dot{g}^{\ \mathbf{p}}$ **(3)**

Effective viscosity: The effective viscosity was calculated using equations (2) as mentioned by Senge (2001) and Senge *et al.* (1996)

$\eta_{eff\ HB} = (t_{0HB} / \dot{g}\,) + K \cdot \dot{g}^{\ n-1}$ **(4)**

$\eta_{eff\ CA} = (t_{0CA} / \dot{g}\,) + \eta_{CA} + 2\,[(t_{0CA})^{0.5} \cdot (\eta_{CA} / \dot{g}\,)^{0.5}]$ **(5)**

Hysteresis area: the evaluation method Hysteresis Area calculates the area between two curves, commonly the up and down curve of a shear rate sweep. This area is given in (Pa/s)

Oscillatory measurements analysis:

The oscillatory evaluated variables: Storage modulus G\`, loss modulus G\`\` and angular frequency ω were described by equation 6 and 7

$G' = K_1' \cdot (\omega)^x$ ***(6)***

$G'' = K_2'' \cdot (\omega)^y$ (7)

Plots of log ω vs log G´, log G´´ dynamic rheological data were subjected to linear regression and the magnitudes of intercepts, slopes, and R^2 were tabled according to Rao and Cooley (1992), Yoo and Rao (1996).

Flow activation energy and the effect of temperature on viscosity:

Flow activation energy was calculated using Arrhenius-type equation as mentioned by El-Mansy *et al.*,(2000a,b), Ibarz *et al.*, (1996a):

$\eta = \eta_\infty \exp(Ea / RT)$ (8)

RESULTS AND DISCUSSION

:

Physical and chemical properties of tomato puree, juice and paste:

Physiochemical changes in the constituents of tomato fruits influence the rheological and sensory properties of the final product and hence its acceptability. The major components of the tomato are mainly reducing sugars, organic acids and pectic substances. In addition, there are some minor constituents, such as ascorbic acid, pigments, starch, ash and other insoluble solids, which contribute to tomato juice quality. Since the quality of processed tomato products depend greatly upon the initial composition of raw material it seems quite important to determine the initial contents of such components and to trace the changes that occur mainly during thermal treatments, as they affect the final quality attributes of the product. Table (2) lists the analysed composition of the investigated tomato products. As expected, a good correlation was found between total solids (TS) and (ash, titratable acidity, pH values, ascorbic acid, starch, total sugars, total pectic substances, pulp content, specific heat capacity and density). From the results obtained, the following equations were proposed (Table 2):

Table (1)

Equ.-No.	Equ.	R^2
5.1	Ash = (0.0409 * TS) + 0.08	0.997
5.2	Acidity = (1.996 * TS) – 14.51	0.990
5.3	pH = (-0.025 * TS) + 4.72	0.932
5.4	Ascorbic acid = (0.9696 * TS) + 9.386	0.980
5.5	Total Sugars = (0.4617 * TS) - 0.156	0.996
5.6	Total Pectic = (0.231 * TS) + 0.766	0.999
5.7	Pulp content = (1.355 * TS) + 2.874	1
5.8	Cp = (0.0173 * TS) + 1.544	0.999
5.9	ρ = (7.290 * TS) + 994.65	0.963

From these results, it could be concluded that the total solid had highest effect on physical and chemical properties of tomato products. On the same time earlier studies have shown that solids loading plays an important role in the rheological behavior of tomato concentrates. The results were in agreement with the result showed by Jimenez *et al.*, (1989 a,b), and Porretta (1993). The importance of determining the density is that it contributes with viscosity and its values are used in calculation the Reynolds number as follows:

$$Re = d.v.\rho / \eta$$

which is the most important in calculation of friction loss, pressure drop and pump sizing. Heat transfer is only portioned by use of the mechanical condition.

$$Pr = \upsilon/\alpha$$

Where υ = Kinematic viscosity ($m^2\ s^{-1}$)

$\alpha = Cp/K$

Table (2) Physical and chemical properties of tomato puree, juice and paste

Components	Puree	Juice	Paste
Moisture %	91.13±0.12	93.55±0.22	73.28±0.27
Total solids %	8.87±0.12	6.45±0.22	26.72±0.27
Ash %	0.47±0.01	0.32±0.02	1.17±0.04
Titratable acidity %	0.82±0.01	0.46±0.01	2.23±0.01
pH value	4.42±0.05	4.63±0.01	4.06±0.03
Ascorbic acid (mg/100 ml)	19.61±0.11	14.21±0.05	35.10±0.09
Starch%	0.18±0.01	0.08±0.00	2.74±0.05
Total sugars %	4.27±0.01	2.53±0.03	12.14±0.14
Reducing sugars %	3.02±0.02	1.91±0.01	9.53±0.12
Non-reducing sugars %	1.25	0.62	2.61
Total pectic substances %	2.89	2.19	6.93
Water soluble pectin %	0.83±0.02	0.52±0.03	2.13±0.09
Ammonium oxalate soluble pectin %	1.51±0.04	1.40±0.04	3.27±0.12
Acid soluble pectin %	0.55±0.02	0.27±0.01	1.53±0.04
Pulp Content (V/V) %	14.8±0.25	11.7±0.11	39.1±0.78
Color index (O.D. at 420 nm)	1.18±0.02	1.02±0.02	3.94±0.03
Lycopene mg/100 g	16.22±0.11	14.40±0.23	37.65±0.31
Carotenoids (mg/L)	2.64±0.05	2.29±0.09	6.76±0.14
Specific heat capacity kJ/kg K	1.696±0.12	1.658±0.08	2.008±0.25
Density at temperature 5 °C (kg/m^3)	1086.74±0.77	1035.06±0.63	1199.24±0.91
Density at temperature 30 °C (kg/m^3)	1076.11±0.89	1026.87±0.53	1187.43±0.85

**Each value is the average of three replicates ±S.E.*

**Chemical composition on wet weight basis*

Rheological properties of some commercial tomato products:

Rheological properties of fluid foods are useful for designing flow and handling systems, quality control and for sensory evaluation. Consistency (viscosity) plays an important role in determining the quality of tomato products. Organoleptic qualities of some of the products such as tomato juice, puree, paste and ketchup depend upon their viscosity, and products with low viscosity may be sold at lower prices or even graded unacceptable: Thakur and Singh (1995).

Much research papers have been published on the relationship between tomato juice viscosity and different compositional characteristics, but few attempts have been made to establish this relationship quantitatively. Ouden and Vliet (2002) have found a correlation between the apparent viscosity of the juice, as well as of the concentrate, and the serum viscosity and the pulp content. The relative contribution of the pulp content to the juice viscosity was larger than that of the serum viscosity, which in turn was also correlated with the concentration of soluble pectin. Similarly, Marsh *et al.* (1980) and Beresovsky *et al.* (1995) have developed an empirical correlation between viscosity of the concentrate and of the juice and the ratio between the water insoluble solids and the total solids.

1.Shear rate examination:

Viscosity is an important quality parameter of tomato (puree, juice and paste) and large numbers of studies have been conducted on factors affecting it. Viscosity of tomato products depends on the method of preparation, the heat and mechanical treatment, in addition to the variety and maturity of the tomatoes. As can be seen, the plots in Figs.1-3 the shape of the curve indicates pesudoplasticity, and yield point. Also in Figs.1-3 illustrates acceleration curves as apparent viscosity versus shear rate. Highly significant differences in apparent viscosity ($P \leq 0.01$) exist at all rotation speeds. In this type of fluids, the shear stress curve does not begin at the origin of the shear stress-shear rate plot, and the curve initially increases rapidly but begins to tail off.

The application of the Herschel-Bulkley and Casson Models are tabulated in Table (3).

Used Herschel-Bulkley (HB) model:

The flow curves data for tomato products were fitted to the HB model, all samples presented a very good fit (r higher than 0.95). Table 3 shows τ_0, n and K values as well as the goodness of the fit and standard deviation. The different concentration and chemical composition for tomato products, has a large effect on the apparent viscosity according to Ouden and Vliet (2002) they found also higher effect for degree of concentration, particle size and process condition on viscosity of tomato products.

Yield stress τ_{0HB}:

There were good linear correlations ($r = 0.995$) between τ_{0HB} and pulp content of tomato products. The following equation (12) described the correlations between τ_0 and pulp content.

$$\tau_{0HB} = (0.6361 * \text{pulp content}) - 5.3841 \qquad (12)$$

Yoo and Rao (1994); found that the yield stress values of tomato puree samples could be correlated with the pulp content. The same results were observed by El-Mansy *et* *al.*,(2000a); they found that the yield stress correlated with pectin content and pulp content.

Flow behavior index:

The values for flow behavior index n were always lower than 1 which indicates the pseudoplastic nature of all tomato products evaluated.

Consistency index (K):

The magnitude of K of the tomato juice, puree and paste increased with increasing in total solid and total pectic substances (see Table 2). It increased from 0.94 Pa.sn for tomato juice to 3.0 and 71.05 Pa.s^n for tomato puree and tomato paste at 20 ° C, respectively.

Casson model (CA):

The CA model was used to describes the rheological behavior for tomato products. The Casson model equation was found a good model to describe the flow behavior of tomato products Table (3). Values of r were ranged between 0.91 to 0.99.

Casson yield point (τ_{0CA}):

The yield value for CA model were higher than HB model yield point values for various tomato products. This value in tomato juice is lower than that of tomato puree and tomato paste. Because the different in pulp content (see Table 2) and may be depended on Particle size (Noomhorm and Tansakul (1992), Yoo and Rao (1994))

Table(3) Herschel-Bulkley and Casson parameters of some selected commercial tomato products

Product	T	*Herschel-Bulkley*						*Casson*					A_{TH}
		τ_0	K	n	r	S.D.	η_{eff}	τ_0	η_{CA}	r	S.D.	η_{eff}	
	°C	Pa	Pa.s^n			Pa	Pas	Pa	Pa.s		Pa	Pa.s	Pa/s
Lidl tomato juice	0	1.7867	1.0131	0.3789	0.9993	0.0504	0.0759	2.4847	0.0162	0.9819	0.2615	0.0812	-18.4718
	10	1.5697	0.9930	0.3556	0.9987	0.0613	0.0668	2.2855	0.0135	0.9790	0.2426	0.0715	-16.8703
	20	1.4259	0.9364	0.3403	0.9979	0.0672	0.0591	2.1208	0.0113	0.9776	0.2168	0.0635	-6.0066
	30	1.5592	0.6815	0.3664	0.9979	0.0563	0.0524	2.0515	0.0085	0.9851	0.1497	0.0554	0.9158
	40	1.1851	0.8138	0.3191	0.9975	0.0558	0.0472	1.8126	0.0082	0.9751	0.1754	0.0507	9.4349
	50	1.0614	0.9368	0.2907	0.9967	0.0622	0.0463	1.8061	0.0080	0.9685	0.1913	0.0501	21.8301
Lidl tomato puree	0	5.4511	2.9055	0.3463	0.9979	0.2120	0.1977	7.6134	0.0334	0.9810	0.6421	0.2104	41.7352
	10	4.9607	2.9557	0.3233	0.9964	0.2501	0.1806	7.2424	0.0288	0.9779	0.6165	0.1926	99.9203
	20	4.4774	2.9972	0.2984	0.9957	0.2397	0.1632	6.8759	0.0241	0.9737	0.5883	0.1743	90.3914
	30	3.2659	2.7488	0.2778	0.9960	0.1862	0.1315	5.5058	0.0199	0.9678	0.5242	0.1412	83.2759
	40	2.8308	2.7715	0.2586	0.9950	0.1856	0.1195	5.1325	0.0174	0.9633	0.4993	0.1285	90.7149
	50	3.0206	3.1447	0.2393	0.9967	0.1511	0.1249	5.7011	0.0162	0.9586	0.5277	0.1340	101.4026
Tomato paste Egypt	0	36.9034	123.6657	0.1995	0.9620	5.9909	3.4682	54.4648	2.8918	0.9877	10.6020	5.9464	-13.0822
	10	29.3603	117.4260	0.2055	0.9727	6.0346	3.3189	52.6683	3.0623	0.9071	10.9782	6.129	-15.1183
	20	19.4185	71.0576	0.3016	0.9478	8.1469	3.044	41.7127	3.2792	0.9890	11.7199	6.0354	-81.1270
	30	18.1887	59.2303	0.3809	0.9794	5.8963	3.6044	44.7665	3.7331	0.9506	9.0911	6.7662	-83.1270
	40	15.5210	39.2571	0.5170	0.9776	6.6861	4.4006	34.4742	4.4317	0.9680	8.0007	7.2485	-99.0721
	50	14.2222	36.5591	0.5422	0.9627	8.5512	4.5824	31.2147	4.7487	0.9657	8.7276	7.4958	-127.9873

Casson dynamic viscosity:

The casson viscosity decreased with increasing in temperatures for tomato products. While the casson viscosity increasing with total solids increasing. It was 0.0113, 0.0241 and 3.279 Pa.s at 20 °C for tomato juice, puree and paste, respectively.

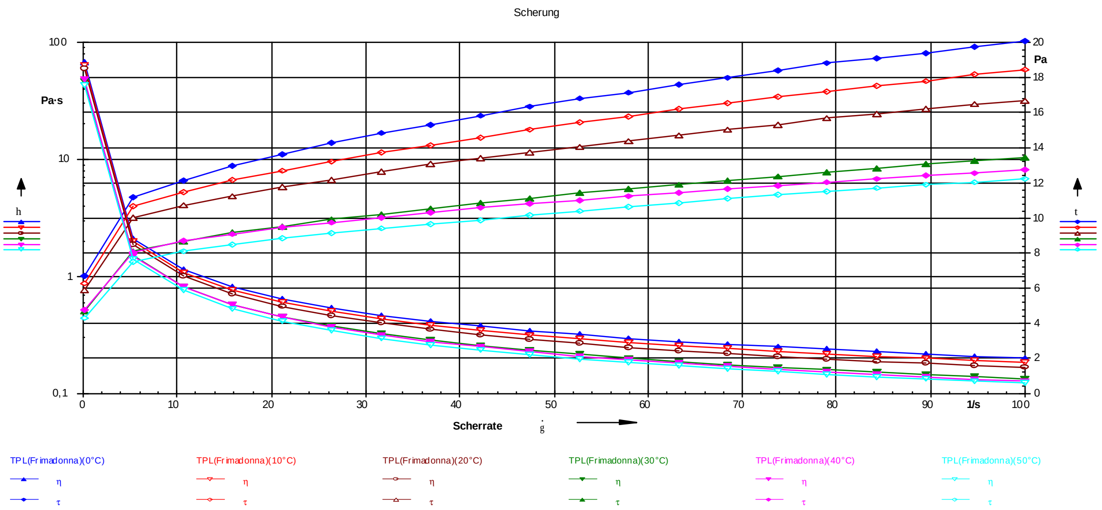

Fig. 1 The flow and viscosity curves for the tomato puree at all investigated temperatures

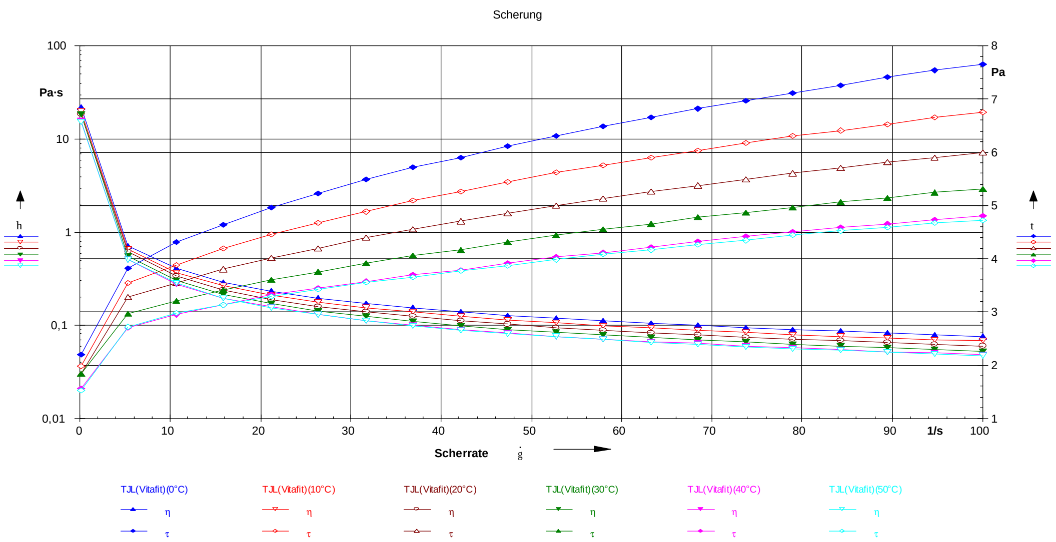

Fig. 2 The flow and viscosity curves for the tomato juice at all investigated temperatures

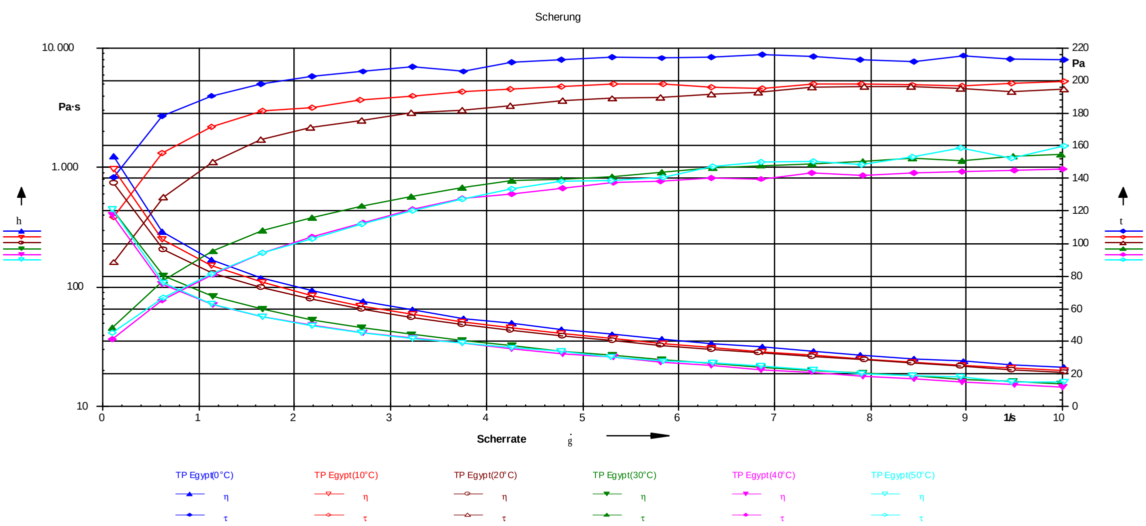

Fig. 3 The flow and viscosity curves for the tomato paste at all investigated temperatures

2. Oscillation tests:

Oscillatory shear, also called dynamic rheological experiment, can be used to determine viscoelastic properties of food. The storage modulus G´ expresses the magnitude of the energy that stored in the material or recoverable per cycle of deformation. G´´ is a measure of the energy that lost as viscous dissipation per cycle of deformation. Therefore, for a perfectly elastic solid, all the energy is stored; that is, G´´ is zero and the stress and the strain will be in phase. In contrast, for a liquid with no elastic properties, all the energy is dissipated as heat; that means G´ is zero and stress and the strain will be out of phase by 90 °C. For a specific food, magnitudes of G´ and G´´ are influenced by frequency, temperature, and strain. These viscoelastic functions have been found to play an important roles in the rheology of structured polysaccharides and all foods, Rao (1999).

2.1 Amplitude sweep:

Typical amplitude sweep profiles for three tomato products are shown in Figs.4-6. From these figures it is obvious that, for all tomato products the storage modulus G´ , was always higher than the loss modulus G´´, there for the tomato products will behave more like a solid; that is, the deformations will be essentially elastic or recoverable; which showed that the tomato products were more elastic than viscous. On the other hand it was noted that G´ and G´´ values had strongly depend on the total solids, G´ and G´´ were increased with an increase in total solids. The dynamic data for tomato products increased with the increase in total solids. The G´ and G´´ values for tomato paste and puree were higher than tomato juice.

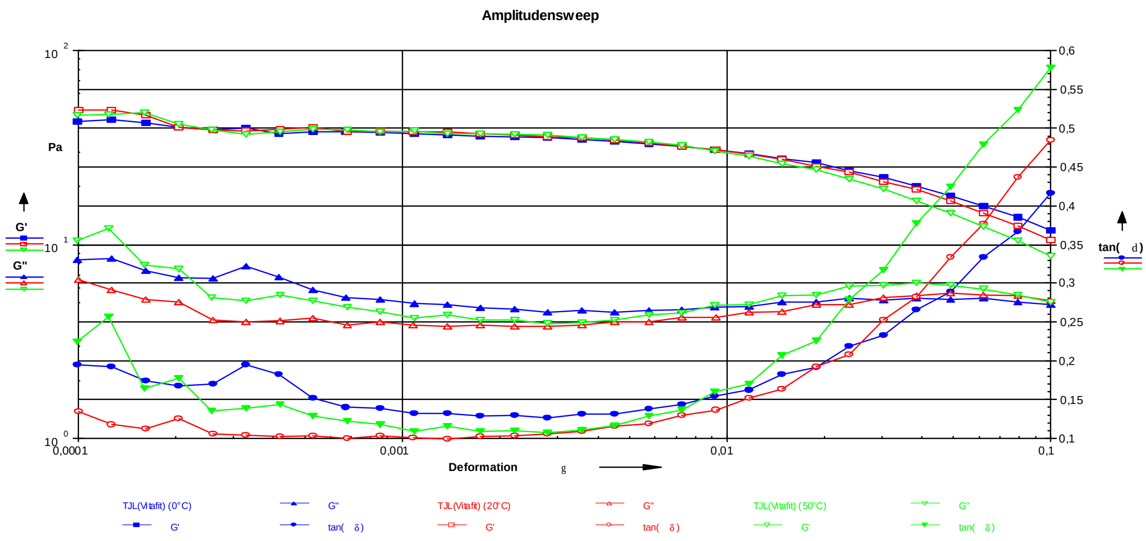

Fig. 4: Amplitude sweeps of tomato juice. The storage modulus G´(elastic behavior) and loss modulus G´´(viscous behavior) curves are shown as a function of the deformation

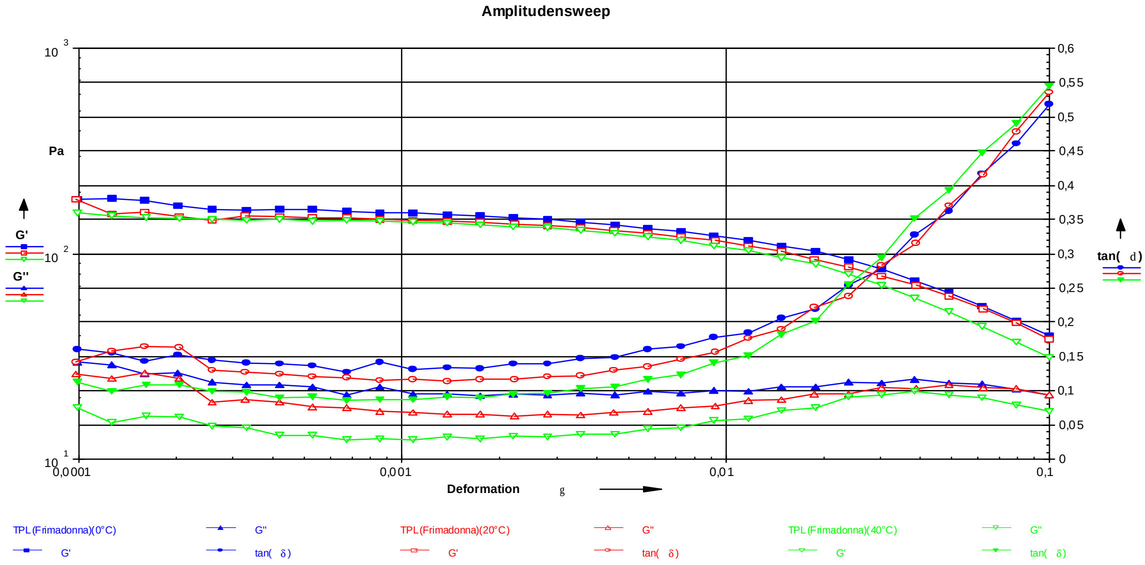

Fig.5: Amplitude sweeps of tomato puree. The storage modulus G´(elastic behavior) and loss modulus G´´(viscous behavior), curves are shown as a function of the deformation.

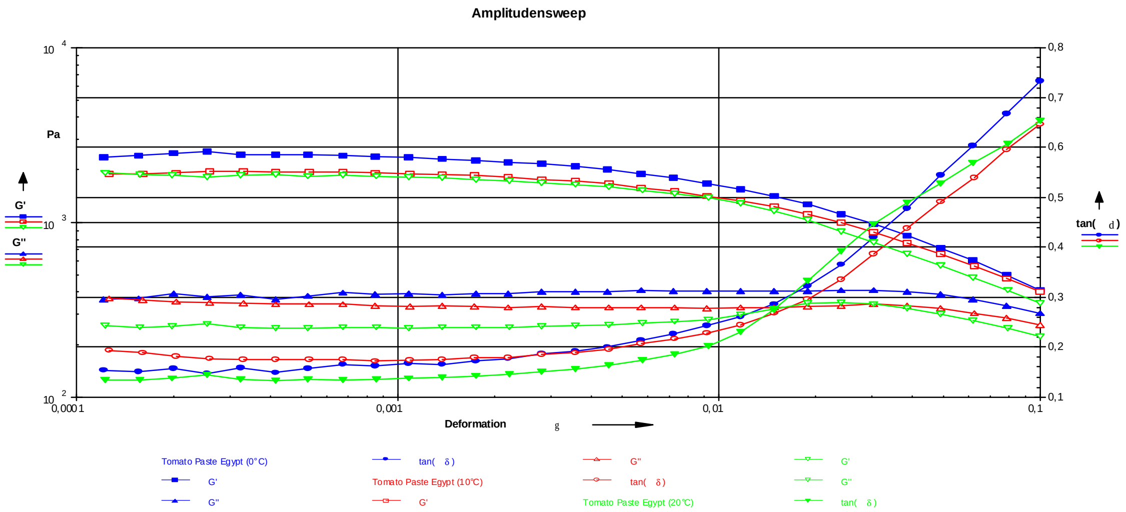

Fig. 6: Amplitude sweeps of tomato products samples the storage modulus G´(elastic behavior) and loss modulus G´´(viscous behavior) curves are shown as a function of the deformation

2.2 Frequency sweep:

Magnitudes of G´ and G´´ as a function of frequency (f) at assay temperature are illustrated in Figs. 7-9, for tomato products. The storage modulus (G´) was greater than the loss modulus (G´´) over the whole frequency range, which indicates weak gel properties; Ouden and Vliet (2002). Tomato products are clearly viscoelastic. The dynamic parameters indicating tan δ increase with increasing f . At low f tan δ had lower values indicating a more solid like behavior. A possible, but at present hypothetical explanation for the

Table (4) Dynamic shear data of tomato juice, puree and paste [Slopes and intercepts of (G´, G´´) versus (frequency, rad S^{-1})]

Product	Temp. °C	G´ Constant (K_1´)	G´ Constant (x´)	G´ R^2	G´´ Constant (K_2´´)	G´´ Constant (y´´)	G´´ R^2
Lidl tomato juice (Vitafit)	**0**	35.959	0.1002	0.997	6.7604	0.2876	0.996
	10	35.555	0.0901	0.998	5.3175	0.2688	0.997
	20	34.869	0.0879	0.994	5.4446	0.2657	0.998
	30	34.571	0.0841	0.998	4.9574	0.2327	0.998
	40	33.727	0.0783	0.993	4.8181	0.2019	0.98
	50	32.811	0.0575	0.999	4.1763	0.1495	0.998
Tomato puree (Frimadonna)	**0**	147.75	0.0961	0.997	23.883	0.2193	0.997
	10	145.69	0.0823	0.999	20.254	0.2164	0.993
	20	141.63	0.0746	0.999	17.802	0.1972	0.994
	30	132.84	0.0665	0.999	16.015	0.1889	0.998
	40	128.29	0.0517	0.999	15.737	0.1854	0.997
	50	125.5	0.0458	0.999	14.567	0.1454	0.998
Tomato paste Egypt	**0**	2381.50	0.1272	0.998	410.66	0.2309	0.998
	10	2355.90	0.1167	0.998	351.28	0.2261	0.998
	20	2126.10	0.1124	0.998	327.31	0.2224	0.999
	30	1725.30	0.1068	0.999	303.64	0.2135	0.999
	40	1699.3	0.1043	0.999	273.83	0.2105	0.999
	50	1686.60	0.0921	0.997	246.17	0.2085	0.998

higher tan δ at high f is that it is caused by an extra contribution due to entanglements between long dissolved macromolecules, which only contribute to the network at higher frequencies. Table (4) contains magnitudes of the slopes (x´ and y´´) and intercepts (K1´ and K2´´) in the equations (6 and 7). From a structural point of view, such plots for true gels have near zero slopes, while for weak gels they have positive slopes (Chen *et al.*, 1996), with slopes of G´´ being higher than those of G´. Therefore, the tomato products displayed weak gel-like behavior. The magnitudes of the slopes (x´ and y´´) and intercepts (K` and K``) were decreased with temperature rose in all tomato products. In contrast, the magnitudes of the slopes (x´ and y´´) and intercepts (K1` and K2``) were increased with increasing in total solids. This tendency was in good agreement with that found in tomato concentrates Rao and Cooley (1992), Yoo and Rao (1996).

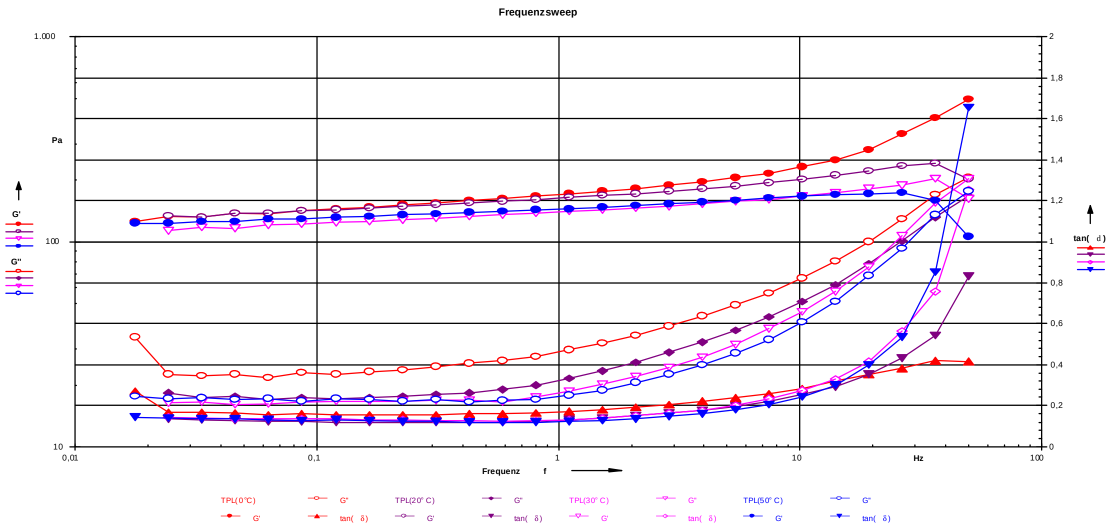

Fig. 7: Frequency sweeps of tomato puree. The storage modulus G´ and loss modulus G´´ curves are shown as a function of the angular frequency

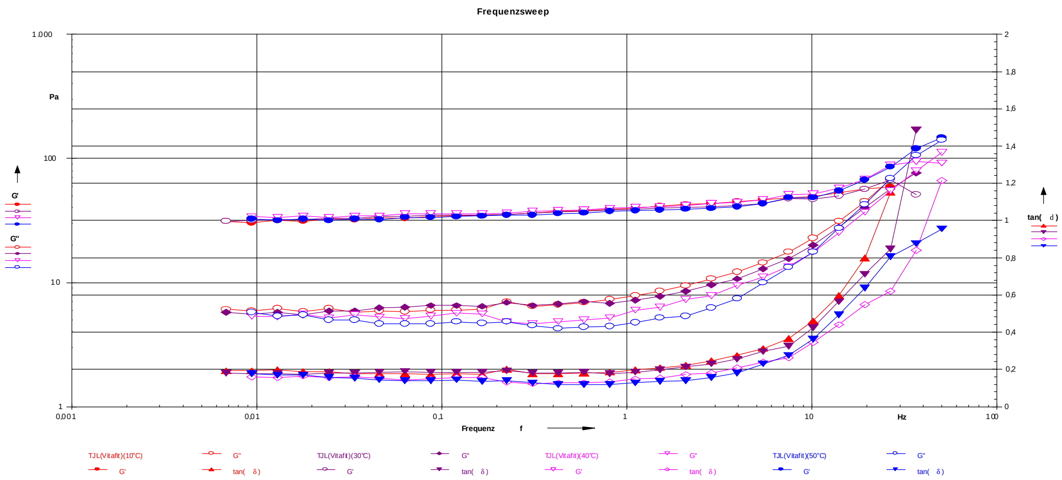

Fig. 8: Frequency sweeps of tomato juice. The storage modulus G´ and loss modulus G´´ curves are shown as a function of the angular frequency

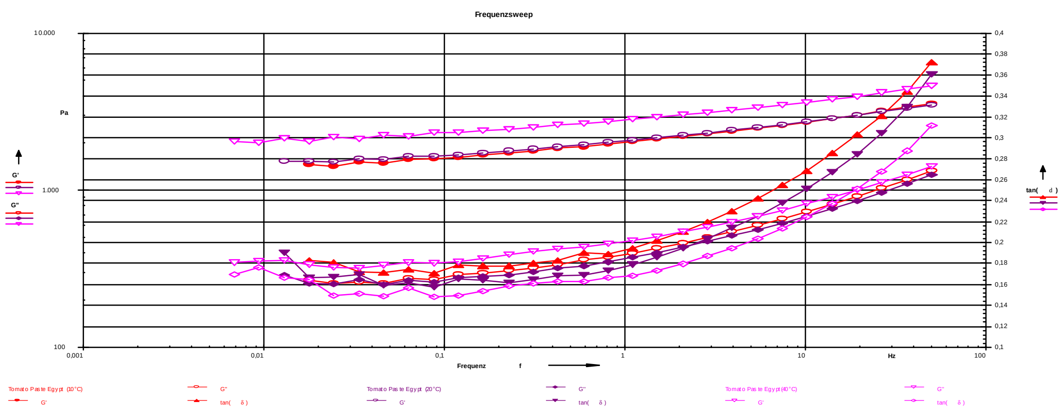

Fig. 9: Frequency sweeps of tomato paste. The storage modulus G´ and loss modulus G´´ curves are shown as a function of the angular frequency

2.3 Loss angle δ (phase angle) values:

The frequency test was made to evaluate the viscoelastic behavior of the tomato products. The loss tangent is the ratio of the energy dissipated to that stored per cycle of deformation. These viscoelastic functions have been found to play important roles in the rheology of structured all foods. The phase lag is measured by phase shift δ, defined as δ = arctg G''/G' or δ = arctg η'/η'' where η' and η'' are the components of the complex viscosity.

For a viscous fluid (Newtonian), $\eta' = \eta a$ $\eta'' = 0$ $G' = 0$ $\delta = \pi / 2$

For an elastic fluid (Hookian), $\eta' = 0$ $G' = G^*$ $G'' = 0$ $\delta = 0$

For a viscoelastic fluid, $(0 \leq \delta \leq \pi /2)$, and δ is a direct index of the relative importance of both the viscous and the elastic component.

Table (5): Tan delta for tomato products temperature depend:

T	Puree	Juice	Paste
0	0.189±0.009	0.197±0.010	0.214±0.006
10	0.160±0.008	0.191±0.004	0.206±0.008
20	0.153±0.011	0.153±0.006	0.191±0.008
30	0.151±0.009	0.183±0.001	0.176±0.007
40	0.129±0.006	0.153±0.005	0.176±0.006
50	0.143±0.007	0.145±0.004	0.165±0.006

Activation energy and the effect of temperature on viscosity of tomato products:

The effect of temperature in decreasing the viscosity of samples is more pronounced at higher concentration. The regression analysis shows that the Arrhenius equation is applicable for all samples ($R^2 \geq 0.98$), Table (6). The range of calculated Ea was 7.73 to 8.17 kJ/ mole. These results were in agreement with those obtained by Rao *et al.*, (1998) who found that Ea values for tomato puree were 9.4 kJ mol^{-1} and η_∞ 0.015 Pa s. Also the results were in agreement with Vitali and Rao (1984) and Rao *et al.* (1981) who reported that activation energy (Ea) increased with decreasing pulp content and increasing total sugars content. The Ea value is depended on the composition of the raw material according to data obtained by Ibarz *et al.*(1996a) and Ibarz *et al.* (1996b), who reported that Ea increases with sugar content and decreases with pulp content. It can be seen in Table (3). On the other hand the η_∞ increases with increase in total solids and pectin content. These results were in agreement with those obtained by Manohar *et al.* (1990).

Table (6) Arrhenius-type constants relating the effect of temperature and viscosity at 100 RPM on tomato products

Products	Ea (kJ/mol)	η_∞ (mPa.s)	Coefficient of Correlation (R^2)	Temperature range °C
Lidl tomato juice (Vitafit)	7.7278	0.9336	0.9879	0 - 50
Lidl tomato puree (Frimadonna)	8.5019	1.5791	0.9787	0 - 50
Tomato paste Egypt	8.1673	6.4179	0.9892	0 - 50

Nomenclature

Symbol	Term	Unit or definition
A_{TH}	Thixotropy	Pa/s
cp	Specific heat capacity	kJ/kg .K
Ea	Activation energy for flow	k J/mol
f	Frequency	Hz
G´	Storage modulus	Pa
G´´	Loss modulus	Pa
HB	Herschel-Bulkley Model	-
K	Consistency index	$Pa.s^n$
K_1´	Constant in eqn (3)	Pa
K_2´´	Constant in eqn (4)	Pa
LSD	Least significant difference	
n	Flow index	Dimensionless
R	Gas constant	8.314 kJ/kg mol. K
r	Correlation coefficients	-
R^2	Adjusted determination coefficient	
S.D.	Standard deviation	
T	Temperature	K
t	Temperature	°C
V/V	Volume per volume	
x	Constant in eqn (3)	Dimensionless
y	Constant in eqn (4)	Dimensionless
τ	Shear stress	Pa
τ_0	Yield Point	Pa
$\dot{g}$	Shear rate	s^{-1}
η	Viscosity	Pa.s
η_{eff}	Effective viscosity	Pa.s
η_∞	Constant in eqn (5)	mPa.s
ω	Angular frequency	rad/s
ρ	Density	kg/m^3

REFERENCES

- A.O.A.C. (1995) Official Methods of Analysis, 16th Ed. Association of Official Analytical Chemists, Inc.USA.
- Alvarado, J.D. (1991) Specific heat of dehydrated pulps of fruits. J. Food Process Engineering 14(1991) 189-195.
- Beresovsky, N.; Kopelman, I.J. and Mizrahi, S. (1995) The role of pulp interparticle interaction in determining tomato juice viscosity. Journal of Food Processing and Preservation; 19 133-146.
- Bistany, K.L. and Kokini, J. L. (1983a) Comparison of steady shear rheological properties and small amplitude dynamic viscoelastic properties of fluid food materials. J. Texture stud. 14;113-124.
- Bistany, K.L. and Kokini, J.L. (1983b) Dynamic viscoelastic properties of foods in texture control, J. Rheol. 27:605-620.
- Chen,C.J.; Liao,H.J.; Okechukwu, P.E.; Damodaran, S. and Rao, M.A.(1996) Rheological properties of heated corn starch + soybean 7S and 11S globulin dispersions. J. Texture stud.; 27 ,419-432.
- El-Mansy, H.A; Bahlol, H.El.M.; Mahmoud, M.H.and Sharoba, A.M.A. (2000a). Rheological properties of juice and concentrates of some tomato varieties. Annals of Agric Sc. Moshtohor 38(3) 1521-1538.
- El-Mansy, H.A; Bahlol, H.El.M; Mahmoud, H.M. and Sharoba, A.M.A. (2000b) Comparative study on chemical and rheological properties of orange juice and its concentrates. Annals of Agric Sc. Moshtohor 38(3) 1557-1574.
- Ibarz, A.; Garvin, A. and Casta, J. (1996a) Rheological Behaviour of sloe (prunvs spinosa) Fruit Juices J. food Eng., 27; 423-430.
- Ibarz, A.; Garvin, A. and Costa, J. (1996b) Rhological behaviour of toquat (Eriobotrya Japonica) juices. J. Texture Stud.; 27: 175-184.
- Jimenez, L.; Ferrer, J.L. and Chica, A. (1989 a) Comparison of Rheological, Chemical and Sensory Properties of Pulped Tomatoes Preserved by Various Techniques. Acta Alimentaria, (18) 167-176.
- Jimenez, L.; Ferrer, L. and Paniego, M.L. (1989 b) Rheology, Composition and Sensory Properties of Pulped Tomatoes. J. food Eng.; 9, 119-128.
- Manohar, B.; Ramakrishna, P. and Ramteke, R.S.(1990) Effect of pectin content on flow properties of mango pulp concentrates. J. Texture stud. 21; 179-190.
- Marsh, G.L.; Buhlert, J.E. and Leonard, S.J. (1980) Effect of composition upon Bostwick consistency of tomato concentrate. J. Food Sci., 45: 703-706.
- Meydov, S.; Saguy, I. and Kopelman, I.J. (1977) Browning determination in citrus products. J. Agri. Food Chem.25 (3): 602.
- Noomhorm, A. and Tansakul, A. (1992) Effect of pulper-finisher operation on quality of tomato juice and tomato puree. J Food Process Eng.; 15 (4) 229-239.
- Ouden, F.C. and Vliet, T.(2002) Effect of concentration on the rheology and serum separation of tomato suspensions. J. Texture stud.; 33 (1) 91-104.
- Pearson, D. (1976) The Chemical Analysis of Food 7th Ed. Churchill London U.D.
- Porretta, S.(1993) Analysis of sensory and physicochemical data on commercial tomato puree with pattern recognition techniques.Zeitschrift-fuer-Lebensmittel-Untersuchung-und-Forschung; 197 (6) 531-536.

- Ranganna, S. (1997) Manual of analysis of fruit and vegetable products. Tata Mcagaw-hill Publishing Company Limited. New Delhi, India.
- Rao, M.A. (1987) Predicting flow properties of food suspensions of plant origin. Food Technol.41 (8), 85-88.
- Rao, M.A.(1999) Rheology of fluid and semisolid foods, principles and applications. A Chapman & Hall Food Science Book, Aspen Publishers, Inc, Gaithersburg, Maryland.
- Rao, M.A.. and Cooley, H.J. (1992). Rheological behaviour of tomato pastes in steady and dynamic shear. J.Texture stud. 23; 415-425.
- Rao, M.A.; Bourne, M.C. and Cooley, H.J. (1981) Flow properties of tomato concentrates. J. Texture Stud.; (12)521-538.
- Senge, B. (2001) Optimierung des transport-und Mischverhaltens nicht-Newtonscher plastischer Medien am Beispiel von Speisequark. GDL-Kongress, Lebensmitteltechnologie, 8-10 November 2001 Berlin, Deutschland.
- Senge, B.; Opel, H. and Kunzek, H.(1996) Rheological examination of material with cellular structure. 1. Communication: conventional examination of apple-material with cellular structure. Z Lebensm Unters Forsch 203:351-365.
- Tanglertpaibul, T. and Rao, M.A. (1987) Flow properties of tomato concentrates: Effect of serum viscosity and pulp content. J. Food Sci. 52(2): 318-321.
- Thakur, B.R. and Singh, R.K.(1995) Effect of homogenisation pressure on consistency of tomato juicec. J. Food Quality (18)389-396.
- Thomas, H.A.; Sidel, J.L. and Stone, H. (1995) Relationships between rheological and sensory properties of liquid foods, Trogon Corp. Symposium, USA.
- Vitali, A.A. and Rao, M.A. (1984). Flow properties of low-pulp concentrated orange juice: Effect of temperature and concentration. J. of Food Sci., 49: 882-888.
- Wettestein, D.V (1957) Chlorophyll-Ltale und der Submikro Skopische from weckses der plastiden experimental Cell Research 12: 427-433.
- Yoo, B and Rao, M.A. (1996) Creep and dynamic rheological behaviour of tomato concentrates: effect of concentration and finisher screen size. J.Texture Stud.; 27,451-459.
- Yoo, B. and Rao, M.A. (1994) Effect of unimodal particle size and pulp content on rheological properties of tomato puree. J. Texture Stud.; 25 (4) 421-436.
- Yoo, B. and Rao, M.A. (1995) Yield stress and relative viscosity of tomato concentrates: effect of total solids and finisher screen size. J. Food Sci., (60) 777-785.

الخواص الريولوجية الدورانية والديناميكية لبعض منتجات الطماطم المصرية والأوروبية

أشرف مهدى شروبه** - حمدى عبداللطيف المنسى* - همام الطوخى بهلول* – برنهارد زينجه*
- رينهارد بلوخفتس*
قسم علوم الأغذية – كلية الزراعة بمشتهر - جامعة بنها – مصر
قسم ريولوجى الأغذية– كلية علوم التصنيع – الجامعة التكنولوجية ببرلين - ألمانيا
عنوان المراسلة: كلية الزراعة بمشتهر – طوخ - قليوبية

التليفون: ٠١٣٢٦٠٢٤٣٢ محمول : ٠١٢١٤٦٣٠٧٩

الملخص العربي

تم قياس السلوك الريولوجي الدوراني لبعض منتجات الطماطم (عصير - بوريه - صلصة) المأخوذة من السوق المصرى والأوربى علي معدل إجهاد بين (٠,١ – ١٠٠ ثانية$^{-١}$) وعلي مدي من درجات الحرارة (صفر،١٠، ٢٠، ٣٠، ٤٠ و ٥٠ °م) كما تم أيضا تم قياس اللزوجة الأرجوحية علي نفس المدي من درجات الحرارة بإستخدام جهاز ريوميتر فيزك يو دى أس ٢٠٠.

وأوضحت النتائج المتحصل عليها أن منتجات الطماطم من المواد الغير نيوتينية و تسلك السلوك الشبه بلاستيكي مع إجهاد خضوع. وتم حساب الثوابت الريولوجية بإستخدام المعادلات الرياضية الريولوجية وخاصة موديلات هيرشي وبلكي وكيزون ومنهما تم حساب دليل القوام ومعامل القوام واللزوجة الظاهرية وإجهاد الخضوع واللزوجة التأثيرية وتم حساب قيمة الثيكسوتروبي. كما تم أيضا استخدام قانون الأس لتوضيح سلوك اللزوجة الأرجوحية وكانت النتائج المتحصل عليها تدل علي أن منتجات الطماطم من المواد ذات القوام شبيه الجل. وبأستخدام معادلة أراهنيوس أظهرت النتائج المتحصل عليها أن للحرارة تأثير واضح على لزوجة منتجات الطماطم . تم أيضا دراسة التركيب الكيماوي والطبيعي لبوريه وعصير وصلصة الطماطم .